# WiMAX Technologies: Architectures, Protocols, Resource Management and Applications

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# Presentation objectives

- Basic architectural stacks of IEEE 802.16 and WiMAX Forum
- Application supported
- Current state of the art
  - Architecture and protocols
    - Point to multipoint and focus on layer two and above
    - Related protocols
    - Resource management and QoS
    - End to end aspects
    - Mobility
    - Mesh topologies
    - Examples
- Future trends

# CONTENTS

1. Introduction
2. Main standards in BWA
3. WiMAX Supported Applications
4. Basic IEEE 802.16 and WiMAX Forum Architectures
5. Summary of PHY,  MAC and Convergence Layers
6. Resource Management and Control, QoS
7. IEEE 802.16/WiMAX Integration in E2E Architectures
8. Micro and Macro-mobility
9. Media Independent Handover
10. Mesh Mode
11. WiMAX versus other Broadband Technologies
12. Future Trends: WiMAX and  4G networks

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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
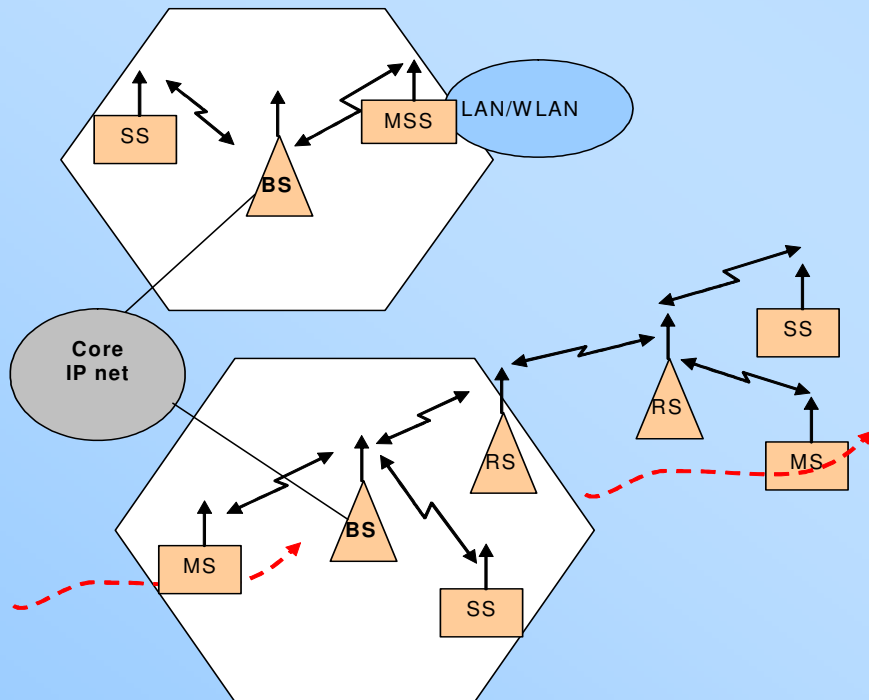
- Line of Sight (LOS) and Non LOS

# 1. Introduction

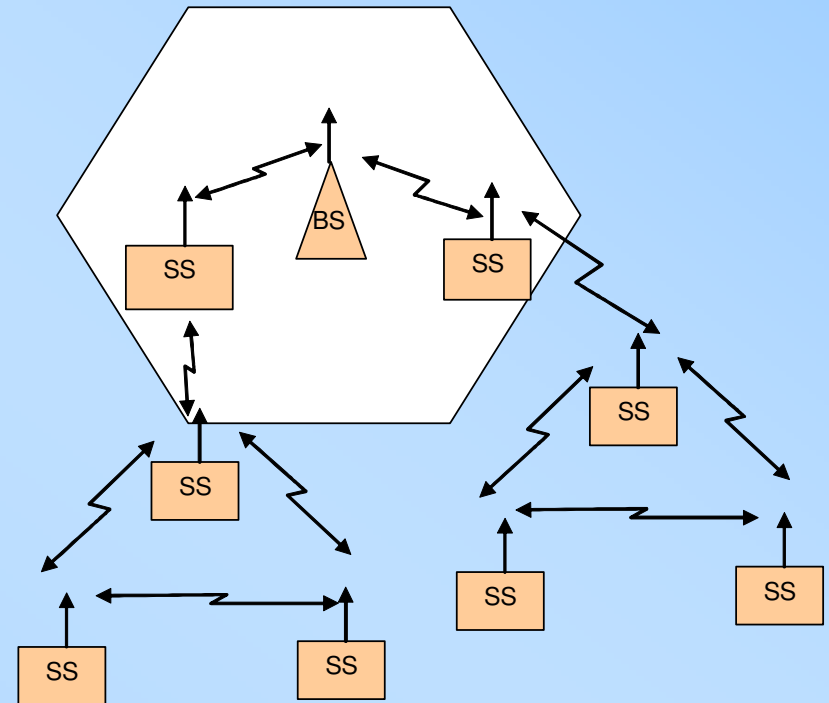## Basic 802.16 topologies and basic components

- Operation modes/topologies

**Point-to-multipoint (PMP)**

**Mesh topology**



**Mobile Multihop Relay (MMR)**

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12. Future Trends: WiMAX and 4G networks

# 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**

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# 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
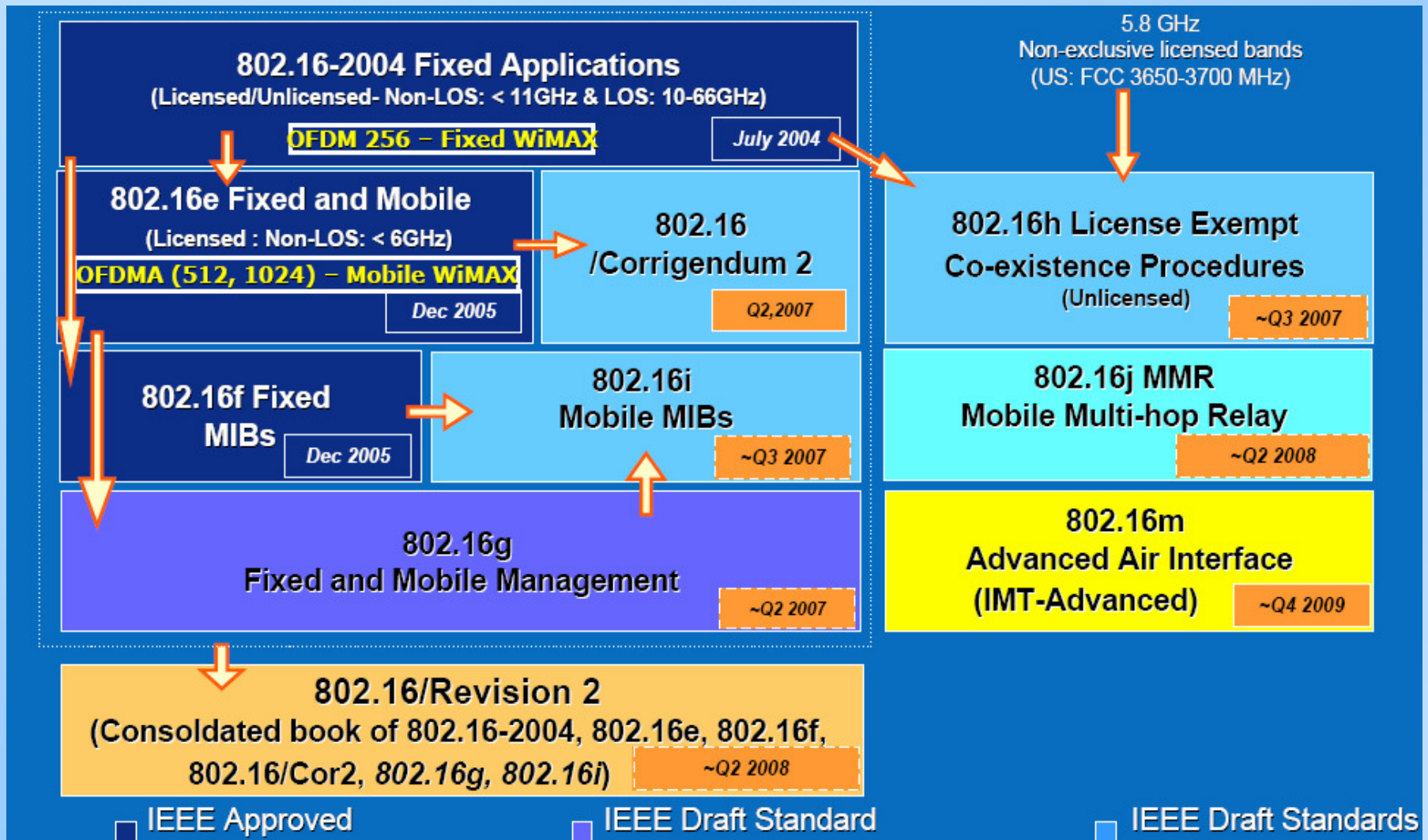
# 2. Main Standards in BWA

- **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**
    - 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

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



**802.16-2004 Fixed Applications**
(Licensed/Unlicensed- Non-LOS: < 11GHz & LOS: 10-66GHz)

OFDM 256 – Fixed WiMAX    July 2004

**802.16e Fixed and Mobile**
(Licensed : Non-LOS: < 6GHz)

OFDMA (512, 1024) – Mobile WiMAX    Dec 2005

**802.16 /Corrigendum 2**    Q2,2007

5.8 GHz
Non-exclusive licensed bands
(US: FCC 3650-3700 MHz)

**802.16h License Exempt Co-existence Procedures** (Unlicensed)    ~Q3 2007

**802.16f Fixed MIBs**    Dec 2005

**802.16i Mobile MIBs**    ~Q3 2007

**802.16j MMR Mobile Multi-hop Relay**    ~Q2 2008

**802.16g Fixed and Mobile Management**    ~Q2 2007

**802.16m Advanced Air Interface (IMT-Advanced)**    ~Q4 2009

**802.16/Revision 2**
(Consoldated book of 802.16-2004, 802.16e, 802.16f, 802.16/Cor2, 802.16g, 802.16i)    ~Q2 2008

IEEE Approved          IEEE Draft Standard          IEEE Draft Standards

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# 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

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10. Mesh Mode
11. WiMAX versus other Broadband Technologies
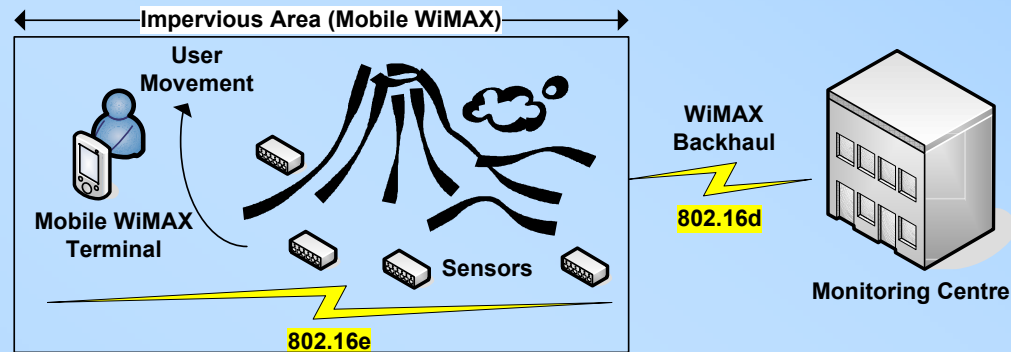12. Future Trends: WiMAX and  4G networks

# 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

**Impervious Area (Mobile WiMAX)**

User Movement

Mobile WiMAX Terminal

Sensors

WiMAX Backhaul

**802.16d**

**802.16e**

Monitoring Centre

## Telemedicine: Remote Assistance

**Patient Location**

**Hospital**

H

VoIP , data, image and video streaming
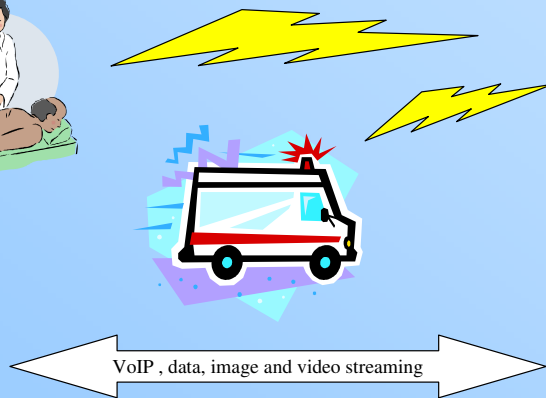
## Fire Prevention: Video Surveillance

Coordination Centre

802.16e

CC equipped with 802.16e BS

802.16e

802.16 e Mobile Video Camera

802.16e

802.16 e Mobile Video Camera

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11. Relevant Actors on WiMAX Market
12. Future Trends: WiMAX and 4G networks

- **IEEE 802.16 : PHY + MAC**
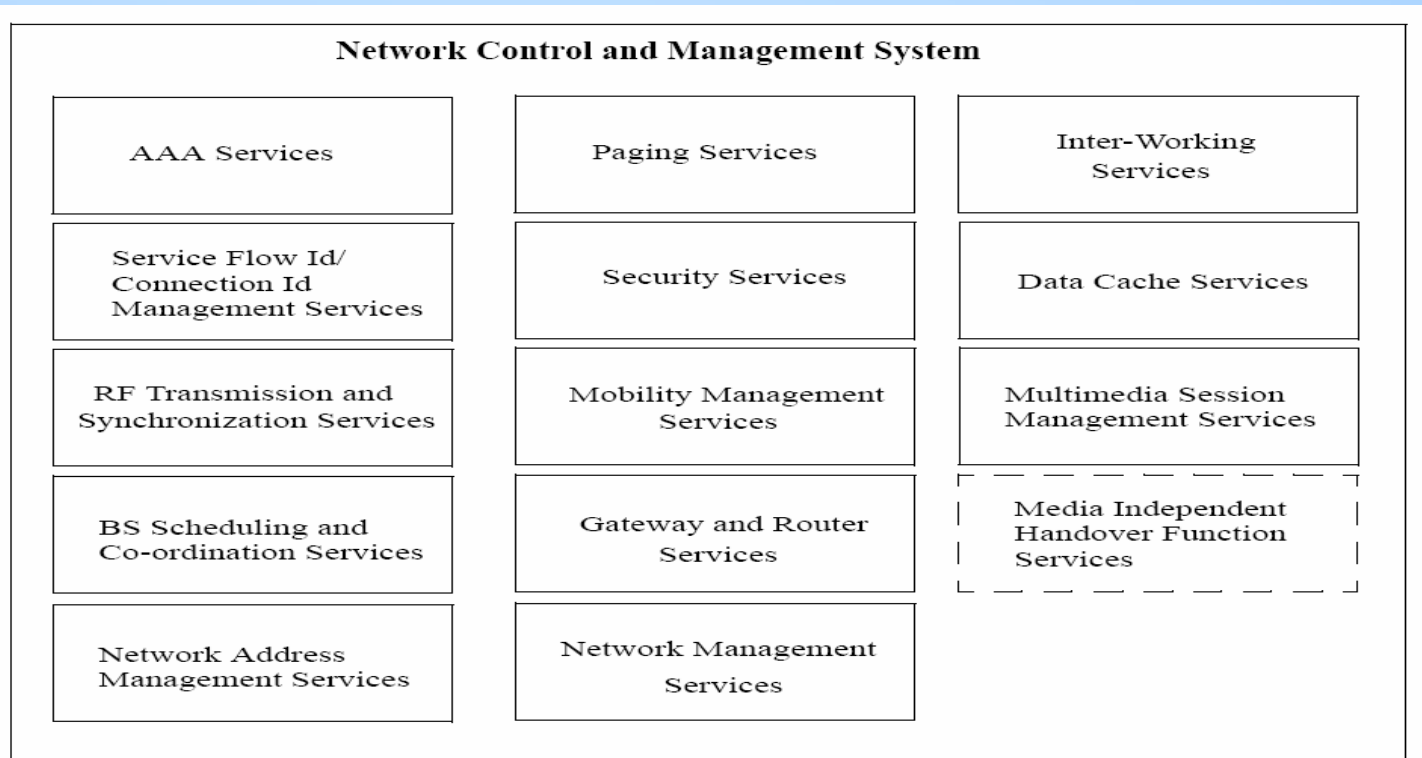- **Multiple plane architecture: Data Plane(DPl), Control Plane (CPl), Management Plane (MPl)**
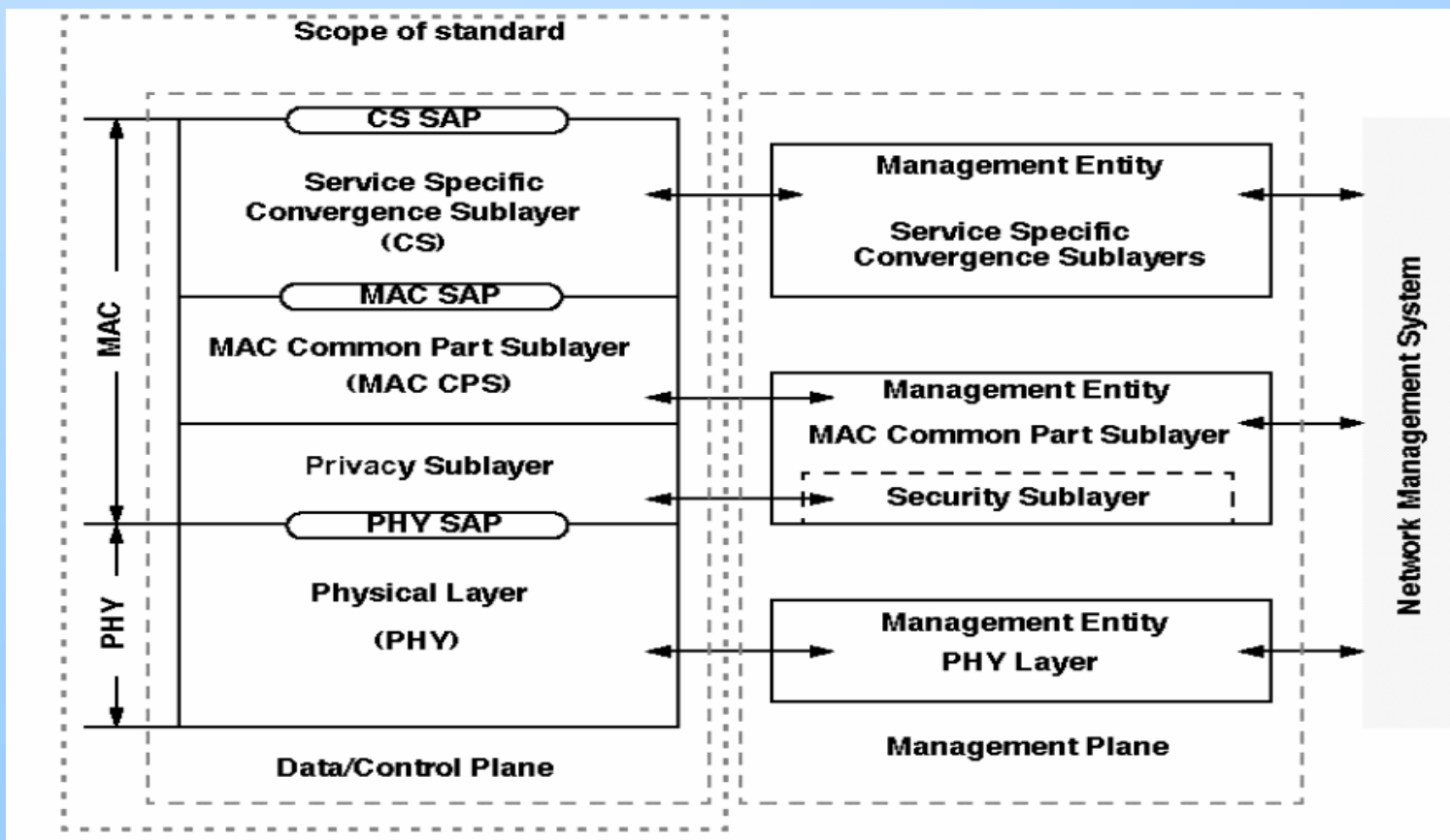
# 4. Basic IEEE 802.16 and WiMAX Forum Architectures
## IEEE 802.16/ WiMAX ForumNRM relationship

- 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
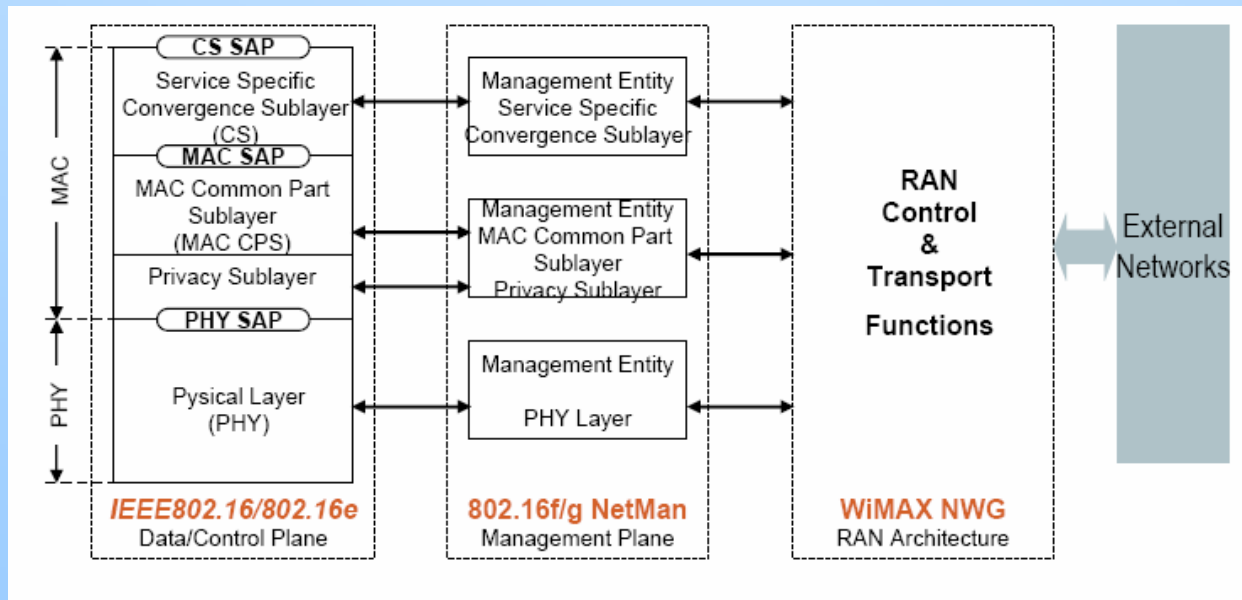
# 4. Basic IEEE 802.16 and WiMAX Forum Architectures

## 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)

### Network Control and Management System

| | | |
|---|---|---|
| AAA Services | Paging Services | Inter-Working Services |
| Service Flow Id/ Connection Id Management Services | Security Services | Data Cache Services |
| RF Transmission and Synchronization Services | Mobility Management Services | Multimedia Session Management Services |
| BS Scheduling and Co-ordination Services | Gateway and Router Services | Media Independent Handover Function Services |
| Network Address Management Services | Network Management Services | |

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

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- **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.
  - If the last FEC block is not filled, that block may be shortened
  - Shortening in both UL and DL is controlled by the BS and is implicitly communicated in the uplink map (ULMAP) and DL map (DL-MAP)

- ## 10–66 GHz
  - Frames duration: 0.5, 1, or 2 ms
  - The frame : divided in PHY slots (PS) for the purpose of 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

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# 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)
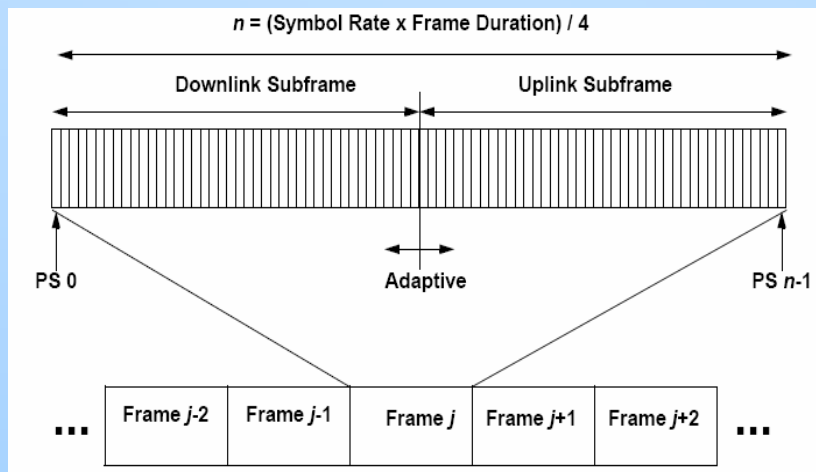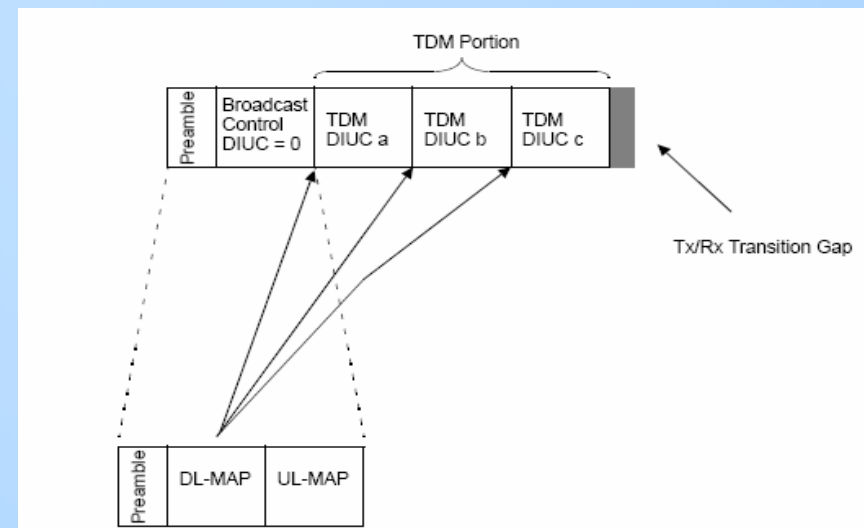


DIUC - Downlink Interval Usage Code
**TDD DL Sub-frame structure:**
*Frame Start Preamble:* synchro and equalization.
*Frame control section:* DL and UL maps stating the no. of the PSs at which bursts begin.

