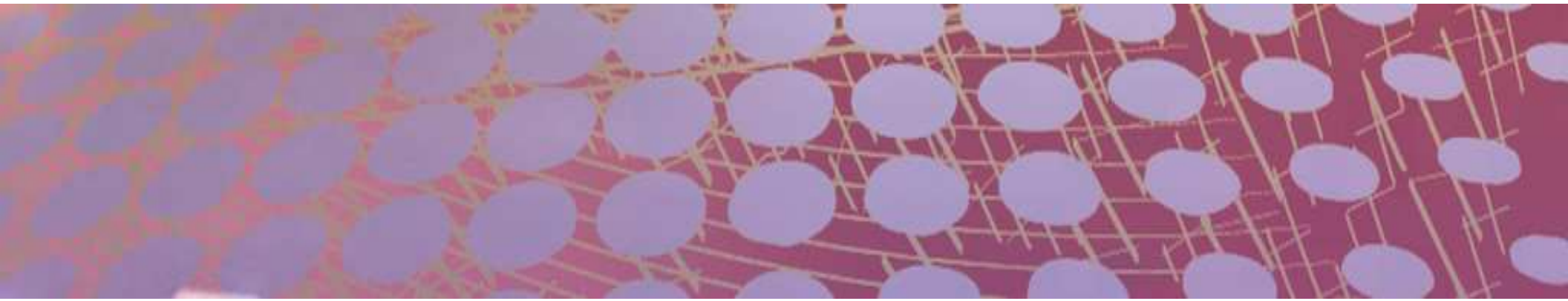


WiMAX Tutorial

December 07, 2010

European Patent Office, Munich

Max Riegel / Dirk Kroeselberg

Overview

- Introduction
- WiMAX Eco-System [Max - 10min]
- Standardization [Max - 15min]
- Network Architecture [Dirk - 50min]

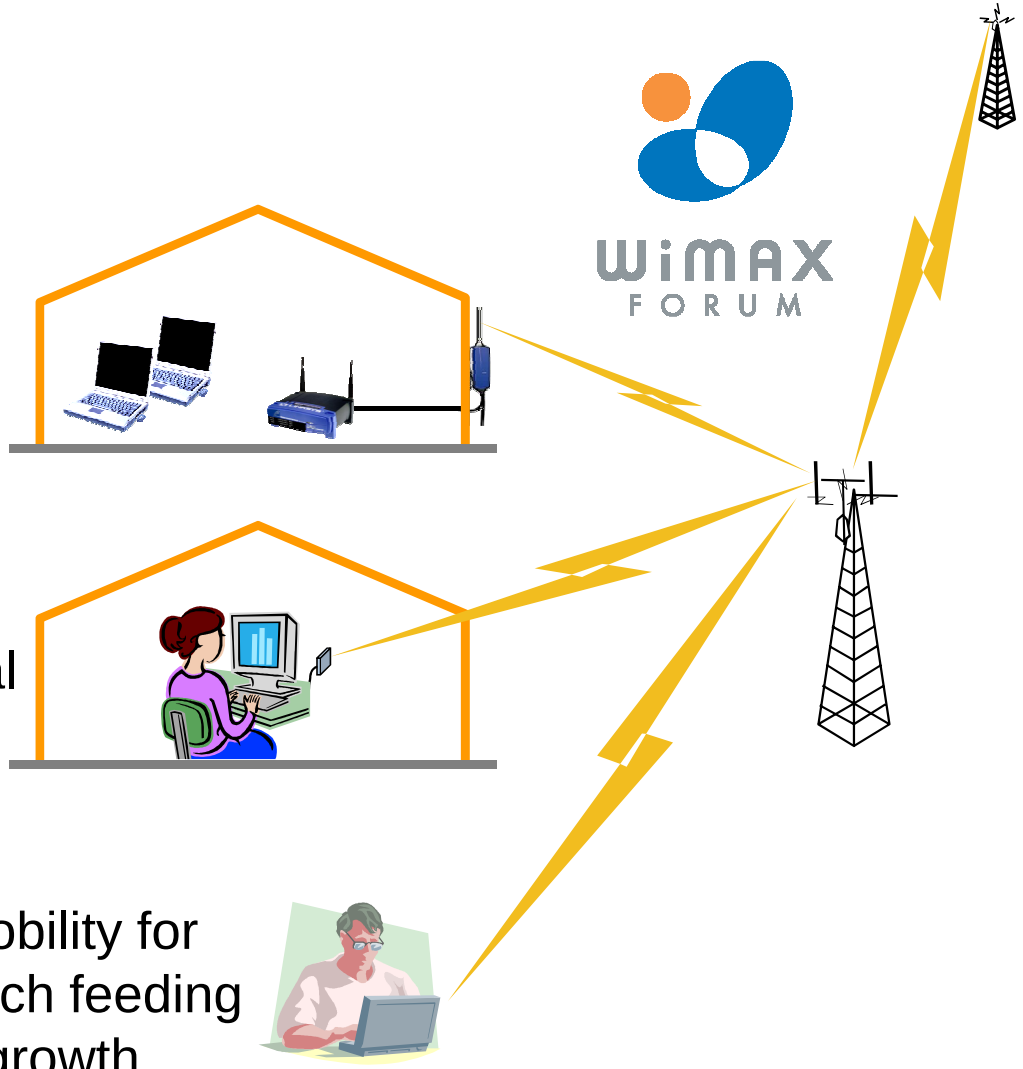
====== Break ======

- Air Interface [Max - 40min]
- Relay [Max - 10min]
- WiMAX 2/802.16m [Max - 10min]
- Information Sources [Dirk - 20min]

1 - WiMAX Ecosystem

WiMAX Technology

- Backhaul feeding
  - PtP links for fixed infrastructure
  - Dedicated market w/ limited size
- Fixed Wireless Access
  - Wireless local loop, hotspot feeding
  - Suffers from poor CPE handling
- Nomadic Access
  - Indoor CPE thanks to better radio
  - CPE may be integrated into terminal
  - Most promising for mass market
- Mobile Access
  - Handover function enabling data mobility for
  - road warriors, train feeding and coach feeding
  - Mobility enables persistent market growth

