WiMAX Technologies: Architectures, Protocols, Resource Management and Applications

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1. Introduction

- IEEE/802.16/WiMAX technologies
  - attractive emerging metropolitan technology for rural and metropolitan area broadband wireless access (BWA)
  - highly efficient and suitable to support a large range of applications for residential and enterprise environments
  - officially named as the WirelessMAN™)
- IEEE 802.16x - basic standards
- WiMAX
  - "Worldwide Interoperability for Microwave Access" - alternative name given by industry group WiMAX Forum
  - WiMAX Forum mission : promote and certify compatibility and interoperability of broadband wireless products

1. Introduction

- **Wireless Broadband Access (WBA)**
  - Set up cellular like systems
  - *Base stations (BS)* that service a radius of several miles/kilometers
  - BS antenna may be located on a rooftop of a tall building or other elevated structure
  - Basic topology: *Subscriber Stations (SS)* – star connection to BSes
- **IEEE 802.16 –** Significant BWA technology
- **Goals:**
  - Provide wireless high-speed Internet access to home and business subscribers, on metropolitan distances
  - BS can handle thousands of subscriber stations (SS)
  - Access control prevents collisions
  - Supports for : Data, Legacy voice systems, VoIP, TCP/IP, Appl. with different QoS, and different level of guarantees
  - Wireless Solution for “Last Mile” (or “First Mile”) problem

1. Introduction

Basic 802.16 topologies and basic components

- **802.16 Entities**
  - **BS- Base Station**
    - PHY and MAC are the main layers
    - Central role in point-to multipoint (PMP) modes
    - Coordination role in resource management
    - Connection/gateway point to other networks (backhaul, core IP, Internet)
    - Usually out-door installation
  - **SS – Subscriber Station**
    - Single user SS – fixed station
    - Mobile Station - MS
    - MSS - Multiple Subscriber Station (playing role of an AP for LAN/WLAN)
    - may be installed in-door or out-door
  - **RS - Relay station**
    - Used in Mobile Multihop Relay (MMR)

1. Introduction

Basic 802.16 topologies and basic components

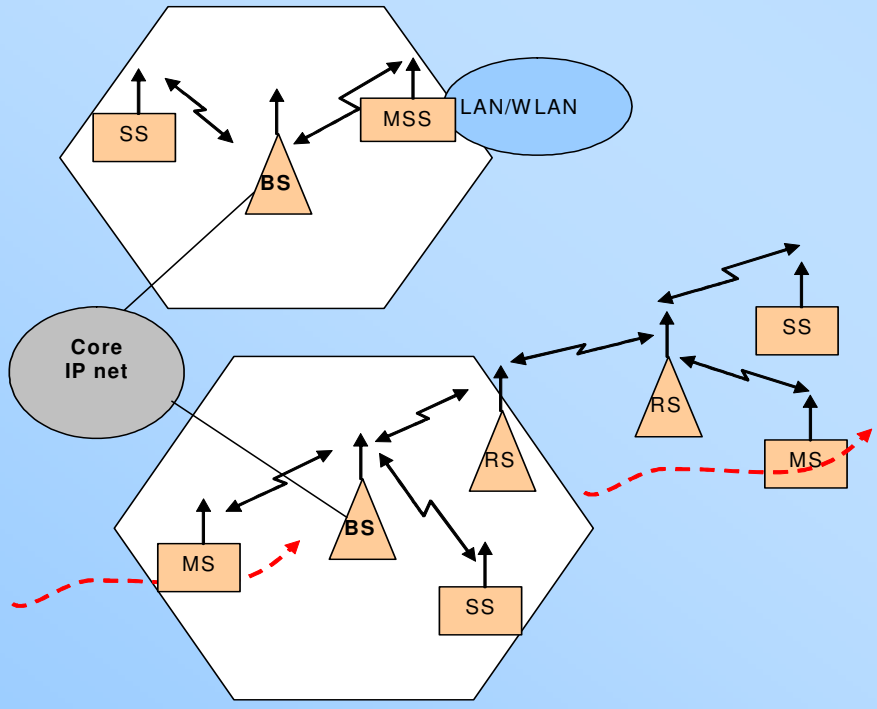
- Operation mode/topologies
  - Point to multipoint (PMP)/star topology
  - Mesh mode/mesh topology
  - (New) Mobile Multihop Relay/tree topology
- **Medium Access Control (MAC)**
  - allocates *uplink (UL)* and *downlink (DL)* bandwidth to SSes as per their individual needs
  - real time (rt)
  - non-real-time (nrt) classes of services
- **Duplex modes**
  - *Frequency Division Duplex (FDD)*
  - *Time Division Duplex (TDD)* modes
- Frequency spectrum:
- 2-11 GHz, 10-66 GHz
- Line of Sight (LOS) and Non LOS

1. Introduction

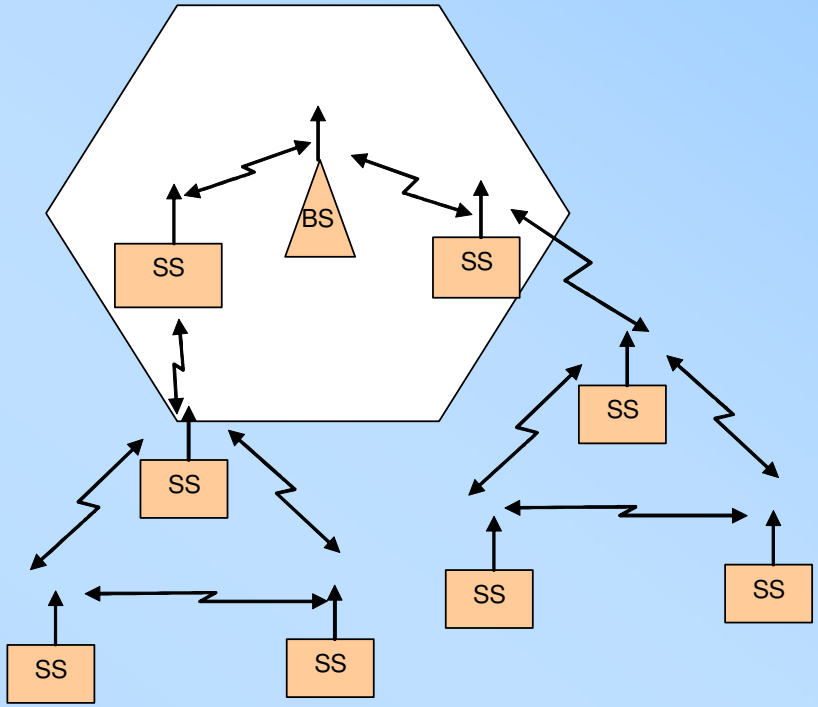
Basic 802.16 topologies and basic components

- Operation modes/topologies

Point-to-multipoint (PMP)



Mesh topology (not deployed very much)



Mobile Multihop Relay (MMR)

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2. Main Standards in BWA

- **802.16 relevant standards**
- **802.16** (Dec. 2001)
  - Basic 802.16 standard
  - Based on Data over Cable Service I/F Specs (DOCSIS)
  - 10-66 GHz licensed spectrum, single carrier (SC) physical (PHY)
  - Line-of-sight (LOS),
  - Theoretical rates up to 134Mbit/s, real < 70Mbit/s, typical < 12MBit/s
  - Fixed technology, point-to-multipoint (PMP) topology
  - Coverage – theoretically- 30-mile radius from BS (real deployments~20Km)
  - **Now withdrawn**
- **802.16a (2003)**
  - 2-11 Ghz - licensed/unlicensed bandwidths
  - Channel size ranges: 1.75 – 20 MHz
  - PMP and Mesh topologies
  - LOS and non-line-of-sigth (NLOS)- applicable to urban areas
  - Rates <70MBps, distances up to 30 miles
  - Extension:
    - Single Carrier (SC)
    - 256 point transform Orthogonal Frequency Division Multiplexing (OFDM)
    - 2048 points transform OFDMA (OFD Multiple Access)
  - **Now withdrawn**

2. Main Standards in BWA

- **802.16 relevant standards (cont'd)**
  - **802.16b** (5-6 Ghz)
    - **Now withdrawn**
  - **802.16c** (2002) - detailed system profiles for 10-66 GHz 802.16 standard
    - **Now withdrawn**
  - **802.16d (2004) basic current fixed mode- standard**
    - Aligned with ETSI HIPERMAN std.
    - includes the a/b/c amendments
    - Topologies: PMP and mesh,70 Mbps
  - **802.16e (Mobile Wireless MAN), 2005**
    - Lower data rates of 15 Mbps, full nomadic and mobile use including handover
    - enhancements to 802.16-2004
      - better support for QoS
      - Scalable OFDMA
    - called "Mobile WiMAX"
    - 2.3, 2.5 GHz bands
    - Supports devices as : mobile smart phones, PDAs, Notebooks, Laptops

EB1

EB1 Other 802.16 stds...

Eugen Borcoci, 6/15/2008

2. Main Standards in BWA

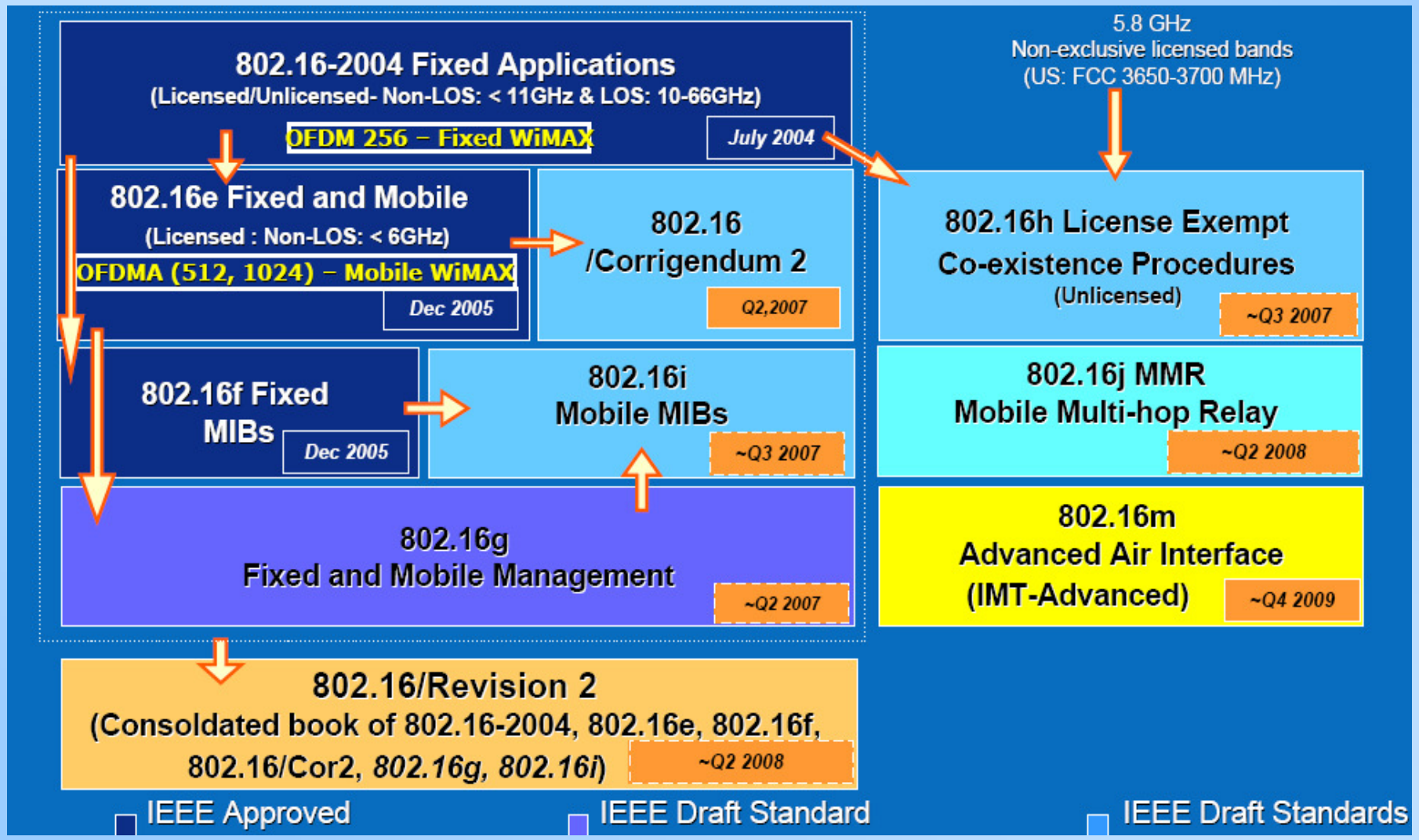
- **802.16 relevant standards (cont'd)**
  - **802.16f**
    - Management information base
  - **802.16g**
    - Management plane procedures and services
  - **802.16h**
    - Improved coexistence mechanisms for license-exempt operation
  - **802.16j – 2009** Multi-hop relay specification
  - **802.16k**
    - 802.16 bridging
  - **802.16m**
    - **amendment for advanced air interface**
    - **looking to the future**
    - **it is anticipated that it will provide**
      - data rates of 100 Mbps for mobile applications and 1 Gbps for fixed applications
      - cellular, macro and micro cell coverage, with currently no restrictions on the RF bandwidth although it is expected to be 20 MHz or more

2. Main Standards in BWA

- **802.16 relevant standards (cont'd)**
  - **802.16m (adopted - march 2011)**
    - performance improvements necessary to support future advanced services and applications for NG broadband mobile communications.
    - In Oct.2010, ITU-R incorporated this technology into its IMT-Advanced Rec.
      - specifying systems that support low to high mobility applications
      - a wide range of data rates in multiple user environments
      - high-quality MM applications
      - significant improvements in performance and quality of service.
    - innovative comm. technologies
      - multi-user MIMO, multicarrier operation, and cooperative communications
      - femto-cells, self-organizing networks, and relays
      - Major worldwide gvt. and industrial organizations, including ARIB, TTA, and the WiMAX Forum, are adopting this standard.

2. Main Standards in BWA

- **IEE 802.16 relevant standards evolution**
  - **Source: INTEL 2007**



2. Main Standards in BWA

- **IEE 802.16 relevant standards evolution**
  - **IEEE 802.16- 2009**
  - specifies the air interface of combined fixed (BWA) systems supporting multimedia services.
  - MAC) supports a primarily point-to-multipoint architecture
  - The MAC is structured to support multiple physical layer (PHY) specifications, each
  - suited to a particular operational environment.
  - For frequencies from 10–66 GHz, the WirelessMAN-SC PHY
  - For frequencies below 11 GHz, where propagation without a direct line of sight must be accommodated:
    - WirelessMAN-OFDM
    - WirelessMAN-OFDMA
  - It is a revision of IEEE Std 802.16-2004 and consolidates material from IEEE 802.16e-2005, IEEE 802.16-2004/Cor1-2005, IEEE 802.16f-2005, and
  - IEEE 802.16g-2007,
    - along with additional maintenance items and enhancements to the management information base specifications.
  - This revision makes obsolete IEEE Std 802.16-2004 as well
  - as IEEE 802.16e-2005, IEEE 802.16-2004/Cor1-2005, IEEE 802.16f-2005, and IEEE 802.16g-2007.

2. Main Standards in BWA

- **IEE 802.16 relevant standards evolution**
  - **IEEE 802.16- 2012**
    - Revision of IEEE Std 802.16-2009
    - specifies the air interface, including the medium access control layer (MAC) and physical layer (PHY), of
    - combined fixed and mobile point-to-multipoint broadband wireless access (BWA) systems
    - providing multiple services.

    - The MAC is structured to support
      - WirelessMAN-SC,
      - WirelessMAN OFDM PHY
      - WirelessMAN-OFDMA PHY
      - specifications, each suited to a particular operational environment.