# 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** (IEEE Std 802.16-2001)
  - *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

- **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*
    - 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

- **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
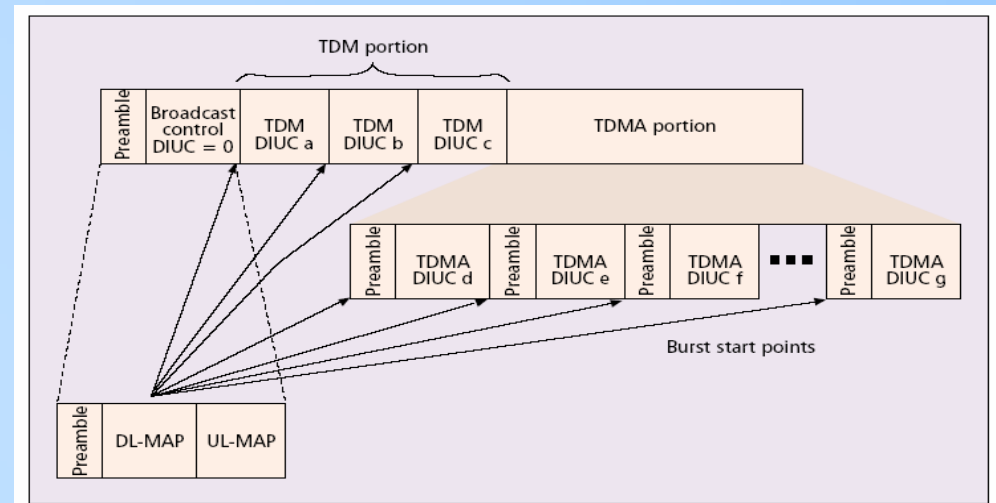


The FDD DL sub-frame structure

- 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
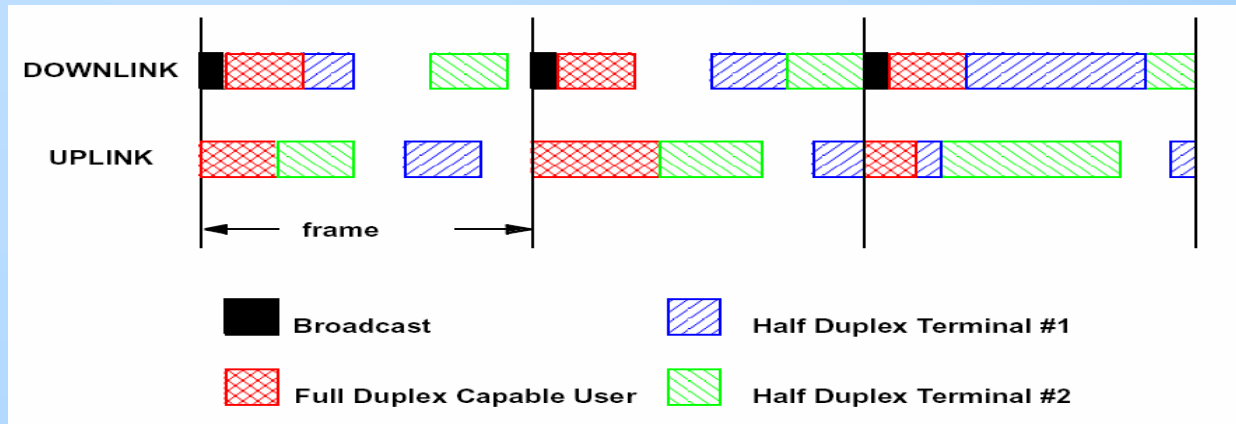


- **PHY Downlink modulation**
  - Multilevel constellation can be selected per SS based on the quality of the RF channel.
  - Better/worse link quality $\Rightarrow$ more complex/simple modulation scheme (max. achievable throughput )
  - BS shall support QPSK and 16-QAM and, optionally, 64-QAM
  - Possibility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

- **(10–66 GHz) Uplink Sub-frame**
- The SSs transmit in their assigned allocation 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
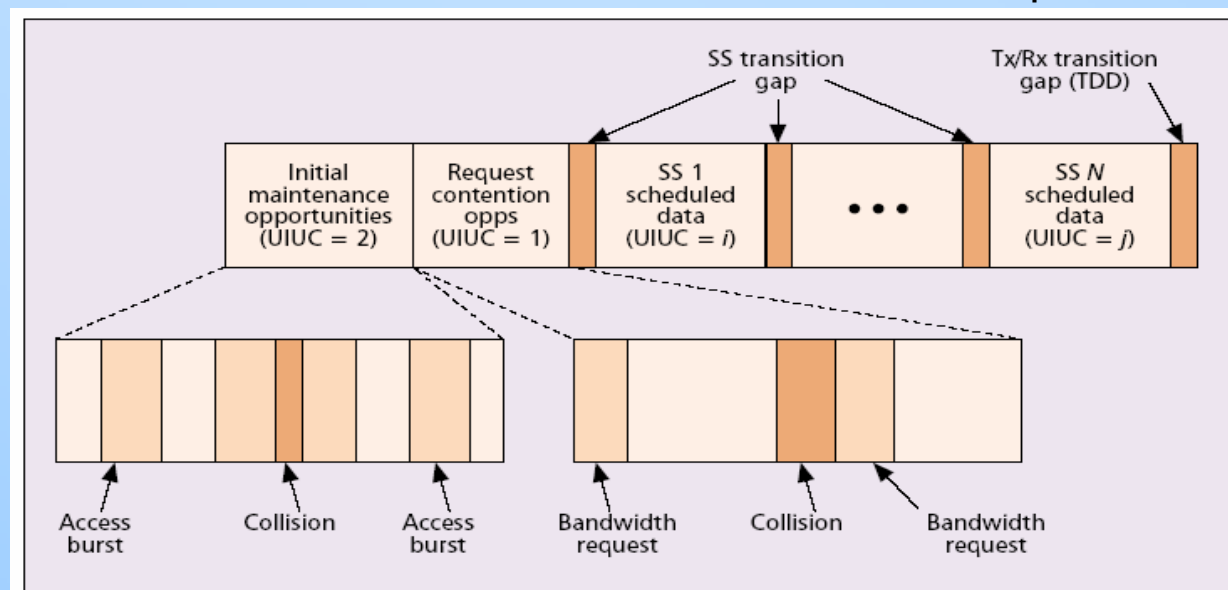
- **(10–66 GHz) Uplink Sub-frame**
- **Uplink Periods**
  - **Initial Maintenance Opportunities (IMO** - is subject to collisions)
    - Ranging
    - To determine network delay and to request power or profile changes.
  - **Request Opportunities (RO** – is subject to collisions)
    - SSs request bandwith in response to polling from BS.
  - **Data grants period** (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.
    - Any of these burst classes may be present in any given frame
      - in any order and any quantity (limited by the number of available PSs) within the frame
      - at the discretion of the BS uplink scheduler as indicated by the UL_MAP
  - The bandwidth allocated for IMO and RO may be grouped together and is always used with the uplink burst profiles specified by (UIUC=2) (UIUC=1)
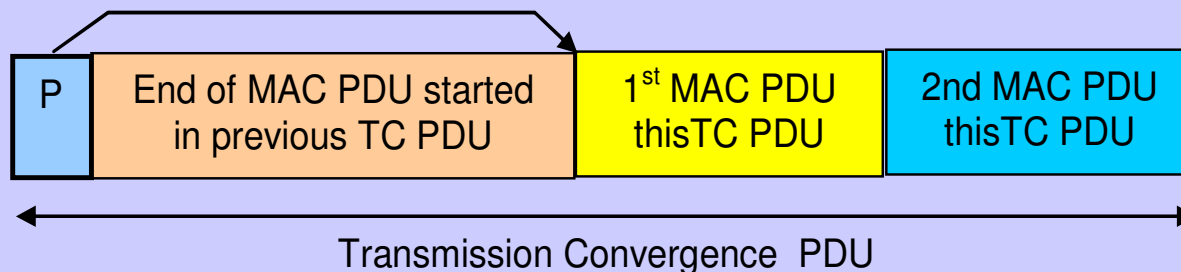  - During its scheduled interval, an SS transmits the burst profile specified by the BS

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

- **Transmission Convergence (TC)**
  - sublayer 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
  - TC layer has a PDU sized to fit in the FEC block currently being filled.
  - Pointer P indicates where the next MAC PDU header starts within this FEC block.
  - The TC PDU format allows resynchronization to the next MAC PDU if the previous FEC block had irrecoverable errors.
  - Without the TC layer, a receiving SS or BS would potentially lose the entire remainder of a burst when an irrecoverable bit error occurred

| P | End of MAC PDU started in previous TC PDU | 1st MAC PDU thisTC PDU | 2nd MAC PDU thisTC PDU |
|---|---|---|---|

Transmission Convergence PDU

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

| | 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 |

- **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
    - (Virtual) Connection identified by CID
  - Uplink and down link radio channels in FDD 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.

- **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 shift (if necessary) to a more reliable one, although it may be less efficient

- **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
  - wide variety of request mechanisms: balancing the stability of contentionless access with the efficiency of contention- oriented access

- **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

  - Open issues exists in *scheduling* if consider
    - SOFDMA and time dimension
    - Recent advances of PHY ( MIMO, multi-radio, smart antennas, etc.)

- **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 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

- ## Common Part Sublayer
  - On the DL, data to SSs are multiplexed TDM
  - The uplink is shared between SSs in TDMA fashion.
  - 802.16 MAC is connection-oriented CO $\Rightarrow$ all services, including inherently connectionless services, are mapped to a connection.

  - This 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.

- **Management connections**

    - Upon entering the network, the SS is assigned three management connections in each direction

    - *1. Basic connection*: transfer of short, time-critical MAC and radio link control (RLC) messages

    - *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)*

- **Data connections**
  - SSs are *allocated transport connections for the contracted services*
  - *Connections are unidirectional* to facilitate different UL and DL QoS and traffic parameters
  - they are typically assigned to services in pairs.
  - 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.
  - Additional connections are reserved for
    - multicast
    - contention-based polling.
  - SSs may be instructed to join multicast polling groups associated with these multicast polling connections.

- *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

| HT = 0 (1) | EC (1) | Type (6) | Rsv (1) | CI (1) | EKS (2) | Rsv (1) | LEN msb (3) |
|---|---|---|---|---|---|---|---|
| LEN lsb (8) | | | CID msb (8) | | | | |
| CID lsb (8) | | | HCS (8) | | | | |
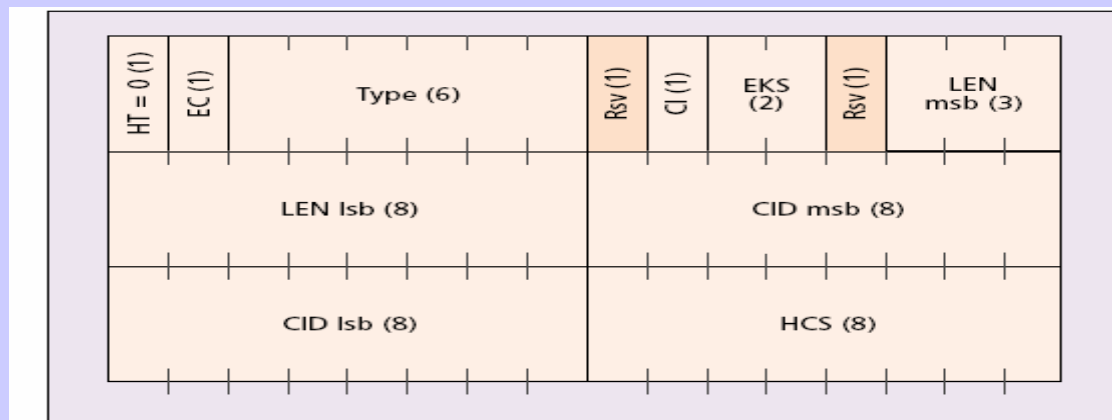
- **SS operation**
- **Network Entry**
- First action: an SS needs to successfully complete the network entry process with the desired BS
- Network entry process is divided into main phases:

  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

- ## Network entry process
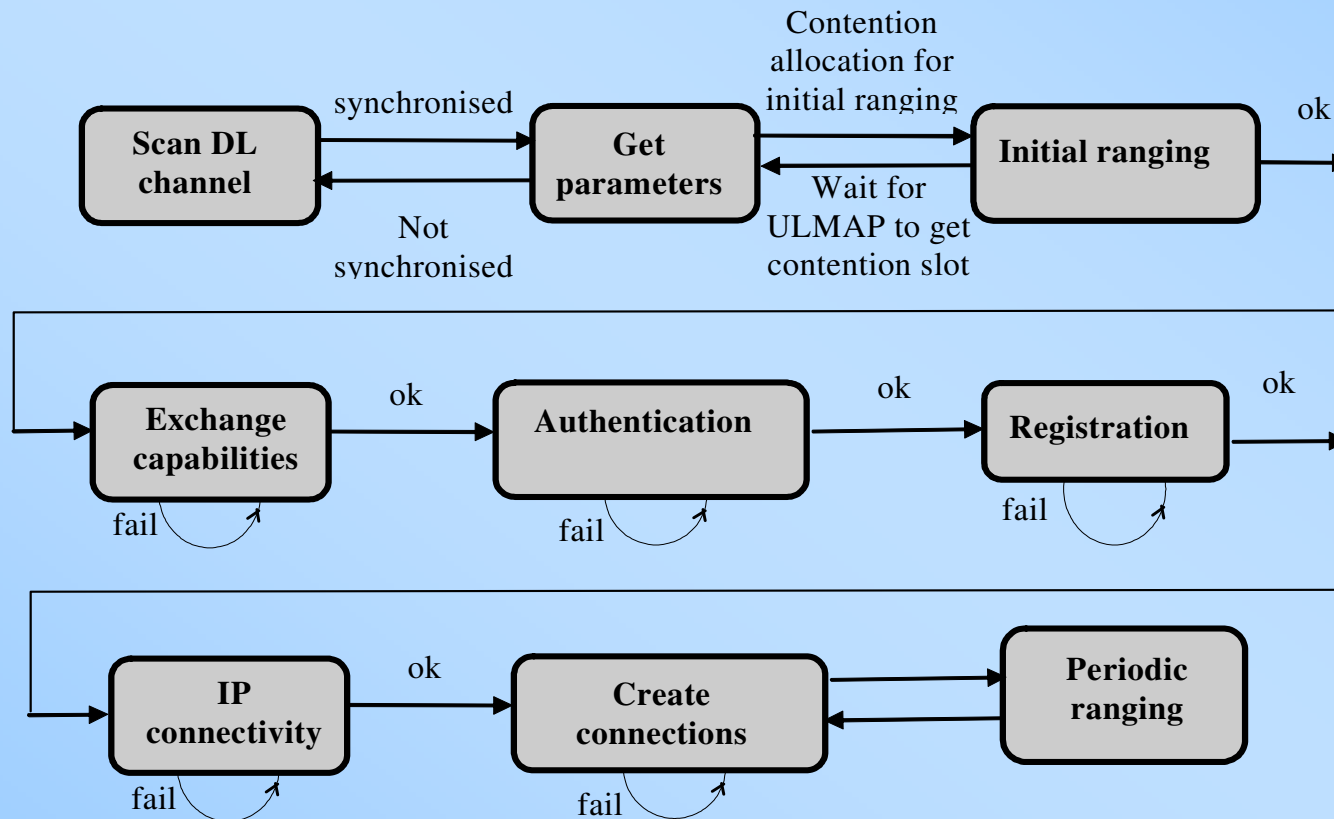
- **DL Channel Synchronization**
  - SS scanning for a channel (usually in a defined specific list of frequencies and BSes)
  - SS finds a DL channel and synchronizes (PHY)
  - MAC to get info on modulation and other DL and UL param. (from DCD and UCD)
- Initial Ranging
  - SS -> BS : *ranging request* MAC message on the initial ranging interval using the minimum transmission power and increasing it if necessary ( for a reliable communication BS-SS)
- **Capabilities Negotiation**
  - SS -> BS capability request message supported modulation levels, coding schemes and rates, and duplexing methods
  - BS accepts or denies the SS, based on its capabilities.
- **Authentication**
  - ***BS authenticates the SS*** and provides key material to enable the ciphering of data
  - SS ->BS: X.509 certificate of the SS manufacturer and a description of the supported cryptographic algorithms to its BS
  - The BS validates SS Id, determines the cipher algorithm and protocol to be used
  - SS <- BS: authentication response (keys to be used)
  - Periodical refresh of authentication.

- **Registration**
  - SS <-> BS: reg _req and reg_rsp
  - Info on : IPv4/.6 SS managed or non-managed support, ARQ, classification, CRC, and flow control.
- **IP Connectivity**
  - SS : DHCP (IETF RFC 2131) to get the IP_addr, etc.
  - BS ,SS maintain the current date and time (time of the day protocol - RFC868)
  - SS <- BS operational parameters using TFTP (IETF RFC 1350)
- **Transport Connection Creation**
  - ***pre-provisioned SF : process is initiated by the BS***
  - SS <-> BS dynamic SF **addition request message and confirmation**
  - non-pre-provisioned SF Connection creation : initiated by the SS –similar way

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12. Future Trends: WiMAX and 4G networks

# 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 with 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 is used. This will include applications such as Skype

# Scheduling Services (cont'd)

| 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

## Scheduling Services (cont'd)

802.16 QoS
mechanism

for MM services,
:TDM voice, VoIP,
video streaming,
TFTP, HTTP, e-mail
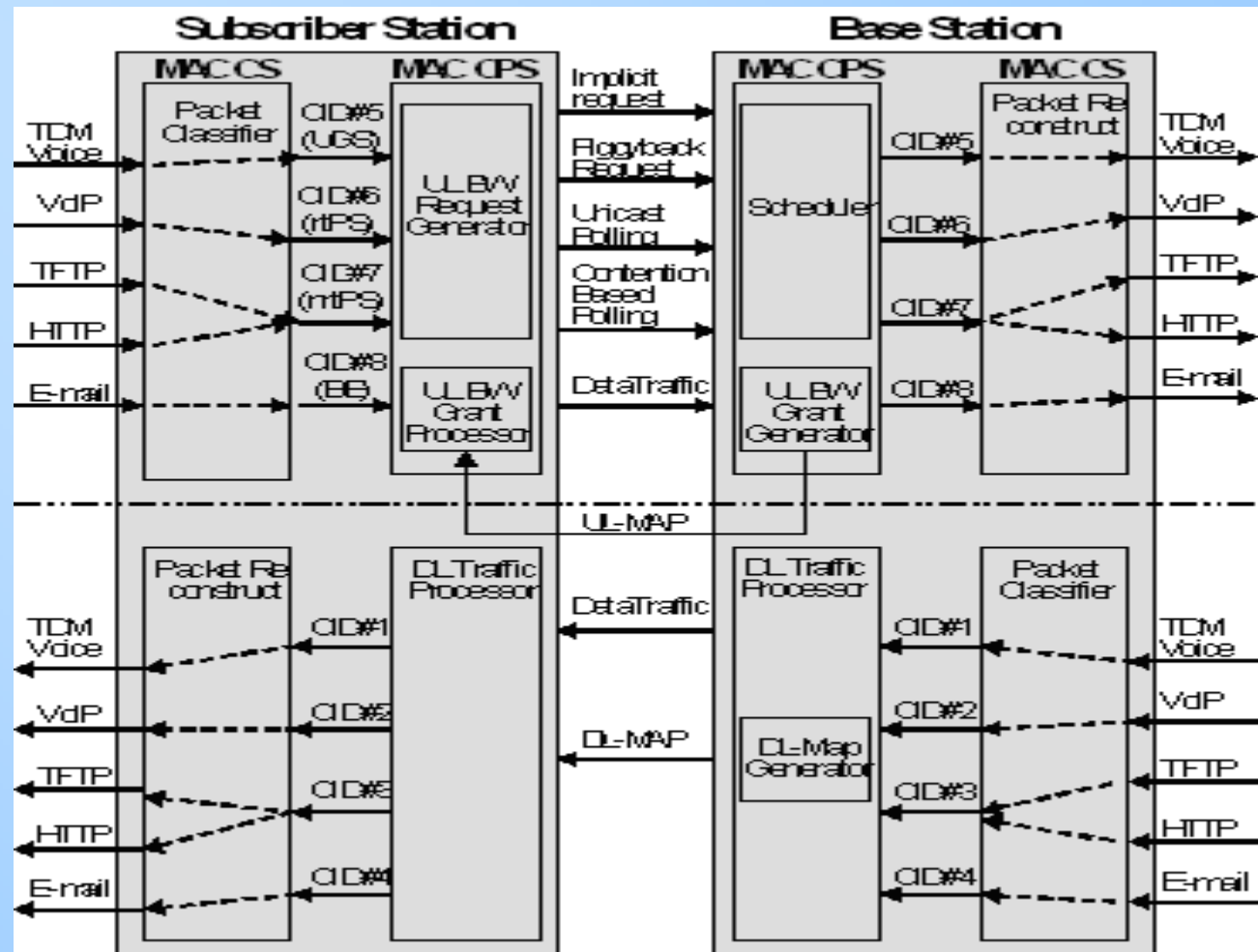
- **Grant methods**
  - Self Correcting, no ACk
  - Connection Bandwidth Requests are always per Connection
  - Grants are either per Connection (GPC) or per Subscriber Station (GPSS)
  - Grants (given as durations) : UL-MAP messages
  - SS needs to convert the time to amount of data using information about the UIUC
  - **Bandwidth Grant per Subscriber Station (GPSS)**
    - BS grants bandwidth to the SS
    - SS re-distributes the bandwidth among its connections, maintaining QoS and SLAs
    - Suitable for many connections per terminal; off-loading BS's work
    - Allows more sophisticated reaction to QoS needs
    - Low overhead for BS but requires intelligent SS
    - Mandatory for P802.16 10-66 GHz PHY
  - **Bandwidth Grant per Connection (GPC)**
    - Mostly suitable for few users per SS
    - Higher overhead, but allows simpler SS

- **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 IEs. The allocations are not in the form of an explicit message, but are contained as a series of Information Elements (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 have 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

- **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*.
  - *Utilization of QoS traffic parameters 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.

- **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

- **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.

- **Service Flows and QoS**
- **SF attributes:**
- ***a) Service Flow ID (SFID) :*** (32 bits) assigned to every existing service flows. An SF has at least an SFID and an associated Direction.
- ***b) Connection ID(CID):*** Mapping to an SFID , only when the connection has an *admittedSF(s)*
- ***c) ProvisionedQoSParamSet:*** provisioned via means outside of the scope of the
- standard, such as the network mng. system.
- ***d) AdmittedQoSParamSet:*** - set of QoS params for which the BS (and possibly the SS) are reserving resources (bandwidth, etc.) required to subsequently activate the flow.
- ***e) ActiveQoSParamSet:*** set of QoS parameters defining the service actually being provided to the SF . ***Only an Active service flow may forward packets.***
- ***f) Authorization Module****:* **A logical function within the BS** that approves or denies every change to QoS Parameters and Classifiers associated with a SF. It defines an "envelope" that limits the possible values of the *AdmittedQoSParamSet* and *ActiveQoSParamSet*.

# Service Flows and QoS

AuthorizedQoSParamSet = ProvisionedQoSParamSet
(SFID)

AdmittedQoSParamSet
(SFID & CID)

ActiveQoSParamSet
(SFID & Active CID)

ProvisionedQoSParamSet
(SFID)

AuthorizedQoSParamSet
(BS only, not known by SS)

AdmittedQoSParamSet
(SFID & CID)

ActiveQoSParamSet
(SFID & Active CID)

**Provisioned authorization model "envelopes"**
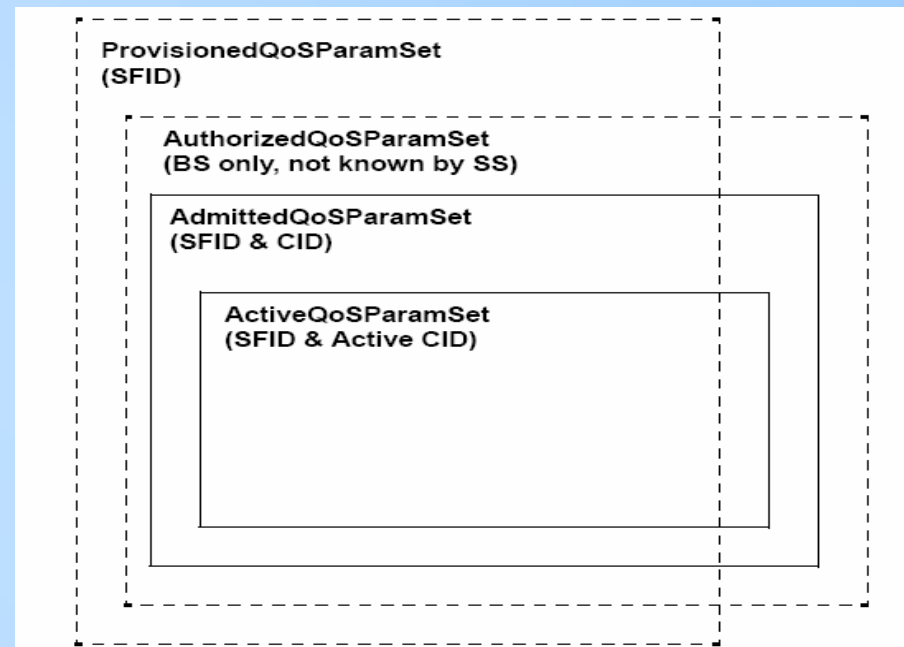
**Dynamic authorization model "envelopes"**

# 6. Resource Management and Control, QoS

- **Service Flows and QoS**

    - a) **Provisioned SF**
        - **may be immediately or later activated** ( "deferred")
        - description of any such SF contains an attribute which provisions but **defers activation and admission**
        - The BS assigns a SFID for such a SF but **does not reserve resources**
        - The BS may also require an exchange with a policy module prior to admission.

    - As a result of **external action beyond the scope of std. 802.16**, the SS may choose to activate a Provisioned SF by passing the SFID and the associated *QoS Parameter Sets* to the BS in the DSC-REQ message.

    - If authorized and resources are available, the BS shall respond by mapping the SF to a CID

- Service Flows and QoS

  - **b) Admitted SF**
  - 802.16 MAC : a *two-phase activation model* (often utilized in telephony).
  - the resources for a "call" are first "*admitted,*"
  - and then once the E2E negotiation is completed (e.g., called party's gateway generates an "off-hook" event), the resources are "*activated.*"
  - Advantages of this approach
    - a) conserving network resources until a complete E2E connection has been established
    - b) performing policy checks and Admission Control (AC) on resources as quickly as possible, and in particular, before informing the far end of a connection request
    - c) preventing several potential theft-of-service scenarios.

- Service Flows and QoS

    - **c) Activated SF**
    - *Active service flow* =  SF that has a non-NULL *ActiveQoSParamSet*
    - It is requesting and being granted bandwidth for transport of data packets.
    - An admitted service flow may be activated by providing an *ActiveQoSParamSet*, signaling the resources actually desired at the current time. This completes the second stage of the two-phase activation model
    - **A service flow may be Provisioned and immediately activated.**
    - Alternatively, a SF may be created dynamically and immediately activated. In this case, two-phase activation is skipped and the SF is available for immediate use upon authorization

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



UGS CIDs

rtPS CIDs

nrtPS CIDs

BE CIDs

Fixed Bandwidth

Earliest Deadline First (EDF)

Wheighted Fair Queuing (WFQ) or WRR

Round Robin

Priority scheduler

UpLink Map

CTRQ Conference June 29 - July 5, 2008 - Bucharest, Romania
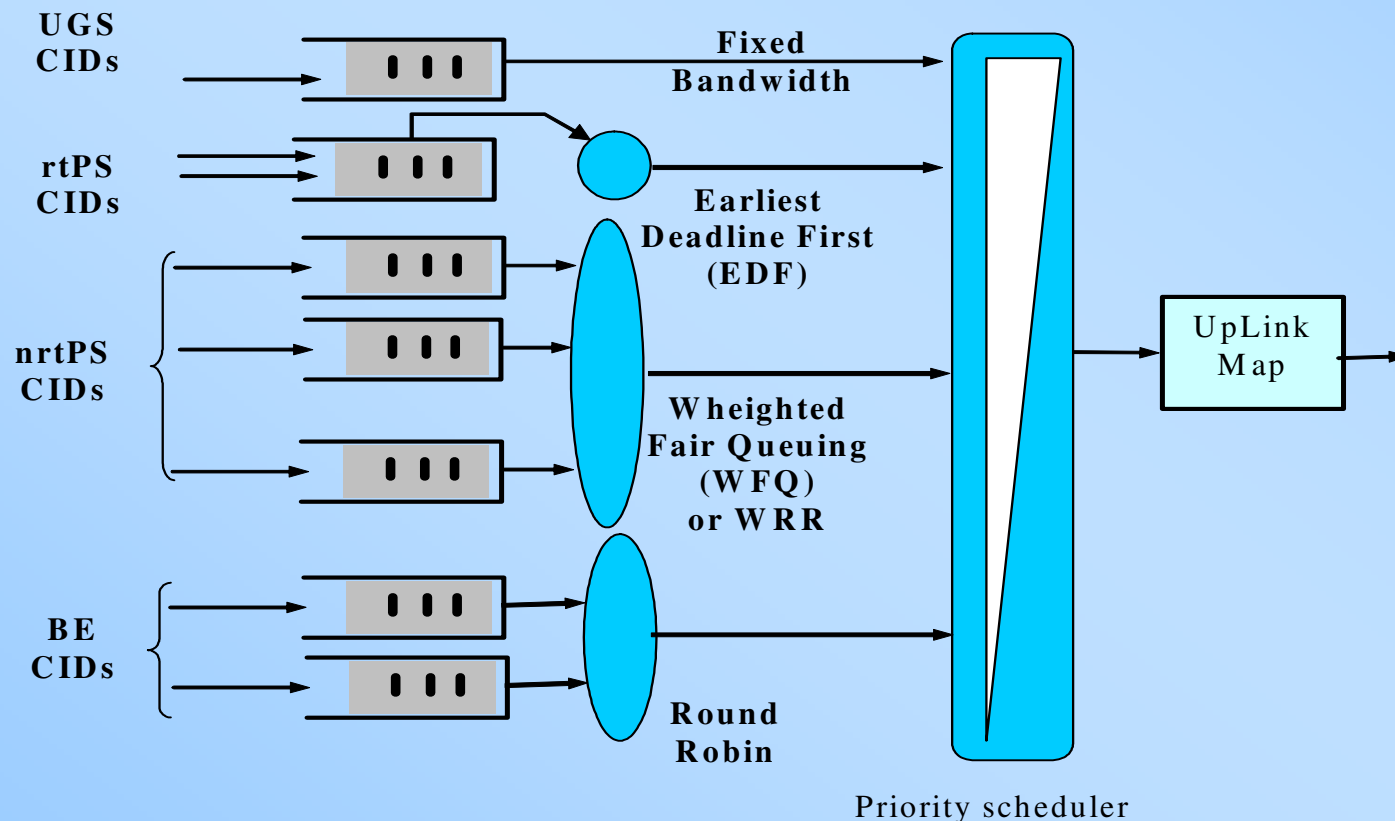
■ **Basic Example of 802.16 QoS architecture:**
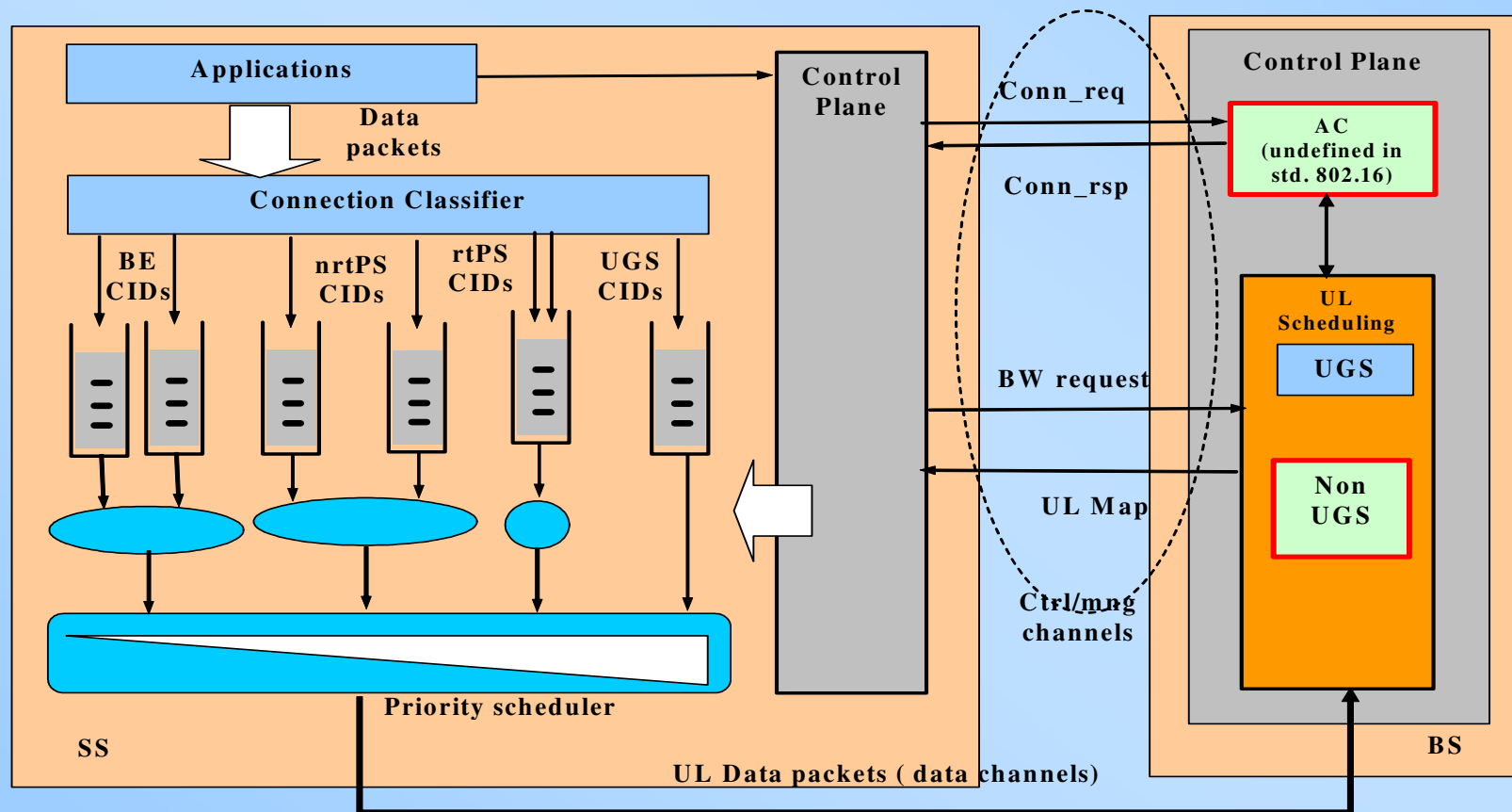
- **Enhancement of QoS architecture:**