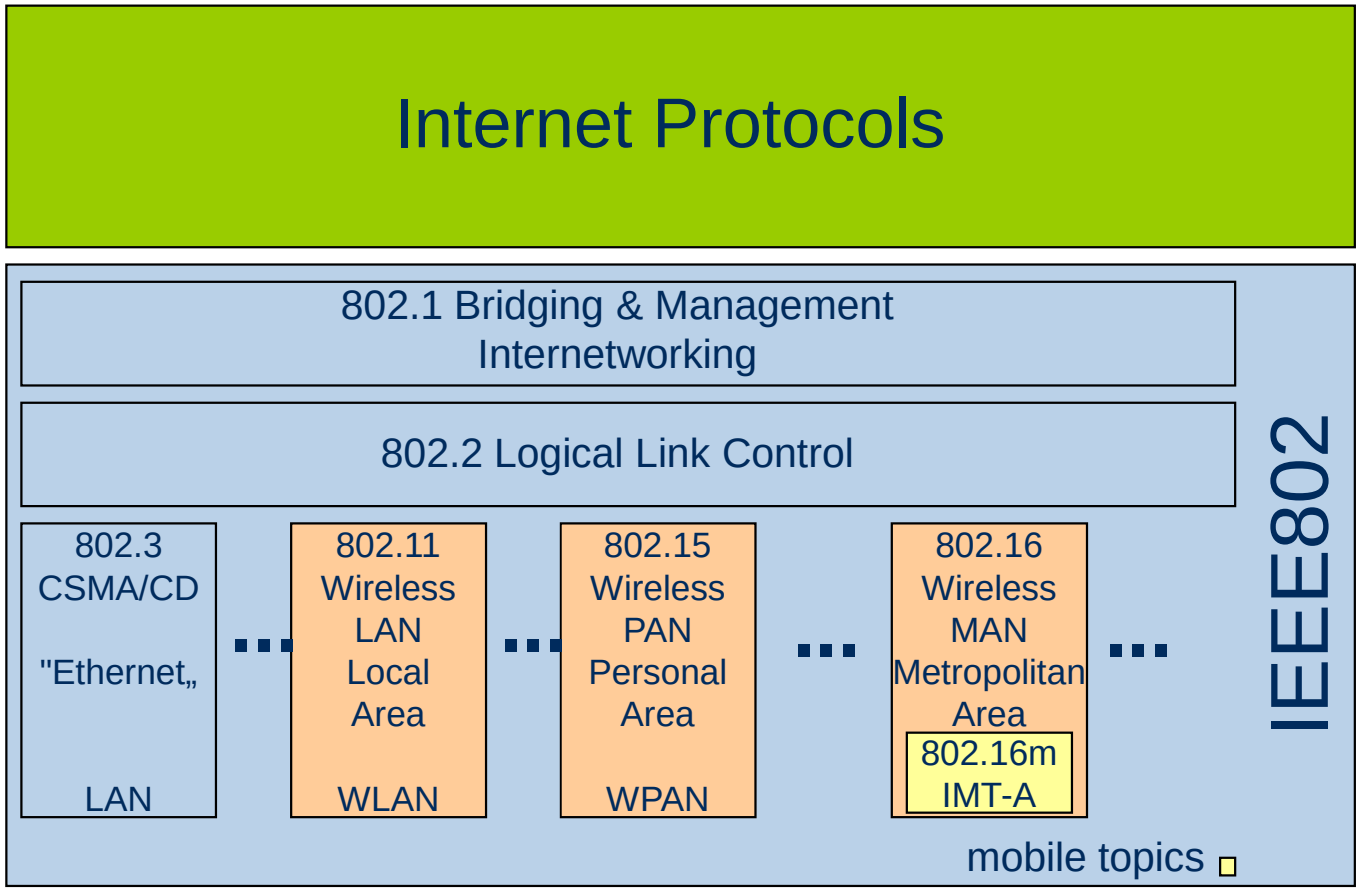


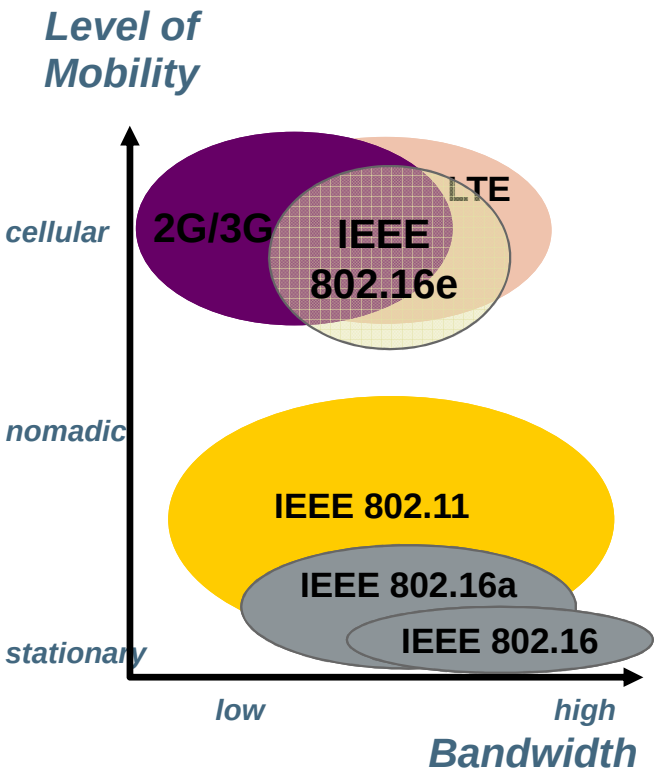
WiMAX Forum Industry Research (12/2010)

592 WiMAX Deployments in 149 Countries

More than 600 Milion people covered

Wireless Mobility in IEEE802





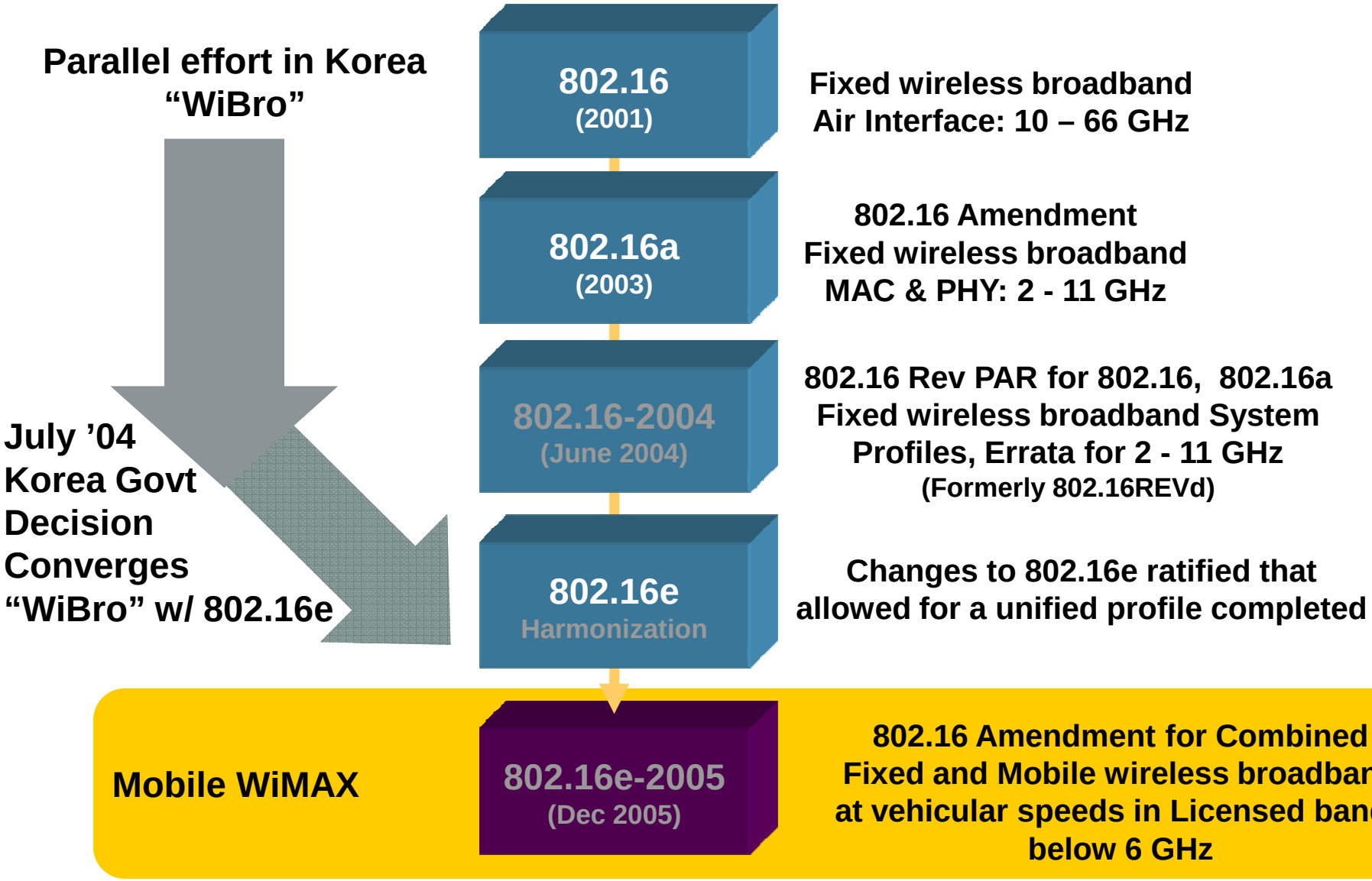
IEEE802 provides specifications for Local and Metropolitan Networks

- Wireless topics: WPAN (802.15), WLAN (802.11), WMAN (802.16)
- IEEE802.16 addresses cellular support including full mobility

IEEE802 has become a leading ‘radio’ standardization organization

- e.g. MMR (802.16j), Cognitive Radio (802.11af, 802.19.1, 802.22)