2. Main Standards in BWA

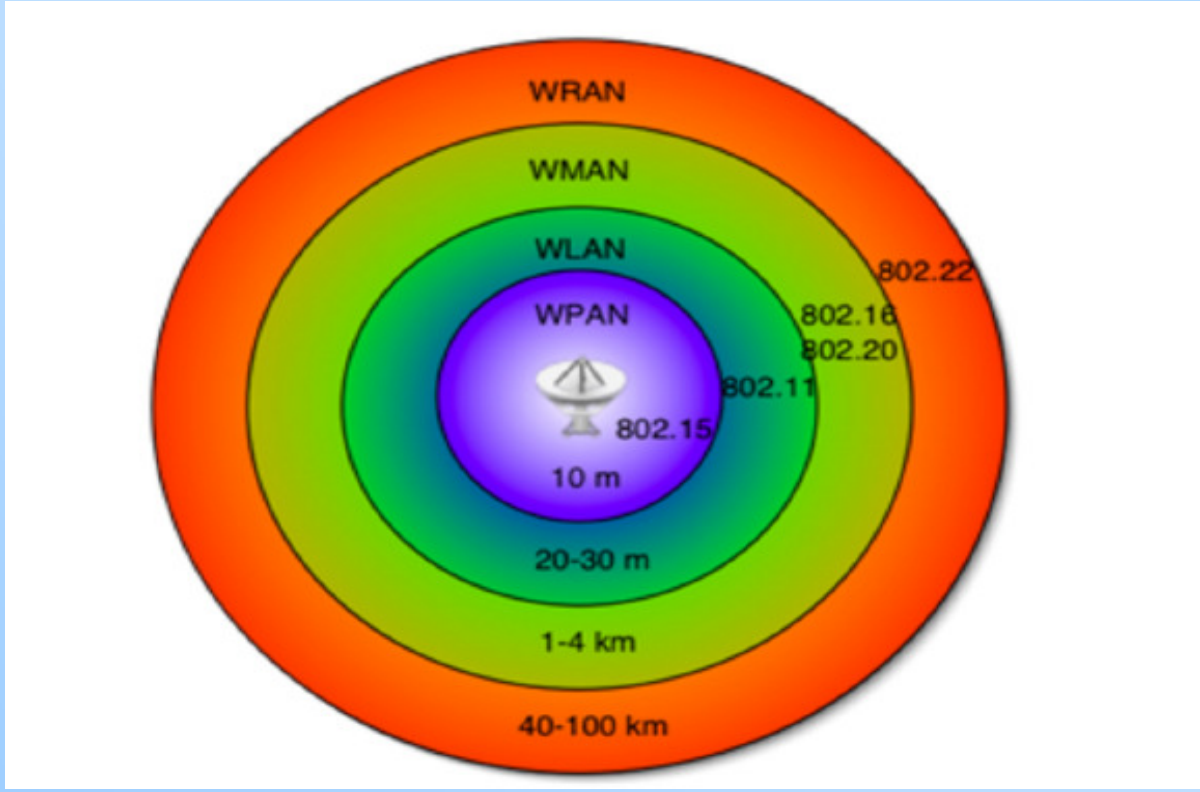
- **Other BWA relevant standards**
- **ETSI Broadband Radio Access Networks (BRAN) – HIPERACCESS**
  - ~ 802.16, fixed LOS access
  - PMP, licensed bands above 11 GHz
  - <120 Mbps (25 Mbps typical data rate) for residential and small business users, MM oriented
  - Access to : UMTS/ ATM/IP networks
- **ETSI Broadband Radio Access Networks (BRAN) – HIPERMAN**
  - ~ 802.16, interoperable fixed BWA, LOS/NLOS
  - 2 -11 GHz
  - PMP/Mesh, FDD /TDD
  - , ATM/IP traffic
  - various service categories with full QoS, fast adaptation of coding, modulation and transmit power to propagation conditions

2. Main Standards in BWA

- **Other BWA relevant standards**
- 802.20: Mobile Broadband Wireless Access (MBWA)
  - 802.20 PHY Layer Overview
  - 802.20 MAY Layer Overview
  - 802.20 vs 2.5/3G Cellular Networks
- 802.22: Wireless Regional Area Networks (WRAN)
  - 802.22 PHY Layer Overview
  - 802.22 MAC Layer Overview

2. Main Standards in BWA

- **Other BWA relevant standards**
  - Classifications and Ranges of the Various IEEE Wireless Networking Standards



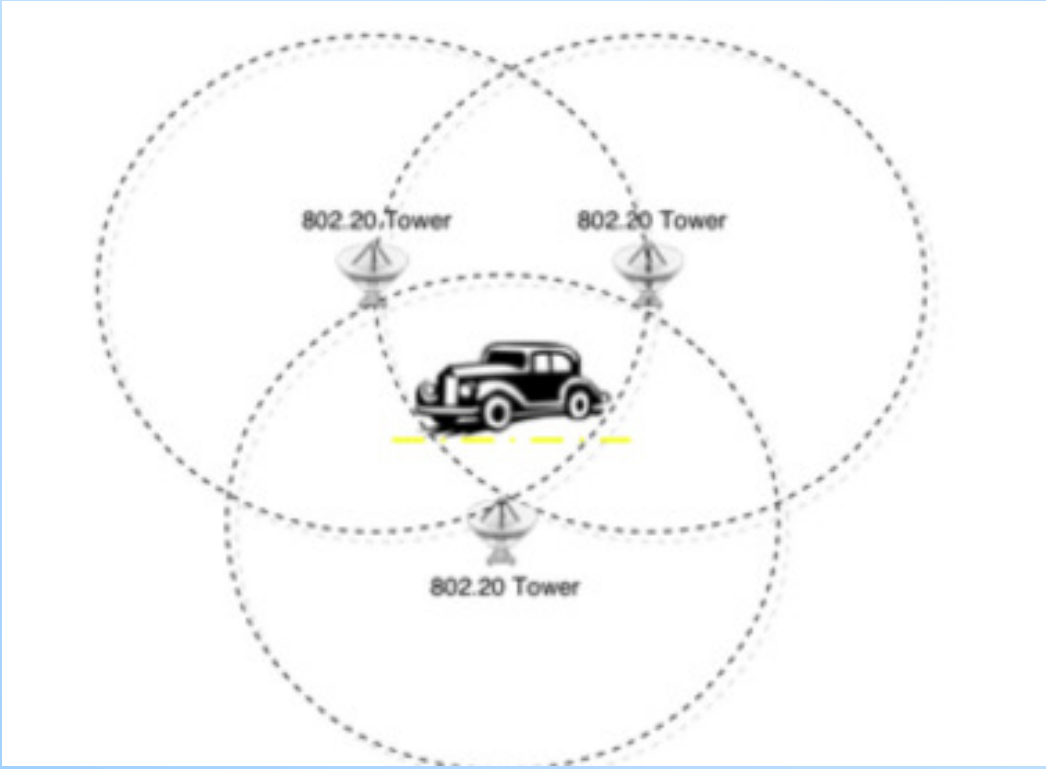
2. Main Standards in BWA

- **Other BWA relevant standards**
- **802.20: Mobile Broadband Wireless Access (MBWA)**
  - It defines a WMAN standard with mobility support. 802.20 differs from 802.16e, however, in that it aims to provide "vehicular" mobility at speeds of up to 250 km/h instead of the much lower 60 km/h speeds offered by Mobile WiMAX
  - Furthermore, unlike 802.16e which has to carry the baggage of the 802.16, 802.16a and 802.16d standards, 802.20 is a clean-sheet design focused exclusively on providing high-speed mobility at speeds similar to ADSL
- operate in licensed bands below 3.5 GHz in a NLOS mode of operation.
- provide a packet-switched connection similar to that of the circuit-switched Metropolitan and Regional Wireless Networking:802.16, 802.20 and 802.22 networks operated by current cellular providers.
- A wide variety of channel bandwidths from 1.25 MHz to 40 MHz are also expected to be supported with both TDD and FDD duplexing
- Still In development

2. Main Standards in BWA

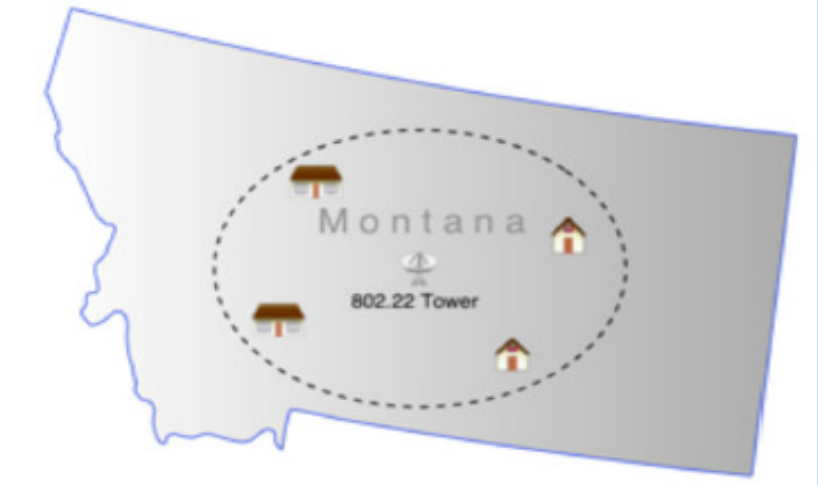
- **Other BWA relevant standards**
- 802.20: Mobile Broadband Wireless Access (MBWA)

Example 802.20 Network Architecture



2. Main Standards in BWA

- **Other BWA relevant standards**
- **IEEE 802.22 Wireless Regional Area Networks (WRAN)**
  - 802.16a/d/e and 802.20 have focused on providing the infrastructure necessary to create wirelessMAN approximately 1 to 5 km in radius,
  - 802.22 defines a standard capable of serving vast regions up to 100 km in size.
  - It hopes to provide fixed wireless access at speeds comparable to ADSL to people living in remote or rural environments that, up until now, have had but a few other options for broadband Internet access.
  - This, could enable thousands of people to experience the power of broadband



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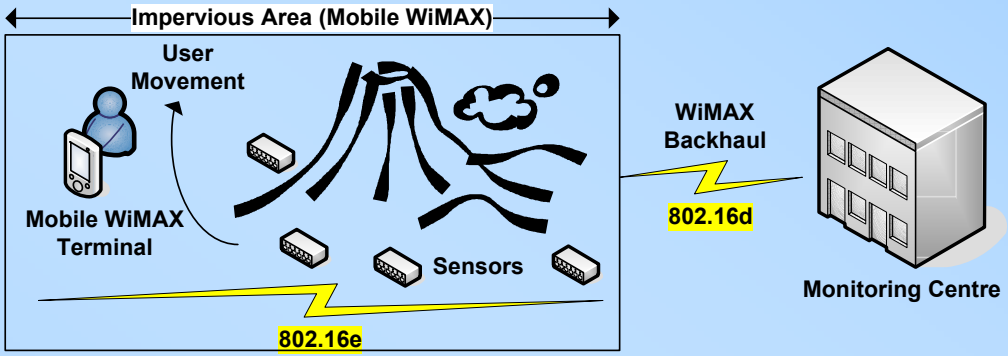
3. WiMAX Supported Applications

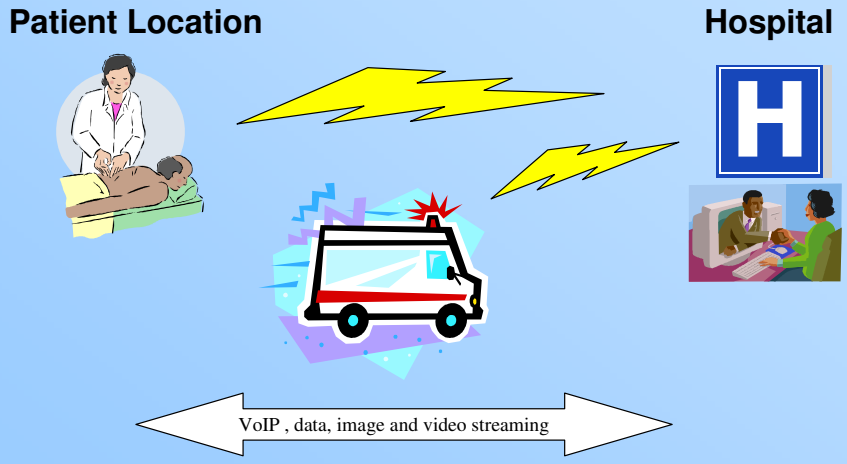
- Typical applications/services
  - Broadband Internet access
  - Real time applications
    - Video streaming
    - VoIP, Video on Demand
    - Telemedicine application/Video Conference
    - Surveillance and monitoring (forests, volcano, etc.)
    - Other possible real time complex applications:
    - E-learning
  - General applications and services based on IP conectivity
  - Application types
    - Legacy (no direct signalling capabilities for QoS)
      - Need an agent to help them
    - Signalling capable: e.g. SIP based
      - Possible direct interaction with control plane for QoS reservation

3. WiMAX Supported Applications- examples

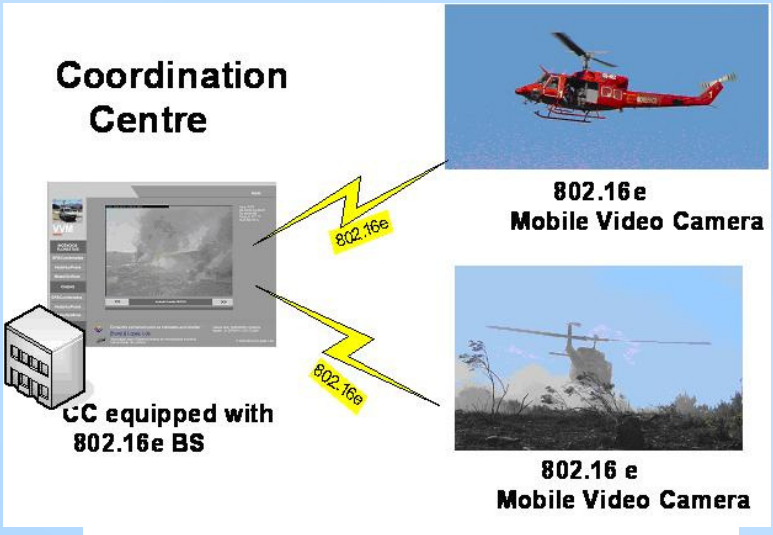
Environmental Monitoring: Volcano Monitoring



Telemedicine: Remote Assistance



Fire Prevention: Video Surveillance



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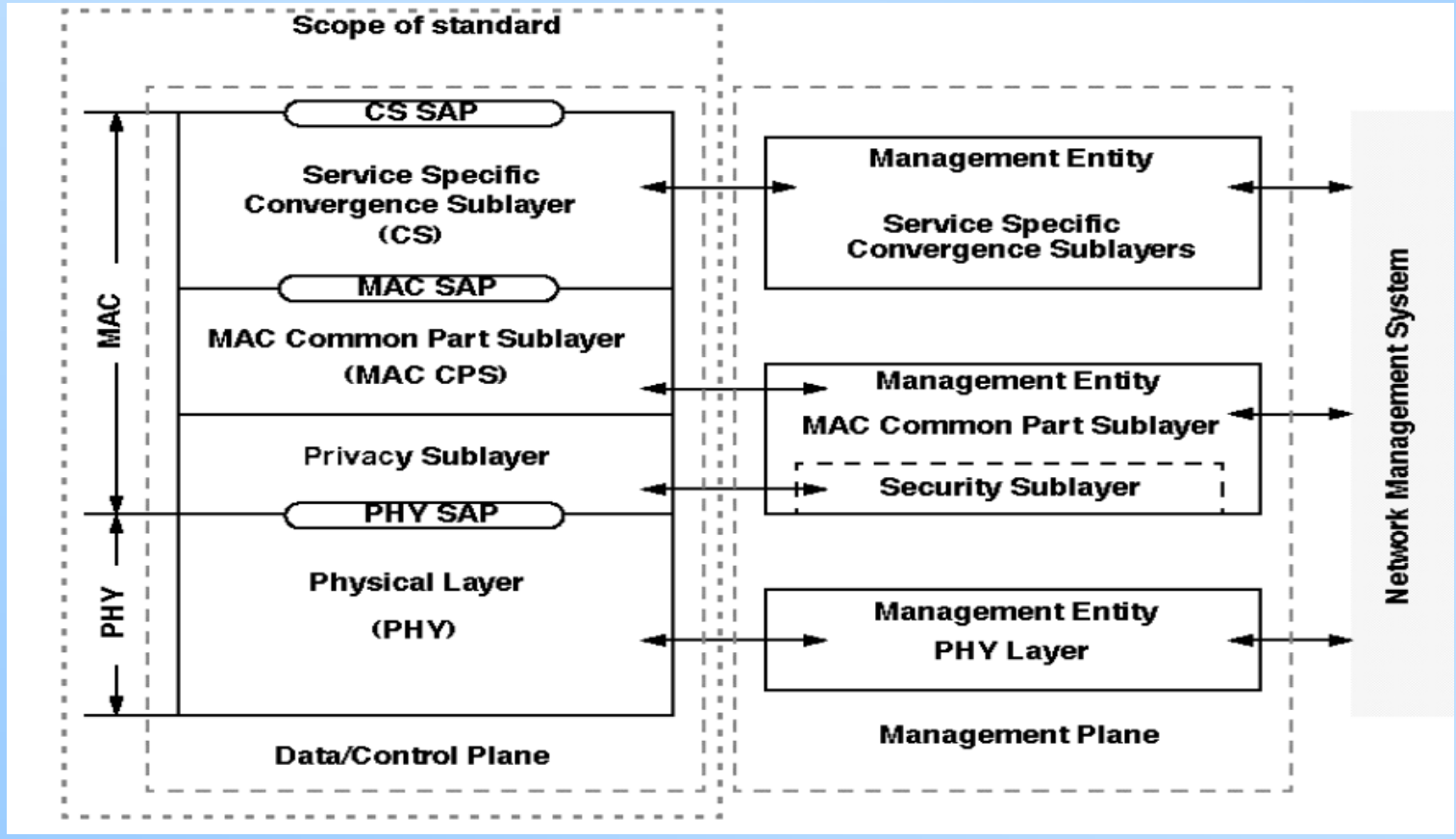
4. Basic IEEE 802.16 and WiMAX Forum Architectures

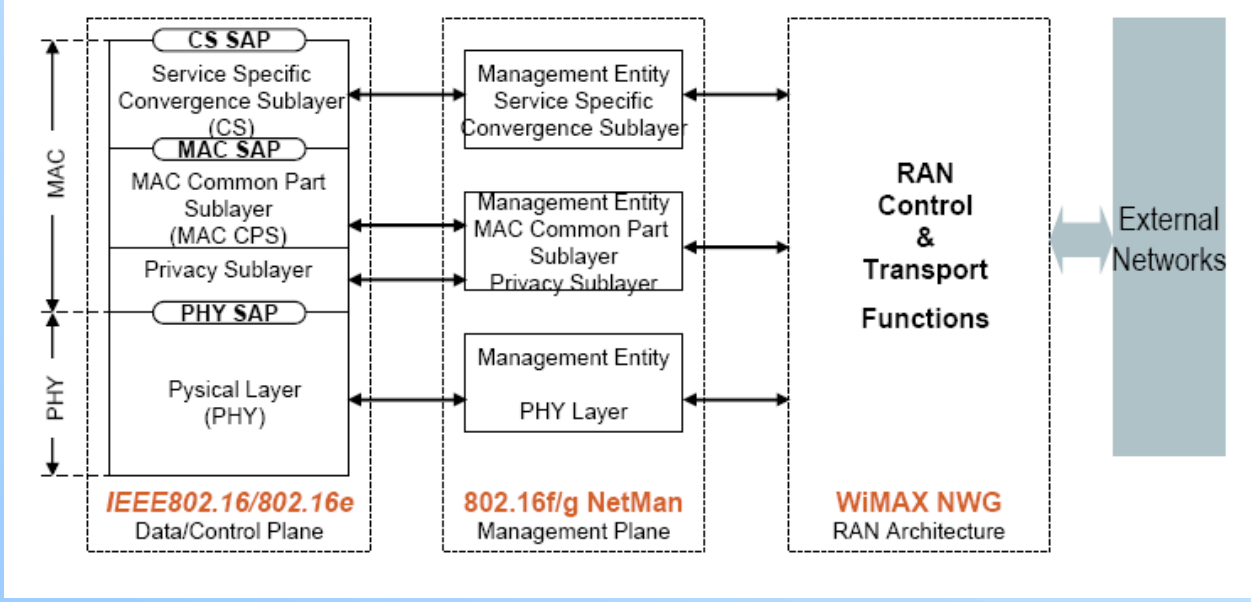
- **IEEE 802.16 : PHY + MAC**
- **Multiple plane architecture: Data Plane(DPI), Control Plane (CPI), Management Plane (MPI)**