- Example:

- Kitti Wongthavarawat and Aura Ganz, "Packet scheduling for QoS support in IEEE 802.16 broadband wireless access systems", INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS, Int. J. Commun. Syst. 2003
  - Traffic Policing at SS at Scheduler input
  - Feedback from AC@BS Traffic Policing@SS

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## WiMAX Forum Reference Model
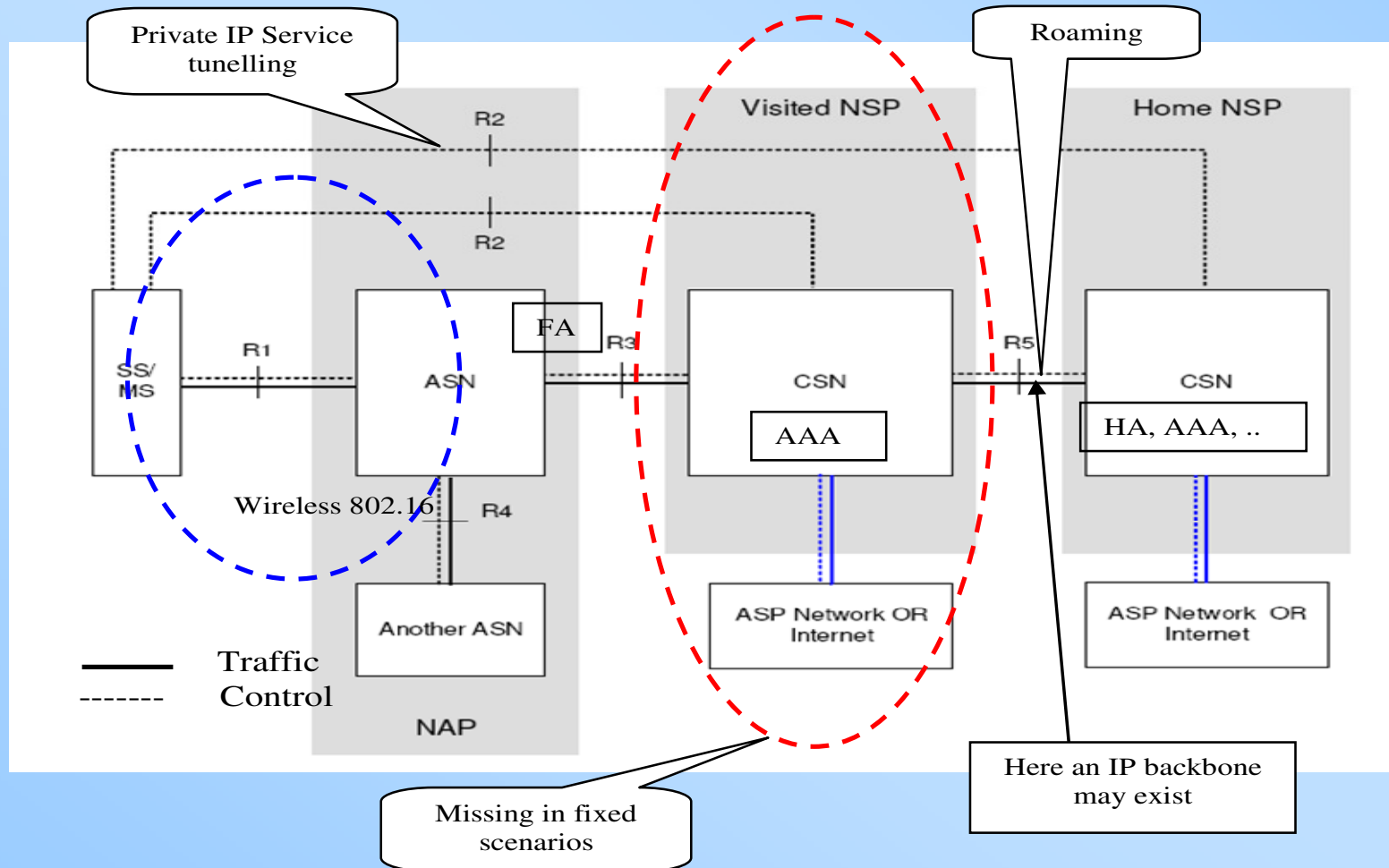
- ## WMF Reference Points
- ## R1
  - protocols and procedures (MS –ASN) for air I/F (PHY and MAC) (IEEE P802.16e/D12  and IEEE P802.16-2004).
  - R1 may include additional protocols related to the management plane

- ## 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)

- **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

- **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

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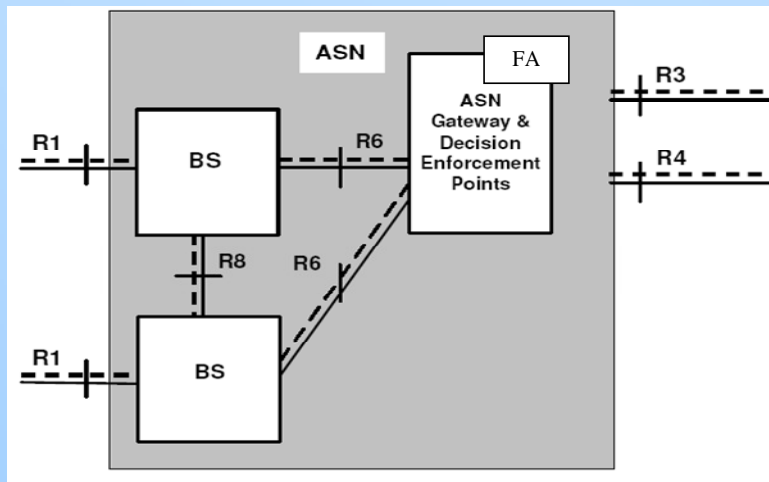
  - Single ASN-GW                                        Multiple ASN-GW
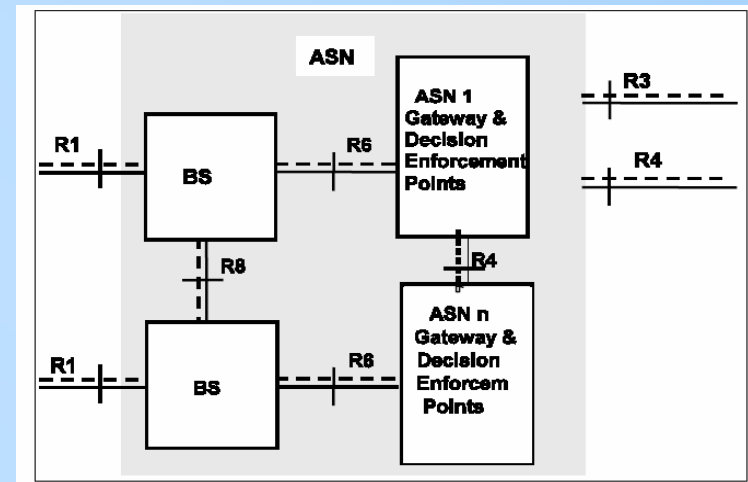


- **WiMAX Reference Points: R6, R8**
- ASN Gateway – ASN-GW
  - control/mng plane and data plane rol
  - Possible: FA - Foreign Agent role – for Mobile IP ( macro-mobility)

- **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

- **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 EP
  - 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)

- **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).
- 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.

- **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 Cashing 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

## Example of function distribution in ASN and CSN
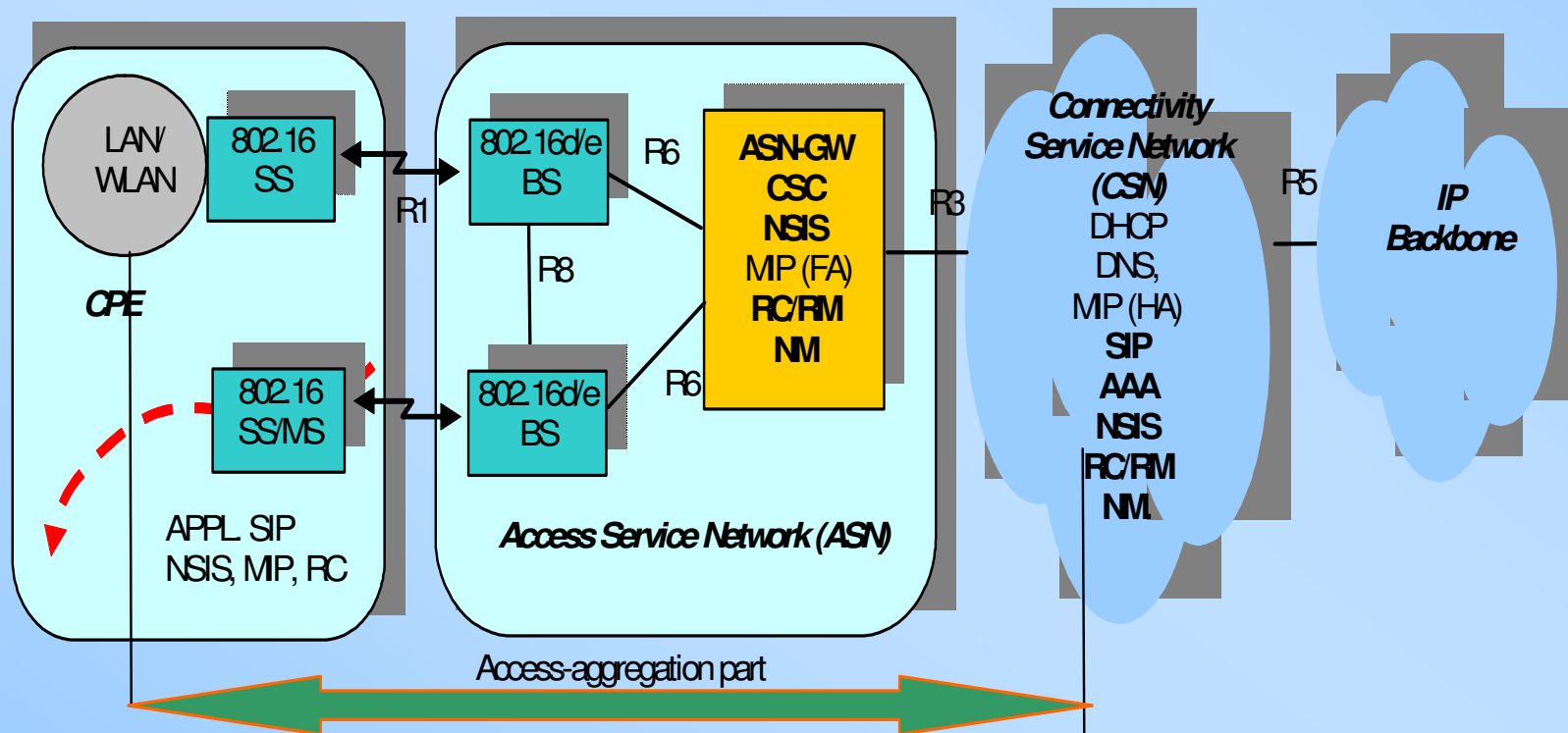
## Example of a multiple ASN configuration
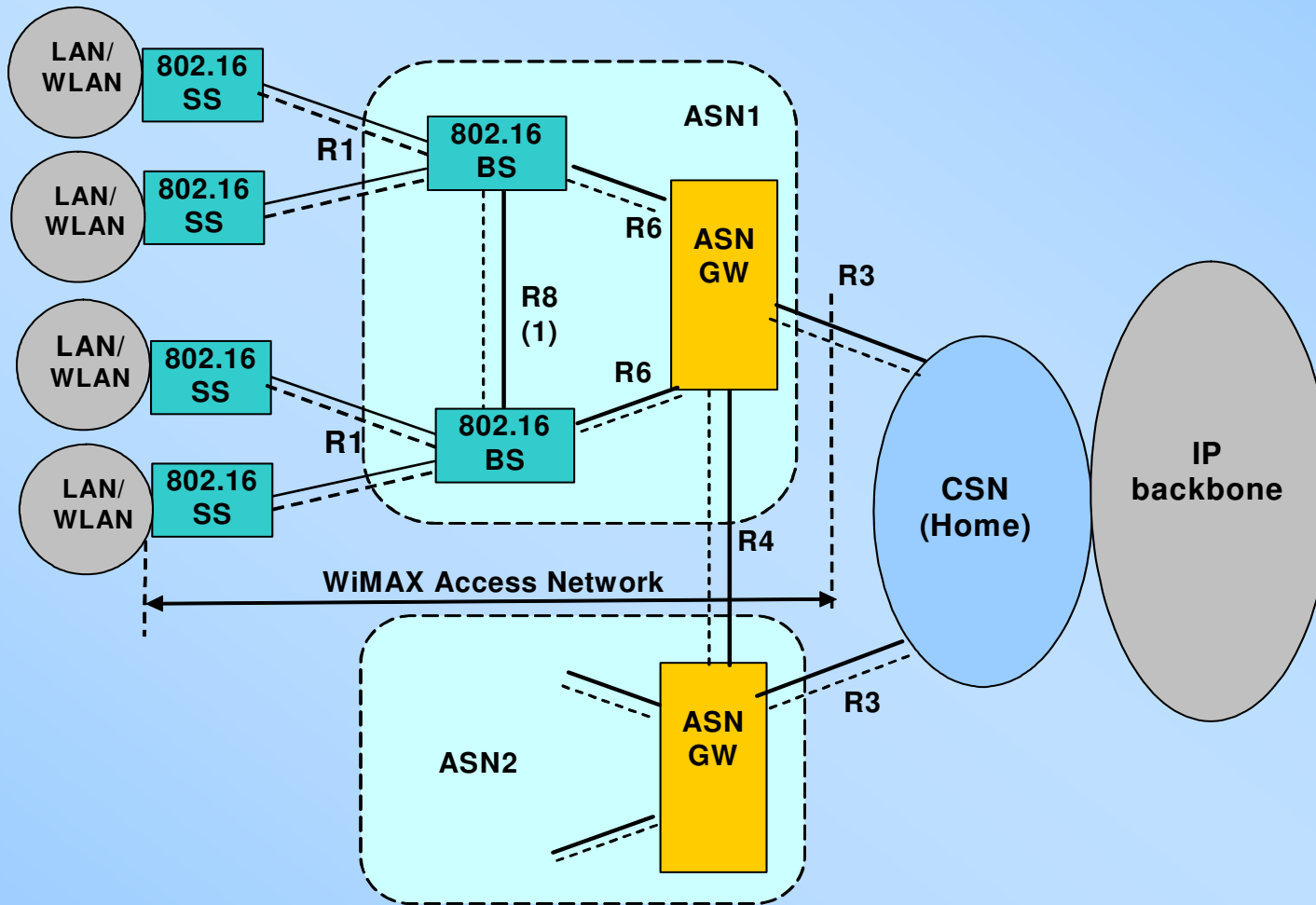


Data traffic

Signalling ( management and control)

- **FP6 project "WiMAX Extension to Isolated Research Data Network" (WEIRD)** (2006-2008) *http://www.ist-weird.org*
- **Main objective:** Integration of WiMAX access technologies in end-to-end QoS enabled architecture
  - Exploit and enhance the WiMAX technology
  - Integrate WiMAX based access networks into E2E IP architecture
  - Develop complex application scenarios on top of WiMAX
  - Offer solutions for future needs of research user communities

- Achievements :
  - Enhancement of the IP Network Control Plane and Management Planes
  - Convergence layer for 802.16 technology
  - Cooperation between service and resource control for QoS guarantees
  - Four test-beds linked via GÈANT2 European research backbone networks and National Research and Education Networks (NRENs)

Consortium
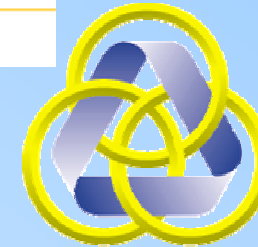


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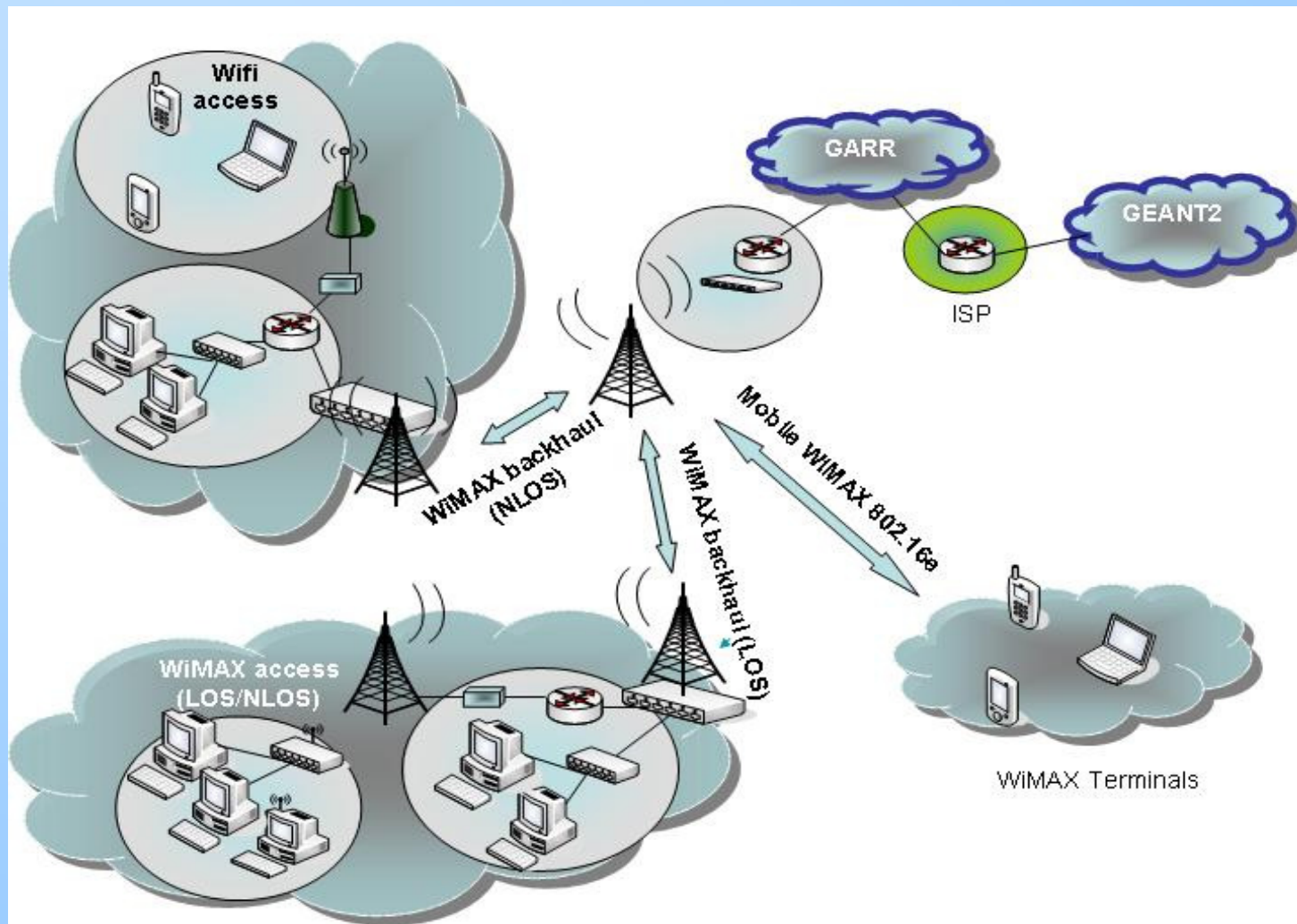
**General Architectural aspects**
**Multiple plane architecture**
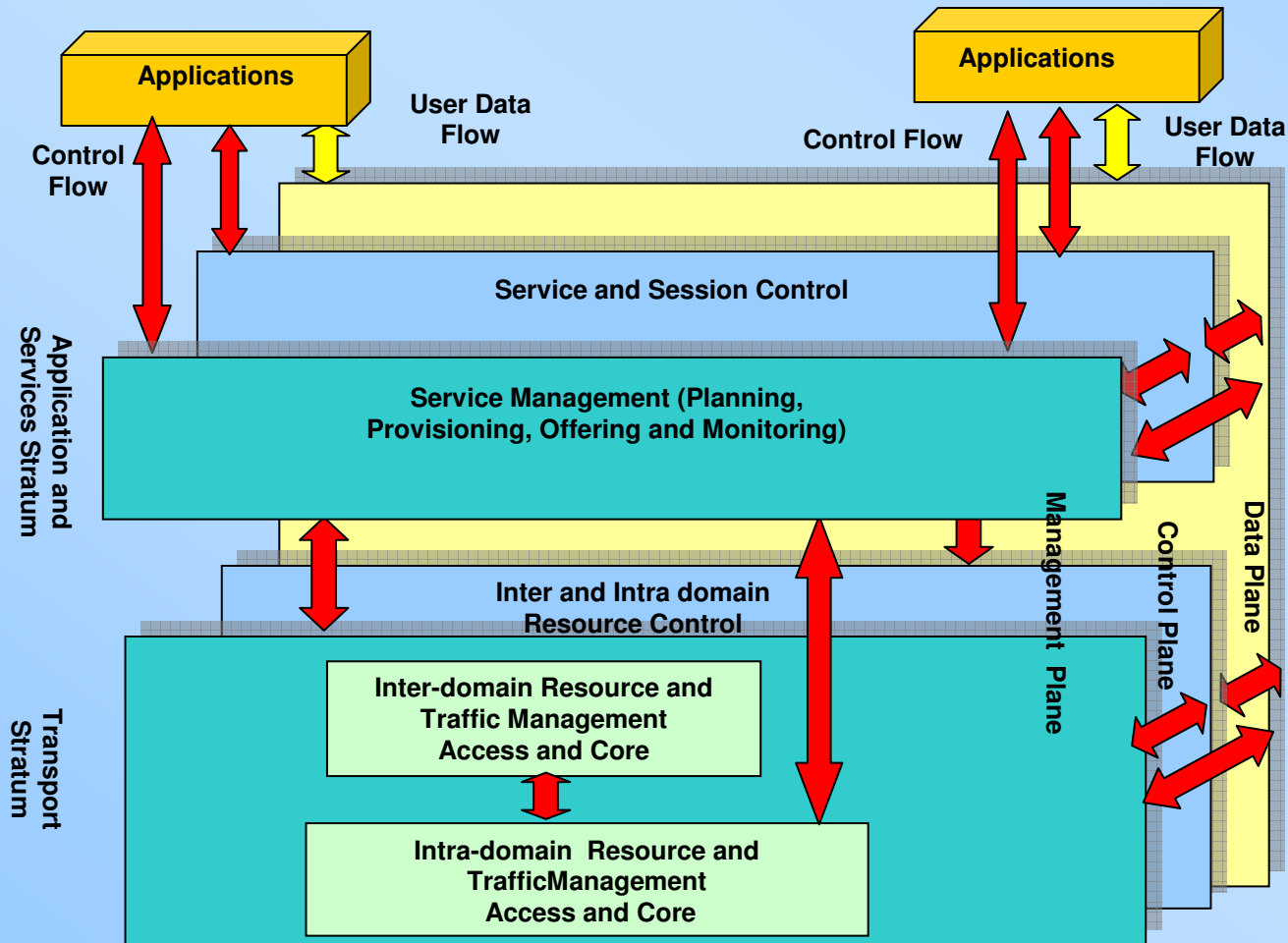


Multiple planes structured

Vertically structured
•Services & Applications
•Transport

Overlay resource management (independent on network dimensioning and routing)

Applications

User Data Flow

Control Flow

Control Flow

User Data Flow

Applications

Service and Session Control

Service Management (Planning, Provisioning, Offering and Monitoring)

Inter and Intra domain Resource Control

Inter-domain Resource and Traffic Management Access and Core

Intra-domain Resource and TrafficManagement Access and Core

Application and Services Stratum

Transport Stratum

Management Plane

Control Plane

Data Plane

## General Architectural aspects

**Main architectural features**

*Flexibility/openess*

- **Vertical**
  - **Supports any L1, L2 WiMAX technology** :
    - 802.16d and/or 802.16e
    - Support different vendors equipments
    - (Airspan, Alcatel, Alvarion, Redline, etc.)

  - **Aplication support :**
  - legacy and signalling capable applications
  - Separation of applications and services from resource control
- **Functional flexibility**
  - Covers fixed, nomadic and mobile environments
  - Interfaces and abstracts IP layer by developing Convergence Sublayers (CS): "802.3/Ethernet CS, "IPv4 CS" and "IPv6 CS"

## General Architectural aspects
**Main architectural features**

### *Flexibility/openess ( cont'd)*
- Horizontal
  - Can cooperate with any CPE network
  - Can cooperate with any CSN – IP based network
    - Extension of the control plane ( SIP, NSIS, mobility, MIH)
    - Extension of Management Plane – possible dynamic SLA/SLS with other domains

### *Scalability:*
- Aggregated or individual resource allocation
- Allows distribution of function in different entities

### *Business:*
- Can accommodate different business models (w.r.t actors involved): Customers, IP Connectivity Network Providers, Access Network Providers, High level Services Network Providers

## General Architectural aspects
**Main architectural features**

**Other characteristics:**

- **Compliancy with standards and reference architectures:**
  - IEEE: 802.16d and 802.16e
  - IETF: Diameter, NSIS, SIP
  - ETSI, TISPAN
  - WiMAX Forum / WiMAX Network Reference Model (NRM)

- **QoS oriented:**
  - Supports IEEE802.16 classes of service
  - Supports any QoS technology in ASN
  - Cooperates with QoS aware core networks (DiffServ, etc.)

- **Security:**
  - Supports AAA for users and devices, Allows accounting
- **SW Modularity**
  - Functional (extensible) modules with well defined interfaces
  - Includes COTS and Open Source software

# 7. IEEE 802.16/WiMAX Integration in E2E Architectures
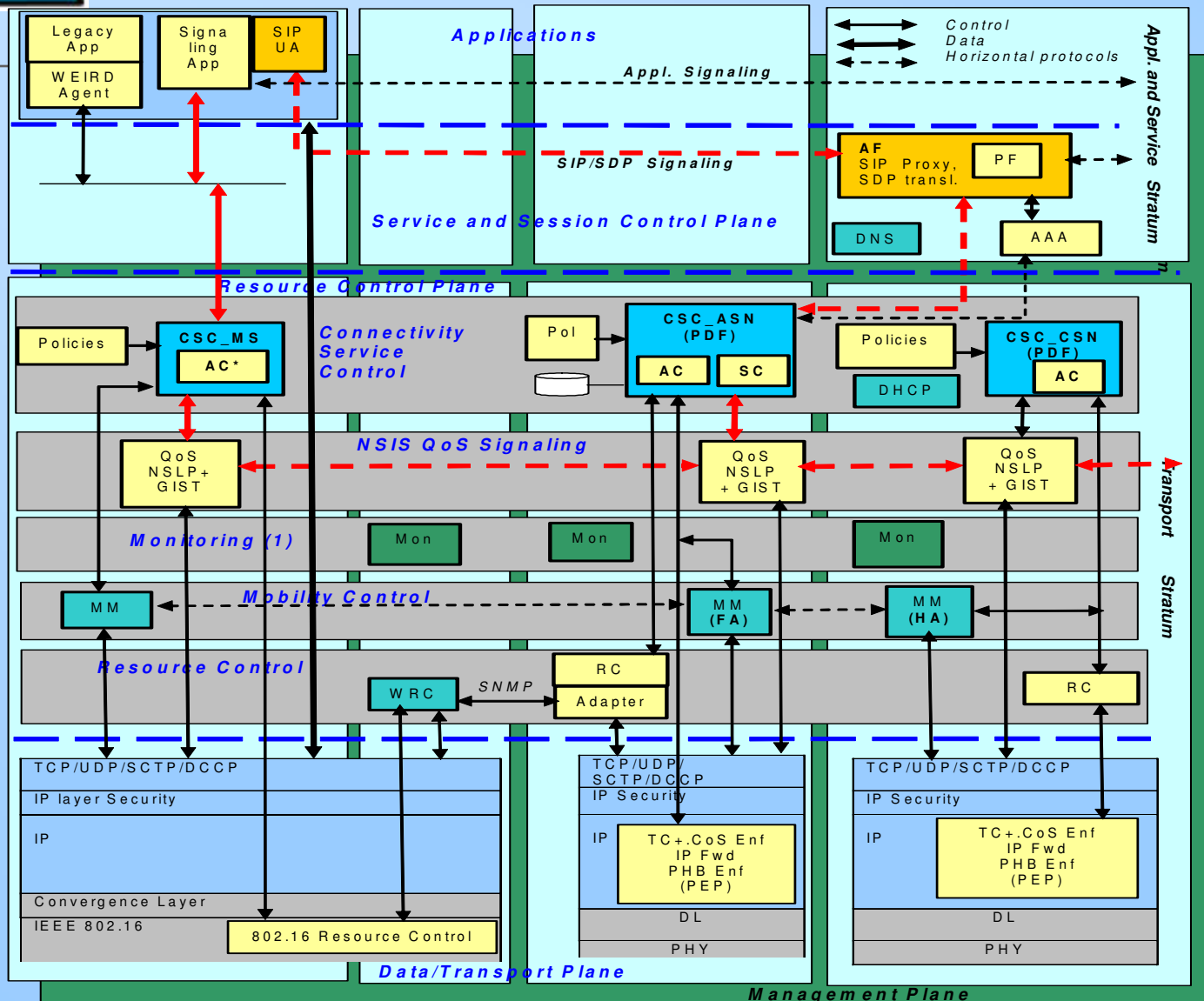


**Example: WEIRD project architecture**
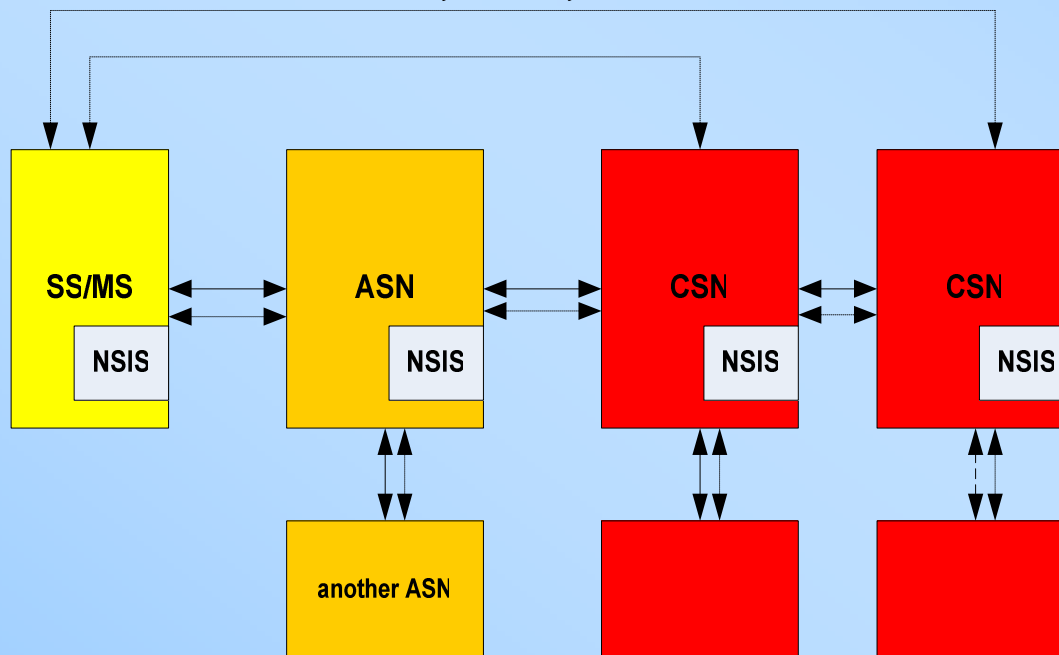
**High-Level Architectural View – first version**
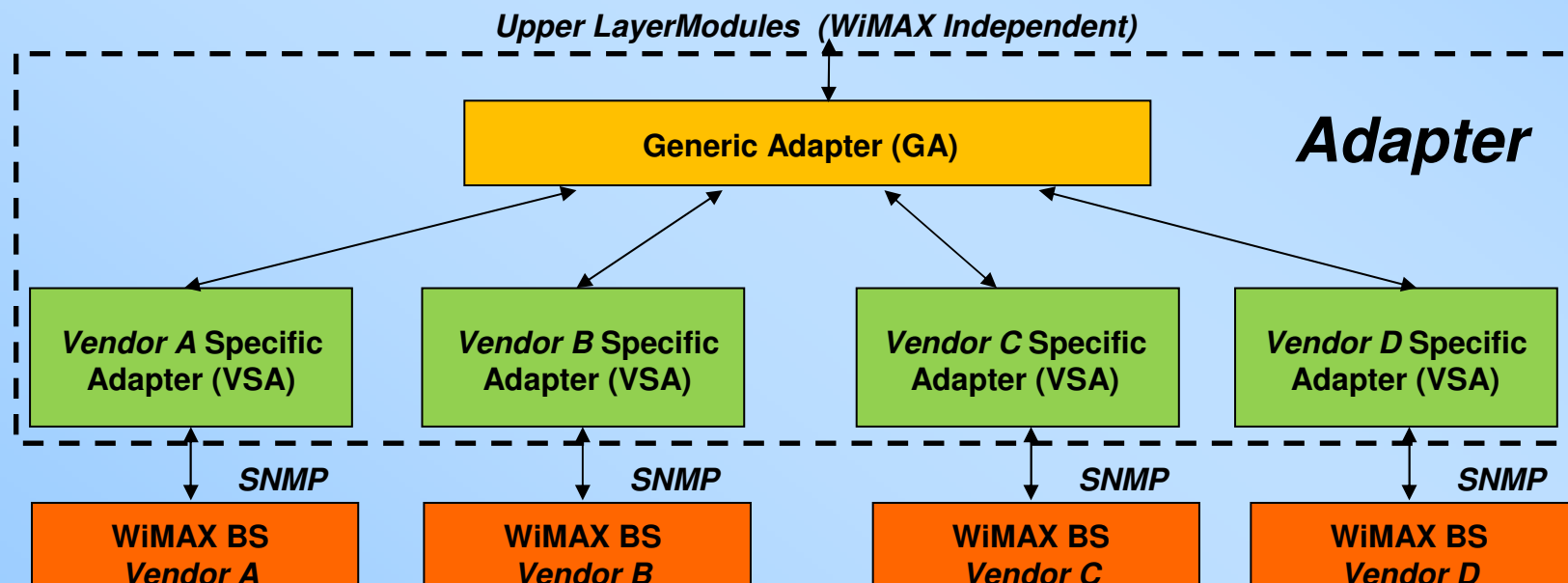
## WEIRD control and mng. subsystems
## NSIS signalling