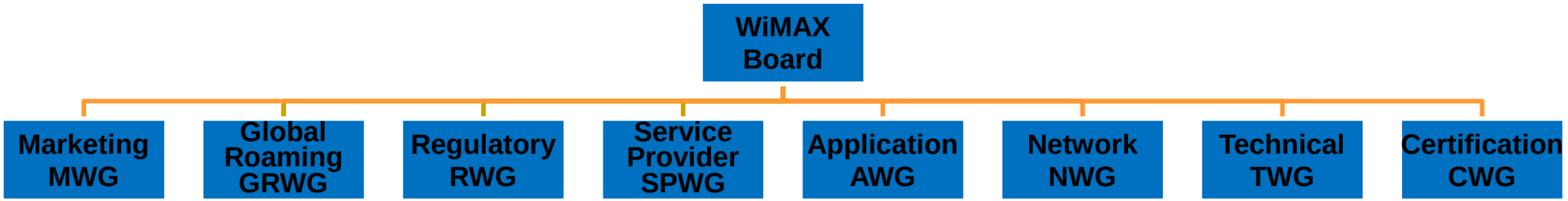
The Evolution of IEEE802.16



WiMAX:
Worldwide Interoperability for Microwave Access

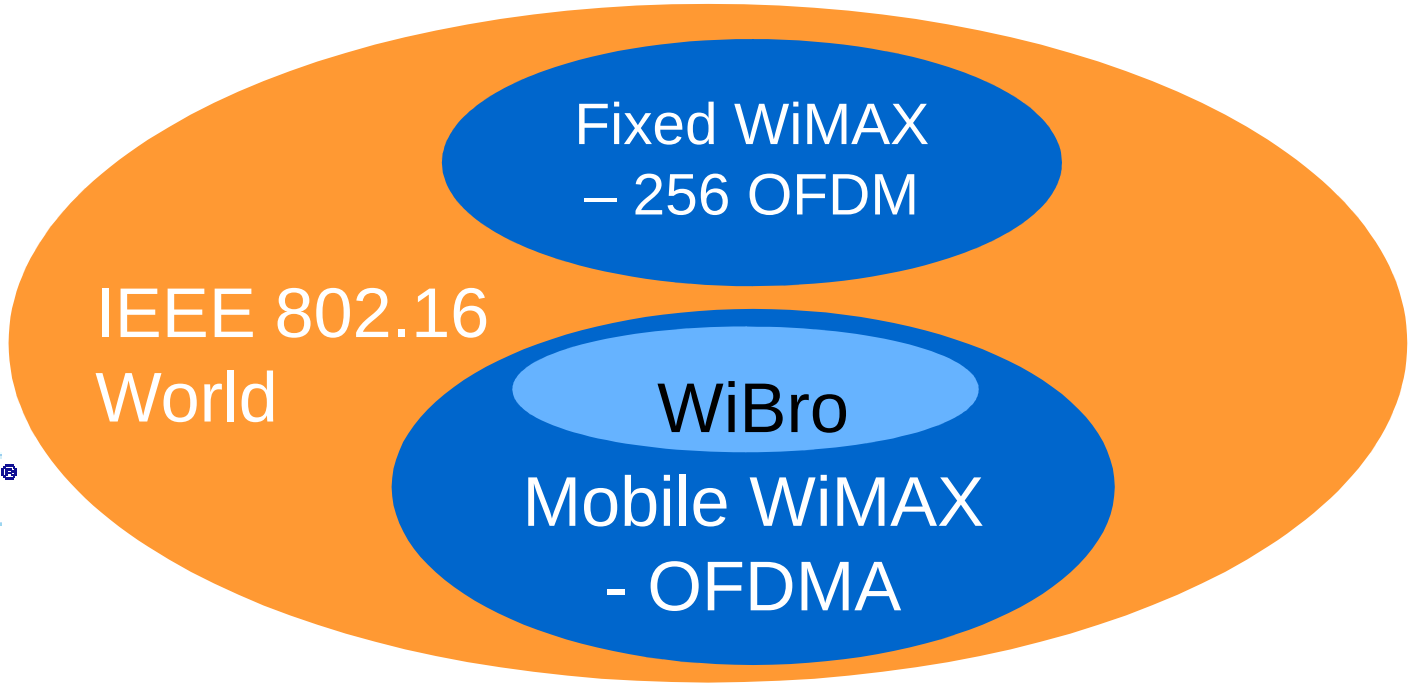
The WiMAX Forum promotes the deployment of broadband wireless access networks by supporting a global standard and certifying interoperability of products and technologies.

- Support IEEE 802.16 standard family
- Propose and promote access profiles for IEEE 802.16
- Certify interoperability levels both in the network (IIOT) and the radio interface (RCT/PCT/NCT)
- Achieve global acceptance
- Promote use of broadband wireless access overall



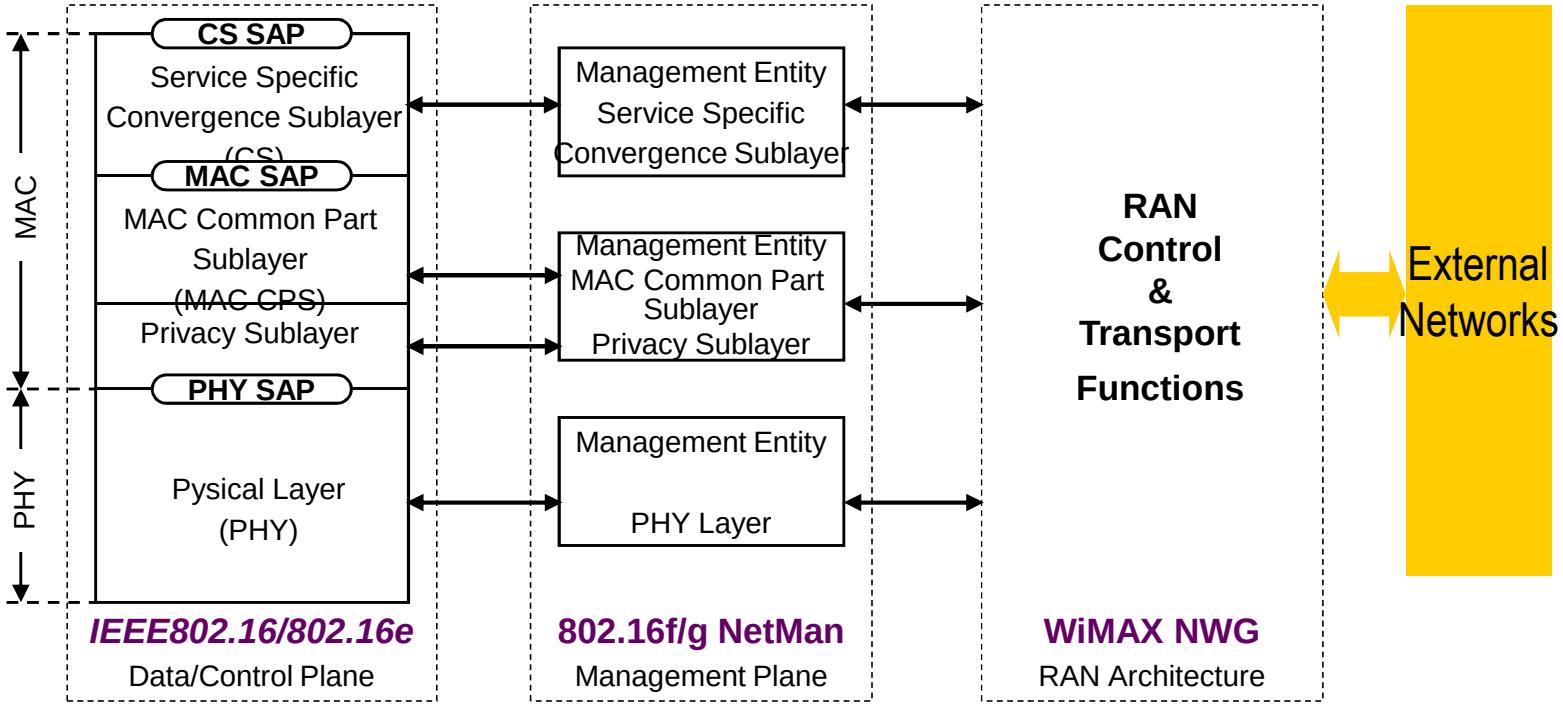
WiMAX and IEEE 802.16

- WiMAX is a subset of IEEE 802.16
  - No new features can be added
- Mandatory features in 802.16 are mandatory in WiMAX, if included
- Optional features in 802.16 may be optional, mandatory or not included



2 - Standardization

Relation IEEE802.16 vs. WiMAX NWG



IEEE802.16-2004 & 802.16e define only data and control plane

Management plane functions are added by 802.16f & g (NETMAN)

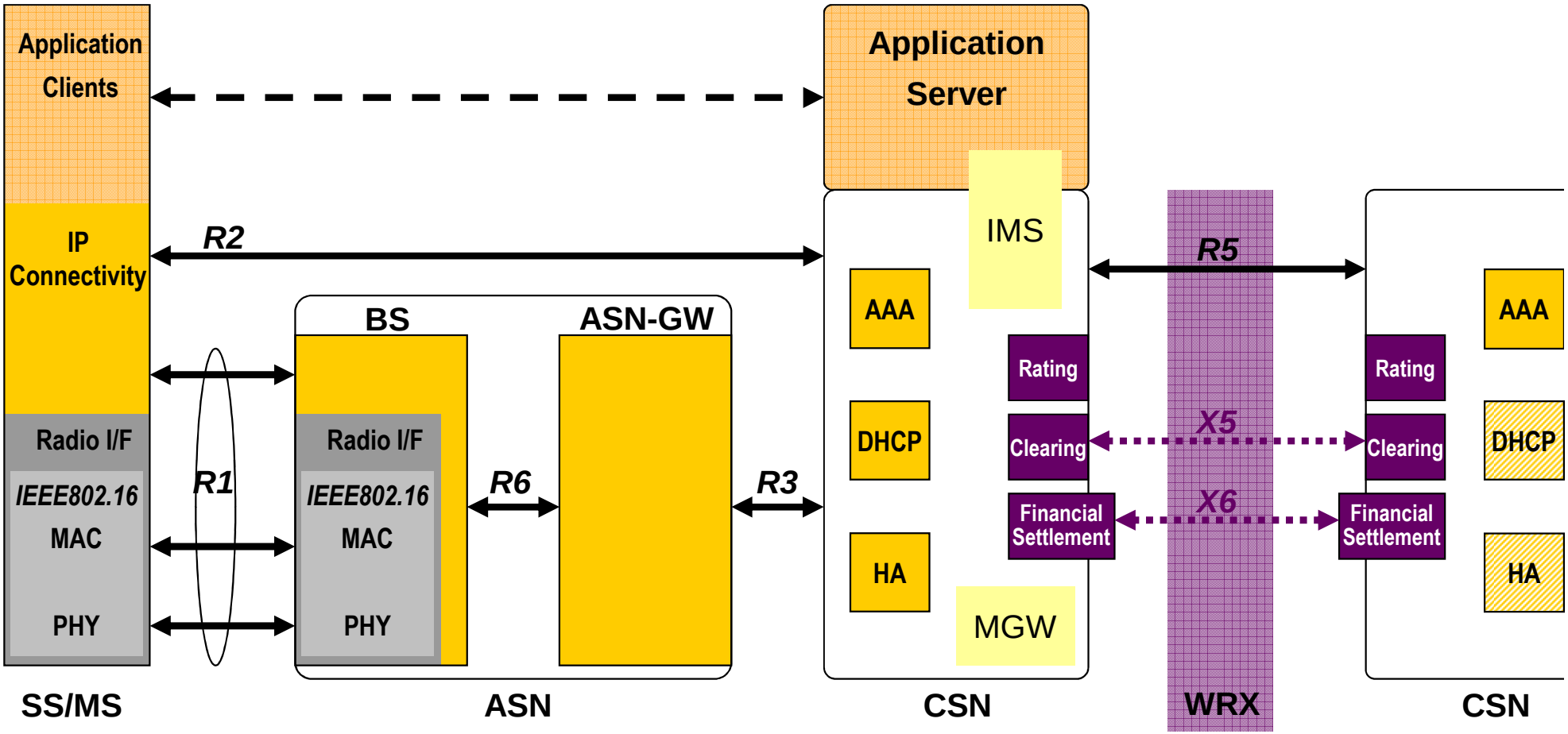
IEEE P802.16 does not deal with functions usually provided by the RAN

- The standardization of these missing parts of a portable/mobile WiMAX access network is the scope of the WiMAX NWG.