4. Basic IEEE 802.16 and WiMAX Forum Architectures

IEEE 802.16/ WiMAX ForumNRM relationship

- IEEE802.16-2004 & 802.16e : define only DPI and CPI
  - 802.16f & g (NETMAN): MPI functions
  - IEEE P802.16 does not deal with functions usually provided by the RAN
  - WiMAX NWG objective: std. of the missing parts of a portable/mobile WiMAX access network
  - MPI: provide conformant 802.16 equipment with procedures and services to
    - enable interoperable and efficient management of network resources, mobility, and spectrum,
    - to standardize management plane behavior in 802.16 fixed and mobile devices



4. Basic IEEE 802.16 and WiMAX Forum Architectures

IEEE 802.16/ WiMAX ForumNRM relationship

- (IEEE 802.16g-05/008r2, December 2005)
  - Network Control and Management System : different functional entities
  - centrally located or distributed across the network
  - exact functionality of these entities and their services is outside the 802.16 scope (but shown here for illustration purposes)

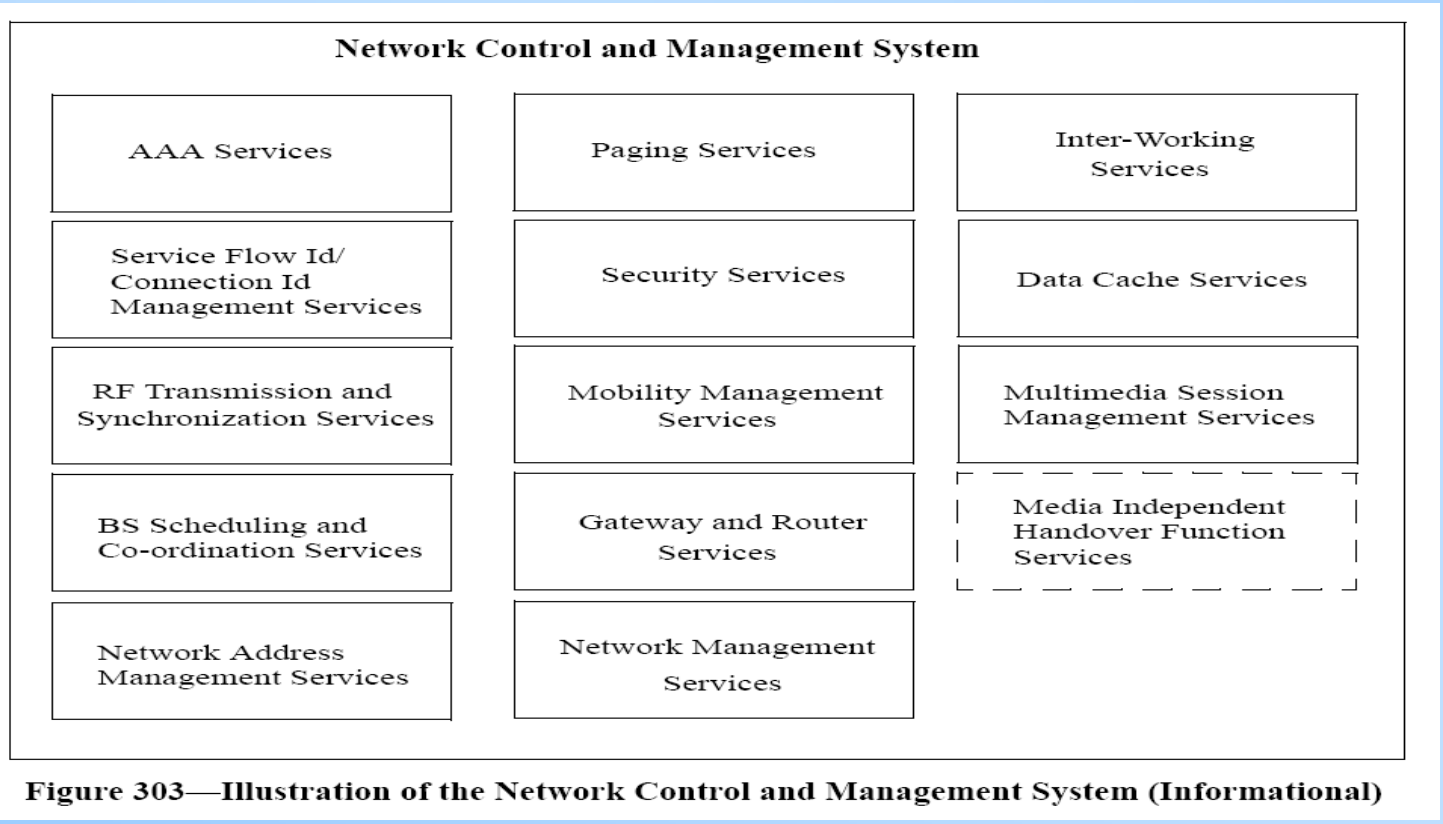


Figure 303—Illustration of the Network Control and Management System (Informational)

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5. Summary of PHY, MAC and Convergence Layers
Physical Layer (PHY)

- **10–66 GHz**
  - Single Carrier
  - adaptive burst profiling : transmission parameters, including the modulation and coding schemes may be adjusted individually to each SS on a **frame-by-frame basis.**
- TDD /FDD Channel : 20 or 25 MHz (U.S. allocation) or 28 MHz (typical European)
- Data randomization (spectral shaping, clock recovery).
- Protection:
  - FEC: Reed-Solomon GF(256), with variable block size and error correction capabilities + inner block convolutional code to robustly transmit critical data, (e.g. frame control and initial accesses)
  - **The FEC options are paired with QPSK,16-QAM, and 64-QAM to form burst profiles of varying robustness and efficiency.**

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

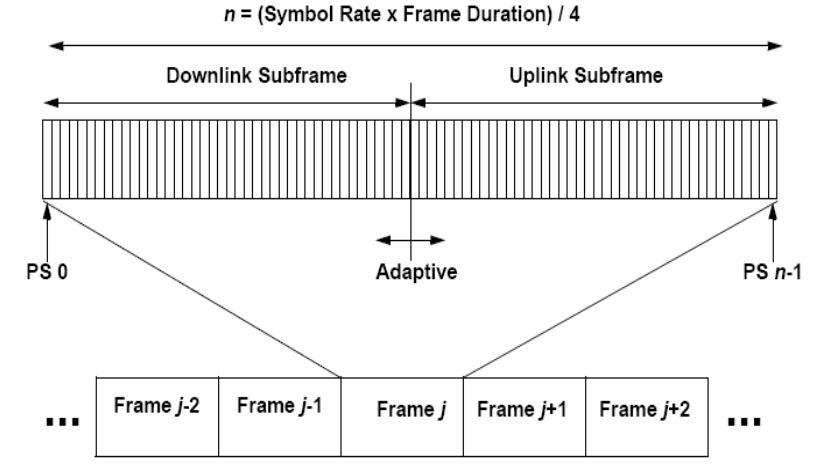
- **10–66 GHz**
  - Frames duration: **0.5, 1, or 2 ms**
  - The frame : divided in PHY slots (PS) for the purpose of **controlled** bandwidth allocation and identification of PHY transitions
  - One PHY slot is defined to be 4 QAM symbols
  - **TDD - PHY:**
    - UL sub-frame follows the DL sub-frame on the **same carrier frequency**.
  - **FDD - PHY:**
    - UL and DL sub-frames are **coincident in time** but are carried on **separate frequencies**

Baud Rates and Channel Size				
Channel Bandwidth (MHz)	Symbol Rate (Msym/s)	Modulation		
		QPSK (Bit Rate Mbit/s)	16-QAM (Bit Rate Mbit/s)	64-QAM (Bit Rate Mbit/s)
20	16	32	64	96
25	20	40	80	120
28	22.4	44.8	89.6	134.4

Bit Rates for different channel bandwidth

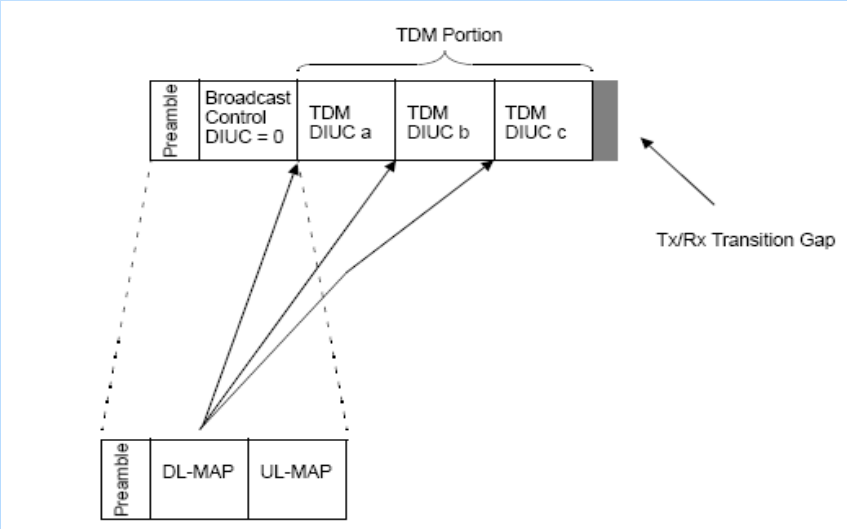
5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

- 10–66 GHz
  - TDD Frame (10-66 GHz)- IEEE Std 802.16-2001



PS = Physical Slots
No of physical slots =
n =Frame Duration/(Tsymbol*4)

TDD Downlink sub-frame (IEEE Std 802.16-2001)



DIUC - Downlink Interval Usage Code

TDD DL Sub-frame structure:

Frame Start Preamble: synchro and equalization.

Frame control section: DL and UL maps stating the no. of the PSs at which bursts begin.

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

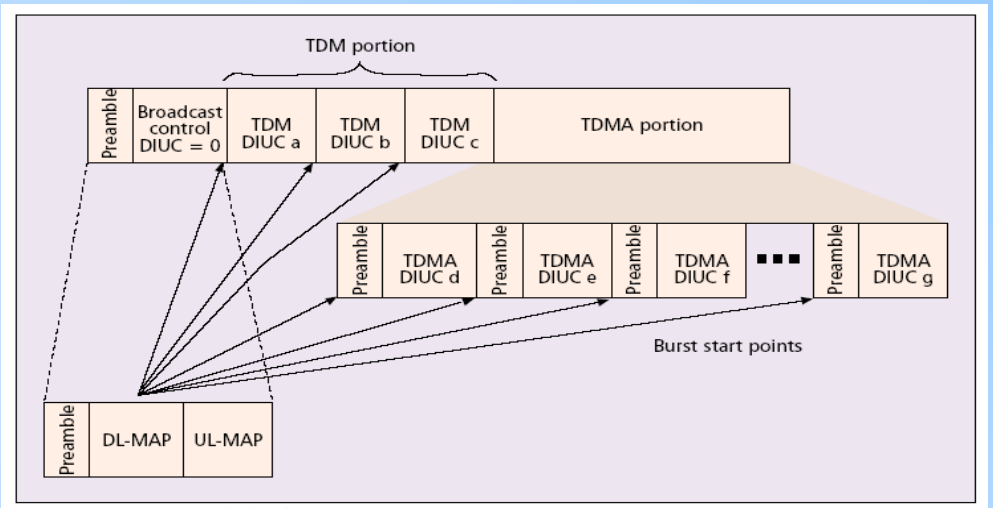
- **10–66 GHz**
  - TDD Frame (10-66 GHz)- IEEE Std 802.16-2001
  - **TDD Downlink sub-frame**
  - *TDM portion* :
    - ***data, organized into bursts*** with **different burst profiles** and different level of transmission robustness.
    - **bursts are transmitted in order of decreasing robustness** e.g: with the use of a single FEC type with fixed parameters, data begins with QPSK modulation, followed by 16-QAM, followed by 64-QAM.
    - *Each SS receives and decodes* the control information of the downlink and looks for MAC headers indicating data for that SS in the remainder of the DL sub-frame

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

- **10–66 GHz**
- **FDD Downlink sub-frame**
  - ***TDM portion*** *:* data transmitted to one or more of the following:
    - full-duplex SSs
    - half-duplex SSs scheduled to transmit later in the frame than they receive
    - half-duplex SSs not scheduled to transmit in this frame.
  - ***TDMA portion*** **(dynamic allocation of time)**
    - used to transmit data to *any half-duplex SSs* scheduled to transmit earlier in the frame than they receive.
    - this allows an individual SS to decode a specific portion of the downlink **without the need to decode the entire downlink sub-frame**
    - each burst begins with the DL TDMA Burst Preamble for phase resynchronization.
    - bursts in the TDMA portion need not be ordered by burst profile robustness
    - the FDD frame control section includes a map of both the TDM and TDMA bursts

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

- **10–66 GHz**
- **FDD DL subframe**
- Dynamics of bandwidth demand ⇒ presence or absence of a TDMA portion both vary dynamically from frame to frame
- The TDD DLsub-frame is identical in structure to the FDD DL sub-frame for a frame in which no half duplex SSs are scheduled to transmit before they receive

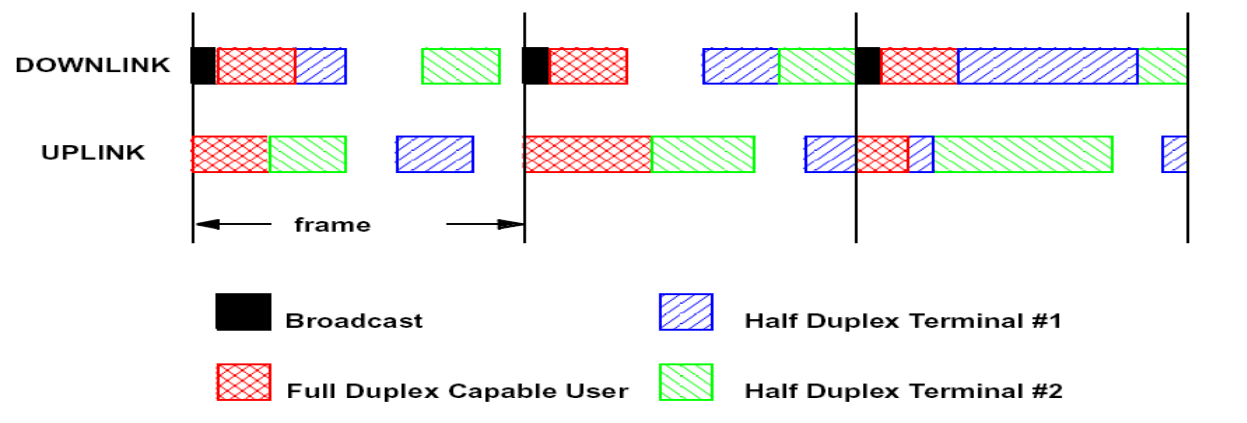


The FDD DL sub-frame structure

- In both TDD and FDD systems, the UL-MAP provides allocations starting no later than the next downlink frame
- **Recipient SS is implicitly indicated in the MAC headers** (not in the DL-MAP) ⇒ SSs listen to all portions of the DL sub-frame they are capable of receiving
- For FD-SSs, this means receiving all burst profiles of equal or greater robustness than they have negotiated with the BS

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

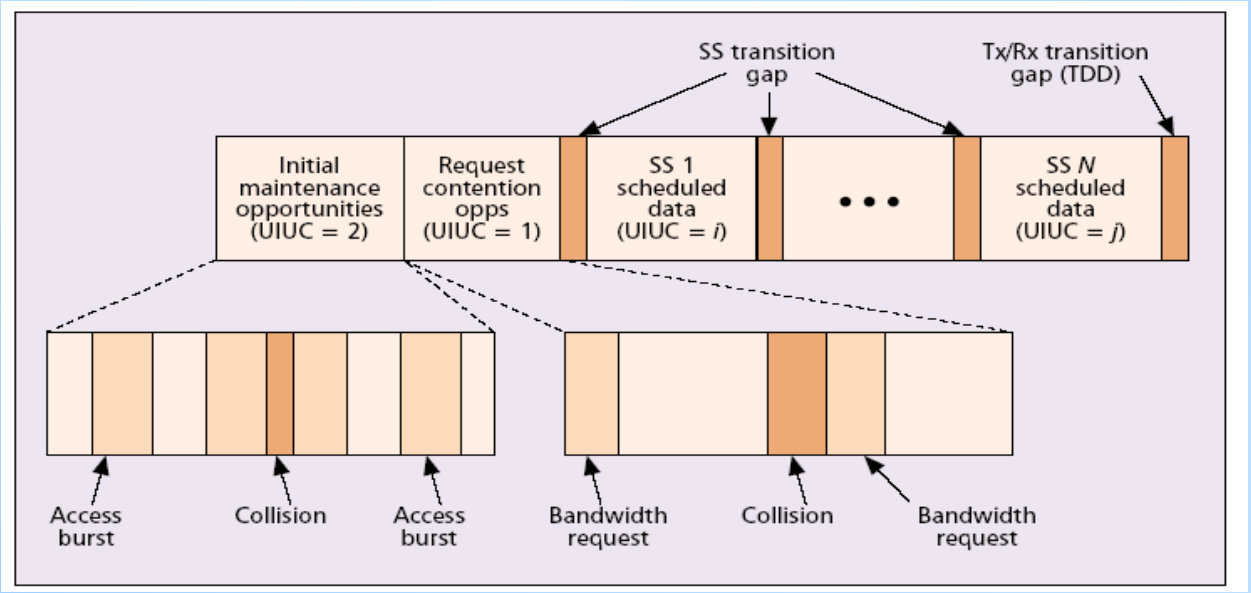
- **10–66 GHz:** Burst FDD Framing



- **PHY Downlink modulation**
  - Multilevel constellation can be selected per SS based on the quality of the RF channel (QPSK /16-QAM /64-QAM)
  - Better/worse link quality ⇒ more complex/simple modulation scheme (max. achievable throughput)
  - BS shall support QPSK and 16-QAM and, optionally, 64-QAM
  - Possibility of a **cross layer optimization** PHY-MAC
    - (scheduling algorithm can be aware of channel capacity)