Signalling protocol for QoS resrvation

NSIS entities in: SS, ASN, CSN

WEIRD Subsystems-802.16 BS adapters

- WiMAX Hardware/Vendor Independency
  - Provide an abstraction layer for the upper modules
  - Seamlessly support all WiMAX vendors through specific adapters

*Upper LayerModules  (WiMAX Independent)*

*Adapter*

Generic Adapter (GA)

*Vendor A* Specific Adapter (VSA)

*Vendor B* Specific Adapter (VSA)

*Vendor C* Specific Adapter (VSA)

*Vendor D* Specific Adapter (VSA)

*SNMP*

*SNMP*

*SNMP*

*SNMP*

WiMAX BS *Vendor A*

WiMAX BS *Vendor B*

WiMAX BS *Vendor C*

WiMAX BS *Vendor D*

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QoS, Resource management and control

QOs Classes, Traffic Trunks

- QoS architecture:
    - E2E compatible (NSIS signalling)
    - WEIRD scope: WiMAX, ASN
    - 802.16 classes: UGS, rtPS, nrtPS, ertPS, BE
    - Two timescale reservation/allocation
        - Mid-long term provisoning at aggregated level
        - Short term – per flow at request
    - two way of signaling resources need:
        - via SIP signalling
        - Via NSIS ( for legacy application)

    - use of provisioning/admission/activation of service flows in 802.16/WiMAX segment
    - Admission control function

    - Use of virtual topology- to describe the resources in terms of traffic trunks

QoS, Resource management and control

QOs Classes, Traffic Trunks

▪*QoS architecture:*

**Main problem: include 802.16 /WiMAX Segment QoS Management and Control into E2E architecture**

Cooperation between management planes and control planes of different network segments: CPE, Access/Aggregation, Core

      - using appropriate QoS technology in each segment

      - signalling ( path coupled/path decoupled – e.g IETEF NSIS)

How to reserve/allocate resources?

      - Scalability problems!

      - Provisioning of individual/aggregated resources on different network segments ( Mid-long term Resource Management)

      - Allocate resources per individual call at demand ( Resource Control)

      - Service contracts: - Service Level Agreements/Service Level Specifications- (SLA/SLS) approach

              - static/dynamic

              - customerSLA/SLS/provider SLA/SLS

QoS, Resource management and control

QOs Classes, Traffic Trunks

- *Concepts*
  - *QoS-class (QC):* a specific set of transport capabilities that can be supported by a network administrative domain  network, specified as: *OA (ordered aggregate), delay-bound, loss-bound, [jitter related bounds].* Note that this QC is not identical with IEEE 802.16 Service Class , although they may have the same values in their parameters

  - *Ordered Aggregate:* the PHB Group with which the packets of a class are treated (possible values: *EF, AF1, AF2, AF3, AF4-* using DiffServ notation*)*

  - *Traffic Trunk in ASN (TT_ASN):* *a QoS-class plus a topological scope* (the basic WEIRD traffic trunk is *unidirectional pipe*, specified as: *ingress, egress, QoS-class.* The TTs are aggregates of traffic having the transfer characteristics of the associated QoS class between specific ASN network edges.
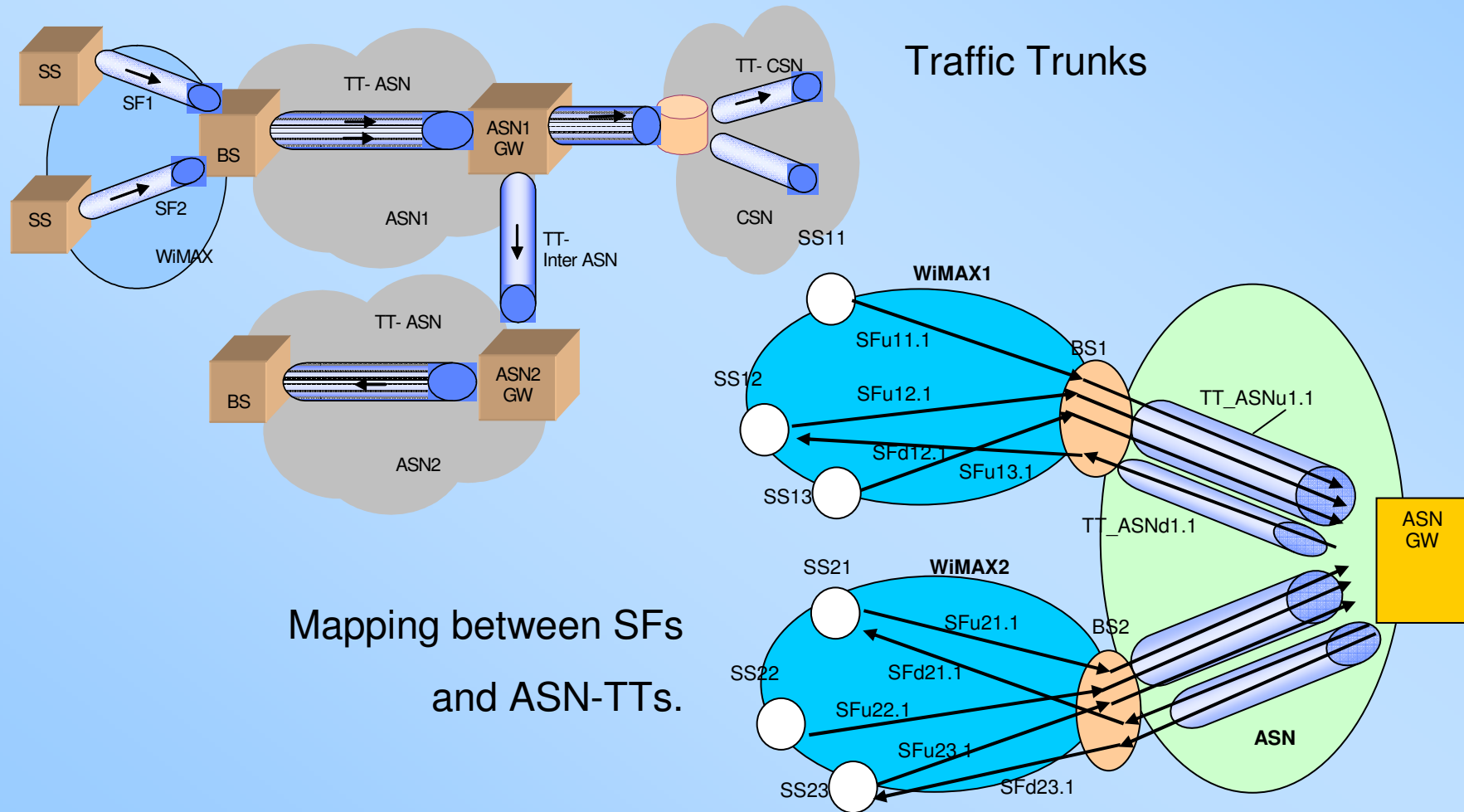
QoS, Resource management and control

Virtual topology:Traffic Trunks



Traffic Trunks

Mapping between SFs

and ASN-TTs.

## QoS, Resource mng. and control - mid long term

**Provisioning of aggregated resources on different network segments**
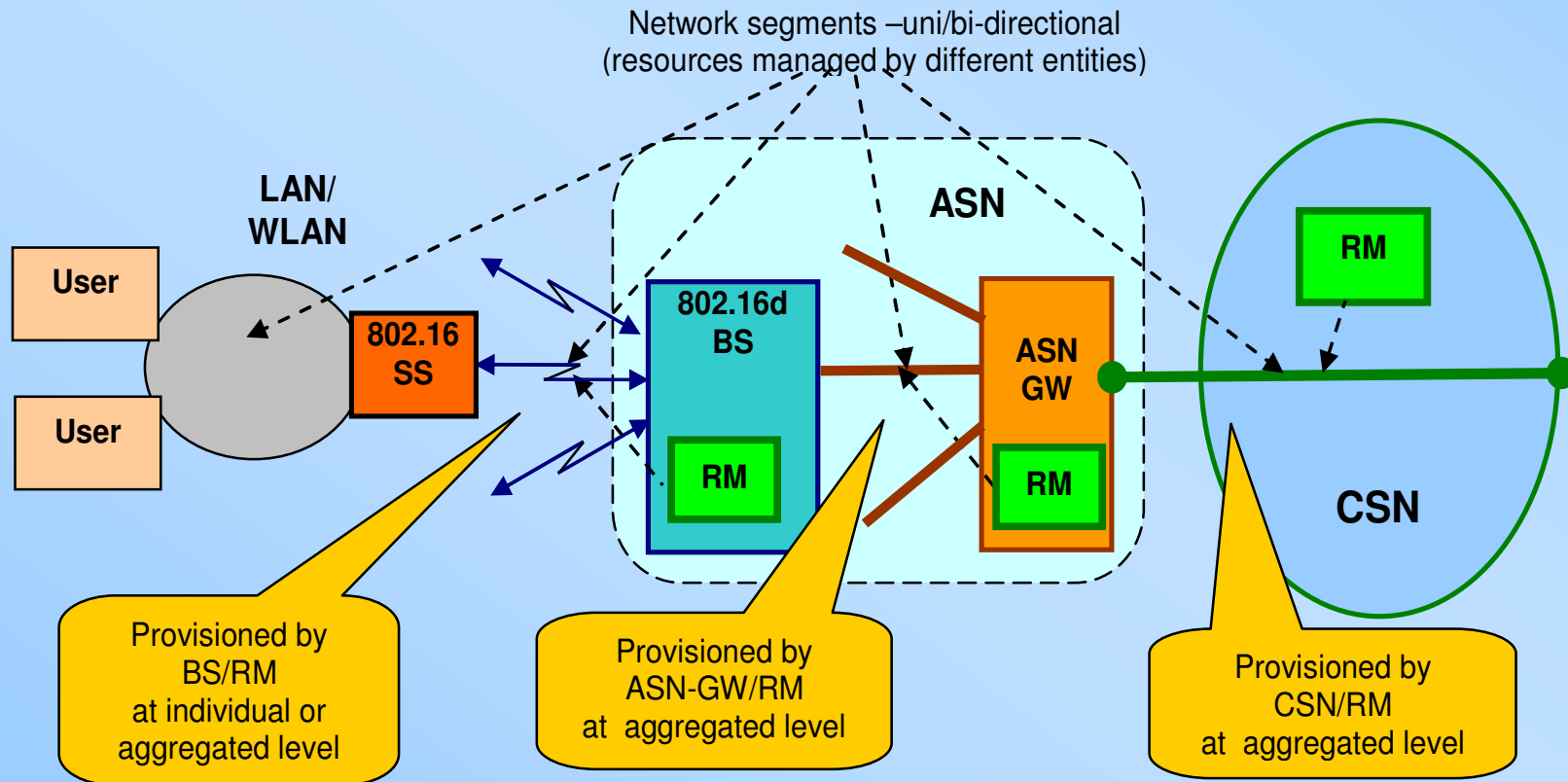
Network segments –uni/bi-directional
(resources managed by different entities)

LAN/
WLAN

User

User

802.16
SS

ASN

802.16d
BS

RM

ASN
GW

RM

RM

CSN

Provisioned by
BS/RM
at individual or
aggregated level

Provisioned by
ASN-GW/RM
at aggregated level

Provisioned by
CSN/RM
at aggregated level

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QoS, Resource management and control
Provisioning of individual resources on different network segments

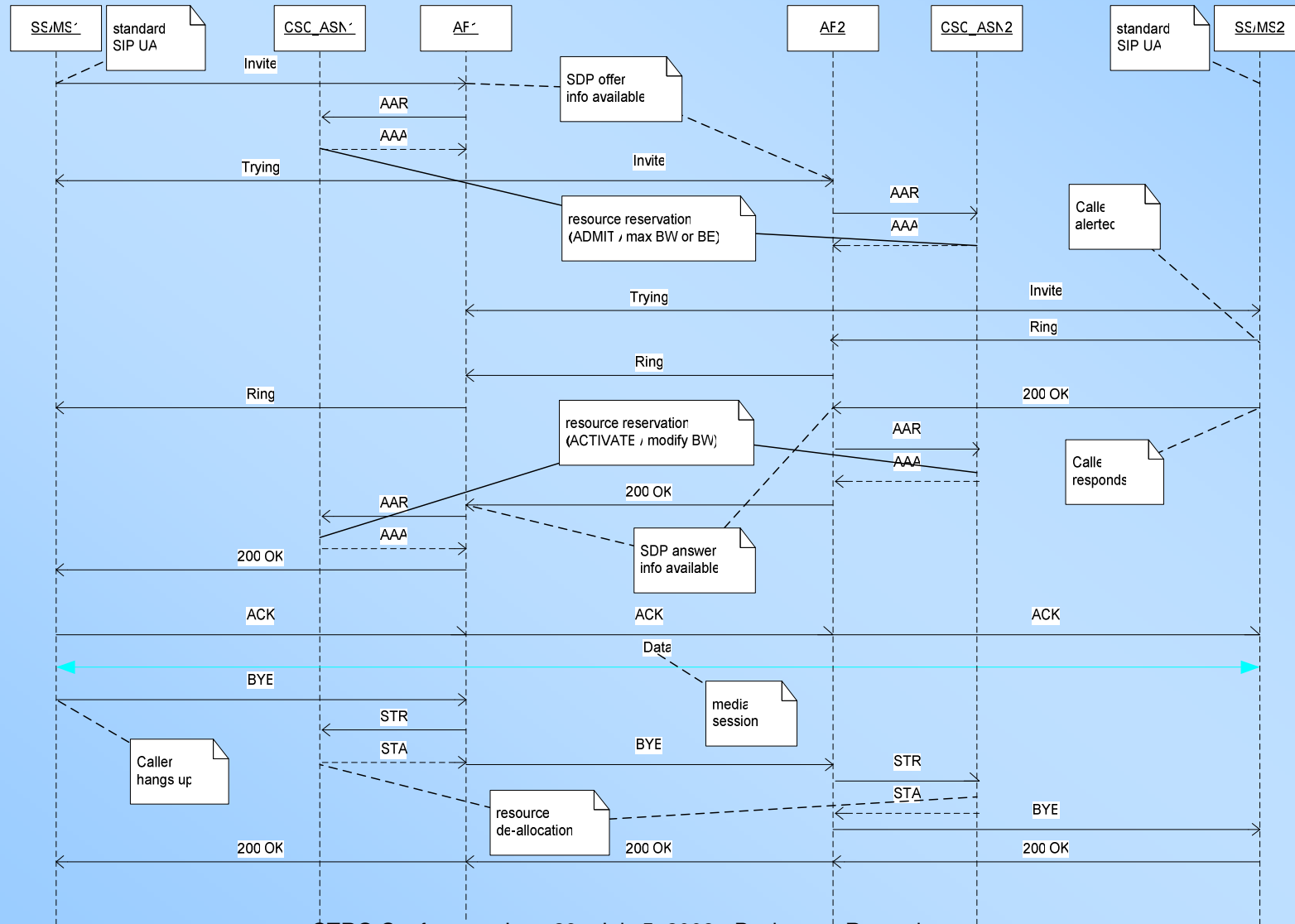**Possible Admission control at service invocation per individual call**
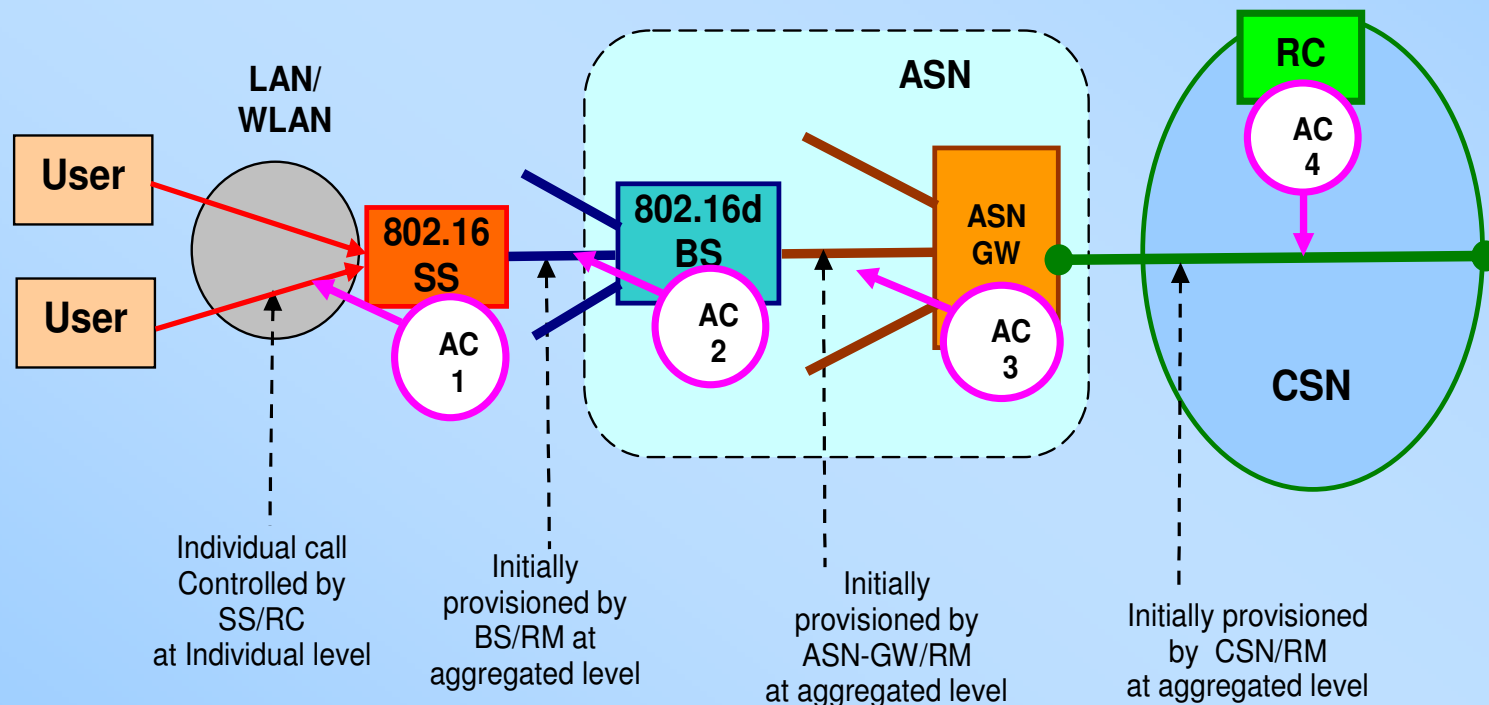
## QoS, Resource management and control: SIP signalling example

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6. **Resource Management and Control, QoS**
7. **IEEE 802.16/WiMAX Integration in E2E Architectures**
8. **Micro and Macro-mobility**
9. Media Independent Handover
10. Mesh Mode
11. WiMAX versus other Broadband Technologies
12. Future Trends: WiMAX and 4G networks

# 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

**IEEE 802.16e main features**

Frame structure



• 2D resource allocation
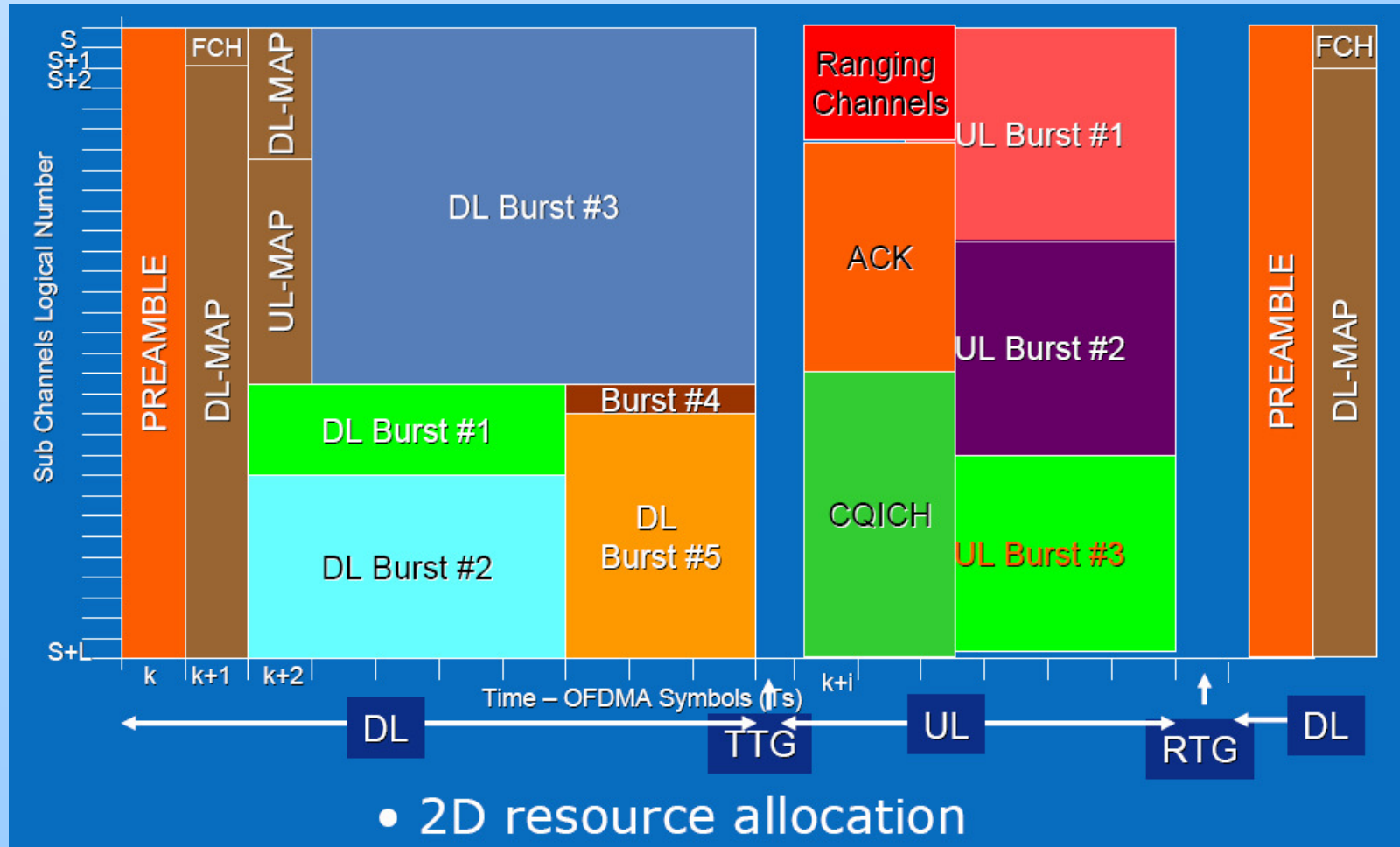
**Possible 802.16/MIP mobility cases:**

- 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)**



HA – Home Agent
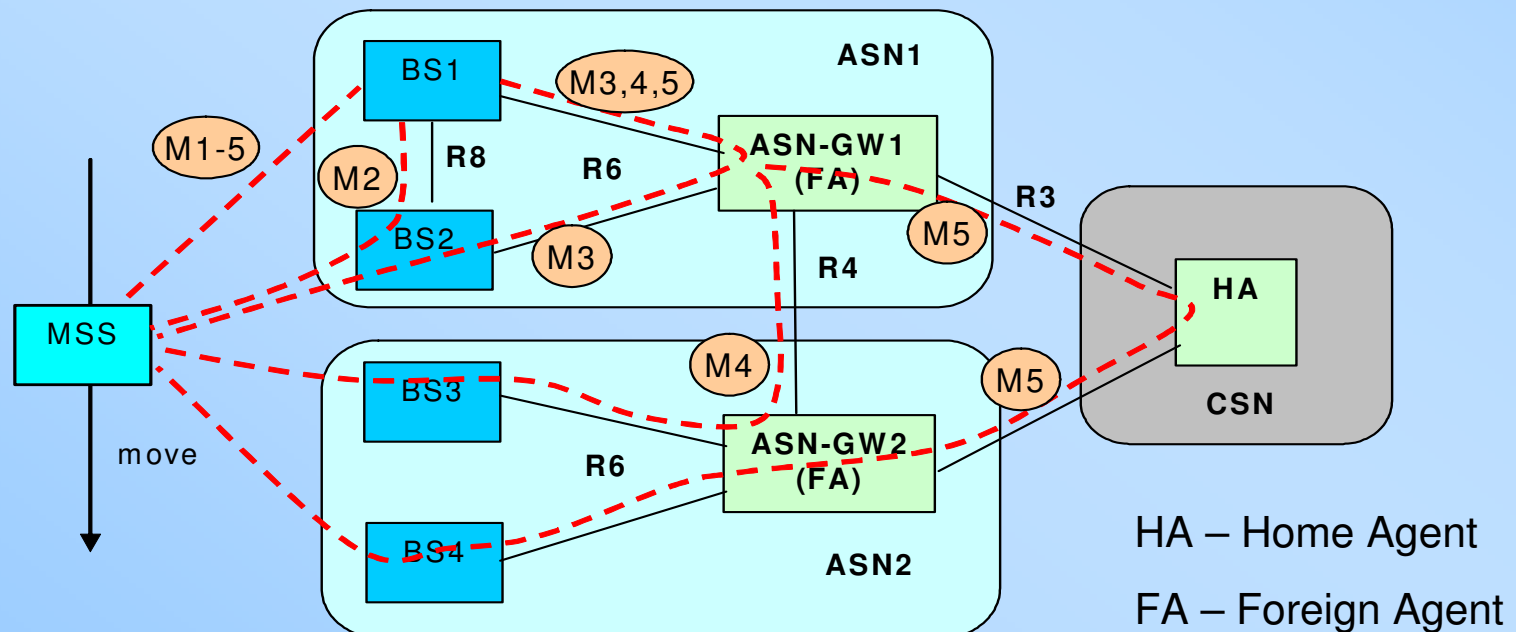
FA – Foreign Agent

# 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
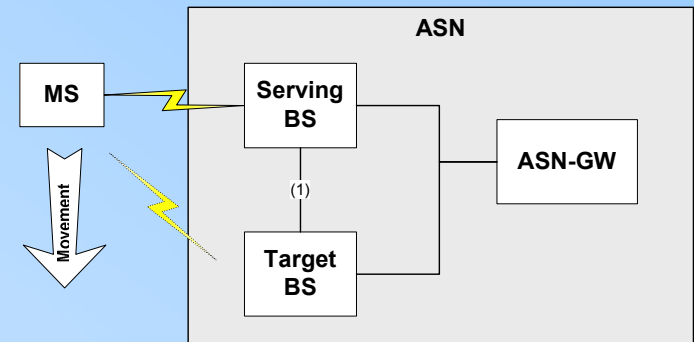
# 8. Micro and Macro-mobility