The roots of the ‘WiMAX Network’: WiMAX E2EARCH WG (MINA)

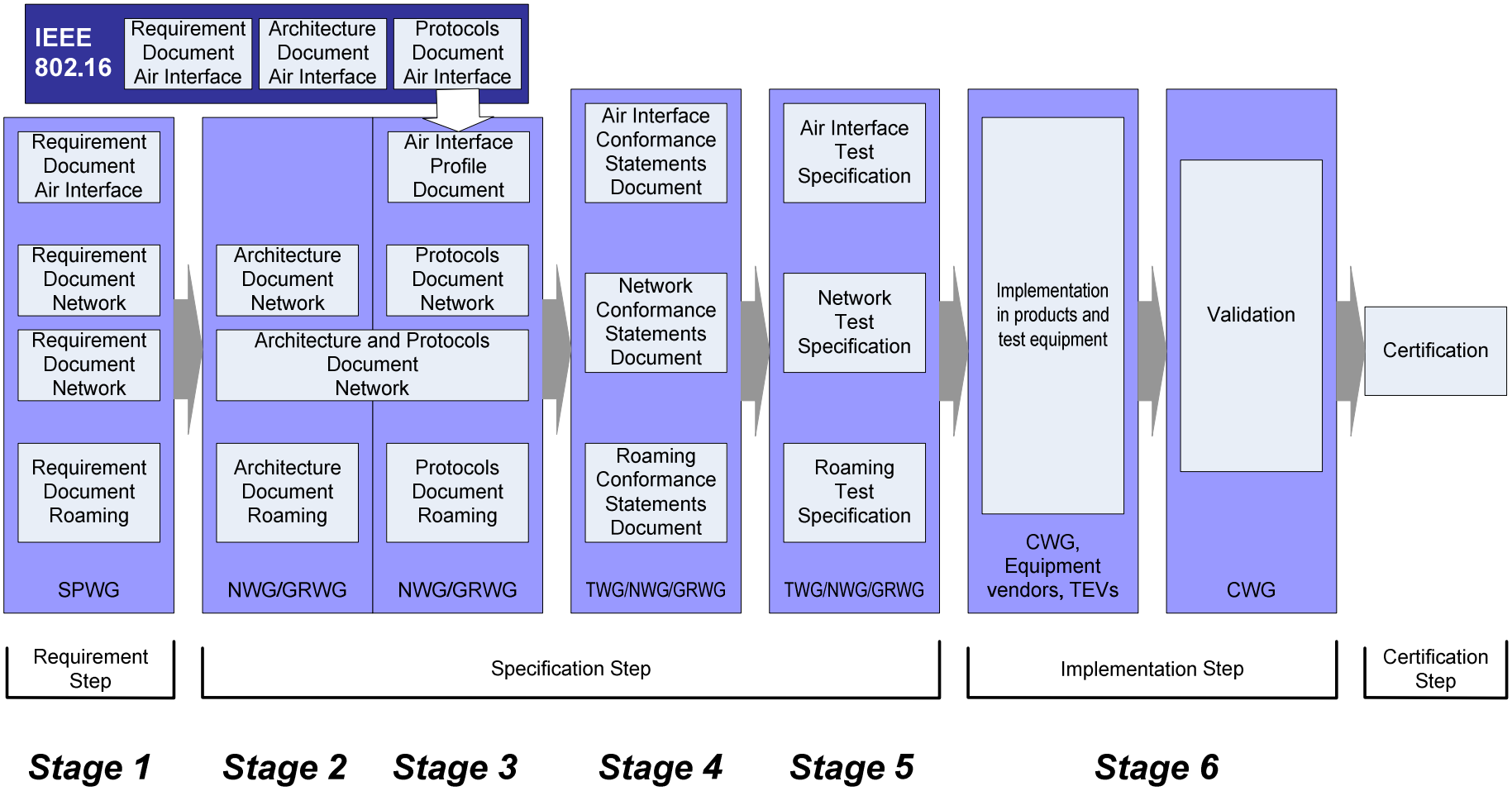
- Founded by Intel in June 2004 for development of an end-to-end industry specification for WiMAX portable and mobile wireless broadband systems
  - Address interfaces, RAN infrastructure elements and interworking - beyond the scope of 802.16
  - Provide foundation for subsequent system level interoperability specs driven through WiMAX Forum
- Invited companies: Alvarion, Arraycomm, Alcatel, Cisco, Intel, Motorola, (Nortel, left in September ‘04) Samsung, Siemens, ZTE
- Process aligned to 3GPP/3GPP2 with Stage 1 (Requirements), Stage 2 (Architecture) and Stage 3 (Protocols)
- Fast progress and demand for more interaction with Service Provider WG led to transition into WiMAX NWG in January ’05
- Extremely tight schedule for completion of Release 1.0:
  - Stage 2 (Architecture): E12/05
  - Stage 3 (Protocols): E03/07

Mobile WiMAX Architecture Framework



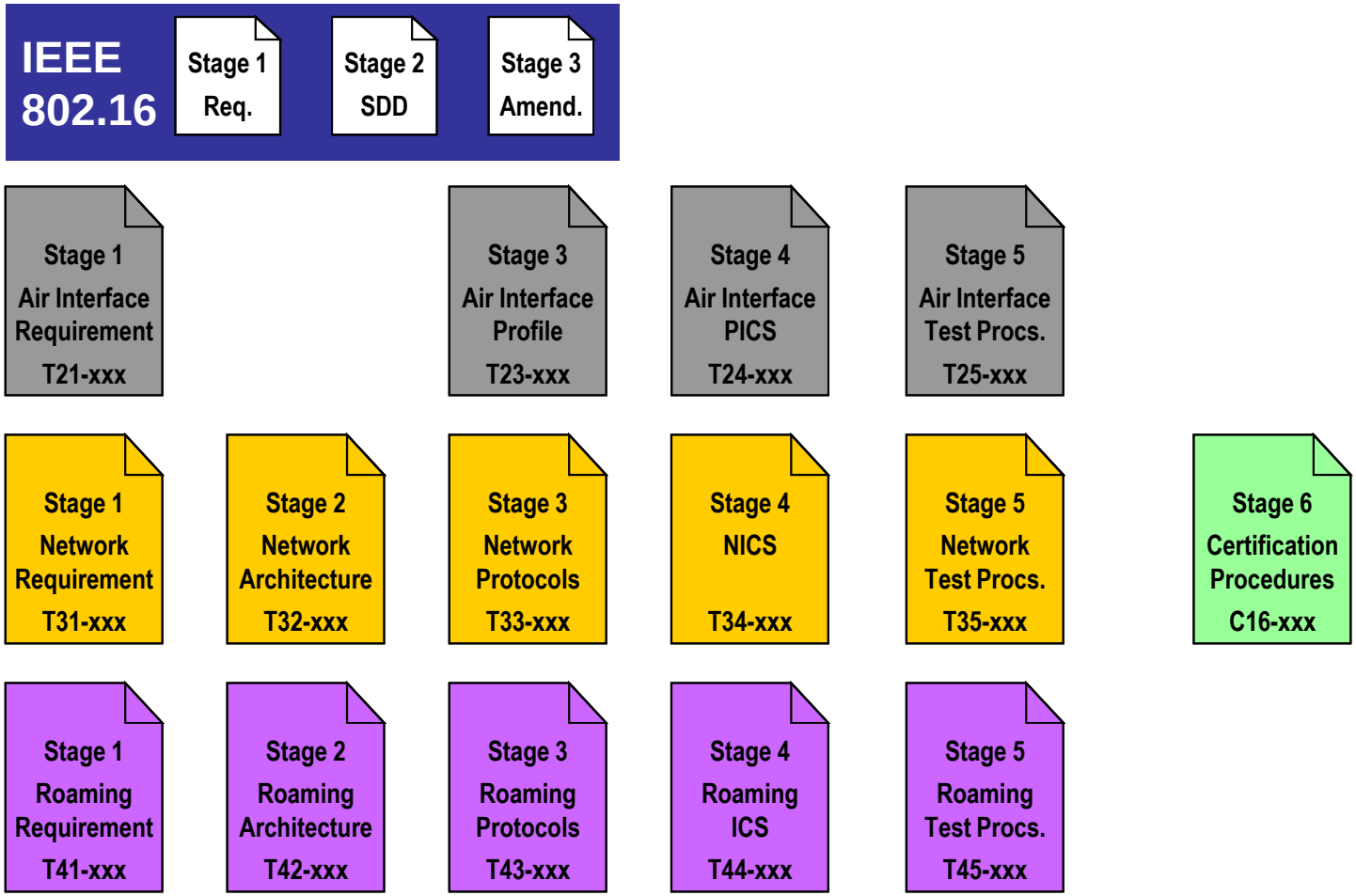
Main WiMAX Standardization Areas: Radio – Network – Roaming

WiMAX Standards Development



WiMAX Forum Standardization extended the legacy 3-stage process to 6 stages to establish certified interoperability in Mobile WiMAX.