5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

- **(10–66 GHz) Uplink Sub-frame**
- The **SSs transmit in their assigned allocation slots** using the burst profile specified by the ***Uplink Interval Usage Code (UIUC)*** in the UL-MAP entry granting them bandwidth.
- The UL sub-frame may also contain contention-based allocations for initial system access and broadcast or multicast bandwidth requests



5. Summary of PHY, MAC and Convergence layers
Physical Layer (PHY)

- **(10–66 GHz) Uplink Sub-frame**
- **Uplink Periods**
  - **Initial Maintenance Opportunities (IMO** - is subject to collisions)
    - Ranging
    - To determine network delay and to request power or profile changes.
  - **Request Opportunities (RO** – is subject to collisions)
    - SSs request bandwith in response to polling from BS.
  - **Data grants period** (no collisions: the UL-MAP grants bandwidth to specific SSs)
    - SSs transmit data bursts in the intervals granted by the BS.
    - Transition gaps between data intervals for synchronization purposes.
  - During its scheduled interval, an SS transmits the burst profile specified by the BS
- ***Transmission Convergence (TC)*** sub-layer
  - between the PHY and MAC
  - transforms variable length MAC PDUs into the fixed length FEC blocks (plus possibly a shortened block at the end) of each burst

5. Summary of PHY, MAC and Convergence layers Physical Layer (PHY)

- **Comparison: 802.16-2001/.16a/16d**

	802.16	802.16a	802.16e
Completed	December 2001	January 2003	Mid 2004
Spectrum	10-66 GHz	<11 GHz	<6 GHz
Channel Conditions	Only line-of-sight	Non line-of-sight	Non line-of-sight
Bit Rate	32-134 Mbps in 28 MHz channel bandwidth	Up to 75 Mbps in 20 MHz channel bandwidth	Up to 15 Mbps in 5 MHz channel bandwidth
Modulation	QPSK, 16QAM, and 64QAM	OFDM 256 sub-carriers, QPSK, 16QAM, and 64QAM	Same as 802.16a
Mobility	Fixed	Fixed, as well as portable	Nomadic portable
Channel Bandwidth	20, 25, and 28 MHz	Scalable from 1.5 to 20 MHz	Same as 802.16a with uplink subchannels
Typical Cell Radius	2-5 km	7-10 km max.; range 50 km	2-5 km

5. Summary of PHY, MAC and Convergence layers
MAC Layer

- **MAC**
- **Designed initially for PMP BWA** allowing – high bit rates UL and DL
  - Access and bandwidth allocation algorithms must accommodate hundreds of terminals per channel
  - terminals may be shared by multiple end users
- **MAC Characteristics**
  - ***Connection orienteded***
    - Service Flows (SF) – concept
      - *Unidirectional* flow of packets between BS and SS (UL or DL) with a particular set of QoS parameters.
      - Identified by a 32-bit service flow identifier (SFID).
      - Allows separate QoS specification and resource reservation for each direction. Typically created in pairs (UL and DL).
    - (Virtual) Connection identified by 16 bit CID
      - *Unidirectional* logical-link between MAC entities in the BS and the SS for the purpose of transporting the traffic of a service flow. Uplink and down link radio channels in TDD or FDD
  - BS – **makes arbitration and access control** for many SSes
- Channel access – **controlled by BS through UL-MAP, DL-MAP**
- **Services offered to higher layers**
  - Legacy time-division multiplex (TDM) voice and data,
  - Internet Protocol (IP) connectivity
  - Support any application flow: data, VoIP,VoD, video streaming, etc.

5. Summary of PHY, MAC and Convergence layers
MAC Layer (cont'd)

- **MAC features:**
  - accommodates : continuous and bursty traffic, QoS classes assured
  - service types ~ ATM service categories and different levels of guarantees
  - support a variety of backhaul requirements, including ATM and packet-based protocols
- **Convergence sublayers**
  - map the transport-layer-specific traffic to a MAC in a flexible way to efficiently carry any traffic type
- **MAC Features for increasing efficiency**
  - payload header suppression, packing, and fragmentation
  - transport efficiency assured at the MAC/PHY IF:
    - **modulation and coding schemes are specified in a burst profile that may be adjusted** adaptively for each burst to each SS
    - MAC can make use of bandwidth-efficient burst profiles under favorable link conditions but **may shift** (if necessary) to a **more reliable one**, although it may be less efficient

5. Summary of PHY, MAC and Convergence layers MAC (cont'd)

- **Resources – request/grant mechanisms for resource allocation**
- scalable, efficient, and self-correcting
- 802.16 is efficient in cases of:
  - multiple connections and multiple QoS levels per terminal,
  - large number of statistically multiplexed users

- **Important:**
  - bandwidth allocation and QoS mechanisms are provided by 802.16x
  - scheduling and reservation algorithms – not defined
  - provide a way for vendors to differentiate their equipment

- **MAC privacy sublayer**
  - authentication of network access and connection setup
  - key exchange and encryption for data privacy

- **802.16a MAC enhancements**
  - automatic repeat request (ARQ)
  - support for *PMP* but also *mesh* network architectures

5. Summary of PHY, MAC and Convergence layers
MAC Layer (cont'd)

- **Service Specific Convergence Sublayer (SSCS)**
  - **ATM CS** - defined for Asynchronous Transfer Mode (ATM) services
  - **Packet CS** is defined for mapping packet services : IPv4, IPv6, Ethernet, and virtual local area network (VLAN)
- **SSCS primary task**
  - **classify service data units** (SDUs) to the proper MAC connection
  - preserve or enable QoS and enable bandwidth allocation
  - The mapping takes various forms depending on the type of service
- Addition SSCS functions:
  - payload header suppression and reconstruction to enhance airlink efficiency

- **Note:** ATM is a L2 CO label switching technology (similar to MPLS) transmitting info by segmenting the upper layer (L3) packets in small labelled frames called cells (5+ 48 bytes)
  - Virtual paths and channels
  - HW high speed implementation of switches
  - Any L1, L3, any distance, any type of traffic, QoS guaranteed
  - Complex and expensive- no more developed today (MPLS is successor)

5. Summary of PHY, MAC and Convergence layers
MAC (cont'd)

Common Part Sublayer

- On the DL, data to SSs are multiplexed in TDM mode
- The uplink is shared between SSs in TDMA fashion.
- 802.16 MAC is connection-oriented CO ⇒ all services, including inherently connectionless services, are mapped to a connection.
-
- 802.16 provides
  - a mechanism for requesting bandwidth,
  - associating QoS and traffic parameters,
  - transporting and routing data to the appropriate convergence sublayer,
  - and all other actions associated with the contractual terms of the service.
- Connections: 16-bit connection identifiers (CIDs)
  - may require continuously granted bandwidth
  - bandwidth on demand.
- SS: has a std. 48-bit MAC address, this serves mainly as an equipment id., since the primary addresses used during operation are the CIDs.

5. Summary of PHY, MAC and Convergence layers
MAC (cont'd)

- **Management connections**
  - Upon entering the network, the SS is assigned **three management connections in each direction**
  -
  - *1.* ***Basic connection*****:** transfer of short messages: time-critical MAC and radio link control (RLC)
  - *2.* ***Primary mng. connection*** *:* transfer longer, more delay-tolerant messages (e.g. used for authentication and connection setup)
  - *3.* ***Secondary mng. connection****:* transfer of std-based management messages such as
    - *Dynamic Host Configuration Protocol (DHCP)*
    - *Trivial File Transfer Protocol (TFTP)*
    - *Simple Network Management Protocol (SNMP)*

5. Summary of PHY, MAC and Convergence layers
MAC (cont'd)

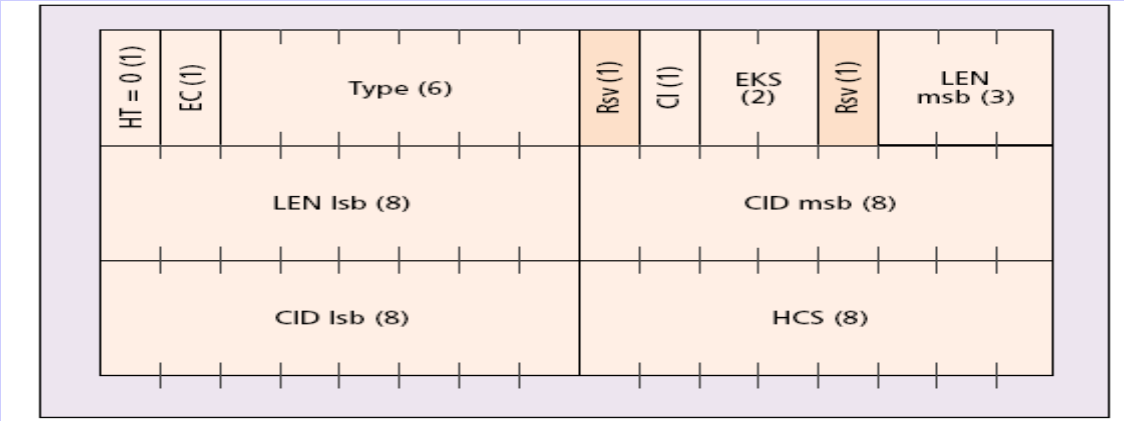
- **Data connections**
  - SSs are *allocated transport connections for the contracted services*
  - ***Connections are unidirectional*** to facilitate different UL and DL QoS and traffic parameters
  - Connections are typically assigned in pairs to services.

  - MAC reserves additional connections for other purposes
    - contention-based initial access
    - broadcast transmissions in the downlink as well as for signaling broadcast contention-based polling of SS bandwidth needs
    - contention-based bandwidth requests
    - multicast

  - SSs may be instructed to join multicast polling groups associated with multicast polling connections.

5. Summary of PHY, MAC and Convergence layers MAC (cont'd)

- *MAC PDU Formats*
  - **fixed-length MAC header**, a **variable-length payload**, optional (CRC)
  - Two header formats, distinguished by the HT field:
    - **generic** header and **bandwidth request** header.
  - Bandwidth request MAC PDUs – have no payload
  - Other MAC PDUs either contains
    - MAC management messages
    - or convergence sublayer data.
  - **Three** types of MAC sub-header may be present.
    - ***grant mng. subheader*** to convey bandwidth mng. needs of SS to its BS
    - ***fragmentation subheader*** : information that indicates the presence and orientation in the payload of any fragments of SDUs
    - ***packing subheader*** indicate the packing of multiple SDUs into a single PDU



Format of generic header for MAC PDU.

5. Summary of PHY, MAC and Convergence layers MAC (cont'd)

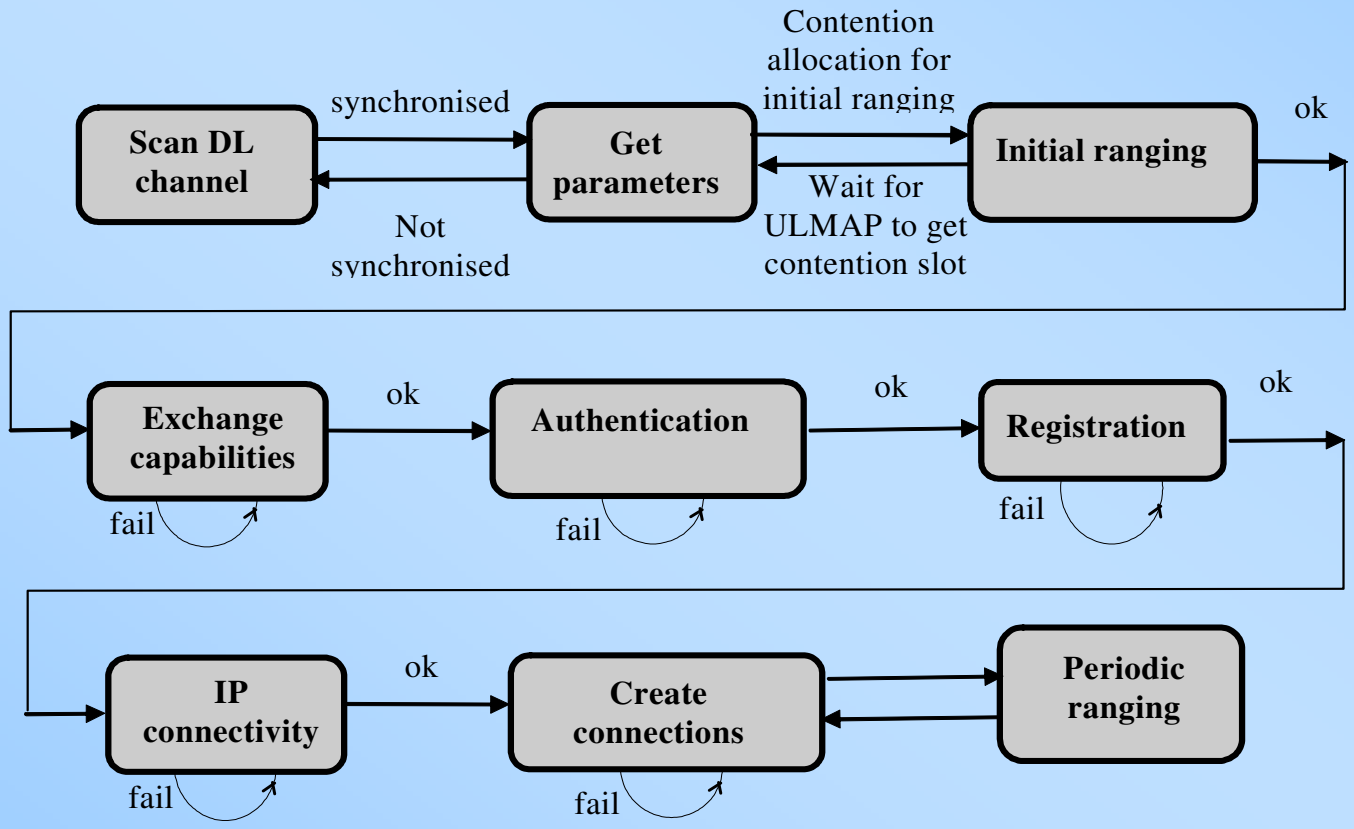
- **SS operation**
- **Network Entry**
- First action: an SS needs to successfully complete the network entry process with the desired BS
- Network entry process is divided into main phases:

1. ***DL channel synchronization***
2. ***Initial ranging***
3. ***Capabilities negotiation***
4. ***Authentication message exchange***
5. ***Registration***
6. ***IP connectivity stages***

- The network entry FSM moves to reset if it fails to succeed from a state.
- Upon completion of the network entry process, the SS creates one or more service flows to send data to the BS

5. Summary of PHY, MAC and Convergence layer

- Network entry process



CONTENTS

6. 802.16 Resource Management and Control, QoS

- **802.16 scheduling services:**
  - **Unsolicited Grant Services (UGS)**
    - Constant Bit Rate (CBR) services,e.g.:T1/E1 emulation, (VoIP) without silence suppression.
  - **Real-Time Polling Services (rtPS)**
    - for services that periodically generate rt VBR and variable size data packets (e.g. MPEG video or VoIP without silence suppression)
    - offers guaranteed minimum rate and guaranteed delay.
    - popular for WISPs to guarantee E1/T1-type data rates with wireline-equivalent SLAs, but to allow customers to burst higher if and when there is extra capacity on the network
  - **Non-Real-Time Polling Services (nrtPS)**
    - for nrt services that require variable size data grant burst types on a regular basis.
  - **Best Effort (BE) Services**
    - BE services are typically provided by the Internet today for Web surfing.
- **New: Enhanced Real-Time Variable Rate (ertPS)** - 802.16e
  - for VOIP services with variable packet sizes as opposed to fixed packet sizes – typically, with silence suppression. This will include applications such as Skype.