- **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
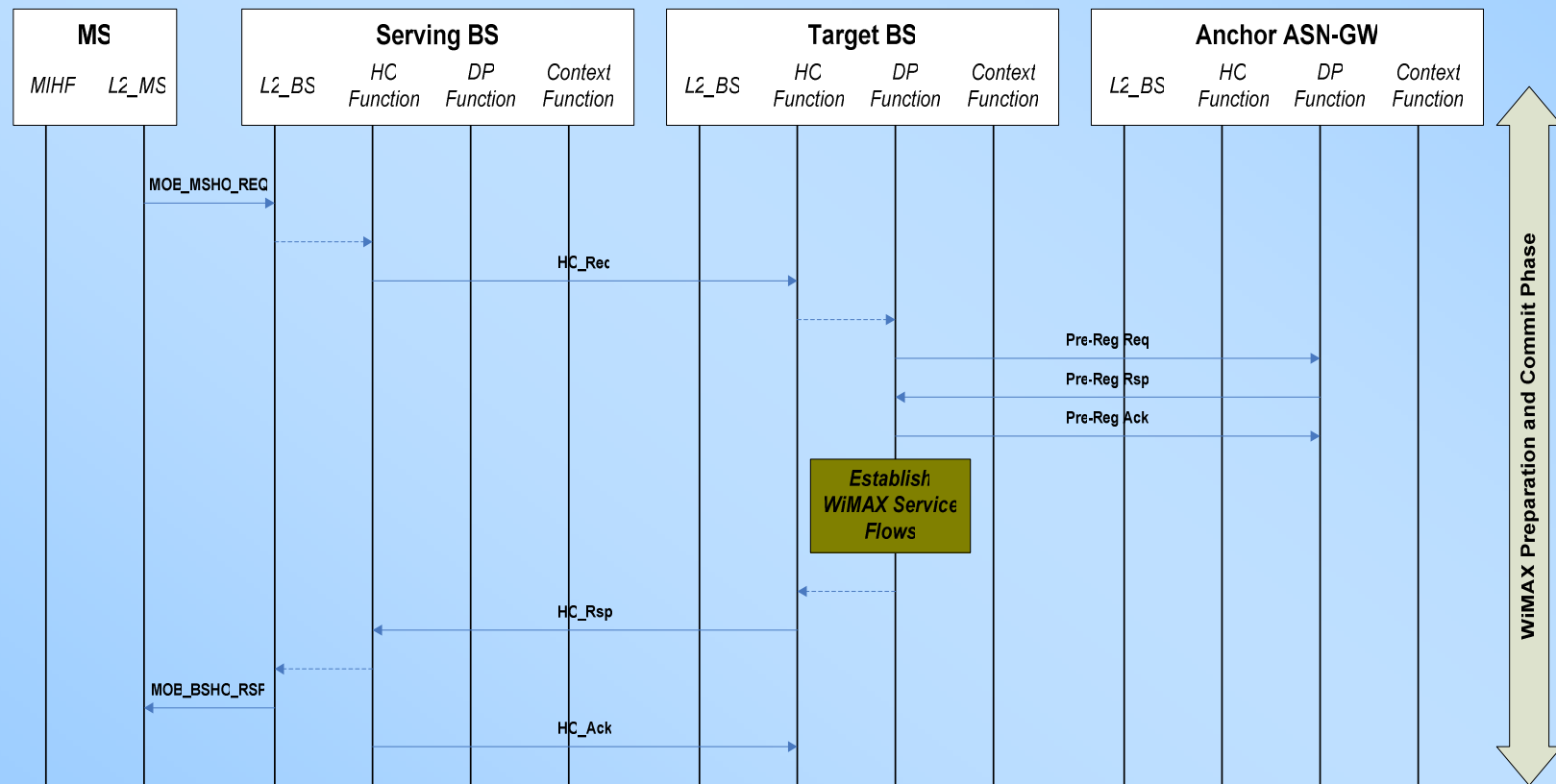  - NCS is aware of the changes in its sub-networks, requiring a link also between the ASN-GW and NCS systems.
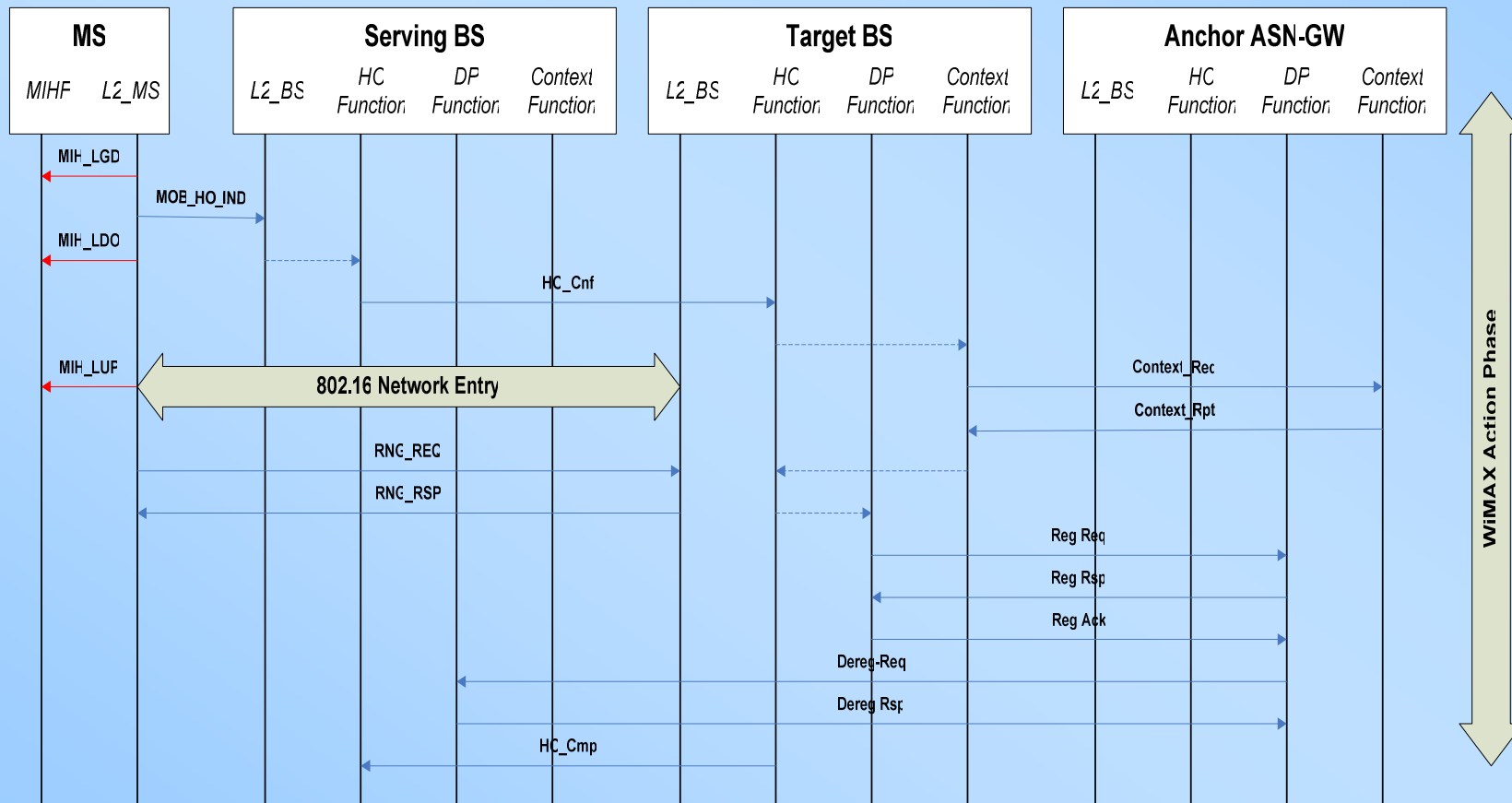
**Protocol stack - example: WEIRD project**
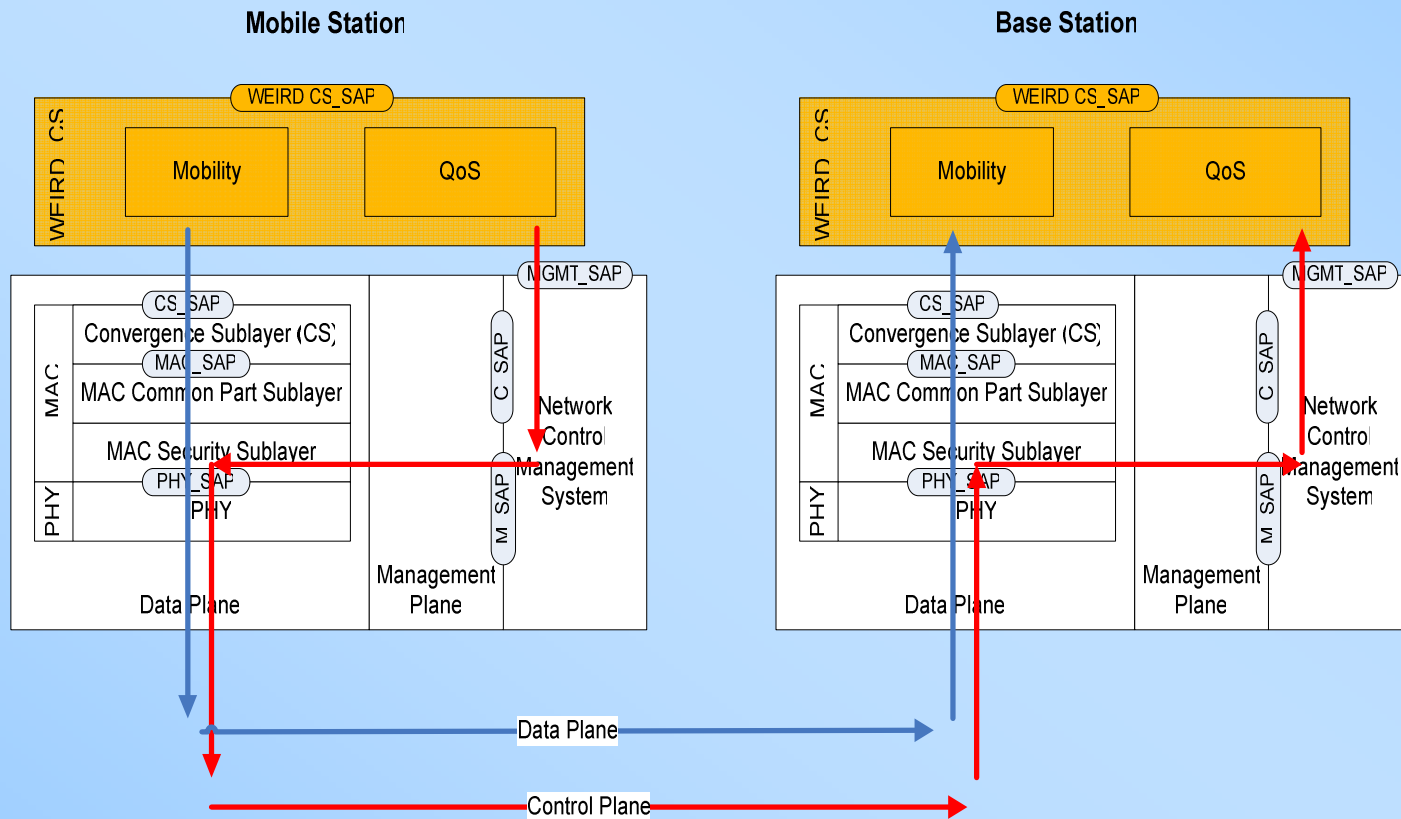
## Micro-mobility: WiMAX Forum approach- scenario example

- Preparation/commit phase

# 8. Micro and Macro-mobility

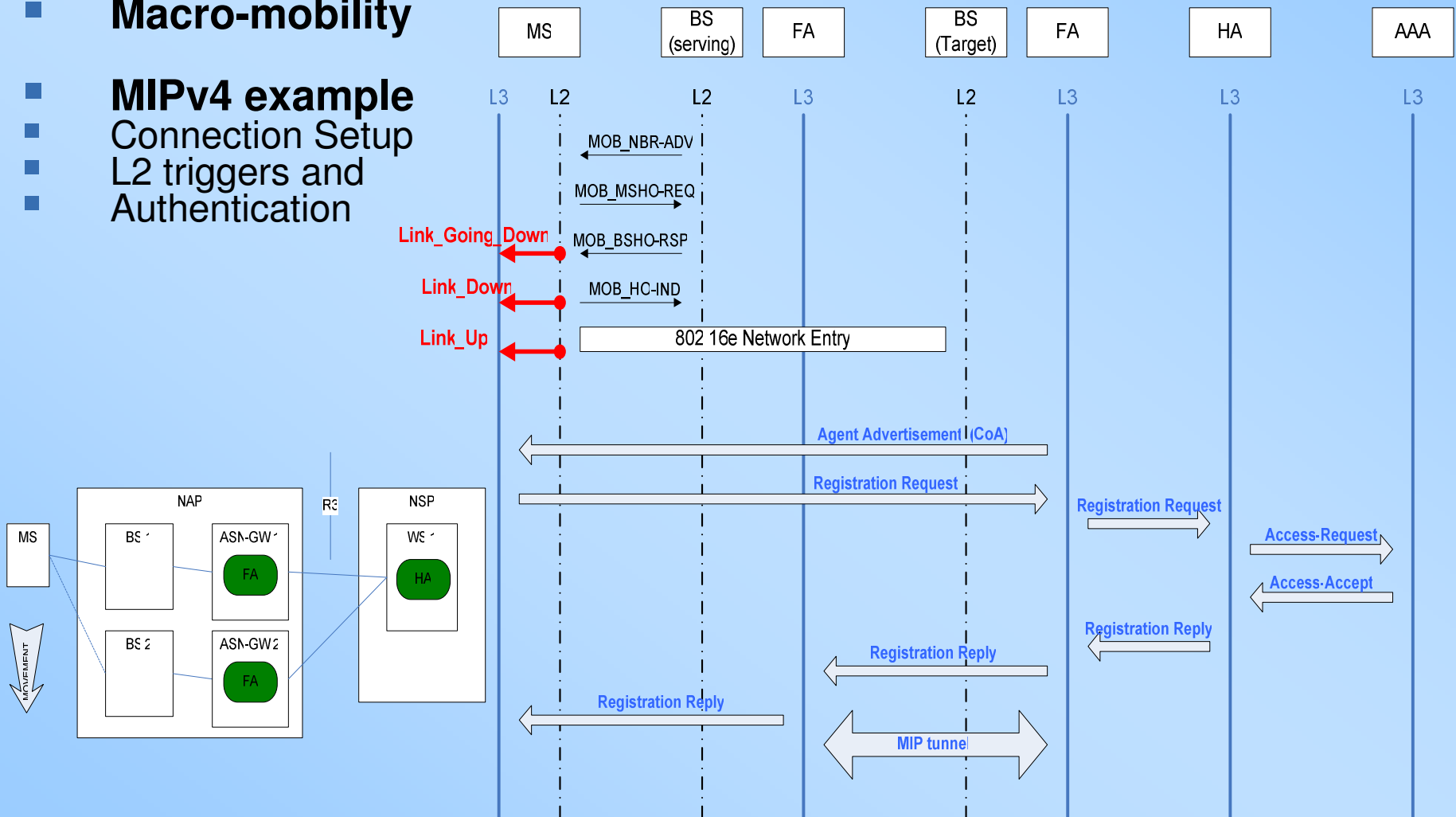- **Micro-mobility: WiMAX Forum approach - scenario example**
  - Action phase

# 8. Micro and Macro-mobility

- **Macro-mobility**

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

MS | BS (serving) | FA | BS (Target) | FA | HA | AAA

L3 | L2 | L2 | L3 | L2 | L3 | L3 | L3

MOB_NBR-ADV

MOB_MSHO-REQ

**Link_Going_Down** | MOB_BSHO-RSP

**Link_Down** | MOB_HC-IND

**Link_Up** | 802 16e Network Entry

**Agent Advertisement (CoA)**

**Registration Request**

**Registration Request**

**Access-Request**

**Access-Accept**

**Registration Reply**

**Registration Reply**

**Registration Reply**

**MIP tunnel**

NAP | R3 | NSP

MS

BS 1 | ASN-GW 1 | FA | WS 1 | HA
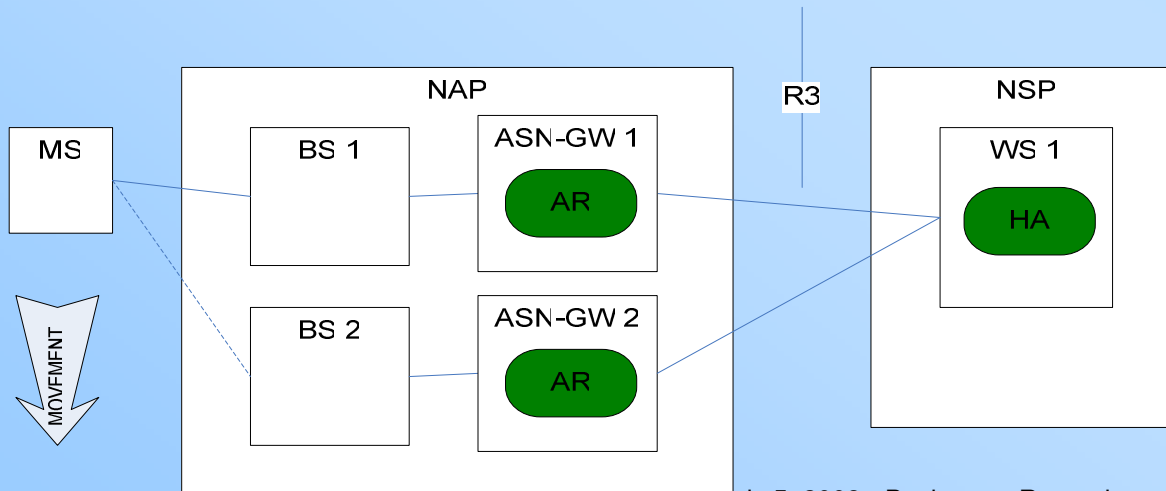
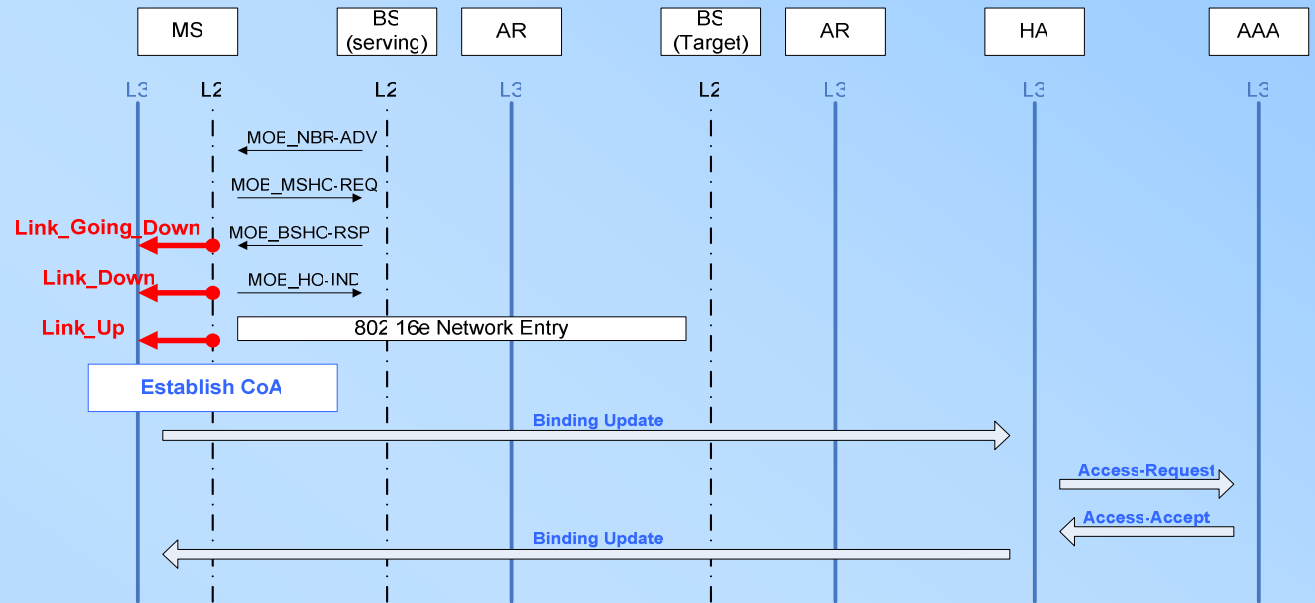BS 2 | ASN-GW2 | FA

MOVEMENT

# 8. Micro and Macro-mobility

- **Macro-mobility**

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

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- **Current situation on Wireless technologies evolution**

  - Multiple Wireless Technologies exist
  - More capable terminals
  - Evolving Usage Models
  - Multi-radio

- **Problems related to HO**
  - best network selection is difficult - by the mobile terminal (MT) alone - based on signal strength criteria only
  - Increasing number of interfaces on devices
    - Problem – how to leverage multiple interfaces
    - Needed – handover across different technologies
- Various fast HO mechanisms are defined in IETF and should be supported better by the L2 layers
  - MIPv4, FMIPv6
- IETF anticipated L2 constructs in standardized form
  - Triggers, events, hints etc, but former 802 docs did not provide a standard framework to use them in a media independent form

# 9. Media Independent Handover

- **Handover Types**
  - **Horizontal/Homogeneous**
    - Within Single Network (Localized Mobility)
      - 802.11r, 802.16e, 3GPP, 3GPP2
    - Limited opportunities
  - **Vertical/Heterogeneous**
    - Across Different Networks (plus possible Macro/Global Mobility)
    - More Opportunistic

- **Solution MIH – IEEE 802.21 (standard draft)** <u>www.ieee802.org/21</u>

- **Initial MIH objectives**
  - Define media independent information to enable MTs to detect and select networks effectively Develop common standard across 802 media
  - Define L2 Triggers to make Fast MIP work well
  - Define a way to transport this information and these triggers over all 802 media
- **MIH is basically targeting vertical handover but it can be used also in horizontal case**
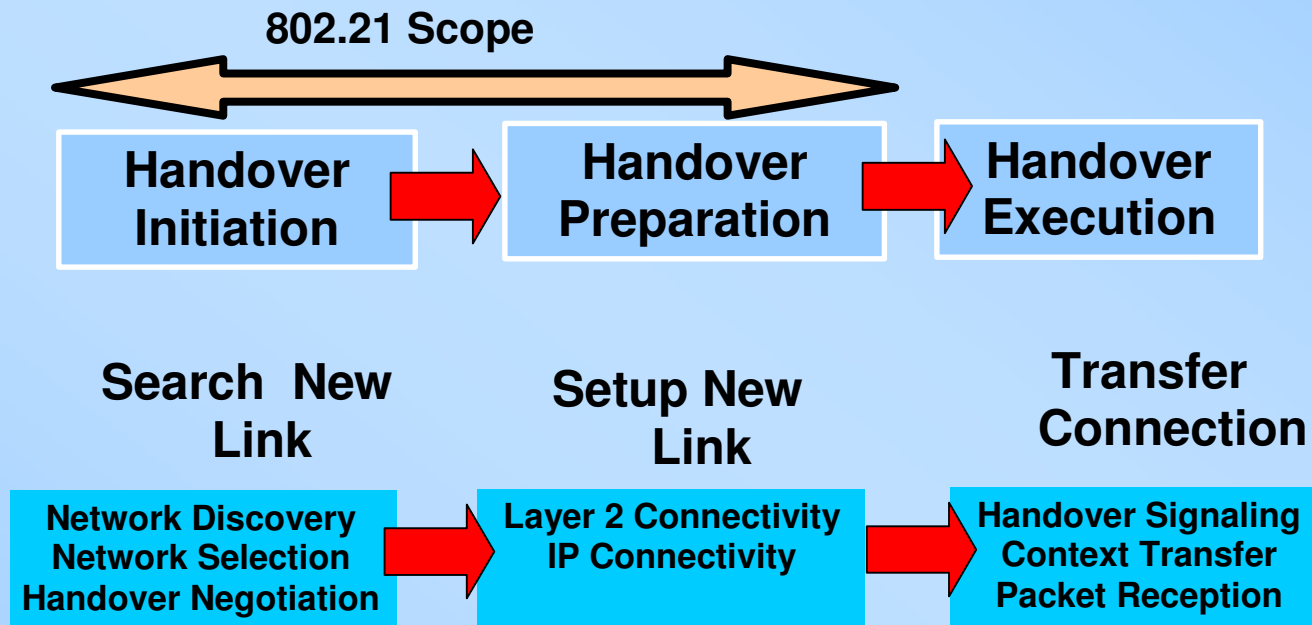
# 9. Media Independent Handover

- **Initial MIH targets**
  - Define media independent information to enable MTs to detect and select networks effectively Develop common standard across 802 media
  - Define L2 Triggers to make Fast MIP work well
  - Define a way to transport this information and these triggers over all 802 media
  - 802.21 is designed for existing and evolving Networks

- **P802.21 Draft D5.2 Issue- approved in June 2007**

- **MIH benefits**
  - MIH is basically targeting vertical handover but it can be used also in horizontal case
  - IEEE 802.21 enables Co-operative Handover Decision Making
  - Facilitates:
    - optimum network selection
    - seamless roaming to maintain connections ( make-before break – approach)
    - lower power operation for multi-radio devices

# 9. Media Independent Handover

- **MIH scope**

**802.21 Scope**

| Handover Initiation | → | Handover Preparation | → | Handover Execution |

**Search New Link**      **Setup New Link**      **Transfer Connection**

| Network Discovery<br>Network Selection<br>Handover Negotiation | → | Layer 2 Connectivity<br>IP Connectivity | → | Handover Signaling<br>Context Transfer<br>Packet Reception |

**IEEE 802.21 facilitates:**
**Handover Initiation,**
**Network Selection**
**Interface Activation**

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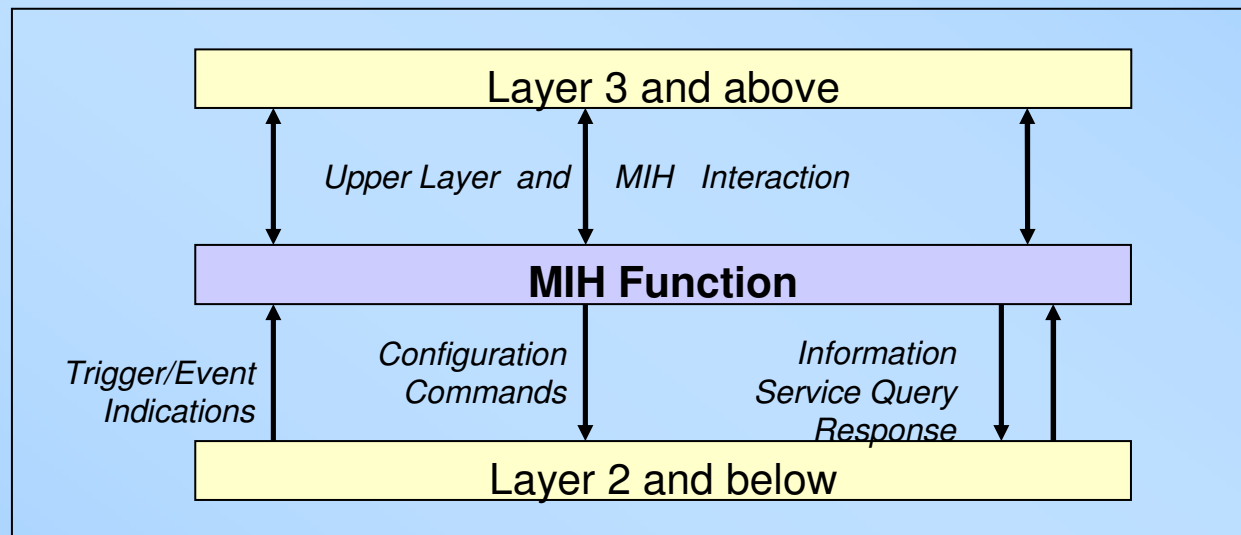
# 9. Media Independent Handover

**MIH Architecture**

The HO is achieved through

- **MIH protocol**
  - Instantiated in MTs and network, supporting 'hard' or 'soft' HO
- **Service Access Points** (SAPs): provide the exchange of service primitives between MIH layer and adjacent layers
- **MIH function**:
  - **Media Independent Event Service**
    - provides a set of events and triggers from local and remote interfaces
  - **Media Independent Information Service**
    - collects information from different ANs and provides the MIH users with the home network directives in order to make effective handover
  - **Media Independent Command Service**
    - enables MIH user to control local link behavior related to handover
- ecision engine in MT: identifies the best available access technology for current connectivity