The WiMAX Standards Suite

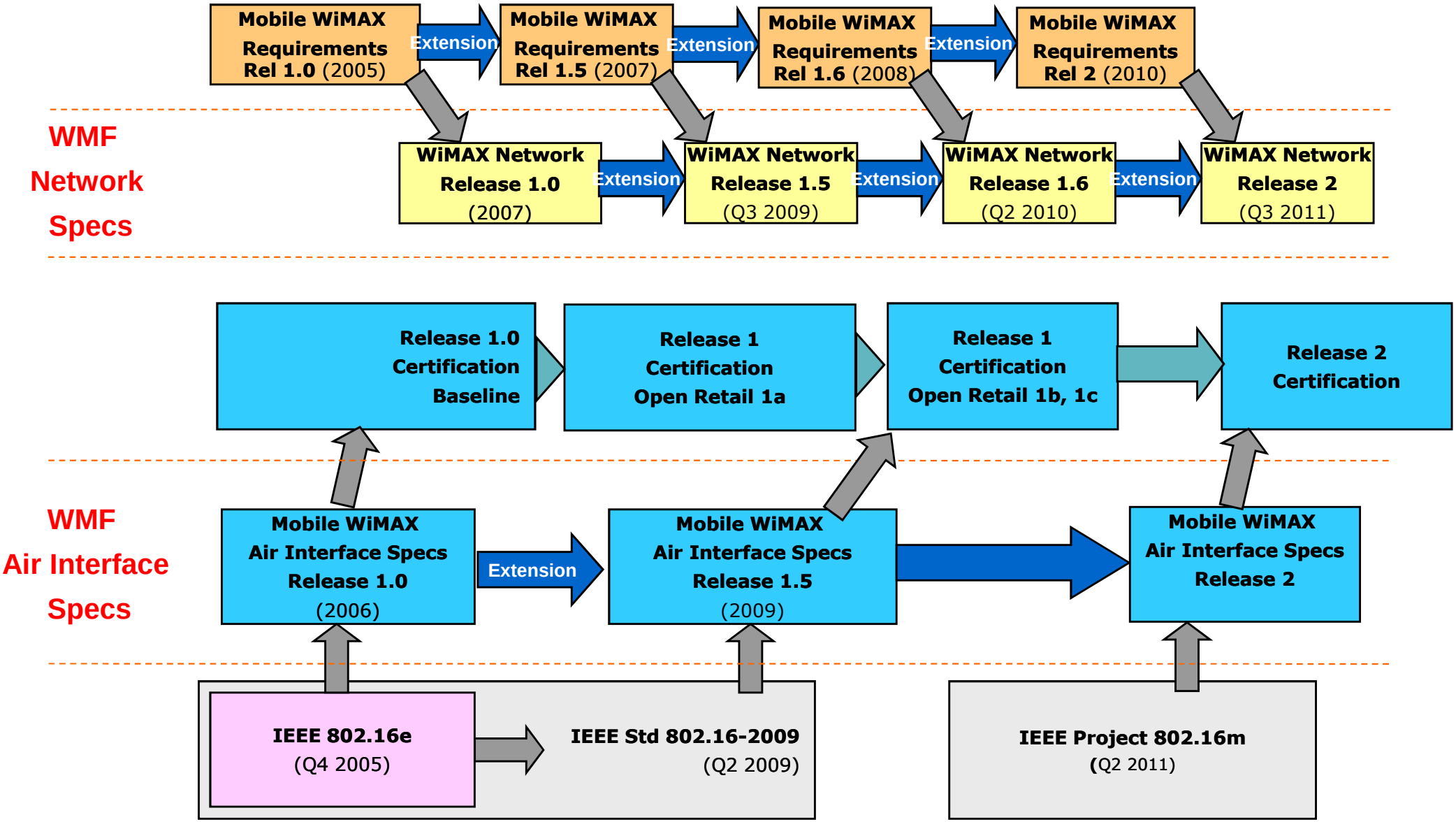


WiMAX Forum introduces common document identification format, e.g.

- WMF-T33-001-R015v01_Network-Stage3-Base.pdf
- WMF-T42-001-R010v02_WRI-Stage-2-Overview.pdf

Standardization Timeline

WiMAX Forum Timeline



Mobile WiMAX Radio Releases

Release 1.0

Underlying Radio Standard

IEEE802.16e-2005

Key Technology Attributes

- Channel BW up to 10MHz
- Focus on TDD
- MIMO
- All IP end to end network
- QoS Support
- *Projected Peak Performance:*
  - *up to 40Mbps DL*

Applications

- VoIP
-

Timeline

- 1st Mobile WiMAX Release 1.0 Certified Equipment in 2008

Release 1.5

Underlying Radio Standard

IEEE802.16-2009

Key Enhancements

- Additional Spectrum Bands
- (H)FDD Profile
- MIMO with AMC
- Persistent scheduling for VoIP
- Load balancing
- *Projected Peak Performance:*
  - *up to 140Mbps DL*

Applications

- Higher VoIP Capacity
- Support for emergency services E-911 & LBS
- Dynamic QoS Provisioning
- Multicast and Broadcast Services

Timeline

- Release 1.5 System Profile approved
- First certified products in 2010

Release 2

Underlying Radio Standard

IEEE802.16m

Target Enhancements

- IMT-Advanced
- Backwards Compatible with Release 1.5 & 1.0
- Wider Band Channels (TDD & FDD in 5,10, 20MHz)
- Higher Data Rates
  - *peak up to 300Mbps*
- Higher Spectrum Efficiency
- Lower Latency

Applications

- Higher throughput
- Higher VoIP capacity

Timeline

- First certified products expected in 2012

Mobile WiMAX Network Releases

Release 1.0

Release date: March 2007

- Radio: *Mobile Profile 1.0*

Features

- Mobile and stationary base specification
- ASN anchored mobility
- CSN anchored mobility (CMIP, PMIP)
- IPv4 & optional IPv6 connectivity
- Pre-provisioned/static QoS,
- Idle mode and paging
- Network discovery/selection
- Optional RRM
- EAP-based authentication
- Pre- and Post-paid RADIUS accounting
- Roaming (RADIUS only)
- 3 ASN profiles
- DSL, 3GPP and 3GPP2 Interworking

NWIOT Release: March '09

- Release 1.0 (NCT/IIOT)

Release 1.5

Release date: Aug '09

- Radio: *Mobile Profile 1.0/1.5*

Additional features

- Network architecture w/o MIP ('Simple IP', 'Simple ETH')
- IMS and PCC
- Emergency services and lawful intercept for VoIP over WiMAX
- RoHC support
- OTA pre-provisioning and device management
- Location based services
- Diameter based AAA
- Dynamic QoS w/o PCC
- Ethernet services
- Fixed/Nomadic Access
- WiMAX SIM
- Proxy MIPv6
- Universal Services Interface
- Multicast/Broadcast Services
- Single ASN profile
- Pre-Rel 8 and Rel 8 EPC IWK
- Enhancements to 3GPP2

NWIOT Release: t.b.d.

- Release 1.5 (NCT/IIOT)

Release 1.6

Release date: Jul '10

- Radio: *Mobile Profile 1.0/1.5*

Additional features

- IPv4/IPv6 Transition
- WiMAX-WiFi IWK
- Femto-cell support
- SON for Femto cells
- DRMD
- OTA Evolution
- Arch Enhancements, e.g.
  - R6 Flex
  - R4 relocations
  - Options clean-up

NWIOT

- t.b.d.

Release 2

Release date: Target Q3 '11

- Radio: *Mobile Profile 2*

Additional features

- Roaming Enhancements
- WiMAX Voice Service
- Emergency Telecom Support
- DRMD Phase 2
- OTA Phase 2
- Lawful Intercept Phase 2
- WiMAX-EPC IWK Phase 2
- Arch Enhancements, e.g.
  - Multiple IP
  - Local Routing
  - Inter NAP HO

NWIOT

- t.b.d.