Scheduling Services (cont'd)

- Important parameters

Class	Description	Minimun rate	Maximum rate	Latency	Jitter	Priority
Unsolicited Grant Service	VOIP, E1; fixed-size packets on periodic basis		x	x	x	
Real-Time Polling Service	Streaming audio/video	x	x	x		x
Enhanced Real-Time Polling Service	VOIP with activity detection	x	x	x	x	x
Non-Real-Time Polling Service	FTP	x	x			x
Best-Effort	Data transfer, Web browsing, etc.		x			x
x = QOS specified. Source: Light Reading, 2006						

- **Scheduling Services (cont'd): polling methods**
- **Unsolicited Grant Service (UGS)**
  - Real-time, periodic fixed size packets (e.g. T1 or VoIP)
  - Restrictions on bw requests (Poll-Me bit)
  - Slip Indicator (SI)
- **Real-Time Polling Service (rtPS)**
  - Real-time, periodic, variable sizes packets (e.g MPEG)
  - BS issues periodic unicast polls.
  - Cannot use contention requests, but piggybacking is ok.
- **Non-Real-Time Polling Service (nrtPS)**
  - Variable sized packets with loose delay requirements (e.g. FTP)
  - BS issues unicast polls regularly (not necessarily periodic).
  - Can also use contention requests and piggybacking.
- **Best Effort Service**
  - Never polled individually
  - Can use contention requests and piggybacking

6. Resource Management and Control, QoS

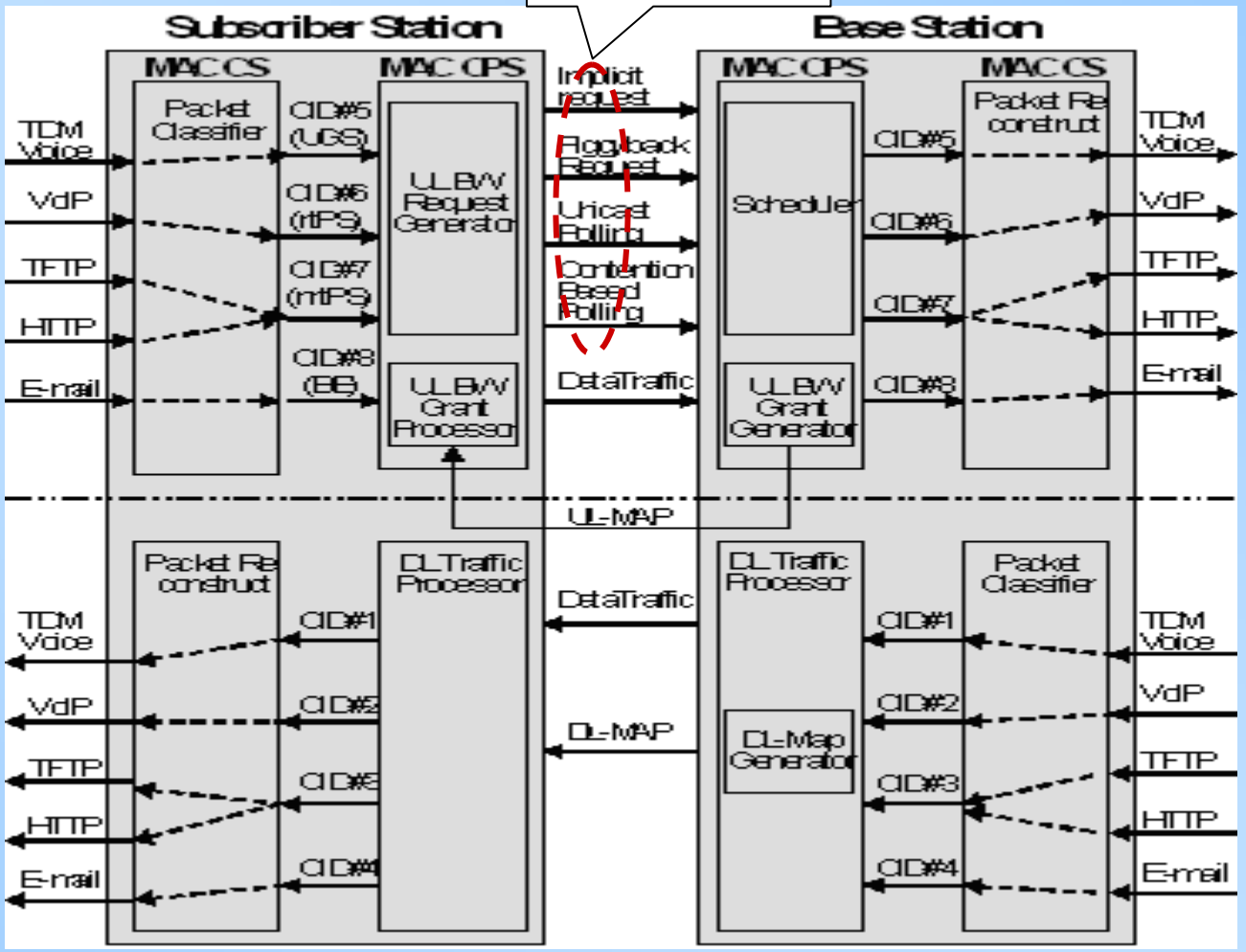
Scheduling Services (cont'd)

802.16 QoS mechanism

for MM services, :TDM voice, VoIP, video streaming,

Low priority:

TFTP, HTTP, e-mail



6. Resource Management and Control, QoS

- **Grant methods**
  - Self Correcting, no ACk
  - Connection Bandwidth Requests are always per Connection
  - Grants are either *per Subscriber Station (GPSS)* or *per Connection (GPC*)
    Grants (given as durations) : *UL-MAP messages*
  - SS needs to convert the time to amount of data using information about the UIUC
  - **Bandwidth Grant per Subscriber Station (GPSS)**
    - BS grants bandwidth to the SS
    - SS re-distributes the bandwidth among its connections, while maintaining QoS and **SLAs**
    - Suitable for many connections per terminal; off-loading BS's work
  - **Bandwidth Grant per Connection (GPC)**
    - Mostly suitable for few users per SS
    - Higher overhead, but allows simpler SS

SLA/SLS – generic examples (partial)

SLS Element/Clause	Attributes	Description
General		
SLS Identification	Key	A unique identification key (set by Service Provider).
Connectivity services requirements		
Topology: (pipe, hose, funnel,..) and scope (ingress, egress points).	Ingress-Egress points Type of topology.	Identifies the: 1. edge points of the topological region over which the QoS applies (IP addresses or layer 2 identifiers); 2. topology (pipe, hose, tree, etc.).
Connectivity class (guarantees): quantitative/qualitative: Delay Jitter Loss, Availability -guarantees.	Delay, loss, jitter	Describes the performance guarantees a provider (CANP) agrees to offer to the packets entitled to this SLS inside the connectivity class
Bandwidth (capacity).	Capacity values assured between edge points.	Depending on the topology, the capacity is specified in abstract way, based on the notion of traffic trunks. This is done in the most general case as a traffic demand matrix.
SLS time life	Time interval (optional)	Optionally define the time interval of validity for this SLS.

6. Resource Management and Control, QoS

- **SLA/SLS – generic examples (partial view ; valid not only for WiMAX))**

SLS Element/Clause	Attributes	Description
Traffic Processing Requirements		
Access and transfer rules:		
Ingress flow Id, Egress flow Id, Ingress point, Egress point.	DSCPs, source, destination, application/	Describe the flows to which the committed treatment in the is to be done.
QoS Guarantees: Class, (dropping, re-marking, shaping).	Ranges of values	Here the former defined class in the Connectivity Service parameters should be specified.
QoS guarantees: conformance algorithm.	Traffic Control (TC) algorithm and parameters for in-profile and out-of-profile packets.	Describes the criteria that injected traffic should comply with to get QoS guarantees specified by Performance Guarantee clause. TC information is required for configuring traffic conditioners at the edge and border routers.
QoS Guarantees Excess traffic treatment.	Action for out-of-profiles packets.	Describes how the excess traffic will be treated: dropping, re-marking, shaping, adapting.
Routing and Forwarding rules.		Describes possible constraints on the way to compute the paths and constraints on forwarding.
Security requirements.	Security Levels of required and	Describes details on how to apply security services to the flows.

6. Resource Management and Control, QoS

- **Polling and Scheduling (cont'd)**
- **Two types of polling mechanisms:**
  - ***Unicast:*** *SS is polled individually;* it gets allocated bandwidth to send bandwidth request messages.
  - ***Contention-based:*** (for many SS case): the *bandwidth for allocation requests is multicasted or broadcast* to a group of SS's that have to contend for the opportunity to send requests

- *Polling:* BS allocates to the SSs bandwidth to send their requests. These allocations may be
  - individual SSs
  - or to groups of SSs
- Allocations to groups of connections and/or SSs actually define bandwidth request contention *Information Elements*.
- The allocations are not in the form of an explicit message, but are contained as a series of (IE)s within the uplink map.
  - Polling is done on either an SS or connection basis
  - Bandwidth is always requested on a CID basis

- **Polling and Scheduling (cont'd)**
- ***Unicast***
  - When an SS is polled individually, *no explicit message is transmitted to poll the SS* but the SS is allocated, in the ULMAP, bandwidth sufficient to respond with a bandwidth request
  - SS/GPSS having an active UGS connection of sufficient bandwidth shall not be polled individually unless they set the *Poll Me (PM)* bit in the header of a packet on the UGS connection (avoid polling all SSs individually)
  - Unicast polling of a GPSS SS would normally be done on a per -SS basis by allocating a Data Grant IE directed at its Basic CID

6. Resource Management and Control, QoS

- **Polling and Scheduling (cont'd)**
- ***Multicast and broadcast***
  - Some SSs may be polled in multicast groups or a broadcast poll may be issued.
  - Certain CIDs are reserved for multicast groups and for broadcast messages
  - *the poll is not an explicit message but bandwidth allocated in the uplink map.* The allocated bandwidth (for SS requests) is not with an SS's Basic CID, but allocation is to a multicast or broadcast CID.
  - When the poll is directed at a multicast or broadcast CID, an SS belonging to the polled group *may request bandwidth during any request interval allocated to that CID in the UL-MAP* by a Request IE
  - to reduce collisions with multicast and broadcast polling, only SS's needing bandwidth reply;
  - A contention resolution algorithm is applied to select the slot in which to transmit the initial bandwidth request

QoS requirements

- A *configuration* and *registration* function for pre-configuring SS-based QoS ***service flows*** and traffic parameters.
- A *signaling function* for *dynamically* establishing QoS-enabled service flows and traffic parameters.
- *Utilization of MAC scheduling* and QoS traffic parameters
  - for *UL service flows*.
  - *for DL* service flows.
- Grouping of SF properties into named *Service Classes,* so upper-layer entities and external applications (at both the SS and BS) may request SFs with desired QoS parameters in a globally consistent way.

6. Resource Management and Control, QoS

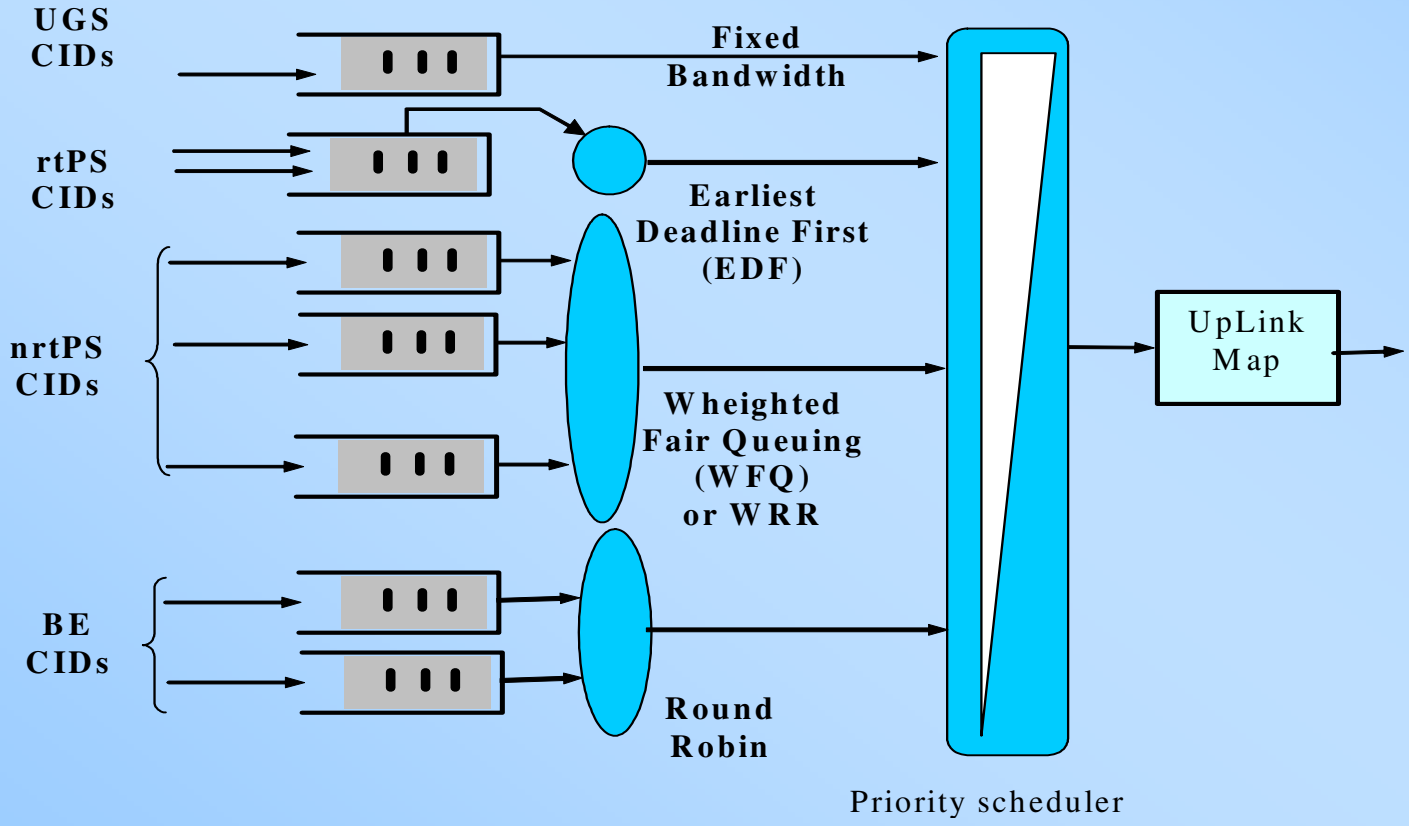
- **Service Flows and and QoS**
- Principal mechanism for providing QoS :
  - associate packets traversing the MAC I/F into a SF (unidirectional packet flow with a particular QoS) as identified by the *CID*
  - SS and BS provide QoS according to the *QoS ParamSet* defined for the SF
  - QoS -> define transmission ordering and scheduling on the air interface.
  - To provide E2E QoS these features need to work in conjunction with other mechanisms in order or to police the behavior of SSs.
  - SFs : UL and DL ; may exist without actually being activated to carry traffic.
  - All service flows have a 32-bit Service Flow Identifier (SFID);
  - Active SF also have a 16-bit CID

6. Resource Management and Control, QoS

- **Service Flows and QoS**
  - The standard defines three types of SFs status:
  - a) ***Provisioned:*** is known via provisioning by, e.g. from the network management system. Its *AdmittedQoSParamSet* and *ActiveQoSParamSet* are both null.
  - *b)* ***Admitted:*** it has resources reserved by the BS for its *AdmittedQoSParamSet*, but *these parameters are not active* (its *ActiveQoSParamSet* is null). *Admitted Service Flows* may have been provisioned or may have been signalled by some other mechanism.
  - c) ***Active:*** it has resources *committed by the BS* for its *ActiveQoSParamSet*, (e.g., is actively sending maps containing unsolicited grants for a UGS-based service flow). Its *ActiveQoSParamSet* is non-null.

6. Resource Management and Control, QoS

- Service Flows and QoS: Scheduling
- Example : Possible Scheduling algorithms at BS/SS for Point-to multipoint mode
  - Priority + EDF + WFQ + RR - combined model



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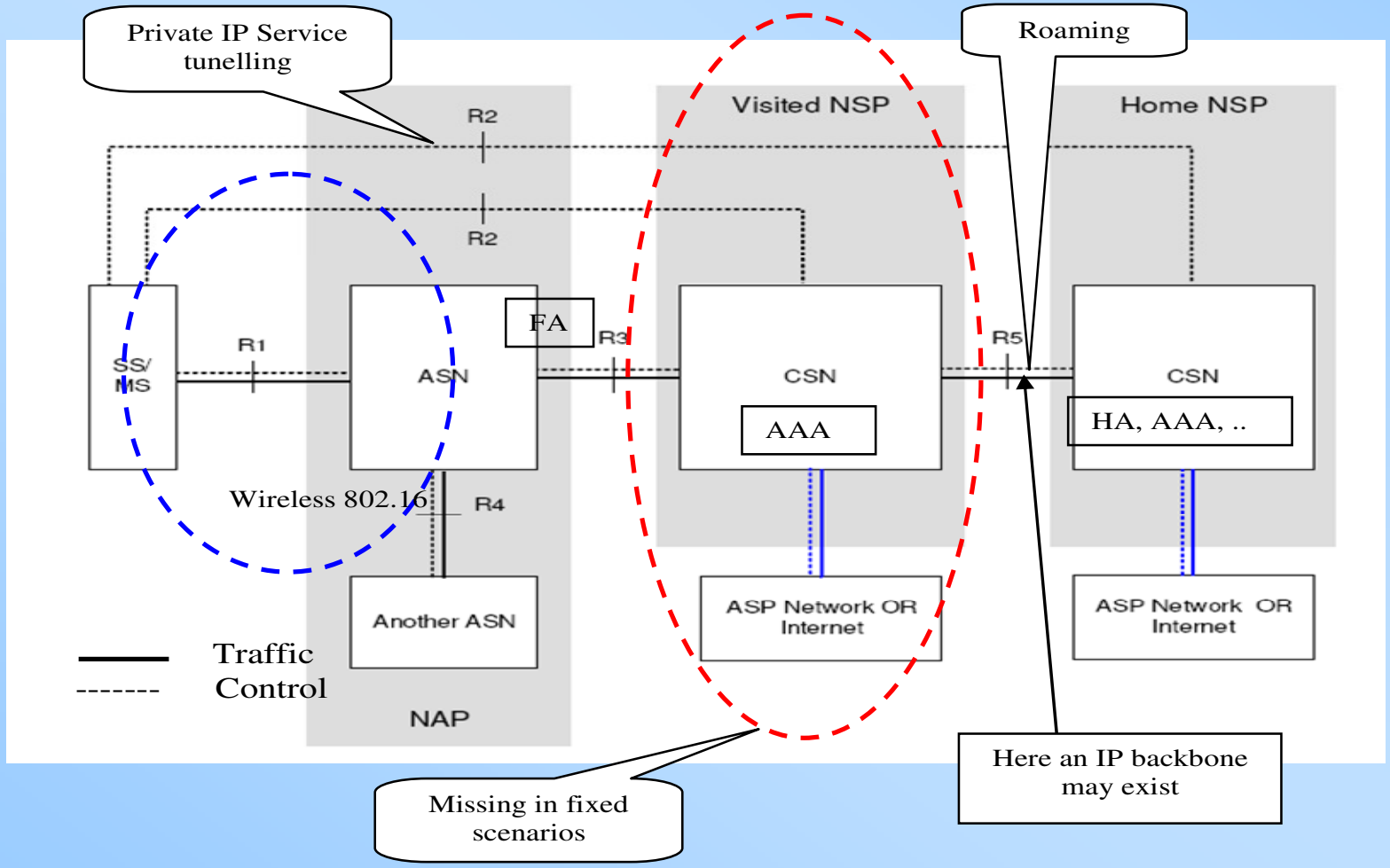
6. IEEE 802.16/WiMAX Integration in E2E Architectures

WiMAX Forum Reference Model (WRM)



6. IEEE 802.16/WiMAX Integration in E2E Architectures

Notations

- ASN Access Services Network (includes the BSes)
- CSN – Core Services Network
- NSP – Network Services Provider
- NAP – Network Access Provider
- R1, R2, … - interfaces (Reference Points of the arch.)
- SS/MS – Subscriber Staion / Mobile StationASP - Application Services Provider
- AAA- Authentication Authorization, Accounting
- HA – Home Agent

- **WMF Reference Points**
- **R1**
  - protocols and procedures (MS –ASN) for air I/F (PHY and MAC) (IEEE P802.16e/D12 and IEEE P802.16-2004).
  - R1 may include additional protocols related to the management plane
- **R2**
  - Protocols and procedures (MS-CSN) associated with Authentication, Services Authorization and IP Host Configuration management
  - R2 is logical, i.e. not a direct protocol I/F MS-CSN
  - The authentication part of R2 usually runs between MS- CSN operated by the H-NSP
  - But ASN and CSN operated by the V-NSP may partially process the aforementioned procedures and mechanisms
  - R2 might support IP Host Configuration Management running between the MS and the CSN (operated by H-NSP or V-NSP)