**MIH reference model**

- MIH layer is placed between L2 and L3 layersMAC and PHY (IEEE interfaces) or RRC and LAC (3GPP or 3GPP2)

| Layer 3 and above |
|---|

*Upper Layer  and   MIH   Interaction*

**MIH Function**

*Trigger/Event Indications*            *Configuration Commands*            *Information Service Query Response*

| Layer 2 and below |
|---|

- MIH Function ( MIHF) help Layer 3 Mobility Protocols
  - To maintain service continuity between heterogeneous interfaces
  - adaptation to QoS
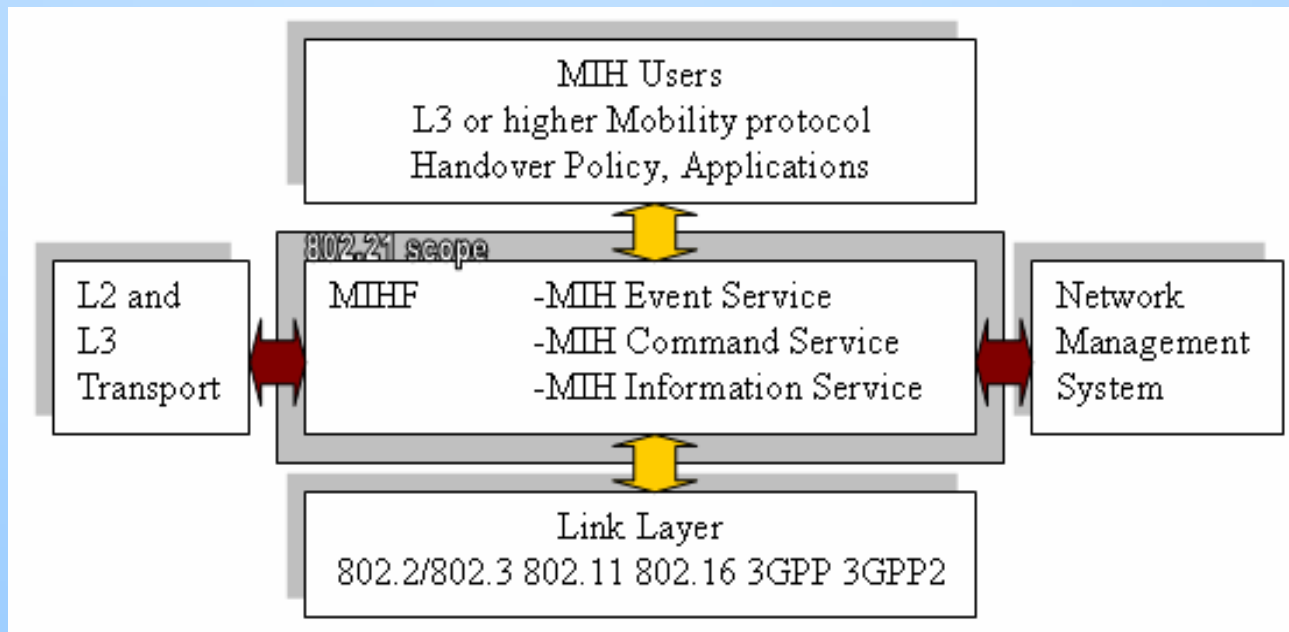  - link selection and network discovery

# 9. Media Independent Handover

**MIH reference model**

- Interaction of MIH with other logical entities
  - upper layers ( MIH users)
  - L2/L3/L4 transport services (through MIH_NET_SAP) to support MIH message exchange with remote MIHF
  - MIHF (MIH_NMS_SAP) with the Network Management System.
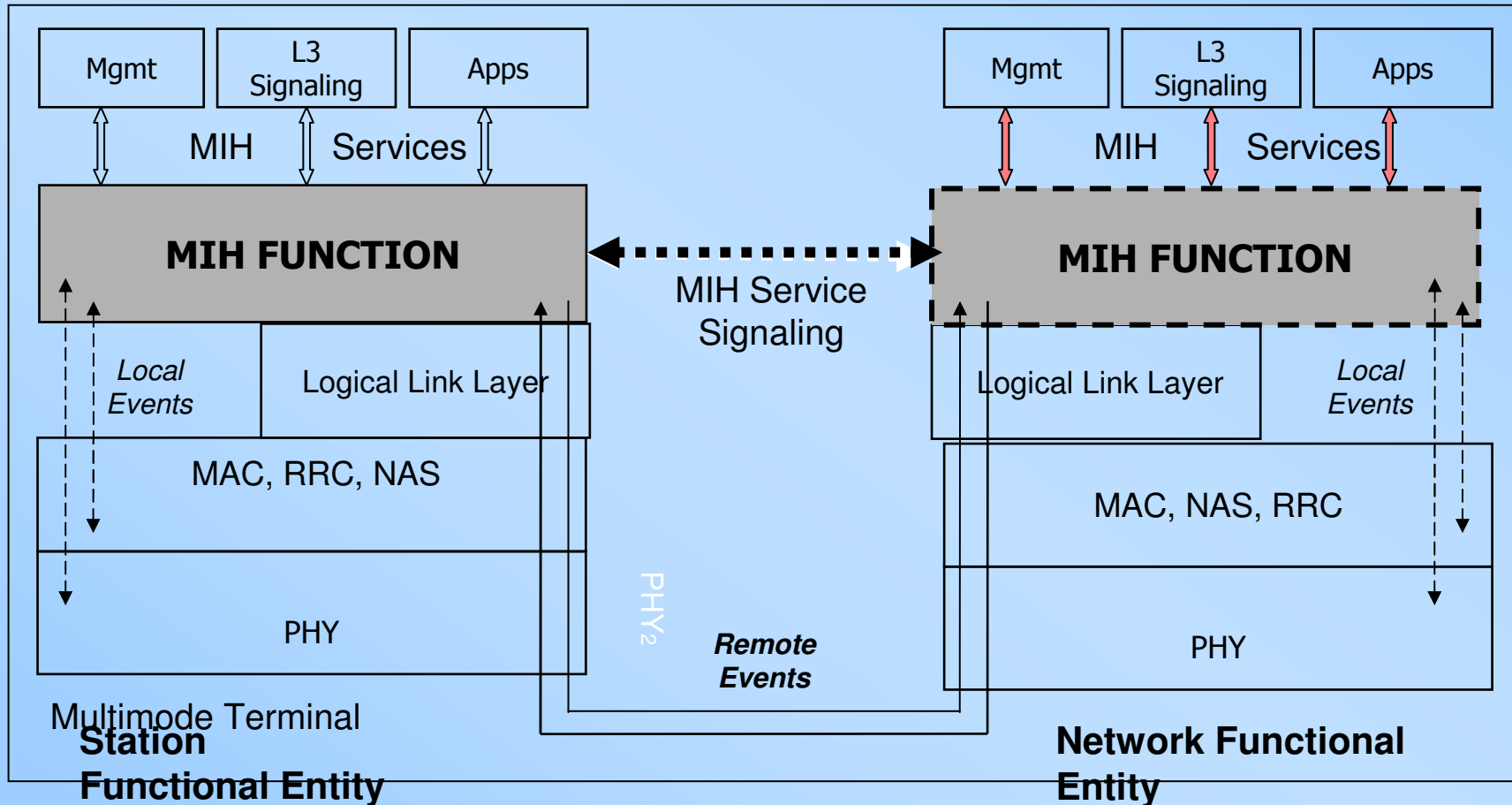  - Technology dependent interfaces between the MIHF and lower layers

**MIH reference model**

**MIH communication model**

MIH Point of Service (MIH PoS)

- MIH Function that communicates directly with the MN
- a MIH Function interacting with a MN using a MIH Proxy does not constitute a MIH PoS for that MN.

**A MIH Function : different roles**

- MIH on the MN
- MIH PoS of the serving PoA for the MN
- MIH PoS of a candidate PoA for the MN
- MIH PoS on a Network Entity that does not include a PoA for the MN
- Non-PoS MIH on a Network Entity that does not include a PoA for the MN

**Reference points**

**R1**: MN.MIHF - MIH PoS of its serving PoA Network Entity.

**R2**: MN.MIHF - MIH PoS of a candidate PoA Network Entity.

**R3**: MN.MIHF - MIH PoS of a non-PoA Network Entity.

**R4**: PoS.MIH - non MIH PoS located in different Network Entities.
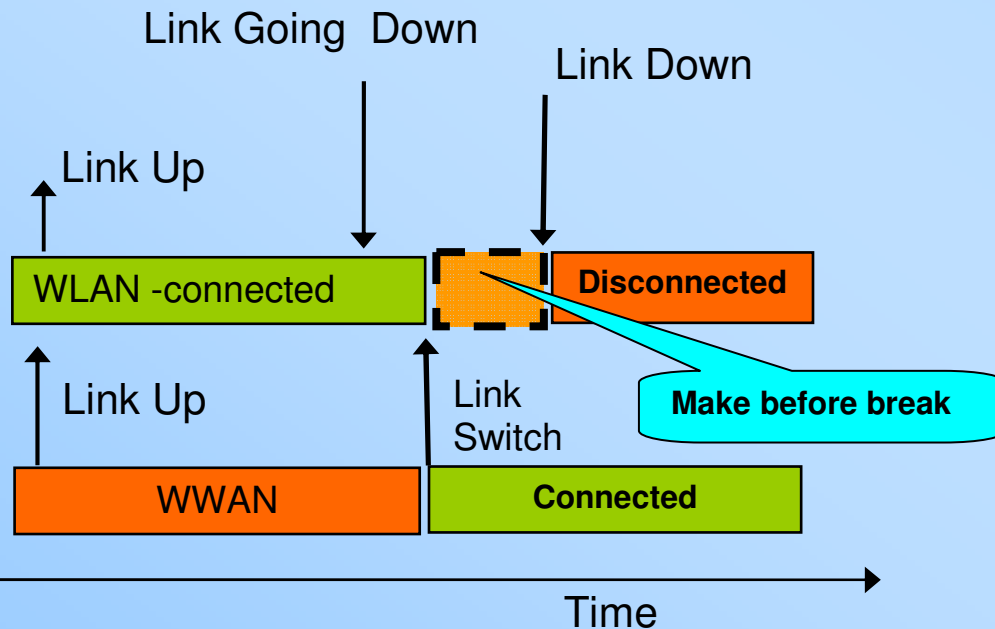
**R5**: between two MIH PoS in different Network Entities.
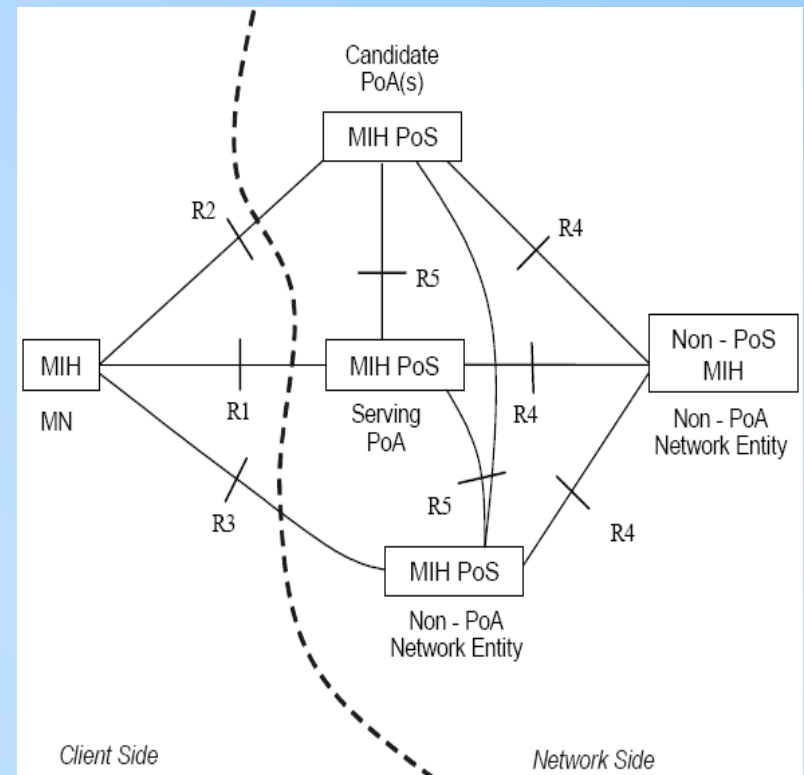
# 9. Media Independent Handover

**L2  Events (Triggers)**
**Triggers minimize connectivity disruption during link switching**



- State Change Events
  - Link Up
  - Link Down
  - Link Parameters Change

- Predictive Events
  - Link Going Down
  -
- Network Initiated Events
  - Load Balancing
  - Operator Preferences

**Examples of Link Layer Events**

| No | Event Type | Event Name | Description |
|----|-----------|-----------|-------------|
| 1 | State Change | Link Up | L2 Connection established |
| 2 | State Change | Link Down | L2 Connection is broken |
| 3 | Predictive | Link Going Down | L2 connection breakdown imminent |
| 4 | State Change | Link Detected | New L2 link has been found |
| 5 | State Change | Link Parameters Change | Change in specific link parameters has crossed pre-specified thresholds (link Speed, Quality metrics) |
| 6 | Administrative | Link Event Rollback | Event rollback |
| 7 | Link Transmission | Link SDU Transmit Status | Improve handover performance through local feedback as opposed to waiting for end-to-end notifications |
| 8 | Link Synchronous | Link Handover Imminent | L2 intra-technology handover imminent (subnet change). Notify Handover information without change in link state. |
| 9 | Link Synchronous | Link Handover Complete | Notify handover state |

# 9. Media Independent Handover

- **Media Independent Information Service**
- MIIS can help with Network Discovery and Selection leading to more effective Handover decisions
- Information about all Networks from Single radio
  - Cellular radio indicates presence of suitable WiFi hotspot
- Common Information Representation across different Networks, Rich Information
  - TLV, XML
  - Enable mobile policies beyond what can be pre-configured
- Media Independent Model
  - Use L2 for initial Network Discovery and Selection
  - Use L3 when available for client specific information

- Media Independent Information Service
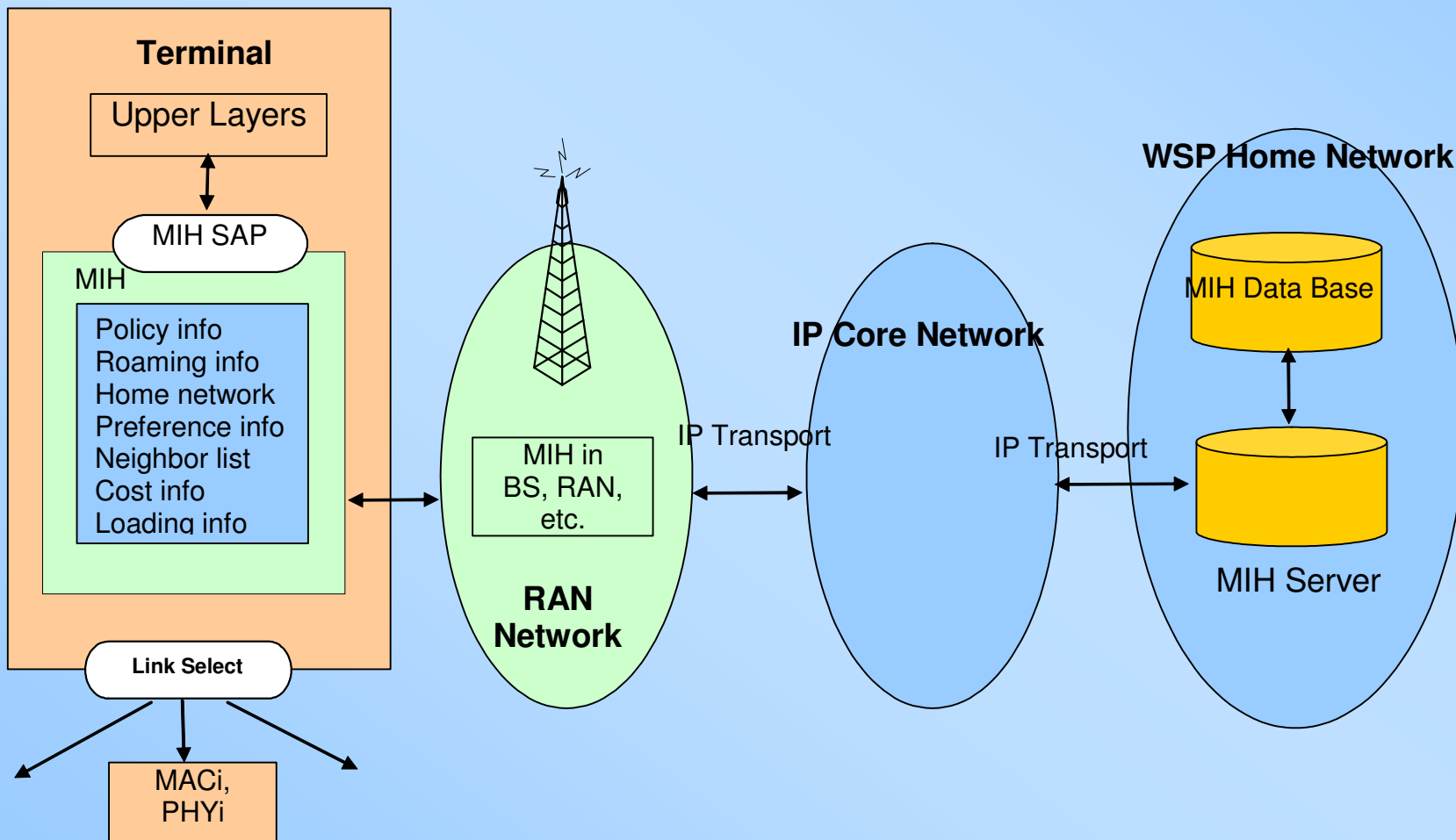
# 9. Media Independent Handover

- **Media Independent Information Service**
- **IS elements classification**
- *General Access Network Information*:
  - overview of different network providing coverage within the area
    - list of available networks
    - Operators
    - cost of connecting to the network
    - network security and quality of security capability
- *Information about PoAs (Point of Attachment)*
  - about different PoAs for each of available access networks (e.g. PoA Addressing information, PoA location, data rate supported, etc.).
- *Other information*: could be vendor specific info and vendor specific IEs
- Example:

| Network Type | SSID/ Cell ID | BSSID | Operator | Security | EAP Type | Channel | QoS | Physical Layer | Data Rate |
|---|---|---|---|---|---|---|---|---|---|
| GSM | 13989 | N/A | Oper-1 | NA | NA | 1900 | N/A | N/A | 9.6 Kbps |
| 802.11n | Enterprise | 00:00:... | Oper-2 | .11i | EAP-PEAP | 6 | .11e | OFDM | 100 Mbps |
| 802.16e | NA | NA | Oper-3 | PKM | EAP-PEAP | 11 | Yes | OFDM | 40 Mbps |

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# 9. Media Independent Handover Approach

**Information Elements**

| Information Element | Description | Comments |
|---|---|---|
| List of networks available | List all network types that are available given client location | E.g., 802.11, 802.16, GSM, GPRS/EDGE, UMTS networks |
| Location of PoA | Geographical Location, Civic address, PoA ID | E.g. GML format for LBS or network management purpose |
| Operator ID | Name of the network provider | E.g. Could be equivalent to Network ID. |
| Roaming Partners | List of direct roaming agreements | E.g. in form of NAIs or MCC+MNC |
| Cost | Indication of costs for service/network usage | E.g, Free/Not free or (flat rate, hourly, day or weekly rate) |
| Security | Link layer security supported | Cipher Suites and Authentication Methods, Technology specific, e.g. WEP in 802.11, 802.11i, PKM in 802.16, etc. |
| Quality of Service | Link QoS parameters | 802 wide representation, application friendly |
| PoA Capabilities | Emergency Services, IMS Services, etc. | Higher Layer Services |
| Vendor Specific IEs | Vendor/Operator specific information | Custom information |

## Types of Handover Based on Control Model

- **Terminal Controlled**
  - Terminal makes use of some MIH services
- **Terminal Initiated, Network Assisted**
  - Terminal makes use of MIH Information Service
- **Network Initiated and Network Controlled**
  - Network makes use of MIH Event and Command Service, plus Information Service knowledge, to decide if HO is needed/desired, to decide the target, and to command the terminal to handover

## Example: Handover Commands for Network Initiated Handovers

| No | Command Name | MIHF <> MIHF | Description |
|---|---|---|---|
| 1 | MIH Handover Initiate | Client <> Network | Initiates handovers and sends a list of suggested networks and suggested PoA (AP/BS). |
| 2 | MIH Handover Prepare | Network <> Network | This command is sent by MIHF on old network to MIHF on suggested new network . This allows the client to query for resources on new network and also allows to prepare the new network for handover |
| 3 | MIH Handover Commit | Client <> Network | In this case the client commits to do the handover based on selected choices for network and PoA. |
| 4 | MIH Handover Complete | Client <> Network Network <> Network | This is a notification from new network PoA to old network PoA that handover has been completed, new PoA has been established and any pending packets may now be forwarded to the new PoA. |

# 9. Media Independent Handover

- **MIH Protocol**
  - Collection of all MIHF messages sent between peer MIH entities
    - Includes Events, Commands and IS exchange
  - Common message payload across different media
    - 802.3, 802.11, 802.16, Cellular...
  - Media specific Transports
    - Use Data plane whenever available
      - e.g: In State 3 for 802.11
    - Use Management plane when Data plane not available
      - Action Frames in State 1 for 802.11

| MIHF Fixed Header | MIHF Variable Header | MIHF Payload |
|---|---|---|

← MIH Function Frame →
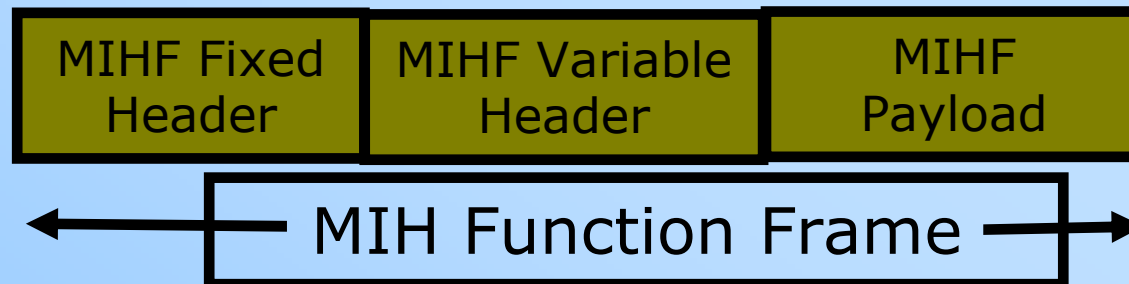
## Media specific Amendments

(picture from Vivek Gupta, IEEE P802.21 Tutorial : "IEEE 802.21 MIH", July 17, 2006
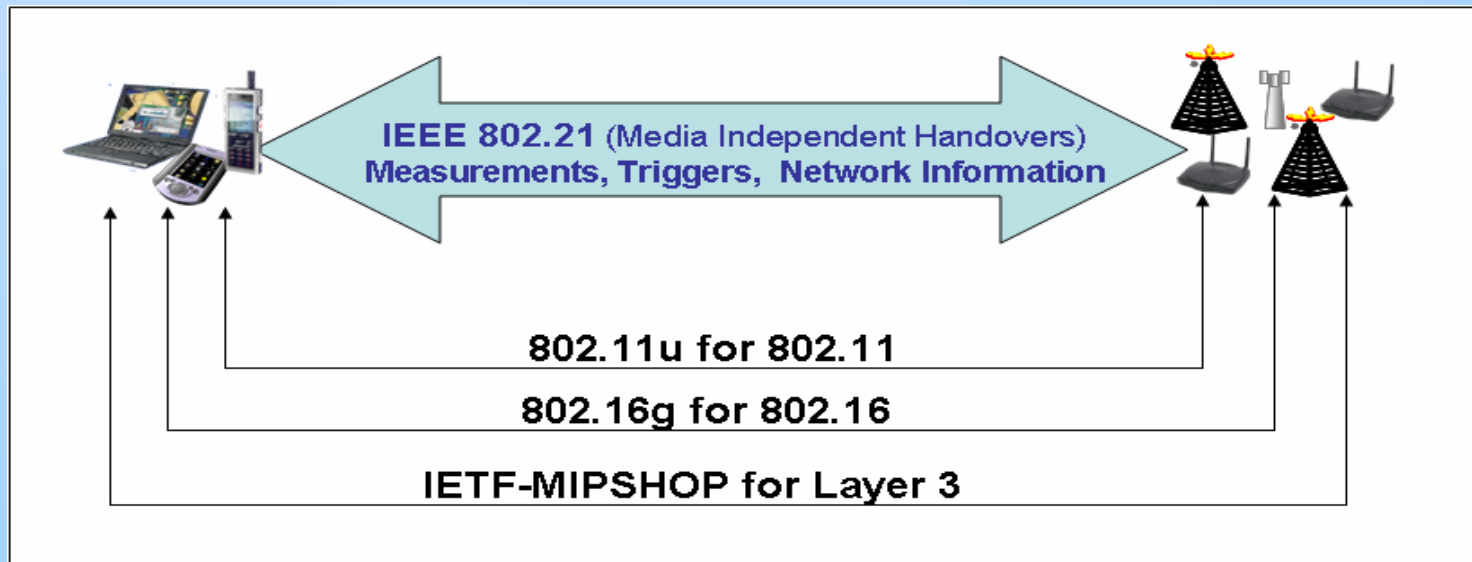


- MIH Protocol (MAC independent messages) defined in 802.21
- Container for MIH messages for 802.11 defined in 802.11u
- Container for MIH messages for 802.16 defined in 802.16g
- Working with 3GPP-SAE for 3GPP specific changes
- Transport for MIH  Protocol defined in IETF (MIPSHOP)

# 9. Media Independent Handover

- **MIH Amendments for 802.16**

  - No New Mobility Protocols
  - No redesign of existing MAC and PHY
  - MIH does not handle HO execution

  - 802.16 Architectural Extension for MIH
    - New SAPs should be defined/extended to support 802.21
    - C_SAP, M_SAP are extended to Support MIH
    - NCMS Extension to support MIH Primitives Delivery to MIH Function
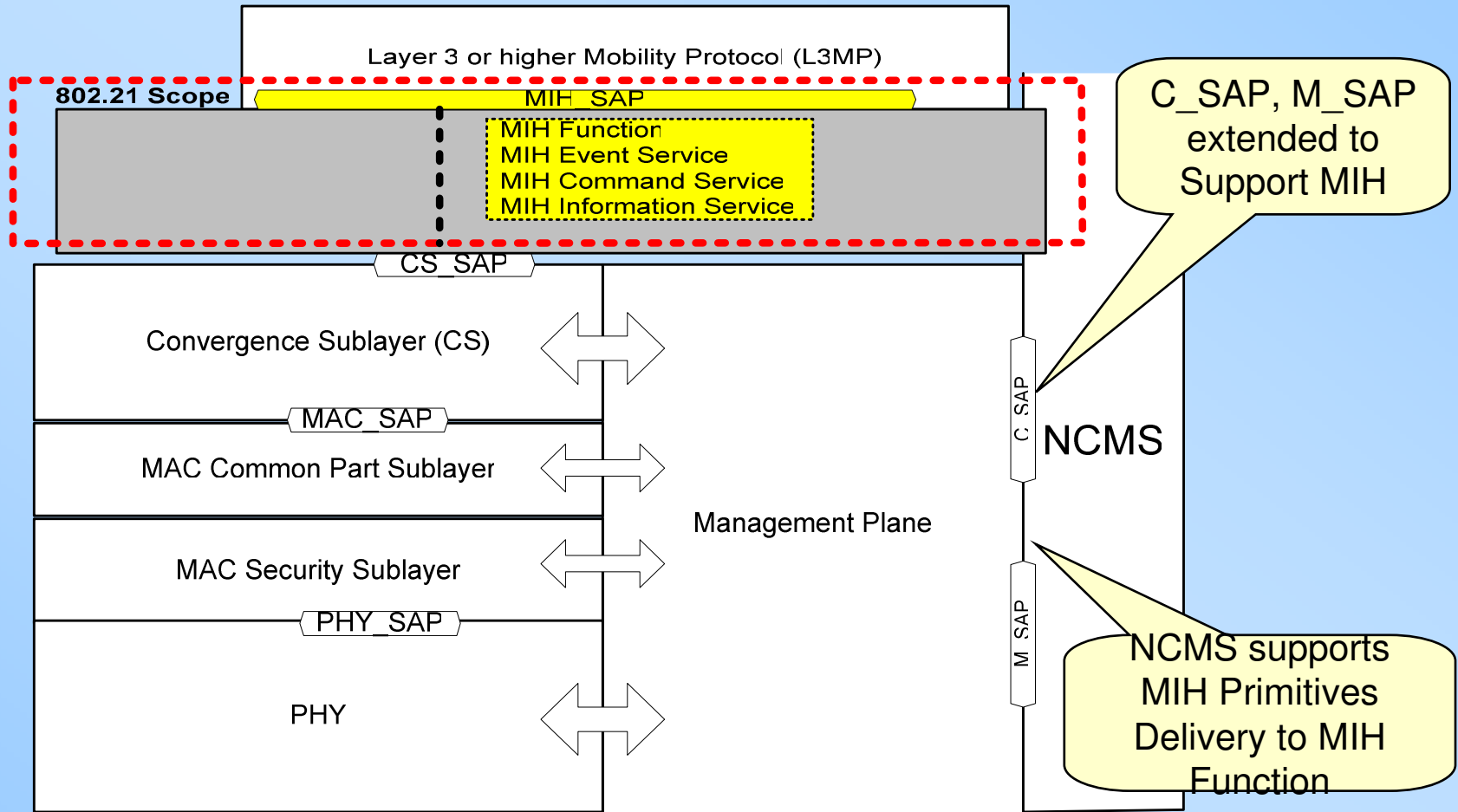    - 802.16 Transport for MIHF Protocol

# 9. Media Independent Handover

## MIH Amendments for 802.16



Layer 3 or higher Mobility Protocol (L3MP)

802.21 Scope

MIH_SAP

MIH Function
MIH Event Service
MIH Command Service
MIH Information Service

CS_SAP

Convergence Sublayer (CS)