3 - Network Architecture

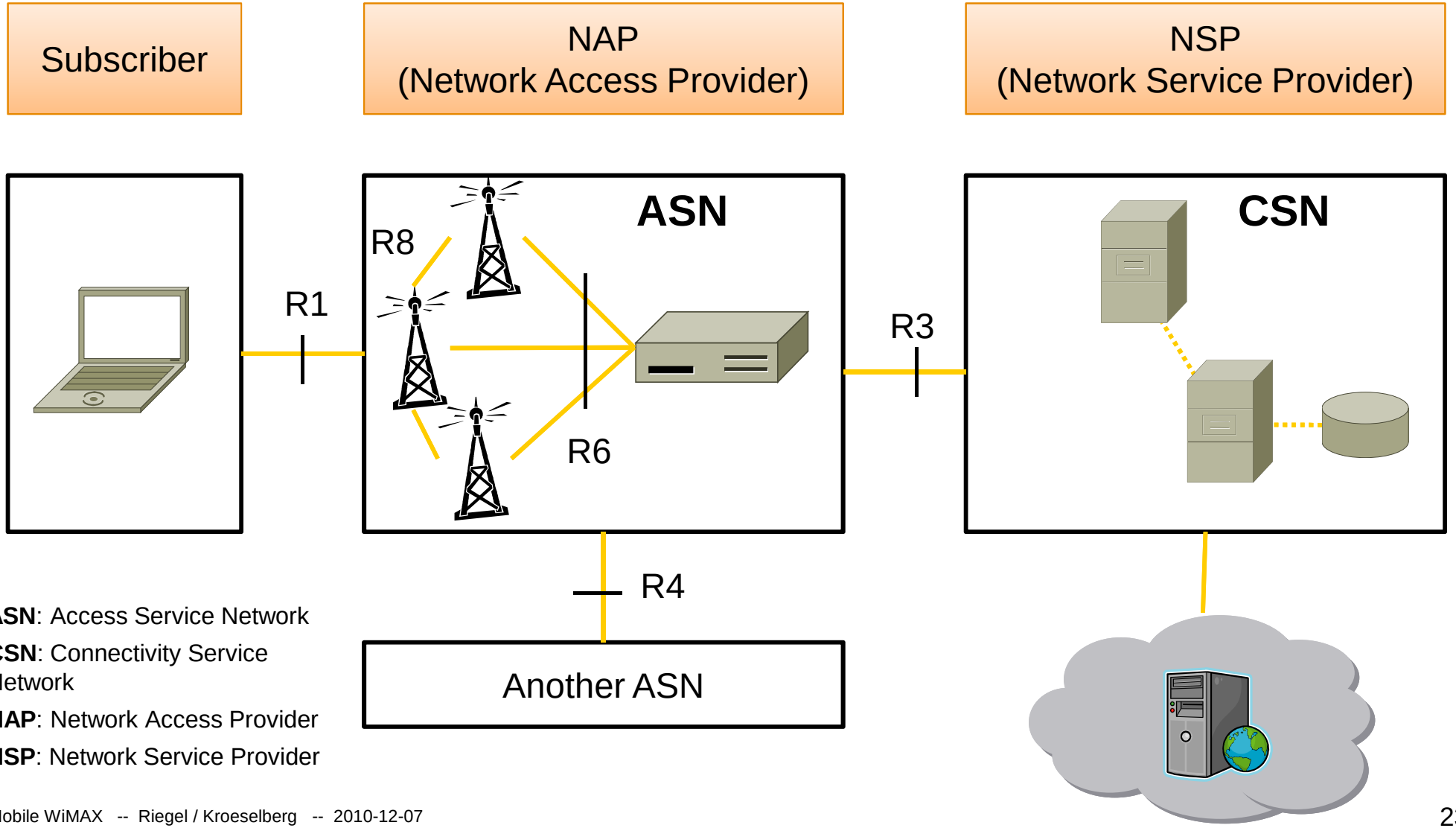
Overview

- The WiMAX network architecture standardizes control and data communication „behind“ the base station (BS)
  - between base stations and gateways that control sets of base stations (the access network)
  - between access and core networks with ISP-like functionality
- WiMAX has similarities with the 3GPP2 network architecture
- Protocols from the Internet standards community (IETF) are used substantially, e.g.,
  - Authentication, Authorization and Accounting (AAA) based network internal signaling based on RADIUS/Diameter
  - IP mobility support, DHCP
- However, a lot of WiMAX-specific functionality is defined
  - WiMAX-developed signaling protocol within the access network
  - RADIUS/Diameter massively extended by WiMAX-specific functions

Fundamental design aspects

- In contrast to the network architecture of other cellular systems like 3GPP, WiMAX supports both fixed-line and mobile deployments
  - Split of access (radio control) and core (ISP) functionality allows to accomodate typical fixed-line business models
  - Access and core can be operated by different business entities
  - The specifications support roaming which is common in the mobile cellular world
- WiMAX devices (MS) can be open retail devices, in contrast to the subsidized, operator-controlled mobile cellular model.
  - Operator control through over-the-air provisioning and device authentication
- Separate documents are available to support different interworking scenarios between WiMAX, 3GPP2, 3GPP or WiFi networks