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **WMF Reference Points (cont'd)**
- **R3**
  - R3 - set of
    - **Control plane (CPI)** protocols between the ASN - CSN to support AAA, policy enforcement and mobility management capabilities
    - **Bearer (data) plane (DPI)** methods (e.g., tunneling) to transfer user data between the ASN and the CSN.
  - Details:
    - DPI : IP tunnels between the ASN and CSN (in case of mobility)
    - CPI
      - protocols for IP tunnel establishment and release control in accordance with the MSS mobility events
      - protocols for AAA
    - Policy and QoS Enforcement coordination between the ASN and CSN.protocols and procedures (MS –ASN) as per the air interface

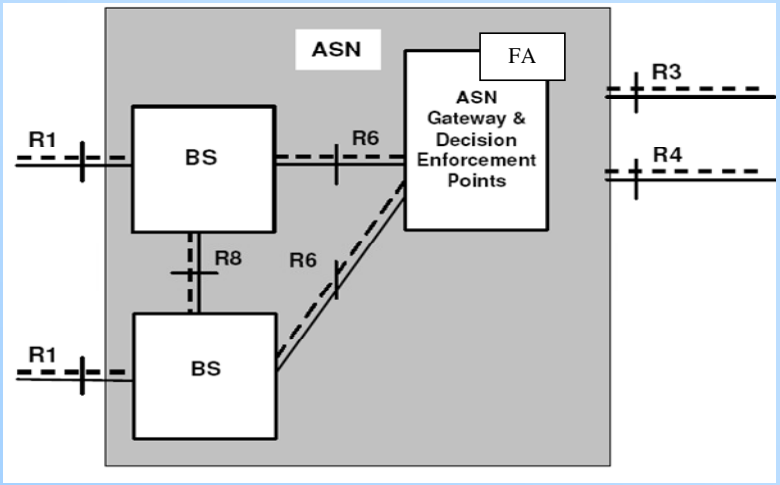
- **WMF Reference Points (cont'd)**
- **R4**
  - ASN-ASN, or beteween ASN-GWs)
  - set of Control and Bearer (Data) plane protocols originating/terminating in various functional entities of an ASN to coordinate MS mobility between ASNs and ASN-GWs.
  - R4 is the only RP between similar or hetero - ASNs
  - (the R4 is used both in and out - ASN since it is the logical link between ASN GWs regardless of whether they are within the same ASN or in different ASNs)
- **R5**
  - R5 - set of control plane and bearer plane protocols CSN – CSN, operated respectively by the H-NSP and V-NSP

7. IEEE 802.16/WiMAX Integration in E2E Architectures

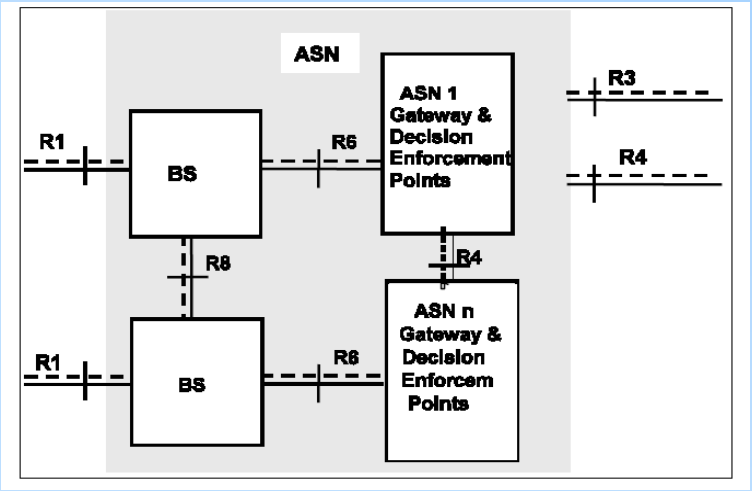
- **Access Service Network (ASN)**
  - **network infrastructure + complete set of functions to provide radio access to WiMAX subscriber**
- **ASN -mandatory functions:**
  - WiMAX L2 connectivity with WiMAX MS
  - Transfer of AAA messages to WiMAX subscriber's H-NSP for AAA operations of subscriber sessions
  - Discovery/selection of an appropriate NSP that WiMAX subscriber accesses WiMAX service(s) from
  - Relay for Layer-3 (L3) connectivity with a WiMAX MS (i.e. IP address allocation)
  - Radio Resource Management
  - ASN-CSN tunneling
- **ASN additional functions, for a portable and mobile environment:**
  - ASN anchor mobility, CSN anchor mobility
  - Paging and Location Management

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **WiMAX architecture Network Reference Model for ASN**
  - ASN Gateway – ASN-GW: control/mng plane and data plane role
  - Single ASN-GW



Multiple ASN-GW



- **WiMAX Reference Points: R6, R8**
- ASN Gateway – ASN-GW
  - control/mng plane and data plane rol
  - Possible: FA - Foreign Agent role – for Mobile IP (macro-mobility)

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **WiMAX architecture Network Reference Model for ASN**
- **Reference Points**
- **R6**
  - set of data *plane* and *control plane* protocols between the BS - (ASN-GW)
  - Data plane : intra-ASN data path BS -ASN gateway.
  - Control plane : protocols for data path establishment, modification, and release control in accordance with the MS mobility events.
  - R6 + R4, may serve as a channel for exchange of MAC states information between BSs that cannot interoperate over R8

- **R8**
  - ***Control plane*** message flows and *optionally Data plane data flows between the BSs*, to ensure **fast and seamless handover:**
    - *Data plane*: protocols for data transfer between BSs involved in HO of a certain MS
    - *Control plane* : inter-BS protocol in line with IEEE 802.16e/d and 802.16g and additional set of protocols that allow controlling the data transfer between the BSs involved in handover of a certain MS

- **WiMAX architecture Network Reference Model for ASN**
- **Base Station (BS)**
- BS : Physical and logical entity
  - full instance of the IEEE 802.16/ WiMAX MAC and PHY
  - may host one or more access functions.
- BS instance : one sector with one frequency assignment.
  - scheduling functions for uplink and downlink resources
  - These are left for vendor implementation and is outside the scope of WiMAX Forum documents.
- Possible connectivity of a single BS to more than one ASN-GW for load balancing or a redundancy option

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **WiMAX architecture Network Reference Model for ASN**

- **Base Station (BS)** functional decomposition:
  - 802.16 interface handling (e.g. PHY, MAC, CS, Scheduler) and processes as handover, power control and network entry.
  - QoS PEP for traffic via air interface
  - Micro Mobility HO triggering for mobility tunnel establishment
  - Radio Resource Management Update
  - MSS Activity Status update (Active, Idle)
  - Supporting tunneling protocol toward ASN GW
  - Traffic classification
  - Key Management
    - TEC/KEK Generation and delivery to the BS/MSS
  - DHCP Proxy
  - Session Management (RSVP proxy)
  - Managing Multicast Group association (IGMP proxy)

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **WiMAX architecture Network Reference Model for ASN**

- **ASN Gateway (ASN-GW)**
  - *logical entity* that represents an *aggregation of control plane functional* entities that are either paired with
    - a corresponding function in the ASN (e.g. BS instance)
    - a resident function in the CSN or
    - a function in another ASN.
- may also perform bearer plane routing or bridging function.
- may include redundancy and load-balancing among several ASN-GWs.
- The ASN-GW implementation details are out of scope for WMF

- **ASN Gateway (ASN-GW) (cont'd)**

- The ASN-GW functions may optionally be viewed (in the perspective of Policy Based Management) as consisting of two groups:
  - Decision Point (DP) and the
  - Enforcement Point (EP)
- EP includes data/bearer - plane functions and the DP includes non-bearer-plane functions (e.g. Radio Resource Management Controller).
- For implementation purposes, the decomposition of ASN functions into these two groups is optional
- In the separation case DP/EP *a new RP which is R7* is defined between DP and EP (e.g. COPS protocol).
- The decomposition of the ASN functions using the R7 protocols is optional
- An ASN-GW DP may be associated with one or more ASN-GW.

7. IEEE 802.16/WiMAX Integration in E2E Architectures

- **ASN Gateway (ASN-GW) (cont'd)**

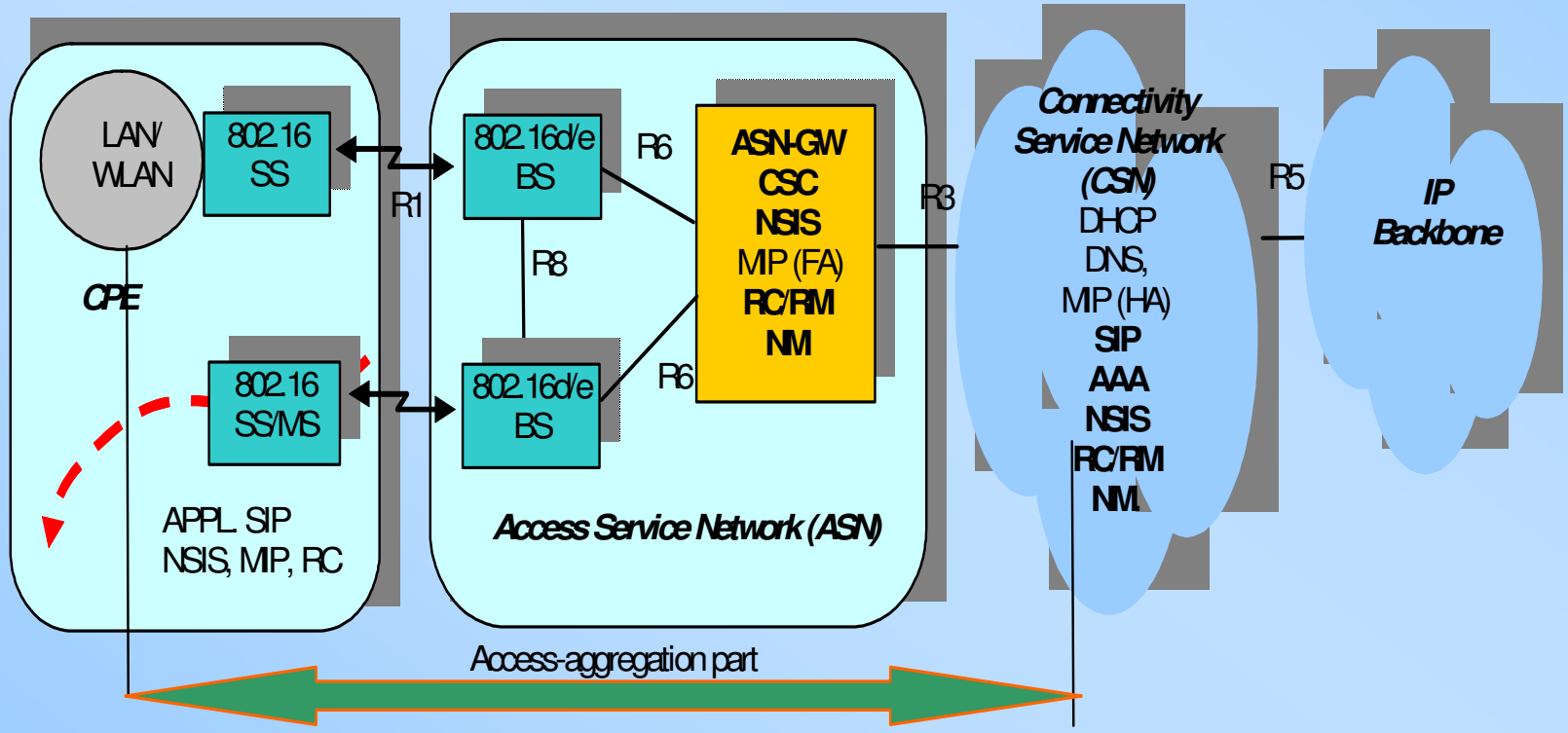
- *Summary of ASN-GW functional decomposition:*
  - Intra ASN Location Management & Paging
  - Network Session/Mobility Management (server)
  - Regional Radio Resource Management & Admission control
  - ASN Temporary Caching subscriber profile and encryption keys (ASN like-VLR)
  - AAA Client/Proxy: delivery Radius/Diameter messaging to selected CSN AAA
  - Mobility Tunneling establishment and management with BSs
  - Session/mobility management (client)
  - QoS and Policy Enforcement
  - Foreign Agent (FA) (with Proxy MIP)
  - Routing to selected CSN

- **Connectivity Services Network (CSN)**
- **Network infrastructure to provide IP connectivity services to the WiMAX subscriber(s)**
  - MS IP address and endpoint parameter allocation for user sessions (IP address management based on PoA management)
  - Connectivity to Internet, ASP and other PLMNs and Corporate Networks
  - User, equipment and services - Authentication, authorization and accounting (AAA): proxy or server
  - Policy and Admission Control based on user subscription profiles
  - QoS management based on the SLA/contract with the user
  - ASN-CSN tunneling support
  - WiMAX subscriber billing and inter-operator settlement

- ***CSN (cont'd)***
  - Inter-CSN tunneling for roaming (between NSPs)
  - Inter-ASN mobility and roaming (including connectivity and transport between multiple ASN coverage zones - subject to hierarchical structure)
  - Offering WiMAX services such as
    - location based services (a service provided to a subscriber based on the current geographic location of the WiMAX client device)
    - connectivity for peer-to-peer services
    - provisioning
    - authorization and/or connectivity to IP multimedia services
    - facilities to support lawful intercept services
  - CSN network elements may be: routers, AAA proxy/servers, user databases, Interworking gateway

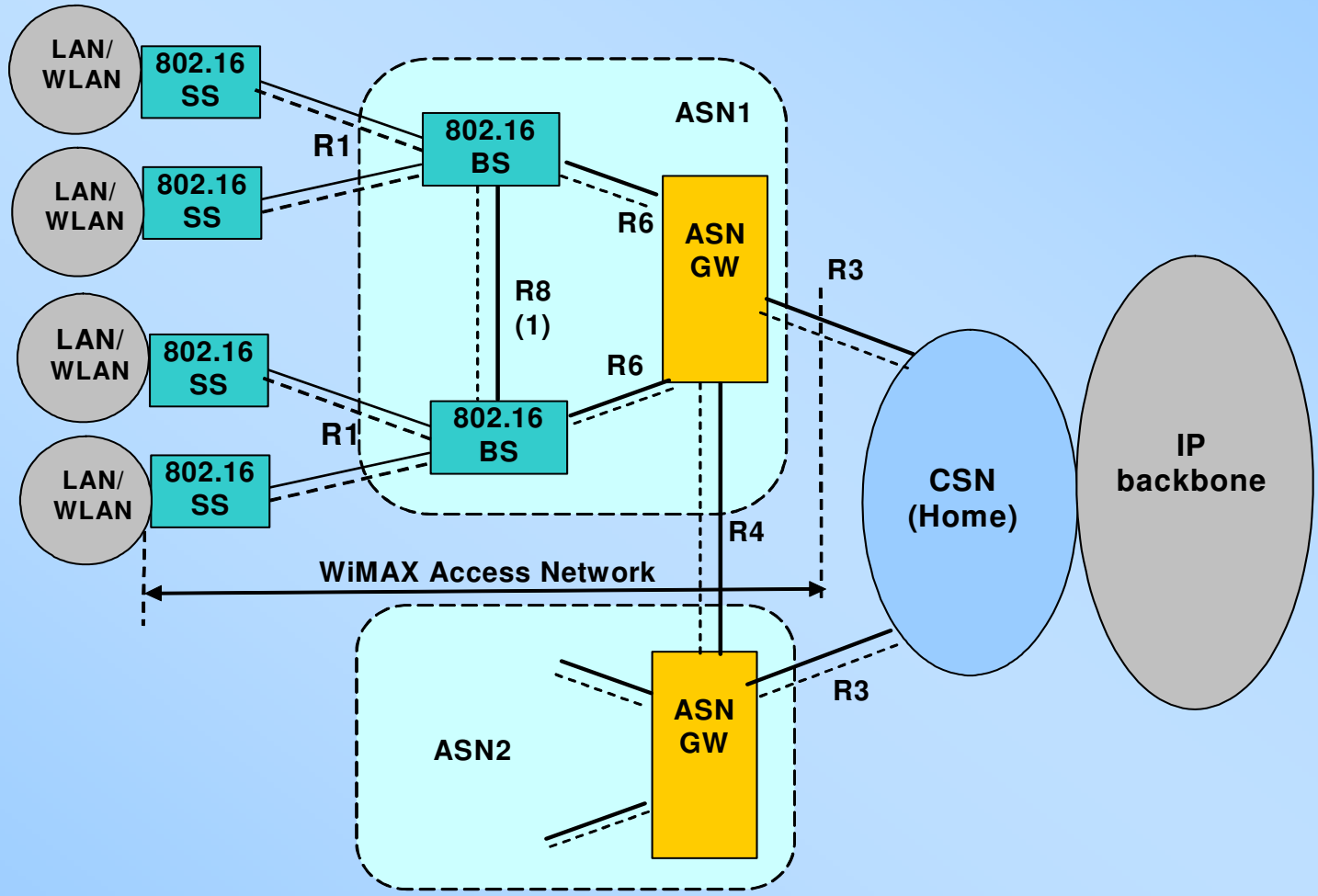
7. IEEE 802.16/WiMAX Integration in E2E Architectures