MAC_SAP

MAC Common Part Sublayer

MAC Security Sublayer

PHY_SAP

PHY

Management Plane

C_SAP

NCMS

M_SAP

C_SAP, M_SAP extended to Support MIH

NCMS supports MIH Primitives Delivery to MIH Function

# 9. Media Independent Handover

## 802.16 Transport for MIH
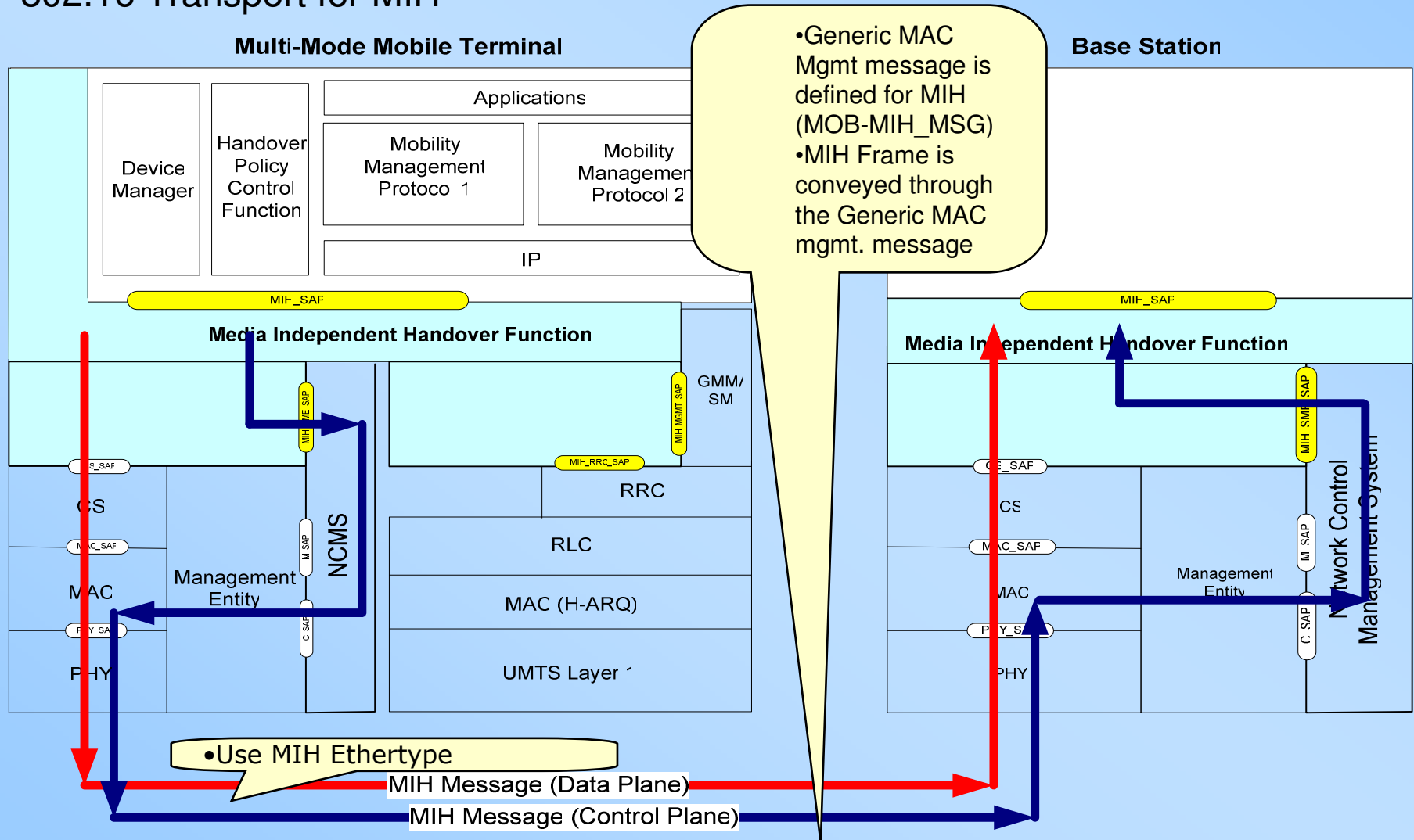
Example : WEIRD Project Mobility Mng. : WiMAX Forum approach + 802.21
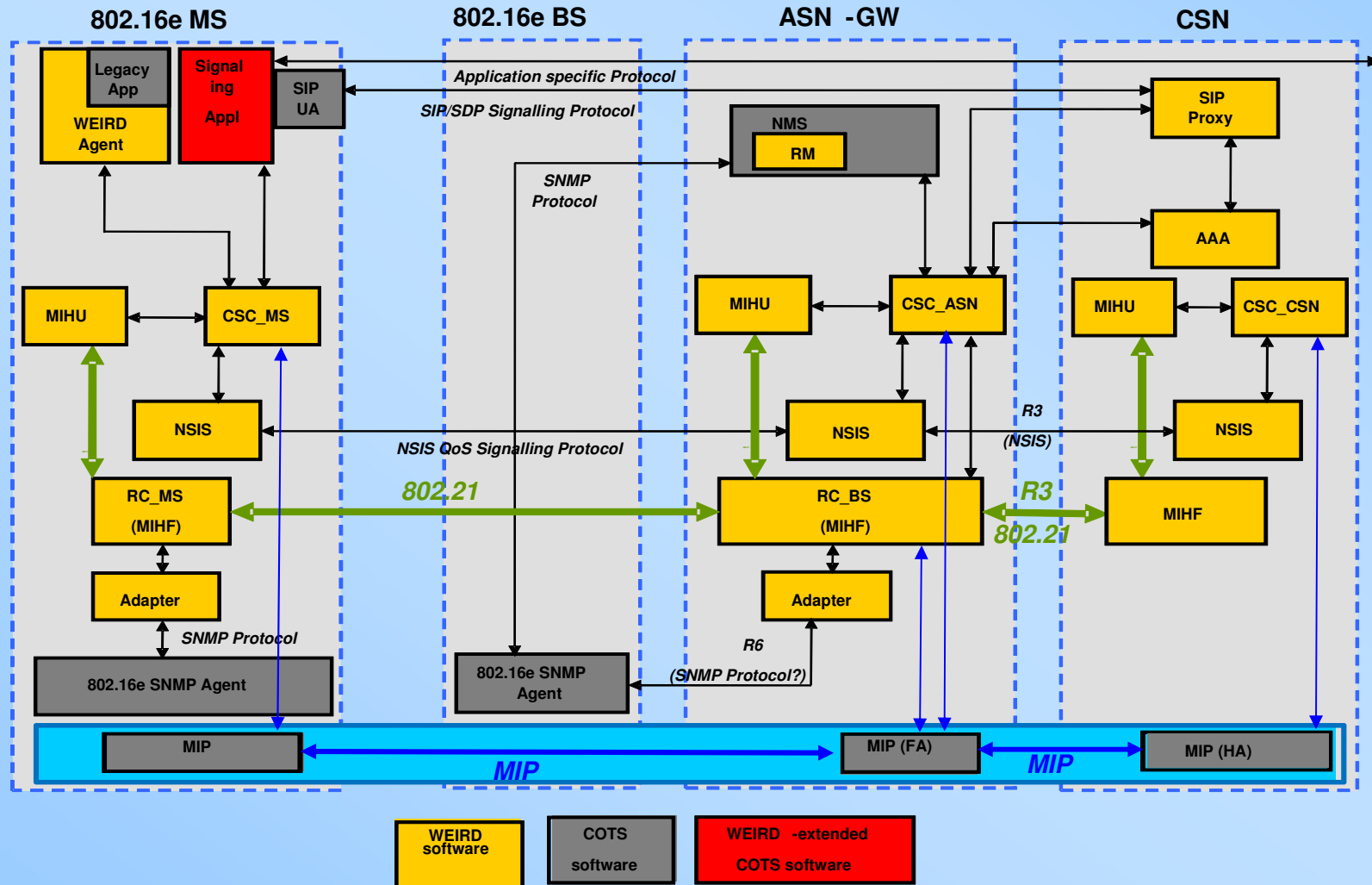
## Example: WEIRD Project Mobility Mng. : IEEE 802.21 approach
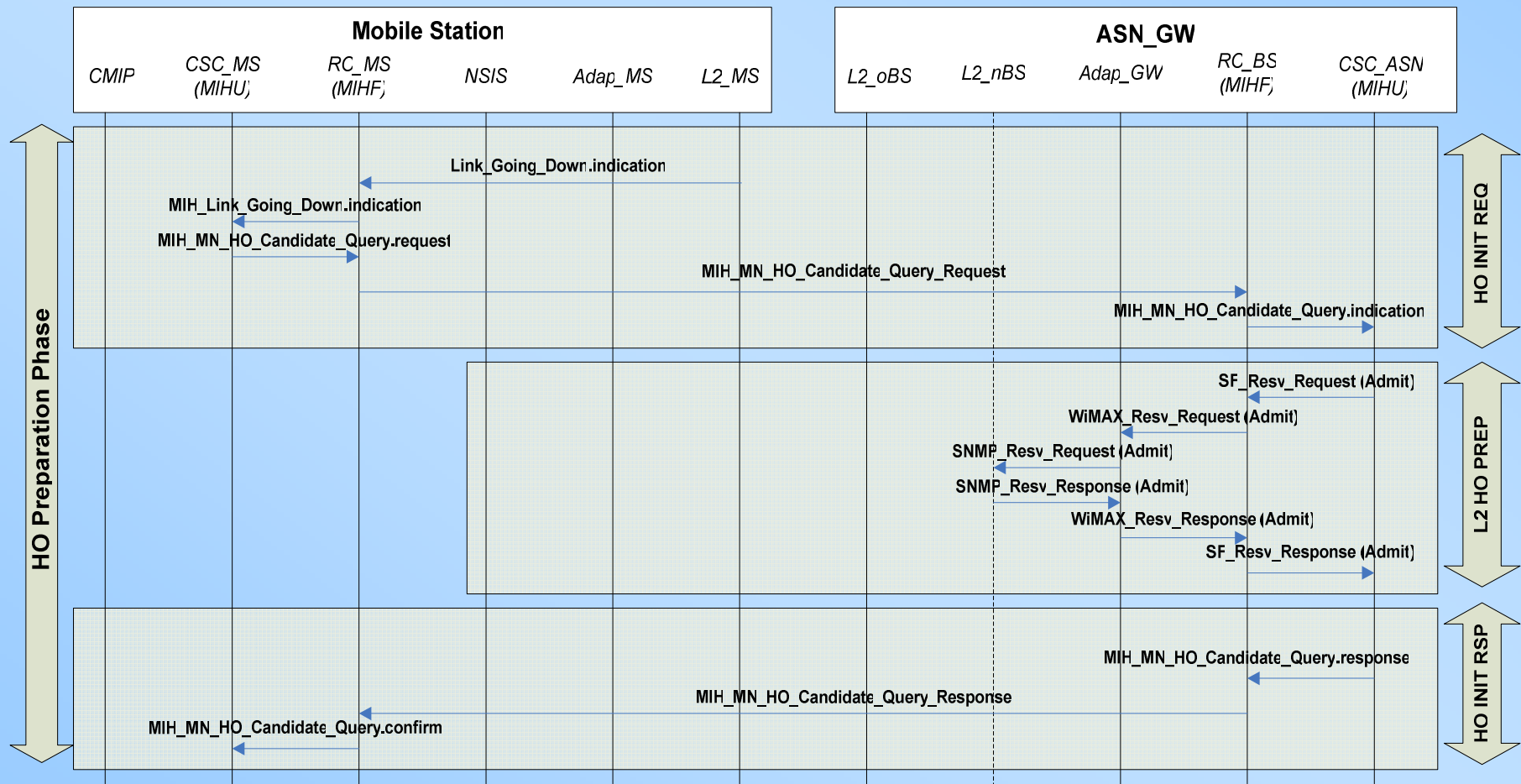
- **Micro - mobility example: WEIRD project**
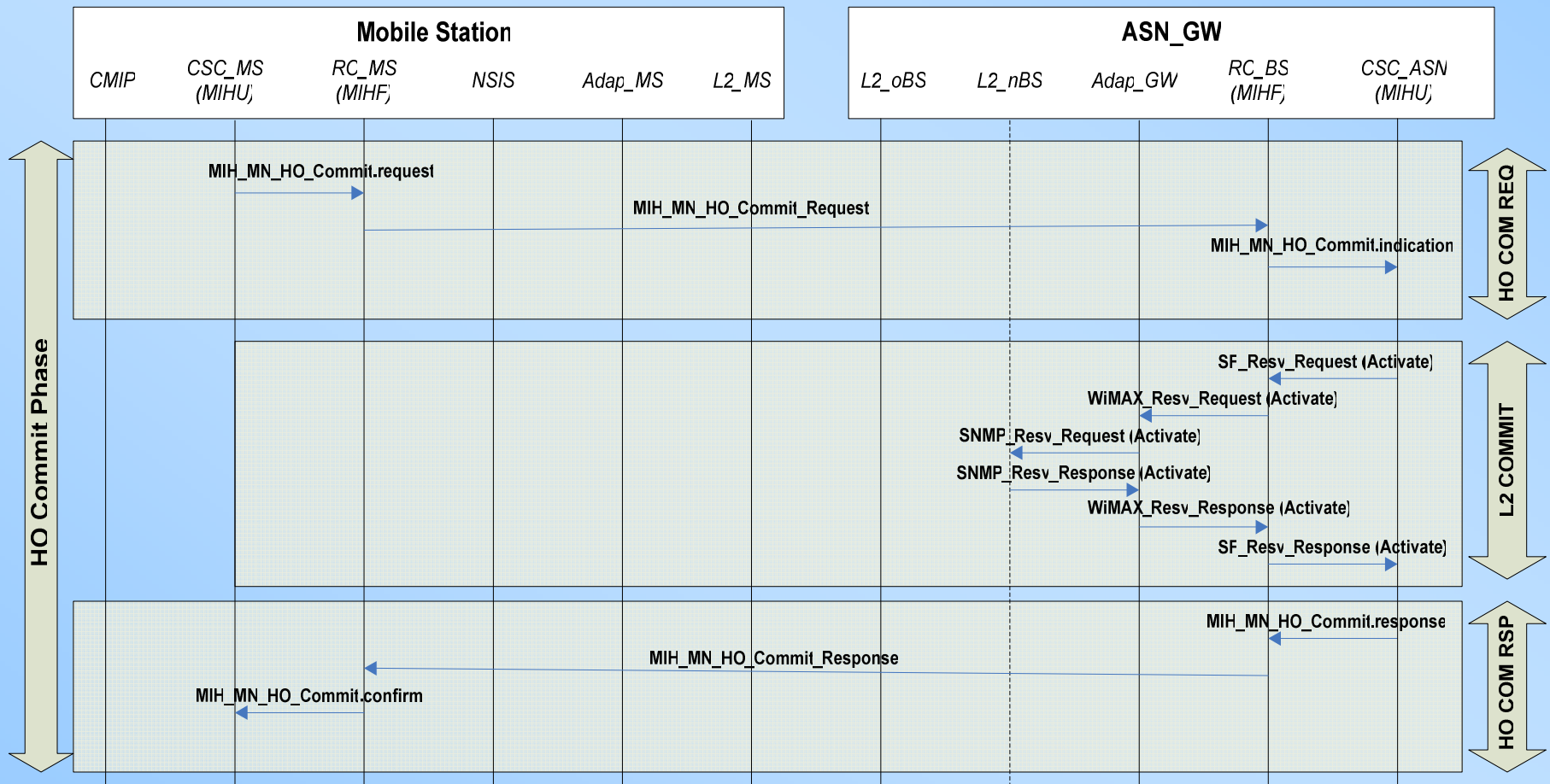- MS-initiated HO: preparation phase

- **Micro - mobility example: WEIRD project**
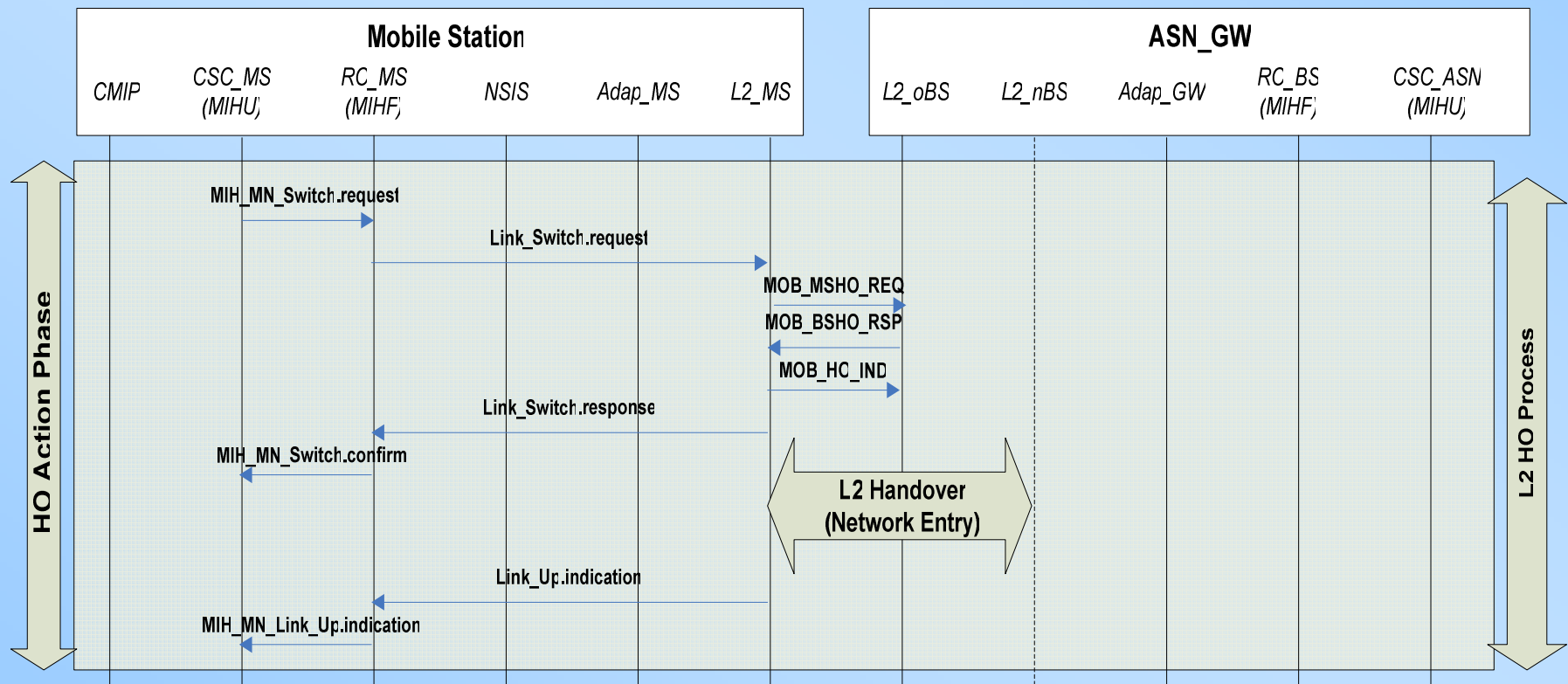- MS initiated-HO:  commit phase
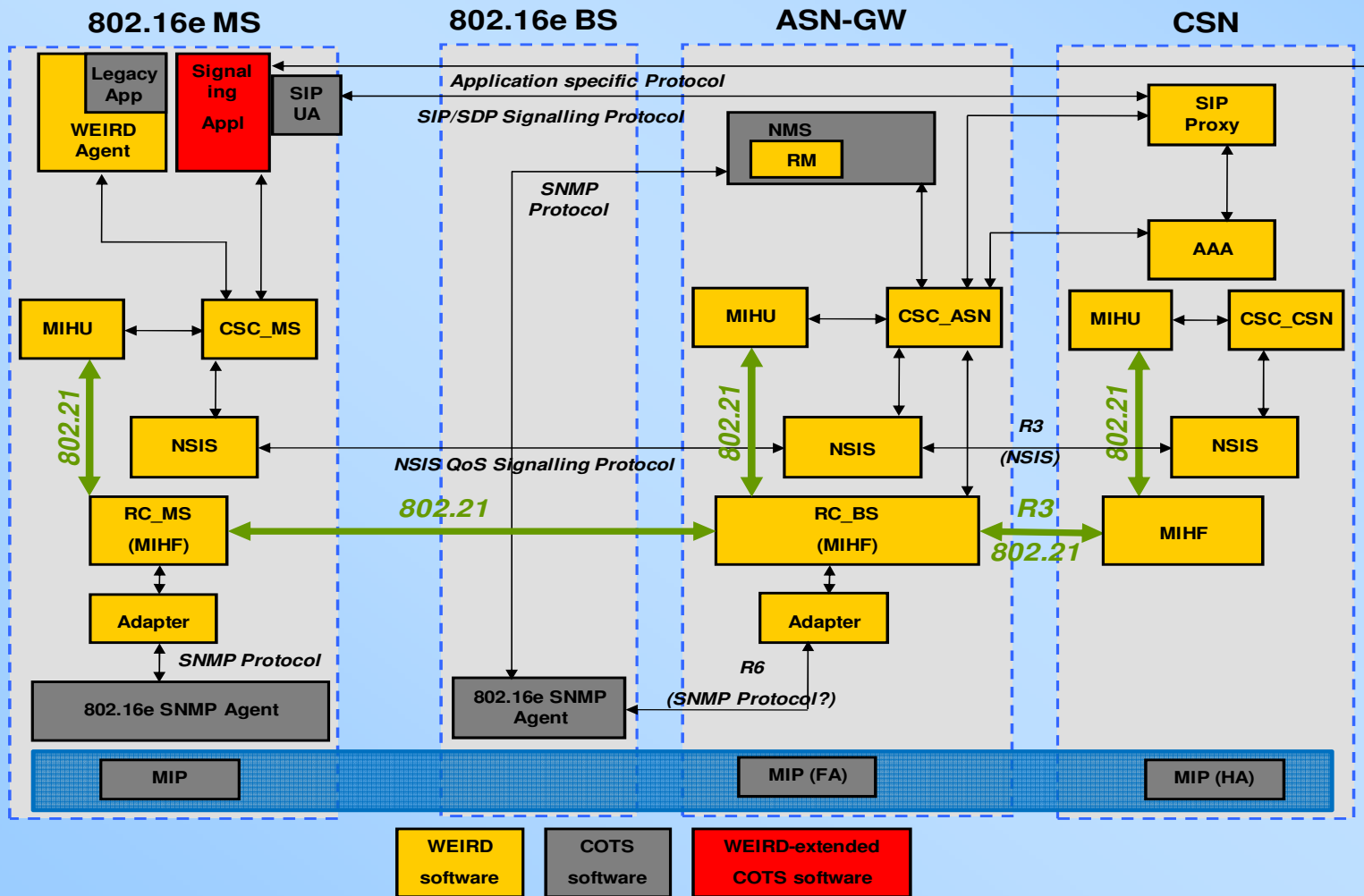
# 9. Media Independent Handover

- **Micro - mobility example: WEIRD project**
- MS initiated-HO: Action phase

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11. WiMAX versus other Broadband Technologies
12. Future Trends: WiMAX and  4G networks

# 10. Mesh Mode

- MESH mode - proposed initially in 802.16d standard
- Benefits
    - Higher coverage
    - Higher reliability
    - Multiple paths
    - Better scalability

- **Open issues/problems of the initial approach**
    - Not so much deployed yet, still in development
    - Currently-developed mesh mode in IEEE 802.16 standards – not compatible with the original PMP mode
    - PHY:
        - Different frame structures-from PMP ones
        - Support only OFDM operation in both licensed and unlicensed bands
    - MAC
        - Network entry procedure is different w.r.t. PMP
        - It does not support mobility

- Intermediate solution:
    - Mobile Multihop Relay (MMR) - Study Group
    - IEEE 802.16j TG – in development

# 10. Mesh Mode

- **Mobile Multihop Relay (MMR) mode**
- IEEE 802.16j (MMR) targets
    - to enhance the normal PMP frame structure
    - Develop new relay networking protocols
    - Coverage extensions
    - Throughput enhancement

    - Actually MMR is not mesh mode  but tree topology
    - Multi-hop relay connections between SS/MS and BS
    - MMR mode
        - is backward compatible with PMP mode
        - Supports both OFDM and OFDMA operation
- **Open MMR issues**
    - **MAC:** Enhanced Frame structure, Fast multi-hop route selection, Security, Scheduling policies

    - **PHY:** Synchronization, Interference management, Frequency reuse strategy

    - **Cross-layer issues**
        - Seamless handover
        - Backward compatible network entry procedure
        - Cross-layer optimization

# 10. Mesh Mode

- **Mobile Multihop Relay (MMR) mode**
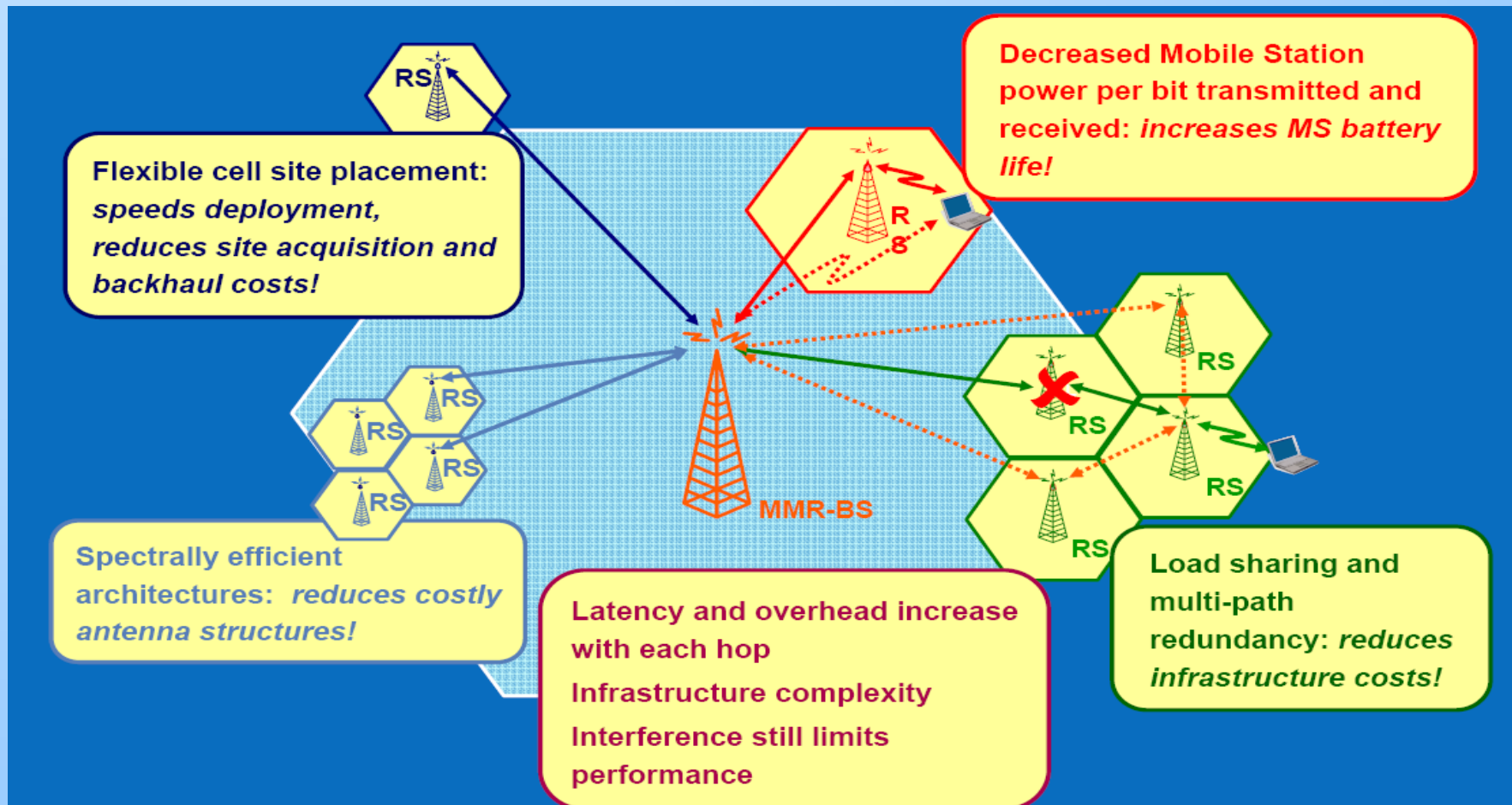


**Source: IEEE® 802.16 based Mobile WiMAX : A Strategic Overview, INTEL, 2007**

# 10. Mesh Mode

- **IEEE 802.16j- draft**
  - R-MAC sub-layer : efficient MAC PDU relaying/ forwarding and control
  - is applicable to the links between MR-BS and RSs and between RSs
  - Figure 2a
    - example protocol stack for MS traffic relaying
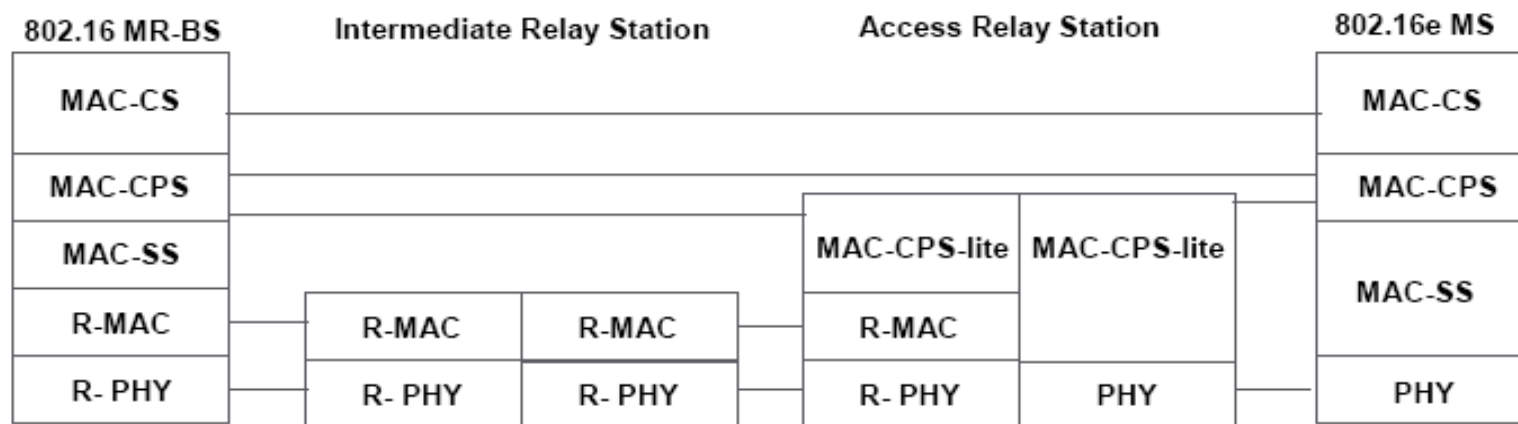    - MS connection and privacy managements is on an E2E basis (between MR-BS and MS).



Figure 2a—Example MR data protocol stack for simple RS (MS traffic relaying).