WiMAX Network Reference Model (NRM): “Box” Model



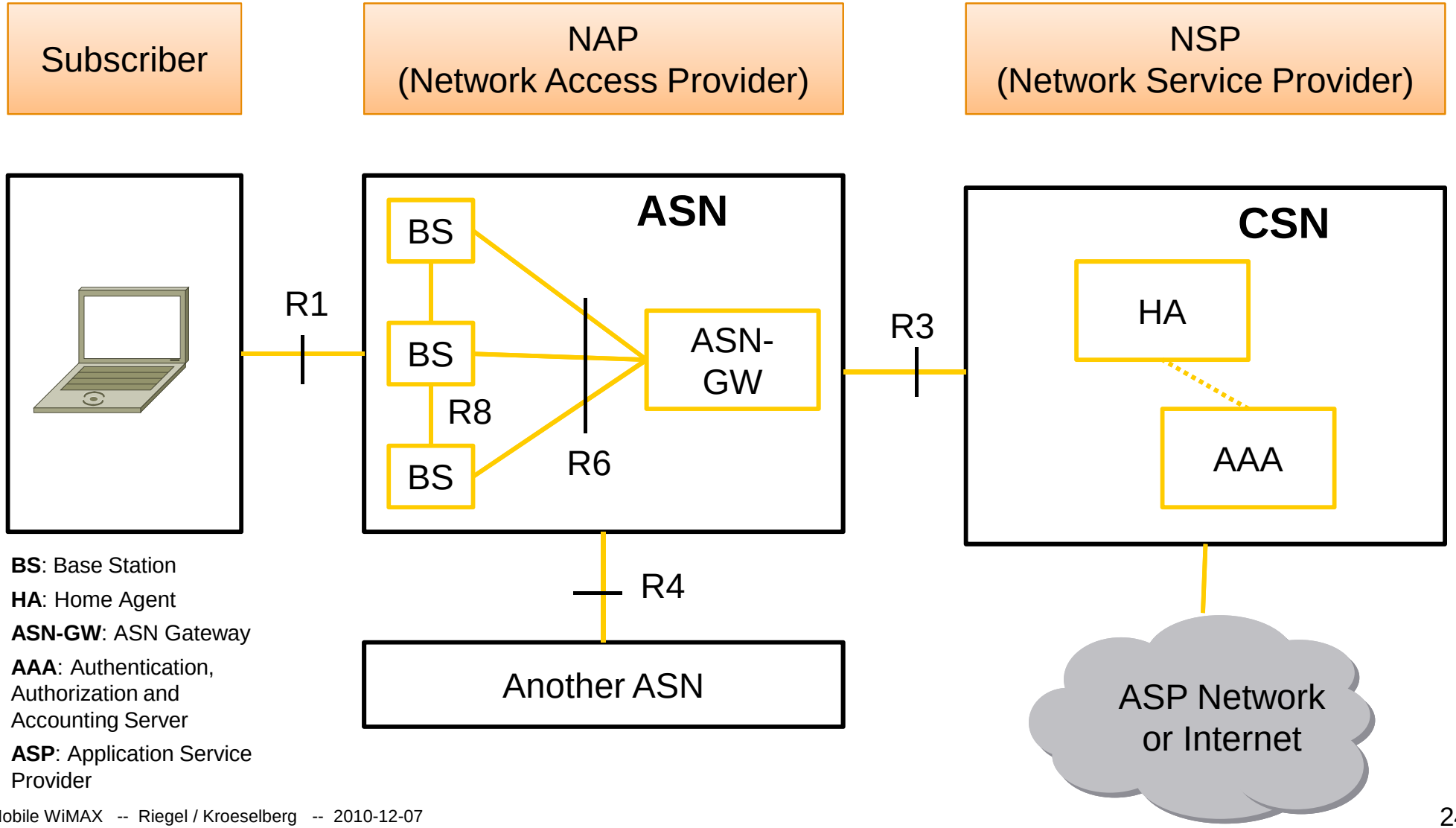
ASN: Access Service Network

CSN: Connectivity Service Network

NAP: Network Access Provider

NSP: Network Service Provider

WiMAX Network Reference Model (NRM), non-roaming case



BS: Base Station

HA: Home Agent

ASN-GW: ASN Gateway

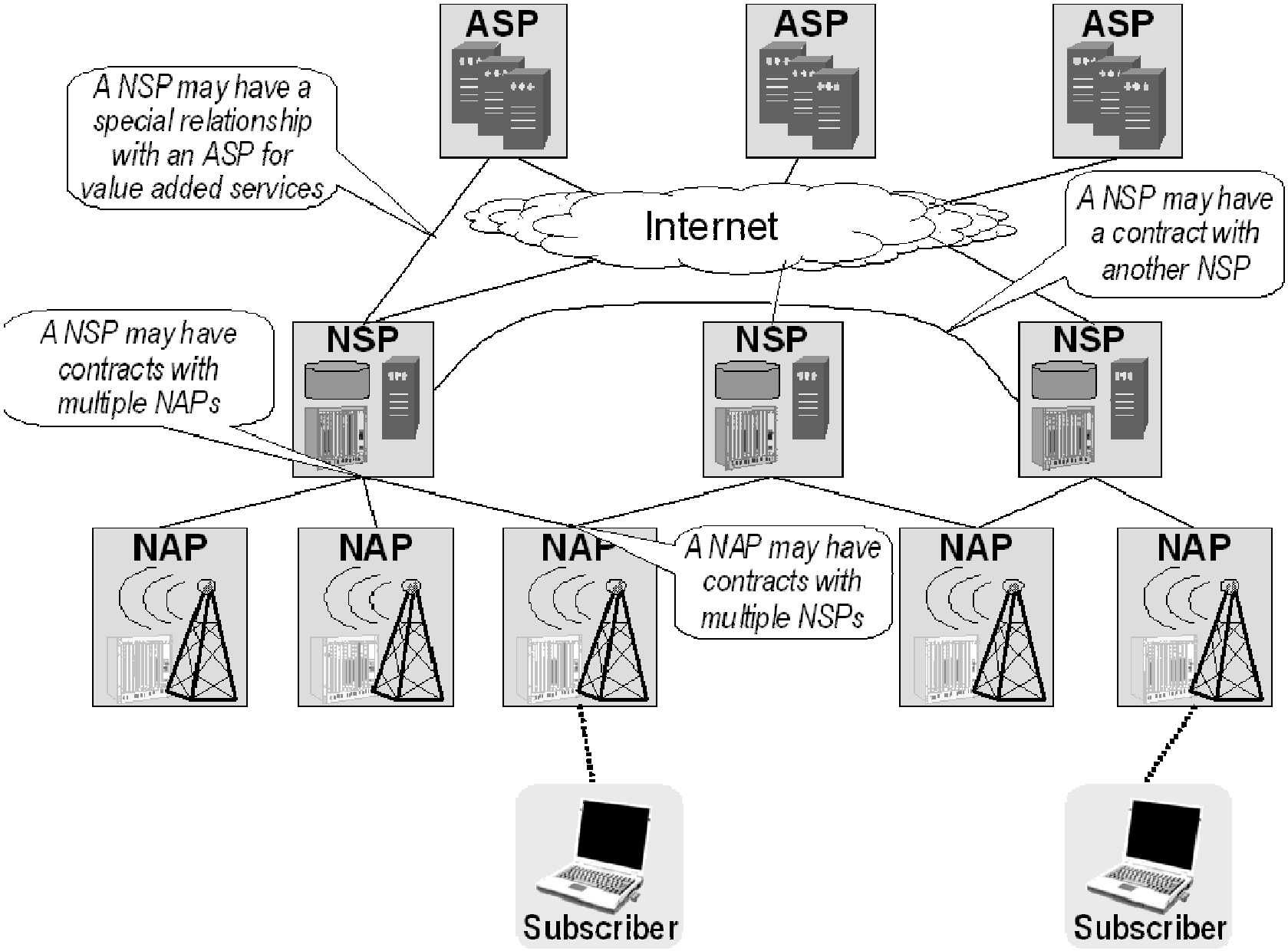
AAA: Authentication, Authorization and Accounting Server

ASP: Application Service Provider

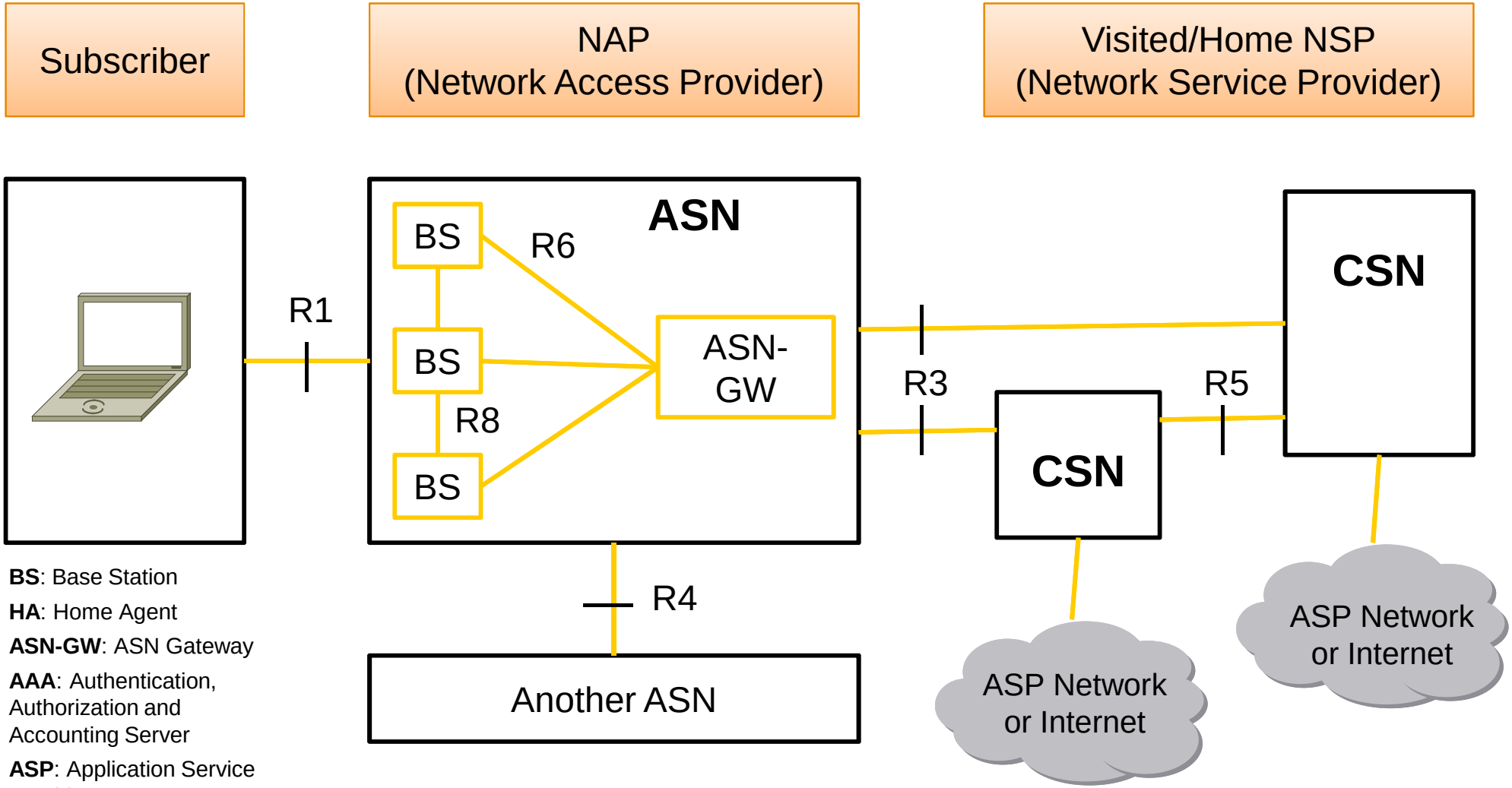
Logical Groupings of the WiMAX NRM

- CSN: Connectivity Serving Network
  - Logical representation of the functions of a NSP
  - Owning the subscriptions
  - Authentication, Authorization and Accounting (AAA)
  - IP address management
  - Connectivity to the Internet and to Application Service Providers
  - Layer-3 (IP) mobility and roaming between ASNs
  - Policy & QoS management
  - Location Information Server
- ASN: Access Serving Network
  - Logical representation of the functions of a NAP
  - 802.16 wireless interface termination (Base Station)
  - Network entry and handover procedures
  - Radio Resource Management
  - Layer-2 session mobility management
  - Policy & QoS enforcement
  - Mobile-IP: Foreign Agent (FA) and Proxy-MIP client
  - Forwarding to selected CSN (ASN/NAP shared by several CSN operators)
  - Location measurements

Possible Operator Relations



WiMAX NRM, roaming case



BS: Base Station

HA: Home Agent

ASN-GW: ASN Gateway

AAA: Authentication, Authorization and Accounting Server

ASP: Application Service Provider

Roaming support

- WiMAX supports roaming deployments similar to other cellular networks
- A simple deployment just consists of an ASN and a CSN (can even be a single ‚box' controlling a few base stations)
- With roaming support, subscribers can connect to any participating WiMAX access globally
  - Today there is initial roaming support between partnering operators in the field
- Technical aspects in roaming:
  - Several CSNs are involved
    - visited CSN as the local operator
    - home CSN that has the subscriber relationship
  - R5 as standardized reference point between CSN operators
    - is more or less a subset of R3 functionality with support for policy negotiation between CSNs
  - AAA routing allows to find the right home CSN for a roaming subscriber during initial network entry

Reference Points

- A reference point groups a set of protocols, or interfaces, that connect
  - logical clusters of the network, like ASN and CSN or two ASNs
  - functional entities like BS and ASN-GW within the same cluster

MS related reference points:

- R1 is the reference point between the terminal (MS) and the access network. It covers the 802.16 PHY and MAC layers between MS and BS.
- R2 comprises all end-to-end communication between MS and CSN. This mainly covers access authentication between MS and the AAA server, based on the EAP protocol.