Example of function distribution in ASN and CSN



7. IEEE 802.16/WiMAX Integration in E2E Architectures

Example of a multiple ASN configuration



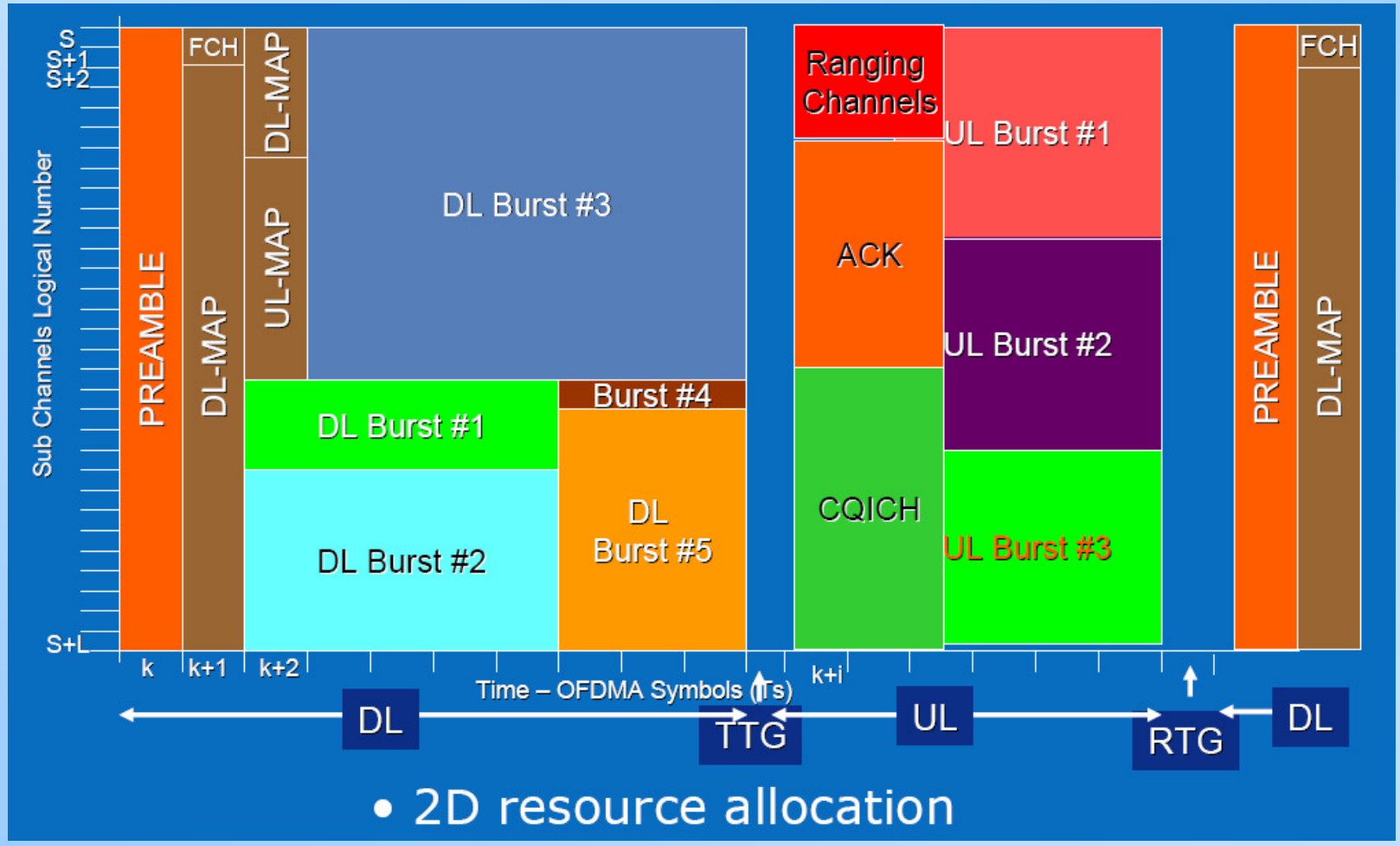
CONTENTS

8. Micro and Macro-mobility

- **IEEE 802.16e main features**
  - **Scalability**
    - Scalable PHY for capable of 1.25-20 MHz
    - Mobile WiMAX Global Profiles of 5 & 10MHz proposed
    - Flexible frequency re-use schemes for network planning
  - **Higher data rates**
    - Larger MAC frames with low overhead, Advanced FEC (CTC),
    - Adaptive modulation, H-ARQ for reducing packet loss,
    - Full MIMO and Beamforming support
  - **QoS**
    - Traffic types, QoS with Service Flows, Advanced Scheduling Framework,
    - Adaptive Modulation & Coding, ARQ, H-ARQ
  - **Mobility**
    - Secure Optimized Hard Handover,
    - Fast BS Switching Handover,
    - Power Management with Sleep and Idle modes
  - **Security**
    - EAP authentication, Encryption with AES-CCM,
    - CMAC Authentication mode, X.509 Certificates, Key Binding,
    - Device and User authentication capability

8. Micro and Macro-mobility

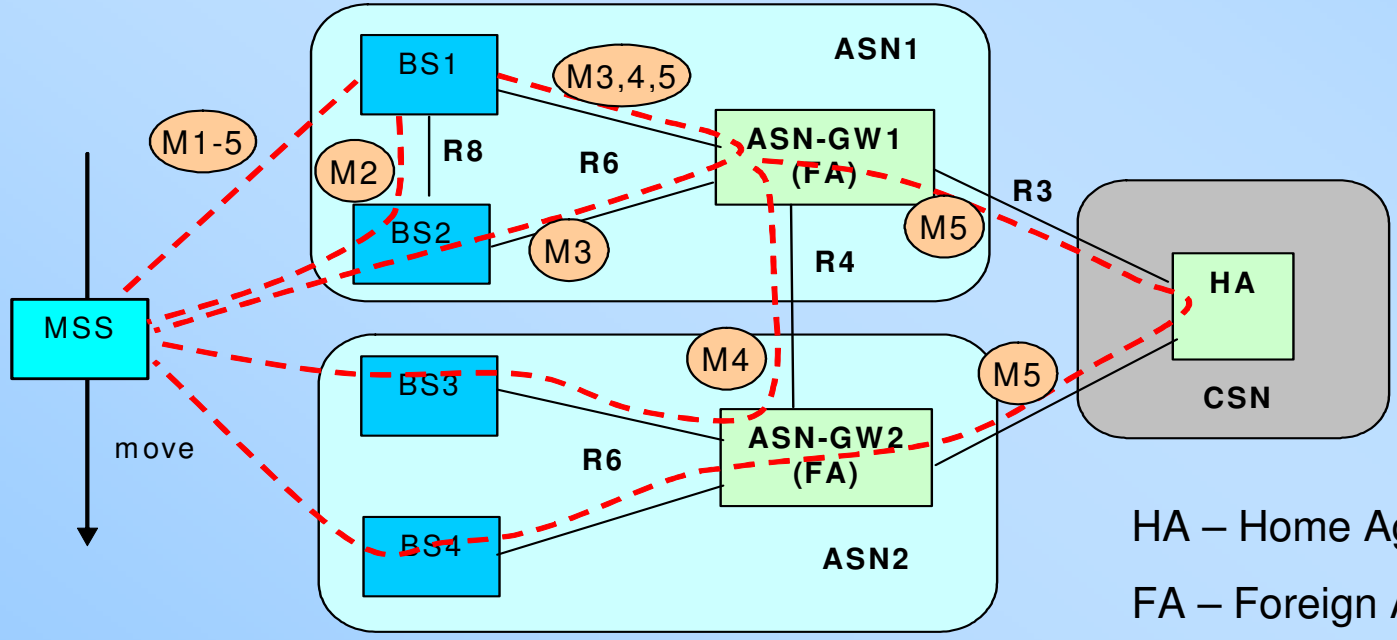
- **IEEE 802.16e main features**
  - **Frame structure**



8. Micro and Macro-mobility

Possible 802.16/MIP mobility cases:

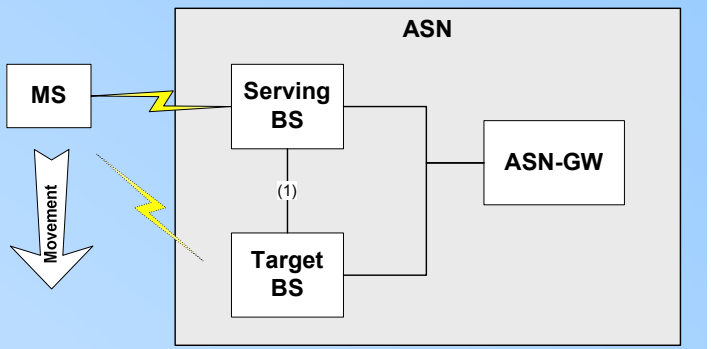
- M1 – intra BS – this is a micro-mobility solved “behind” a given instance of BS
- M2 – inter-BS, intra-ASN – via R8 I/F
- M3 – inter-BS, intra-ASN via R6 and ASN-GW
- M4 - inter-BS, inter-ASN via R6 , ASN-GW1, R4, ASN-GW2, R6..
- M5 – inter-BS inter-ASN plus **IP mobility (MIP v4/6)**



8. Micro and Macro-mobility

- **Mobility types**
- **Micro-mobility or ASN anchored mobility**
  - CSN is unaware of this mobility because there is no change of the Foreign Agent (FA)
  - RP involved: R6 (BS and ASN-GW) and the R8 (between BSs) for HO functions, context transfer, and data path registrations
  - This kind of mobility is provided mainly by the mobility features supported by the mobile WiMAX profile
  -
- **Macro-mobility or CSN anchored mobility**
  - occurs when the MS changes to a new FA
  - mobility IP facilities are required
  - includes the the IEEE 802.16e mobility and WiMAX mobility together with the MIP mgmt. facilities
  - These are specified in the mobile WiMAX profile

8. Micro and Macro-mobility



- **Micro-mobility**
- HO modes specified in the IEEE 802.16e-2005
  - Hard handover mode (HHO)
  - Fast Base Switching (FBSS)
  - Macro Diversity handover (MDHO)
- HHO
  - mandatory HO - "break-before-make HO"
  - abrupt transfer of connection from one BS to another
  - HO decisions : BS, MS, or another entity, based on measurement results reported by the MS
  - The MS periodically scans a radio frequency (RF) and measures the signal quality of neighboring BSes
  - Scanning is performed during *scanning intervals* allocated by the BS
  - While scanning, the MS is also allowed to optionally perform initial ranging and to associate with one or more neighboring BSes
  - After HO decision the MS
    - begins synchronization with the DL of the target BS
    - performs ranging if it was not done while scanning
    - then terminates the connection with the previous BS
  - Any undelivered MPDUs at the BS are retained until a timer expires

8. Micro and Macro-mobility

- **Micro-mobility**
- **Fast Base Station Switching (Optional)**
  - MS and BS maintain a list of BSs involved (Active Set) and monitors them
  - An Anchor BS (ABS) is defined (to this the MS is registered, synchronized, performs ranging and monitors the downlink for control information
  - ABS = serving BS : transmit/receive data to/from the MS
  - HO from one ABS to another (i.e. BS switching) is performed without invocation of explicit HO signaling messages
  - Anchor update procedures are enabled by signal strength of the serving BS via the Channel Quality Indicator (CQI) channel
  - HO begins with a decision by an MS to receive or transmit data from the Anchor BS that may change within the active set
  - MS scans the neighbor BSs and selects those that are suitable to be included in the active set
  - MS reports the selected BSs and the active set update procedure is performed by the BS and MS
  - MS continuously monitors the signal strength of the BSs that are in the active set and selects one BS from the set to be the Anchor BS
  - MS reports the selected Anchor BS on CQI or MS initiated HO request message

8. Micro and Macro-mobility

- **Micro-mobility**
- **Macro Diversity Handover (MDHO)**
  - The process in which a MS migrates from the air-interface provided by one or more BS to the air-interface provided by one or more other BSs
  - MS and BS maintain an active set of BSs, with an anchor BS defined and the MS communicates with all BSs in the active set of uplink and downlink unicast messages and traffic
  - MDHO begins when a MS decides to transmit or receive unicast messages and traffic from multiple BSs in the same time interval
  - DL: two or more BSs provide synchronized transmission of MS DL data such that diversity combining is performed at the MS
  - UL: the transmission from a MS is received by multiple BSs where selection diversity of the information received is performed

8. Micro and Macro-mobility

- **HO initiator**

Network Initiated Handover

- HO decision is based on the uplink (UL) channel quality measurements at the BS.
- HO is decided by the network control system (NCS) co-operating with the ASN-GW
- HO: inter-BS, intra-ASN-GW and inter-ASN-GW
  - inter-BS HO: MS is moved from one BS to the other BS
  - Inter-ASN-GW HO: the path moves through the different ASN-GWes , controlled by the NCS.

Mobile Assisted Handover

- MS participates in the HO decision by sending the CSI-feedback, including the DL channel quality measurements to the BS
- The CSI-feedback is delivered in channel quality information channel (CQICH) in the PHY UL frame
- NCS and ASN-GW use an I/F (SNMP, etc.) to control and manage the related BS, SS/MS and CPE in the sub-networks
- The management actions are made horizontally via the available management I/F of the related WiMAX equipment.

8. Micro and Macro-mobility

- **HO initiator**
- **Mobile Controlled Handover**
  - MS takes the HO decision
  - MS is aware of the candidate BSs, maintaining a list of the potential BSs
  - MS would aid also from being aware of the potential ASN-GWs and NCSs
  - MS needs info for HO decisions
    - some conventional sub-set of link QoS
    - CSI
    - application QoS parameter values.
  - MS takes HO decision based on input info and the defined thresholds
  - MS triggers the HO to the appropriate BS (need a sgn. link MS/ and ASN-GW
  - NCS is aware of the changes in its sub-networks, requiring a link also between the ASN-GW and NCS systems.

Backup Slides

2. Main Standards in BWA

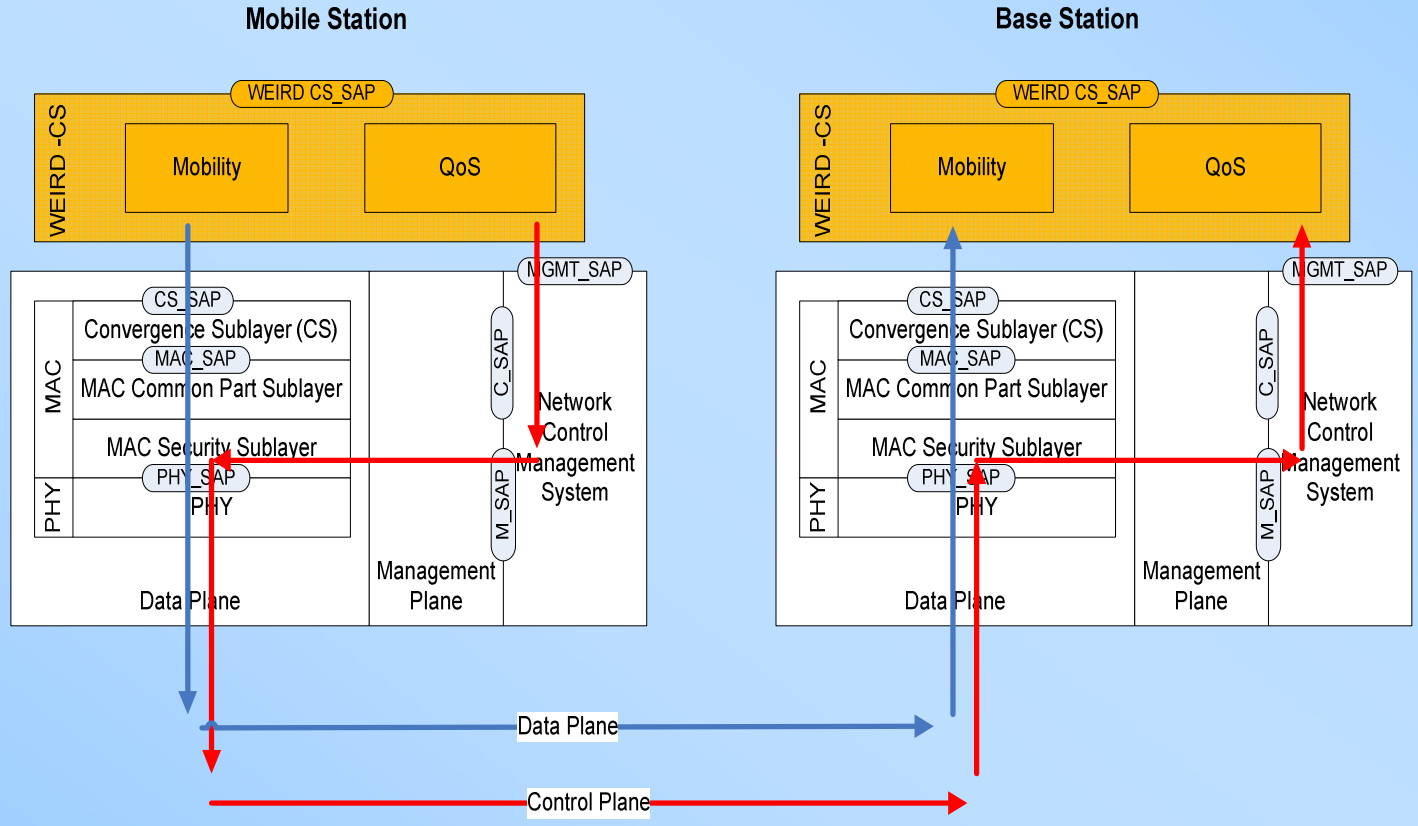
- **Other BWA relevant standards**
- **ETSI Broadband Radio Access Networks (BRAN) – HIPERACCESS**
  - BB multimedia fixed wireless access
  - PMP, fixed wireless and high-QoS access up to 120 Mbps (25 Mbps typical data rate) for residential and small business users
  - Access to : UMTS core networks, ATM networks, IP based networks, Supporting MM applications.
  - licensed bands above 11 GHz (e.g., 26, 28, 32, 42 GHz)
  - high spectral efficiency under LOS (Line Of Sight) conditions
  - many commonalities with IEEE 802.16
  - difference: HIPERACCESS it is based on fixed size PDUs (i.e. optimization for ATM and CES traffic as well as IP)
  - 802.16 - variable size PDUs (i.e. optimisation for IP only stations)
  - ETSI BRAN cooperates with IEEE-SA (Working Group 802.16) to harmonize the interoperability standards for broadband multimedia fixed wireless access networks.