# 10. Mesh Mode

- **IEEE 802.16j- draft**
  - Figure 2b
    - protocol stack for MS traffic relaying
    - the MS connection and privacy management are managed by the RS and the RS connection and privacy management are controlled by MR-BS
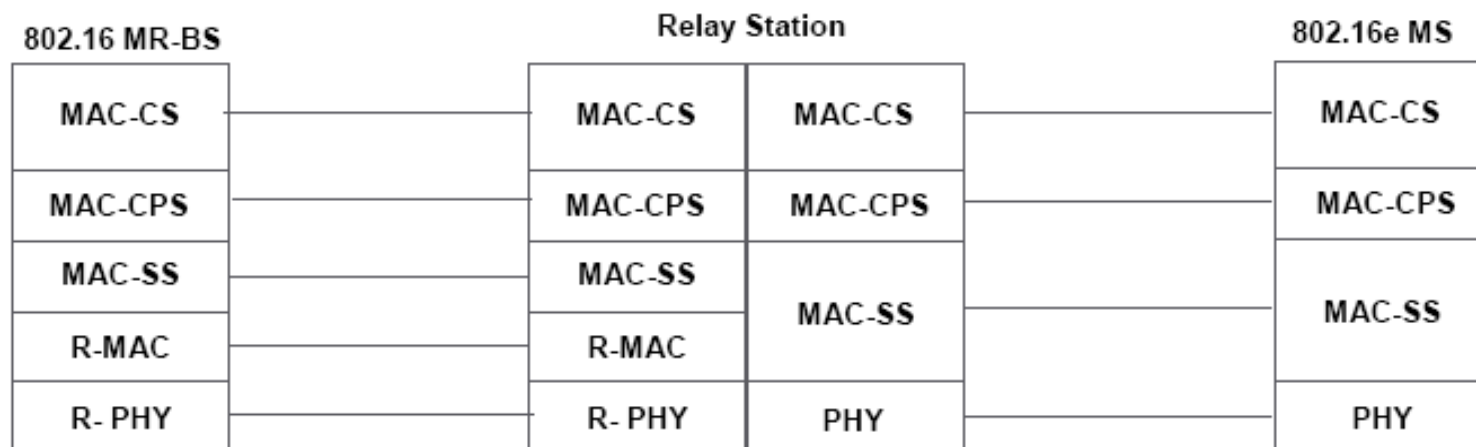


Figure 2b—Example MR Data Protocol stack for moving RS in moving BS mode (MS traffic relaying)

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- Complementary access technologies; Source INTEL 2007
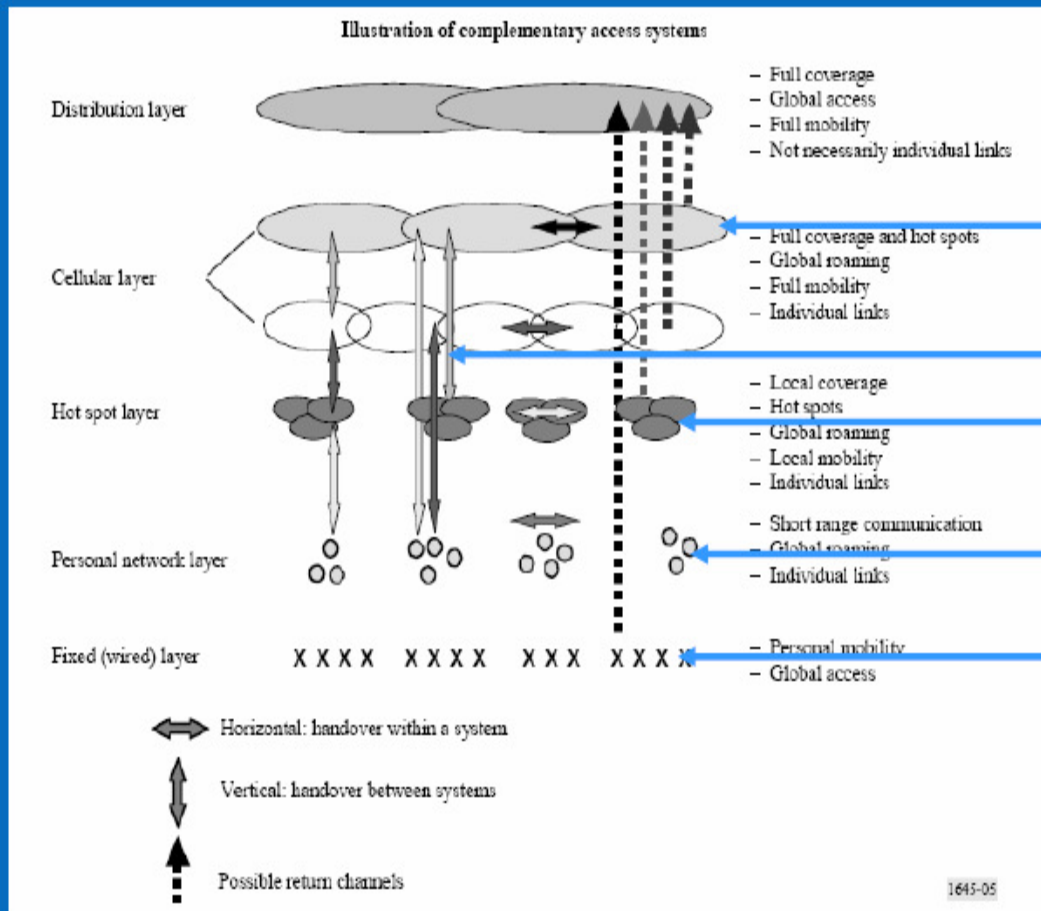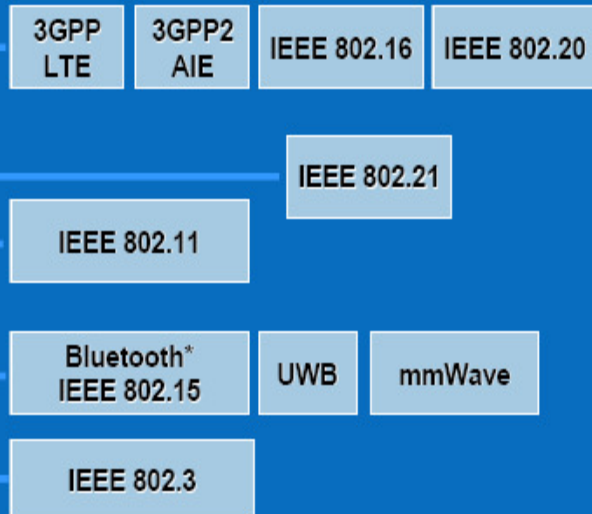
## Comparison of User Planes & Data Flows

- Source INTEL 2007

### 3G User Plane and Data Flow

*too many protocols, too many nodes*
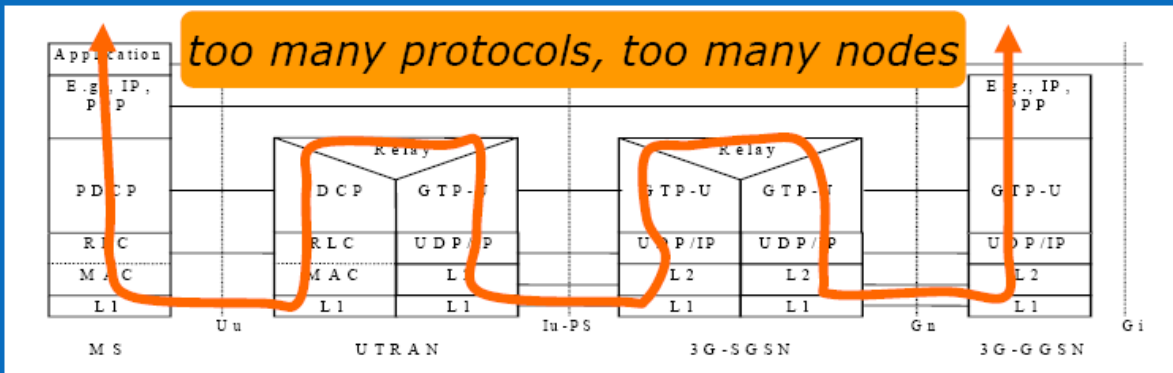
A lot of complexity from evolution of circuit switched protocols for packet data applications

### Mobile WiMAX User Plane and Data Flow

*Simple. Few protocols. Easy-to-implement. Mostly, IETF protocols. Few MS requirements*

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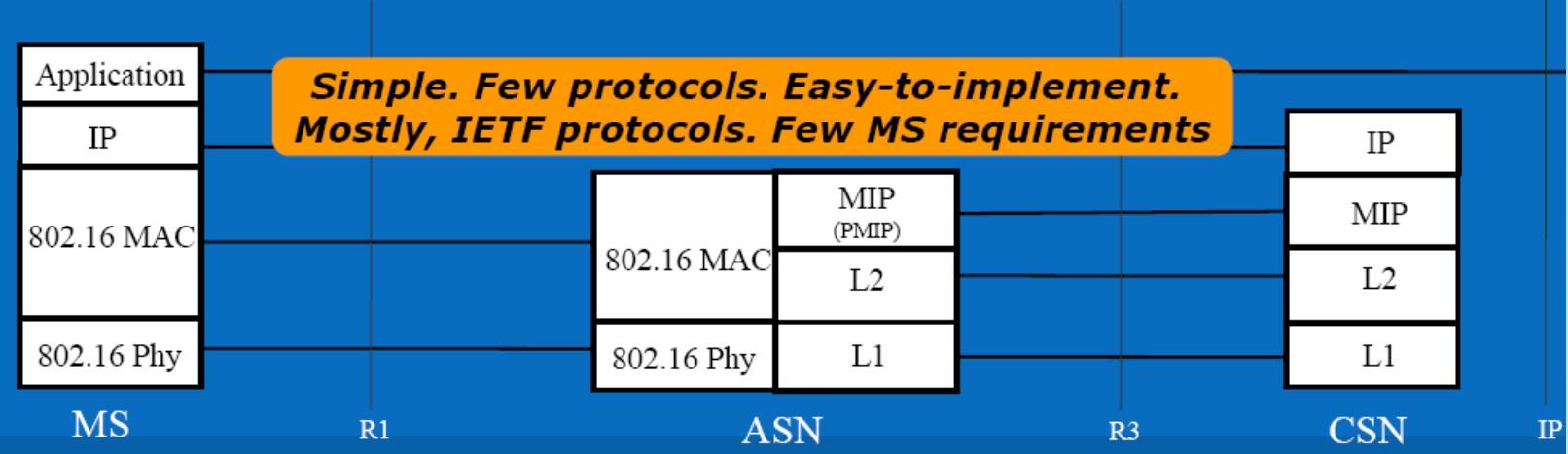
- **3GPP SAE - 3G SAE - UMTS SAE**
- 

  **(System Architecture Evolution)**

-  3GPP SAE or 3G SAE SAE (System Architecture Evolution) is a  3GPP work item to develop a new core network architecture for UMTS that addresses cost-efficient deployment and operations for mass-market usage of IP services as well as improvements in integration of other access technologies in the network
- 
- **Main drivers are:**
- to be able to meet the targets for the evolution of the radio-interface (LTE),
  - Symplified network architecture;
- to enable the evolution towards an All-IP Network
  - All services are packet switched, no circuit switched
- to support mobility and service continuity between heterogeneous access networks.
  - 2G/3G, LTE, non 3GPP access systems (e.g.WiFI, WiMAX)
- 3G SAE is a framework for a higher-data-rate, lower-latency, packet-optimized system that supports multiple RAT with a focus on packet-switching, including support of VoIP.

**Mobile WiMAX** / **3GPP SAE - 3G SAE - UMTS SAE:** Source INTEL 2007
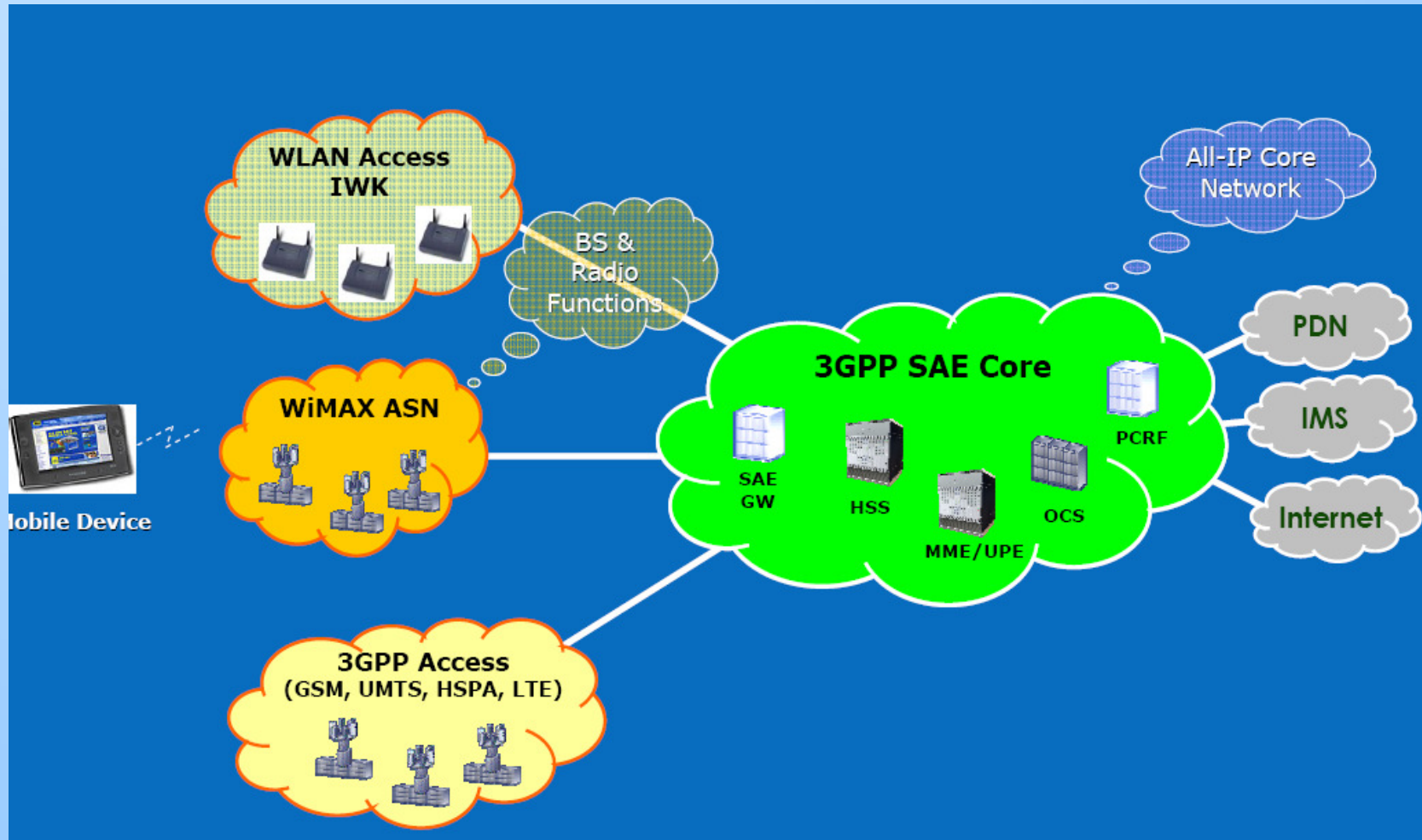
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12. **Future Trends: WiMAX and  4G networks**

# 12. Future Trends: WiMAX and 4G networks

- **WiMAX vs 3G/4G-LTE Debate**
  - **At WiMAX World Europe, May 2008**
  - **Opinions:**
    - Mobile WiMAX will not succeed in the European market unless its proponents achieve greater clarity in defining and targeting the true addressable market for the technology

    - Mobile WiMAX has much promise for both mobile and fixed operators, but has only begun to deliver

    - The mobile community, led by 3GSM, has responded to WiMAX by developing 3G-LTE which offers a migration path from 3G to an OFDMA based technology and similar network topology to that associated with mobile WiMAX

    - With competing technologies emerging in the marketplace, service providers are faced with the challenge of choosing between WiMAX or 3G-LTE technologies

    - Some analysts say that the WiMAX and LTE will eventually converge

    - **Several authors' opinion: the support of one or another technology is more related to financial interests of actors than strictly technical arguments**

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# 12. Future Trends: WiMAX and 4G networks

- **WiMAX vs 3G-LTE**
- **Opinion Samples:**
- **Pros:**
  - **WiMAX is clearly 4G technology**
  - **4G builds are a ways off, as most mobile providers haven't really gotten the value out of their 3G networks**
  - **802.16m will offer a lot of bandwidth comparable with LTE**
  -
- **Cons:**
  - Dr. Hakan Eriksson, Ericsson
  - "4G LTE seems to be the winning technology,"
  - "It is the first time the industry will get one technology worldwide."
  - "WiMAX is a bit late," …
  - "While WiMAX will get to market before LTE, the established mobile providers then will move to a platform that offers much more bandwidth than WiMAX , with an ability to leverage global volumes for devices"
  - HSPA offer more bandwidth…

# 12. Future Trends: WiMAX and 4G networks

- **802.16/WiMAX standards evolution**

  - WiMAX is currently the only major commercialized MIMO OFDM based system.
  - IEEE 802.16e-2005 was developed before other beyond-3G standards, such as 3GPP LTE and 3GPP2 UMB
  - key areas where the 802.16 performance can now be improved.
  - The Rev. 2 project in IEEE 802.16 incorporates all of the available addendums, and addresses key areas
  - The commercial IEEE 802.16 Rev. 2 system is expected in 2009-10 ( earlier than the time frame for LTE based systems)

  - **Task Group m (TGm): IEEE 802.16m**
    - Tries to meet the IMT-Advanced requirements.
    - Based on IEEE 802.16e-2005, is expected to exceed twice the throughput of current WiMAX systems
    - An evolved 802.16m system is required to provide
    - support for legacy Wireless MAN OFDMA equipment, including mobile stations (MSs) and base stations (BSs).
    - support green-field deployment by turning off the legacy support feature.

- **IEEE 802.16m**
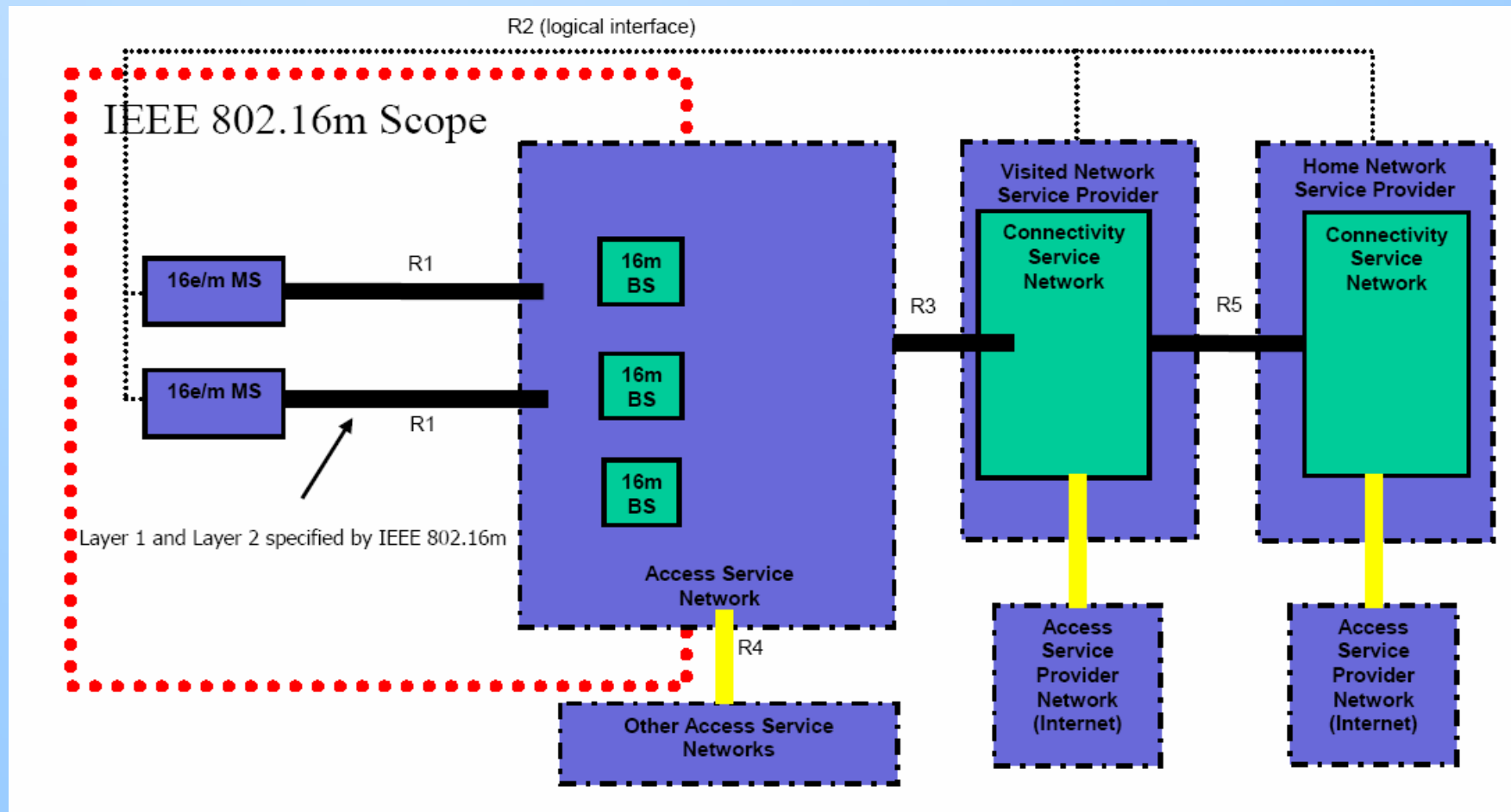
# 12. Future Trends: WiMAX and 4G networks

- **802.16/WiMAX standards evolution**
  - **IEEE 802.16m (cont'd)**
    - Approved System Requirements Document (SRD).
    - SRD describes a set of requirements which meet the IMT advanced requirements.
    - TGm develops the system description document (SDD), which is a Stage 2 description of the 802.16m (Nov 2008)
    - TGm will also work on the proposal for IMT-Advanced, expected to be adopted by the (ITU) before Oct. 2009
    - 802.16m Amendment: completed in March 2010

    - The 802.16m improves:
      - spectral efficiency, improve voice capacity, reduce latency
      - support for location-based services, and improve
      - multicast broadcast services.

    - Recent (May 2008) focus:
      - DL MIMO schemes
      - UL control structure
      - UL pilot structure
      - UL physical resource allocation unit, preamble
      - and HARQ timing.

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# 12. Future Trends: WiMAX and 4G networks

- **802.16/WiMAX standards evolution**
  - **IEEE 802.16m (cont'd)**
  - **Define a new frame structure**
    - In 802.16e, the 5msec frame duration is a limiting factor for scheduling, HARQ latency, feedback, micro sleep, etc.
    - 16m solution: a frame structure divided into 8 subframes; each subframe = 6 OFDM symbols (~ 0.625msec).
    - new super frame concept (4 frames = super frame) -> reduce control channel overhead:
  - **Rev 2 improvements:**
  - **FDD**
    - 802.16e-2005 std - optimized for TDD
    - But FDD systems provide an large market opportunity for the WiMAX industry
    - Rev.2 Dev. has focused also on half duplex FDD (H-FDD) systems
  - **VoIP**
  - reduce the VoIP overhead,
    - Concept of a persistent assignment: periodically recurring resource and modulation/coding assignment is signaled once or infrequently to the user
    - . Persistent assignments reduce the MAP overhead by 40 - 50% for VoIP only traffic -> bidirectional VoIP capacity increase of 15 - 20%.

- **802.16/WiMAX standards evolution**
  - **Rev 2 improvements:**

    - 802.16: uses asynchronous HARQ -> BS can schedule
    - a particular HARQ retransmission at any time.
    - to establish a unique relationship between a particular initial transmission and the associated retransmission, the persistent assignment includes a set of HARQ channel identifiers which cycle in an implicit manner
    - the BS can schedule retransmissions for a particular packet during the interval between successive occurrences of a particular HARQ channel identifier
    - This cycling uses a scheme consistent with 802.16e, meaning that the BS can schedule retransmissions for persistent assignments with legacy messages.
    - Since retransmissions are dynamically scheduled, the BS can fill resource holes with either new persistent allocations or retransmissions
    - In some cases, it may be necessary to relocate some users in the time-frequency space to fill resource holes.

- **802.16/WiMAX standards evolution;** Source INTEL 2007
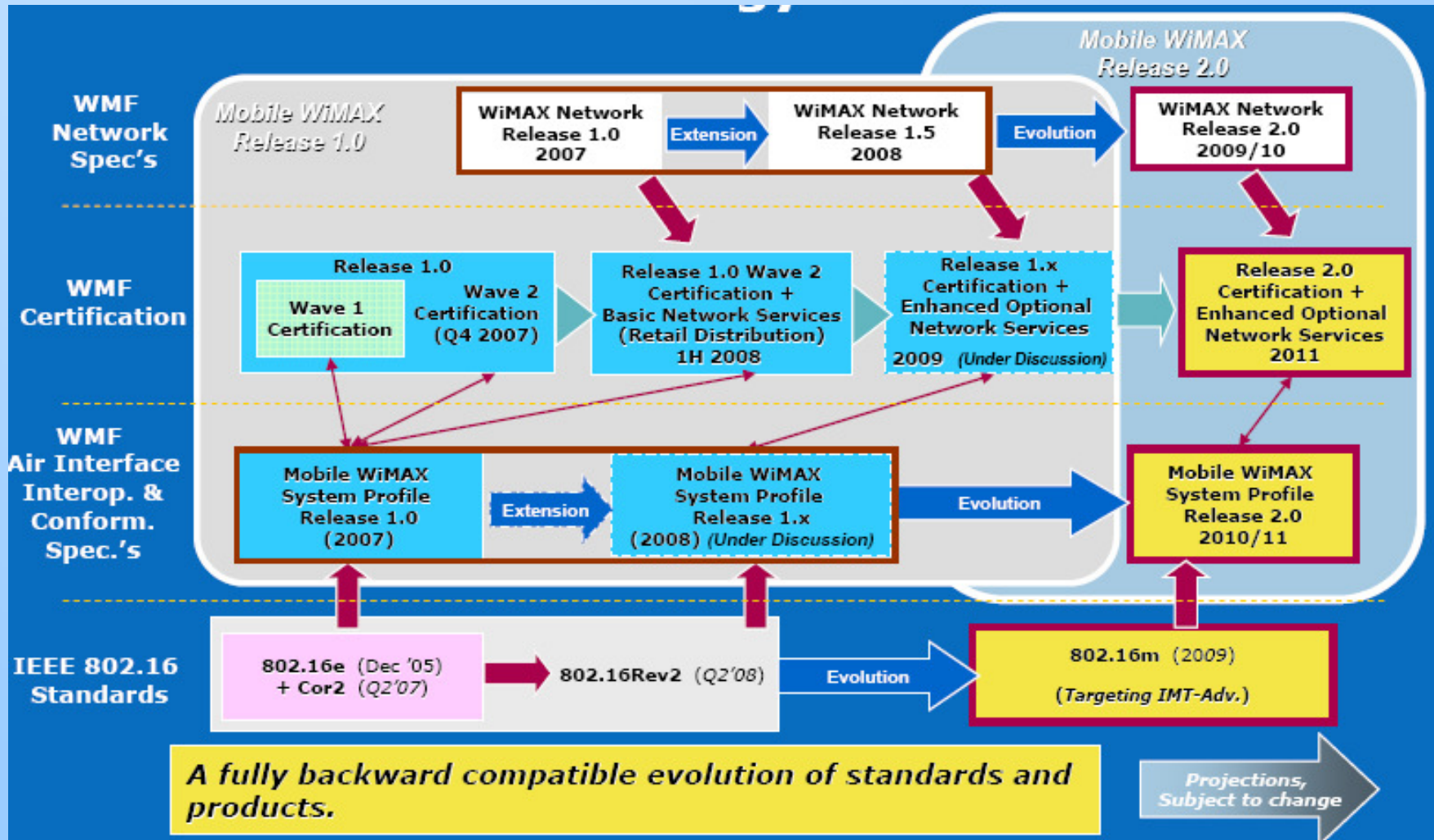
# 12. Future Trends: WiMAX and 4G networks

- **WiMAX future – pros and cons**
  - **Cons:**
    - June 2008 : Sprint-Nextel recently announced a delay to the commercial roll-out of its Mobile WiMAX service, Xohm

    - has now stated that the first commercial service of Xohm will be in Baltimore in Sept. 2008 and Washington DC and Chicago by Q4 2008 (provided the new WiMAX venture 'ClearWire' deal closes by Q4 2008)."

    - Currently: 97% of laptops are shipped with Wi-Fi

    - 3G LTE is expected to be a fully ratified standard by the end of 2008 or beginning of 2009 with deployments slated to occur in late 2009 or first months of 2010 offering peak data rates of up to 170Mbps

    - dual-mode Wi-Fi/Cellular mobile phones is also on the rise with newer models emerging at lower costs, with better battery life

    - Frost & Sullivan believes that the work carried out on Mobile WiMAX could potentially lead Mobile WiMAX to merge with 3G LTE

- **WiMAX future – pros and cons**
  - **Cons:**
  - **Frost and Sullivan (2008):**

    - "2009 will be the year when operators begin to realize that Mobile WiMAX can no more be considered as a feasible mobile broadband "access" technology"

    - "In terms of indoor BWA , Wi-Fi fits well in this space and with the emergence of 802.11n, which includes MIMO, throughputs would be better than what Mobile WiMAX can deliver"

    - With respect to outdoor mobile broadband environments, users would expect Mobile WiMAX to seamlessly hand off to cellular networks in the absence of WiMAX reception

    - But in reality this is not possible as Mobile WiMAX is not backward compatible with existing cellular technologies"

# 12. Future Trends: WiMAX and 4G networks

- **WiMAX future – pros and cons**
  - **Cons:**
    - it is still ambiguous if consumers will want one mobile device for voice, based on cellular technology and another for 'personal broadband' based on Mobile WiMAX. (HSPA coupled with Wi-Fi can do both in a single mobile device)

    - recent WiMAX Forum workshop in Dubai, participants accepted that Mobile WiMAX is not optimised to simultaneously handle both data and voice applications as efficiently as HSPA, or 3G LTE

# 12. Future Trends: WiMAX and 4G networks

- **802.16/WiMAX evolution**

- **Open research issues**

  - **Capable 2D scheduling**
  - **Cross layer optimsation Media Independent Handover**
  - **Seamless Handover**
  - **MIMO, smart antennas and beamforming technologies**
  - **Cooperation with 3G technologies**
  - **Mesh networking**

  - **Convergence WiMAX-LTE?**

# Thank you
# Questions?

# 9. References

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# 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.

## 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

# Acronym List

- AAS adaptive antenna system
- BER bit error ratio
- BW bandwidth
- CCI co-channel interference
- CINR carrier to noise and interference ratio
- CDMA code division multiple access
- CSCF centralized scheduling configuration
- CSCH centralized schedule
- CP Cyclic Prefix
- DFS dynamic frequency selection
- DSCH distributed schedule
- FFT fast Fourier transform
- FSS fixed satellite service
- FWA fixed wireless access
- GPS global positioning satellite
- GS guard symbol
- H-FDD half-duplex FDD

# Acronym List

- IE Information Element
- LOS line of sight
- MS Mini-Slot
- MSH Mesh
- NCFG network configuration
- NENT network entry
- NLOS non line of sight
- OFDM orthogonal frequency division multiplexing
- OFDMA orthogonal frequency division multiple access
- PMP point-to-multipoint
- PRBS pseudo random binary sequence
- Q quadrature
- REQ request
- RLAN Radio Local Access Network
- RNG ranging
- RSP response
- SC single carrier
- SNR signal-to-noise ratio
- STC space time coding

# Acronym List

- 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

- 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