2. Main Standards in BWA

- **Other BWA relevant standards**
- **ETSI Broadband Radio Access Networks (BRAN) – HIPERMAN**
  - interoperable fixed BWA system, 2 -11 GHz
  - provisioning to SMEs and residences using the basic MAC (DLC and CLs) of the IEEE 802.16-2001 standard
  - developed in cooperation with IEEE 802.16 (they can will interoperate seamlessly)
  - supporting ATM, though the main focus is on IP traffic
  - **It offers :**
    - various service categories with full QoS
    - fast connection control management, strong security
    - fast adaptation of coding, modulation and transmit power to propagation conditions
    - LOS/NLOS operation
    - PMP and Mesh network configurations
    - FDD and TDD frequency allocations and H-FDD terminals
    - HIPERMAN ≈ WiMAX's equivalent or competitor in Europe
    - Active liaisons between the two groups leads to seamless interoperation

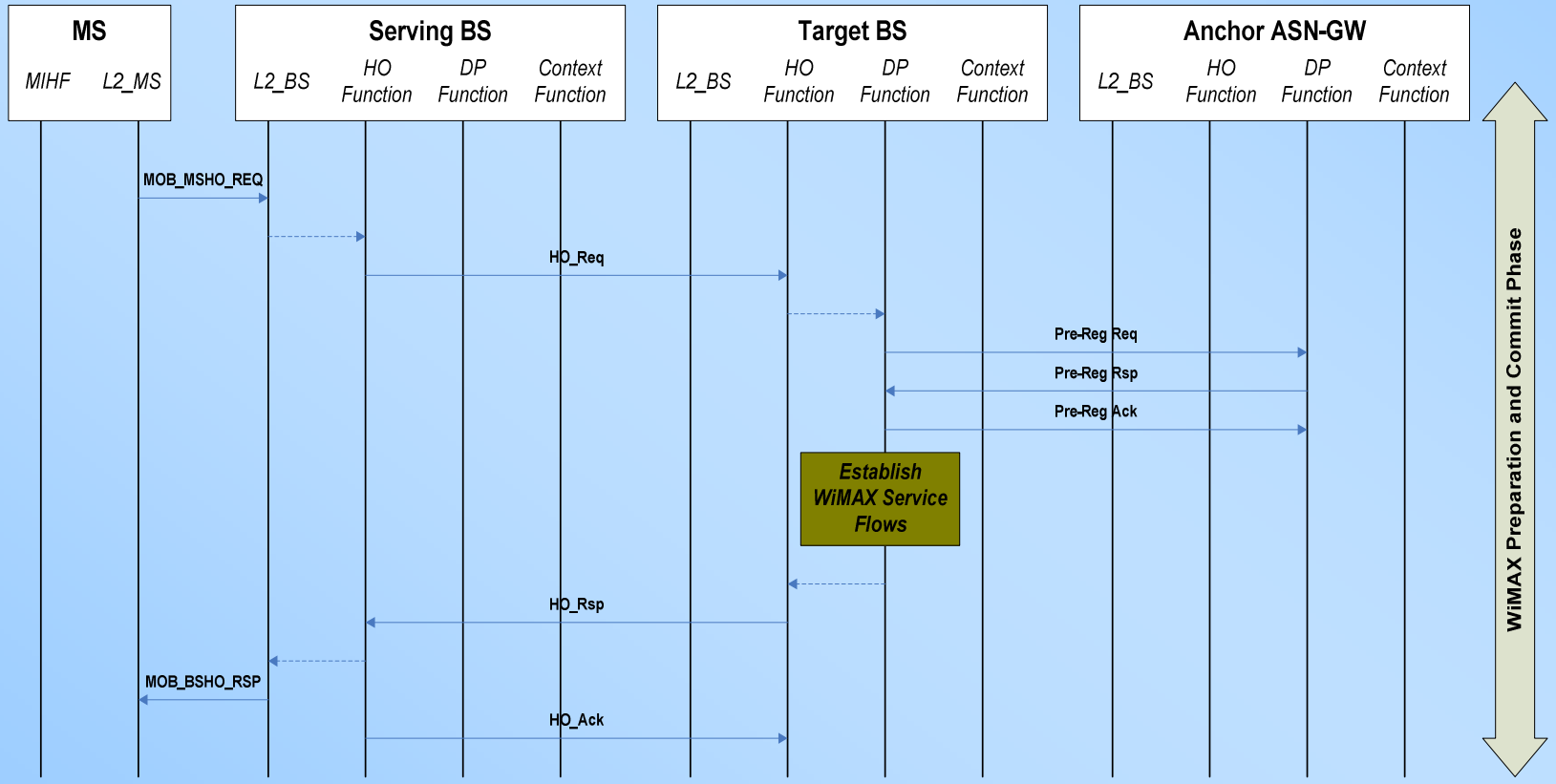
8. Micro and Macro-mobility

- **Protocol stack - example: WEIRD project**



8. Micro and Macro-mobility

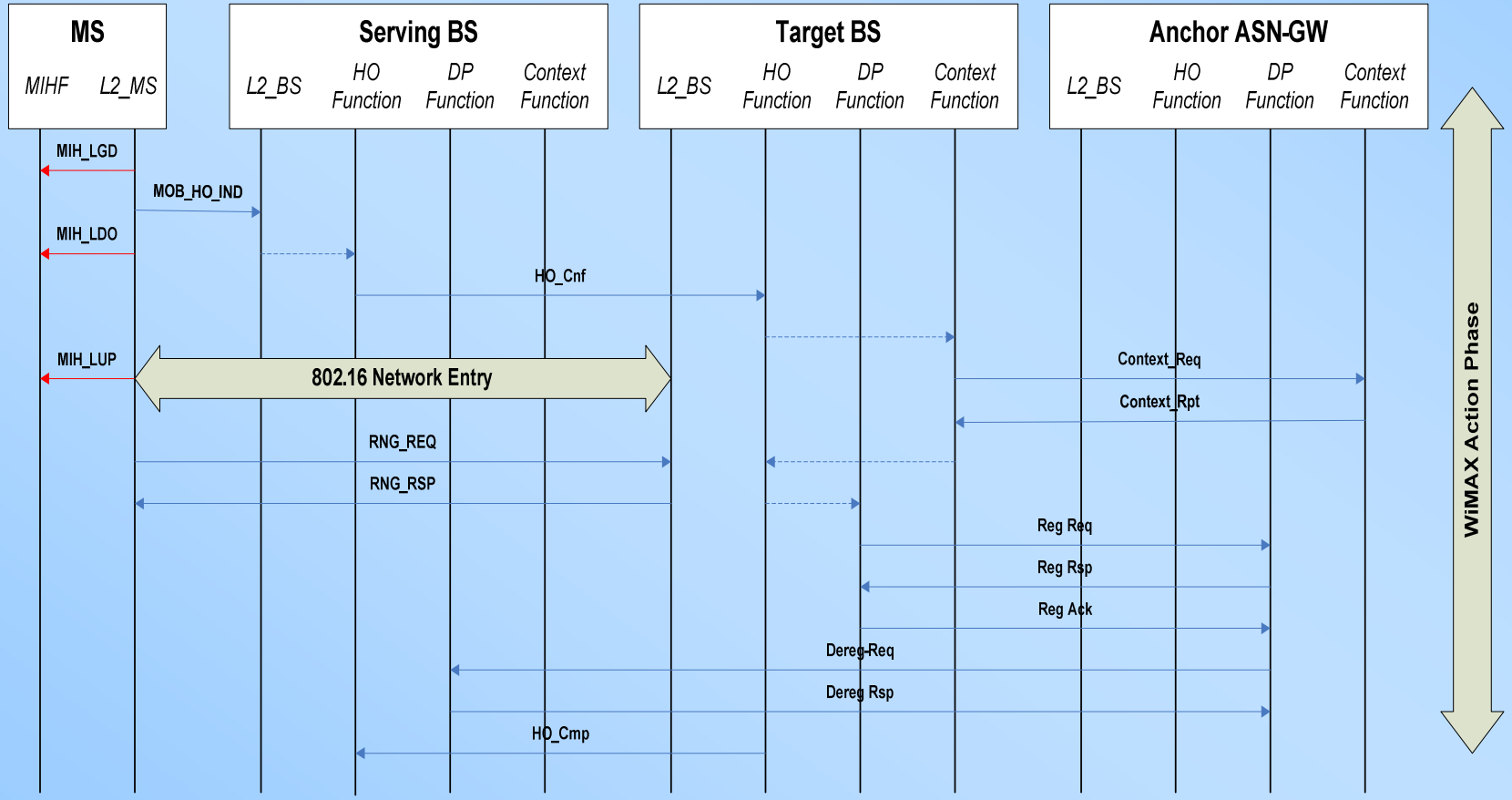
- **Micro-mobility: WiMAX Forum approach- scenario example**
  - Preparation/commit phase



8. Micro and Macro-mobility

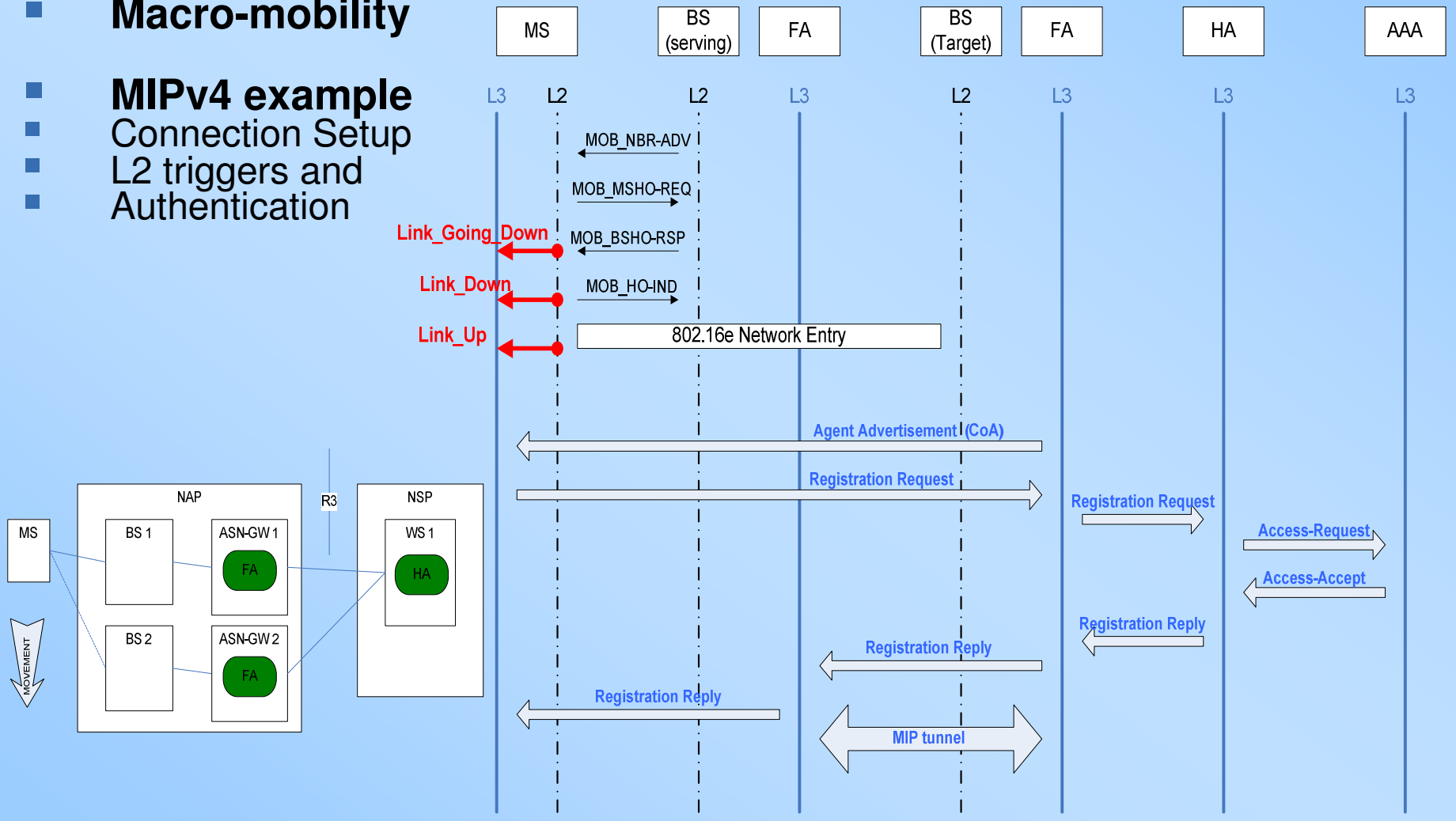
Micro-mobility: WiMAX Forum approach - scenario example

- Action phase



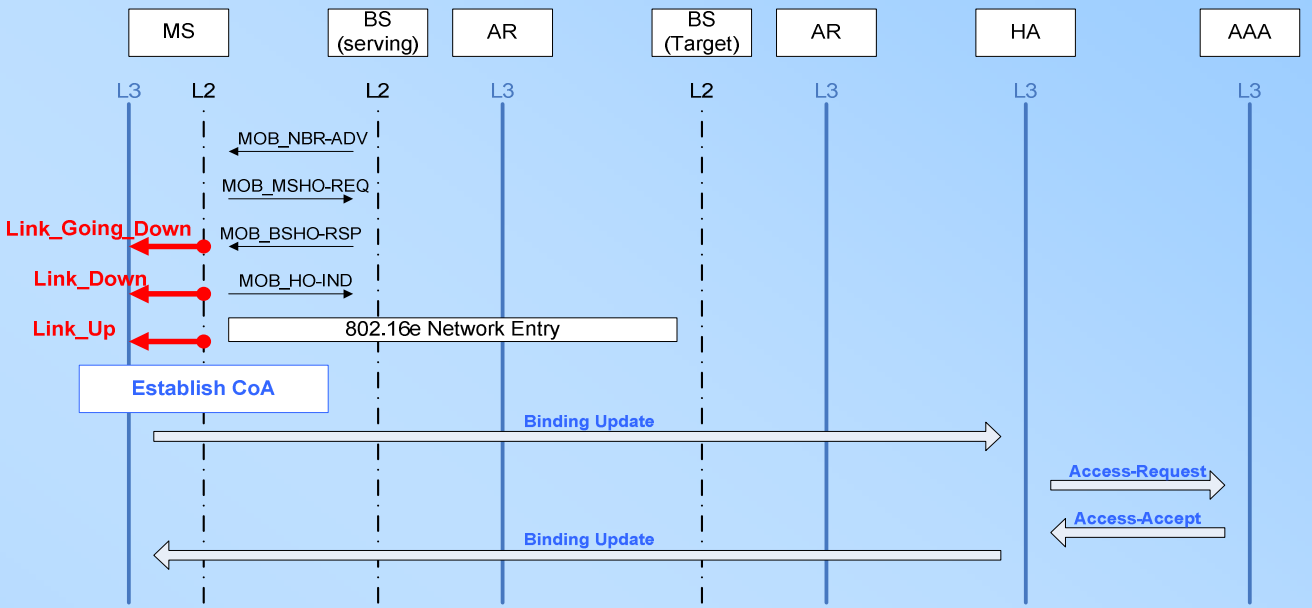
8. Micro and Macro-mobility

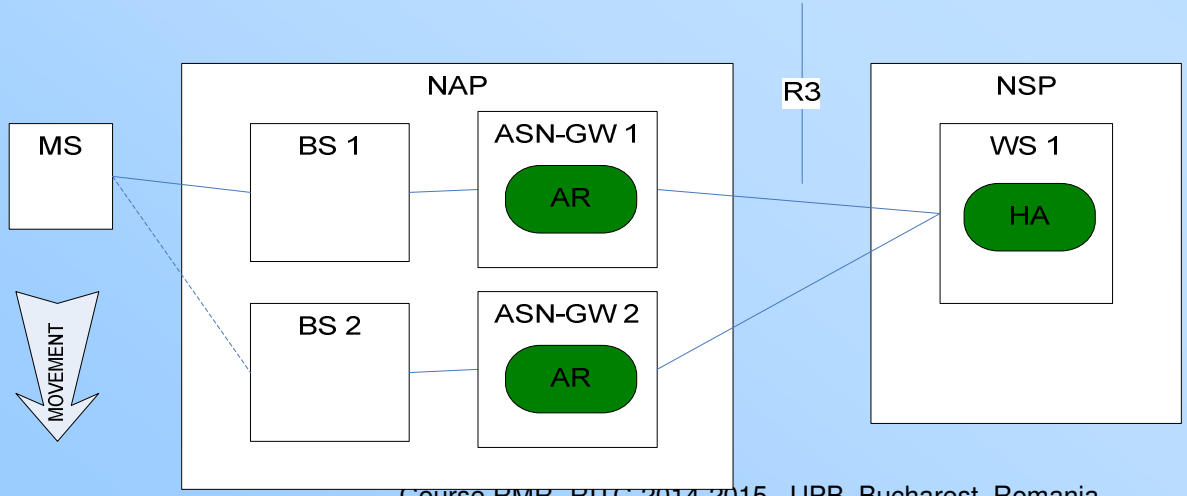
- **Macro-mobility**
- **MIPv4 example**
- Connection Setup
- L2 triggers and
- Authentication



8. Micro and Macro-mobility

- **Macro-mobility**
- **MIPv6 example**
- Connection Setup
- L2 triggers and
- Authentication





Acronym List

- NOTATIONS
  - SIP –Session Initiation Protocol
  - SDP - Session Description Protocols
  - UA – User Agent
  - AF – Application Function
  - PF – Policy Function

  - MS – Mobile Station
  - SS – Subscriber Station
  - BS – Base Station
  - DNS – Domain Name Server
  - PDF - Policy Decision Function
  - CSN – Connectivity Services Network
  - ASN – Access Services Network
  - AAA – Authentication, Authorization, Accounting
  - CSC -ASN Connectivity Service Controller of ASN
  - AC - Admission Control
  - SC – Session Control
  - DHCP – Dynamic Host Configuration Protocol
  - QoS - Quality of Services

Acronym list

- NOTATIONS
  - NSIS – Next Step in Signalling
  - NSLP - NSIS Signalling Layer Protocol
  - NTLP – NSIS Transport Layer Protocol
  - GIST - General Internet Signaling Protocol

  - NMS - Network Management System
  - NRM - Network Reference Model

  - FA - Foreign Agent
  - HA – Home agent
  - MM - Mobility Management
  - RC – Resource Controller
  - TC - Traffic Control (Diffserv blocks)
  - PHB - Per Hop Behaviour
  - PEP - Policy Enforcement Point
  - MON - Monitoring

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