Reference Points (2)

CSN related reference points

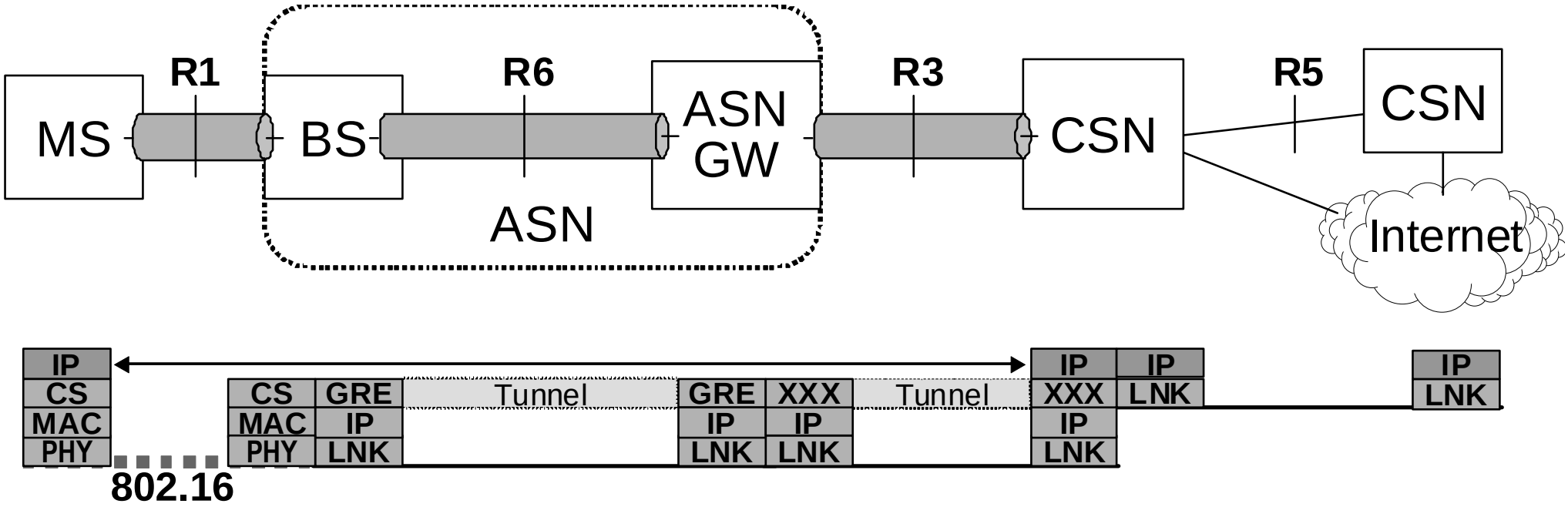
- R3 interconnects ASN and CSN. It includes control signaling for AAA (authentication, authorization, accounting) or Mobile IP, and the data path.
- R5 interconnects two CSNs, e.g. a visited and a home CSN in roaming scenarios. It can largely be considered a subset of R3.

ASN-internal reference points:

- R4 connects two ASN-GWs. It supports intra-ASN mobility and allows for extension of capacity or coverage area of an ASN. R4 can also interconnect two ASNs. It may include a data path.
- R6 connects a BS with an ASN-GW. Control signaling on R6 covers a wide set of network functions focused on the access network, like for network entry, or service flow handling. R6 includes the data path.
- R8 allows direct exchange of control signaling between two BSes.

Note: WiMAX did not introduce explicit reference points within a CSN.

Data Path


R1
R6
R3
R5
MS
BS
ASN GW
CSN
CSN
Internet
ASN
IP
CS
MAC
PHY
802.16
CS
MAC
PHY
GRE
IP
LNK
Tunnel
GRE
IP
LNK
XXX
IP
LNK
Tunnel
IP
XXX
IP
LNK
IP
IP
LNK
IP
LNK

Main Control Plane Functions

- Network entry discovery and selection
  - MS scans and detects available WiMAX access; NAP selection
- Authentication, Authorization and Accounting (AAA)
  - Network access authentication and authorization based on the home CSN‘s subscriber profile; accounting procedures
- Network entry and exit
  - Procedures for establishing initial connectivity with a WiMAX network and leaving the network gracefully.
- IP addressing
  - Assignment of IP address to MS via DHCP, MIP/AAA or stateless autoconfiguration for IPv6.
- Security
  - Distribution of keying material within the ASN and CSN; reference point protection; control of air interface security

Control Plane Functions (2)

- QoS and Service Flow Management
  - Creation, modification and deletion of service flows; installation of static QoS profiles in the ASN
- ASN anchored mobility management
  - Handover support of the radio link between base stations within the same ASN or between ASNs
- CSN anchored mobility management
  - Mobility management based on Mobile IP or Proxy Mobile IP between ASNs where the mobility anchor is in the CSN
- Radio Resource Management
  - Support function within the ASN to increase deployment efficiency of available radio resources
- Paging and Idle Mode support
  - Control procedures in the network to support the 802.16 functions for paging, location update and entering/exiting idle mode.

Network Features Overview per Release
(dates indicate technical document approval by NWG)

Rel. 1 (03/2007) (published)

- Core specification
- WiMAX PKI
- Prepaid Accounting

Rel. 1.5 (08/2009) (published)

- Core Spec Update
- Over-the-Air (OTA) Device Provisioning
- IMS (VoIP)
- PCC Support
- Location Support
- Lawful Interception
- Emergency Calls
- R8 reference point
- Mobility Restrictions
- Network Rejection
- RoHC
- Ethernet Services
- MCBCS (Multicast/Broadcast)
- WiMAX SIM
- USI (appl. interface)

Rel. 1.6 (07/2010) (completed)

- Core Spec Update
- IPv4/6 transition
- Femto
- Femto Management Interface
- Femto-SON
- ASN signaling improvements (R6-Flex, R4 re-location optimization, optimized re-authentication)
- OTA enhancements
- DRMD
- Emergency Telecommunications Service (ETS)

Rel. 2 (Q3/2011) (ongoing)

- Core Spec Update
- 802.16m Support
- WiMAX VoIP
- ASN Local Routing
- QoS Enhancements
- Several other smaller enhancements

WiMAX Interworking Specifications

(dates indicate technical approval by NWG)

- WiMAX – 3GPP Interworking
  - (01/2008) WMF-T37-001-R010v03_3GPP-Interworking
    Initial specification, not maintained any more.
  - (08/2010, not yet published) T37-008-R016v01-A_PreRelease8-3GPP-IWK
    Supporting scenarios with 2G/3G deployment for voice and WiMAX complemented by WiMAX for data.
  - (08/2010, not yet published) T37-009-R016v01-A_3GPP-EPS-WiMAX-IWK
    WiMAX access attached to 3GPP EPC (LTE) core
- WiMAX-3GPP2 Interworking
  - (01/2008) WMF-T37-004-R010v03_3GPP2-Interworking
    Relevant e.g. for U.S. market (e.g. USB sticks switching between 3G/4G radio).
- WiMAX-DSL
  - (01/2008) WMF-T37-005-R010v03_Interworking-with-DSL
    Connecting WiMAX access to DSL infrastructure
- WiMAX-WiFi
  - (06/2010, not yet published) DRAFT-T37-010-R016v01-A_WiFi-WiMAX-IWK
    WiMAX - WiFi Interworking, considers WiSPR (Wireless ISP Roaming)
- Single-Radio Interworking
  - (08/2010, not yet published) DRAFT-T37-011-R016v01-A_SR-IWK
    Generic document for single-radio interworking

Backup slides Network Architecture:

- Security
- Femto
- Interworking

Security Aspects

- The mobile WiMAX network architecture comes with similarities with WLAN security (EAP), or 3GPP2 (Mobile-IP/AAA model) networks.
- For network security:
  - EAP (RFC3748) based device **and** subscription authentication
  - Device Certificates (X.509) shipped in all *WiMAX Forum certified* devices
  - Bootstrapping security for „services“ like IP mobility, over-the-air device provisioning or location protocols from network access
  - Handover aspects of authentication, authorization and accounting (AAA)
- For the 802.16 wireless link:
  - Wireless MAC layer security: PKMv2 (.16e) and PKMv3 (.16m)
  - New key hierarchy (different from WLAN/802.11)

User and Device Authentication

Goals from an operator‘s perspective:

- Device Authentication:
  - Is the device connecting to my network a 'good' device?
  - Secure anchor for initial provisioning over-the-air („bootstrapping“) or re-provisioning
- Subscription Authentication:
  - Identify and validate the subscription
  - Ensure proper billing of service usage

Examples from other networks

WLAN

- single auth only (PSK or EAP-based).
- Hard to map this to WiMAX device or subscription authentication. Often no concept of a permanent ‚subscription' in reality.

DSL

- device auth closest to implicit „authentication" of fixed line (port)
- additional subscription auth via username/password

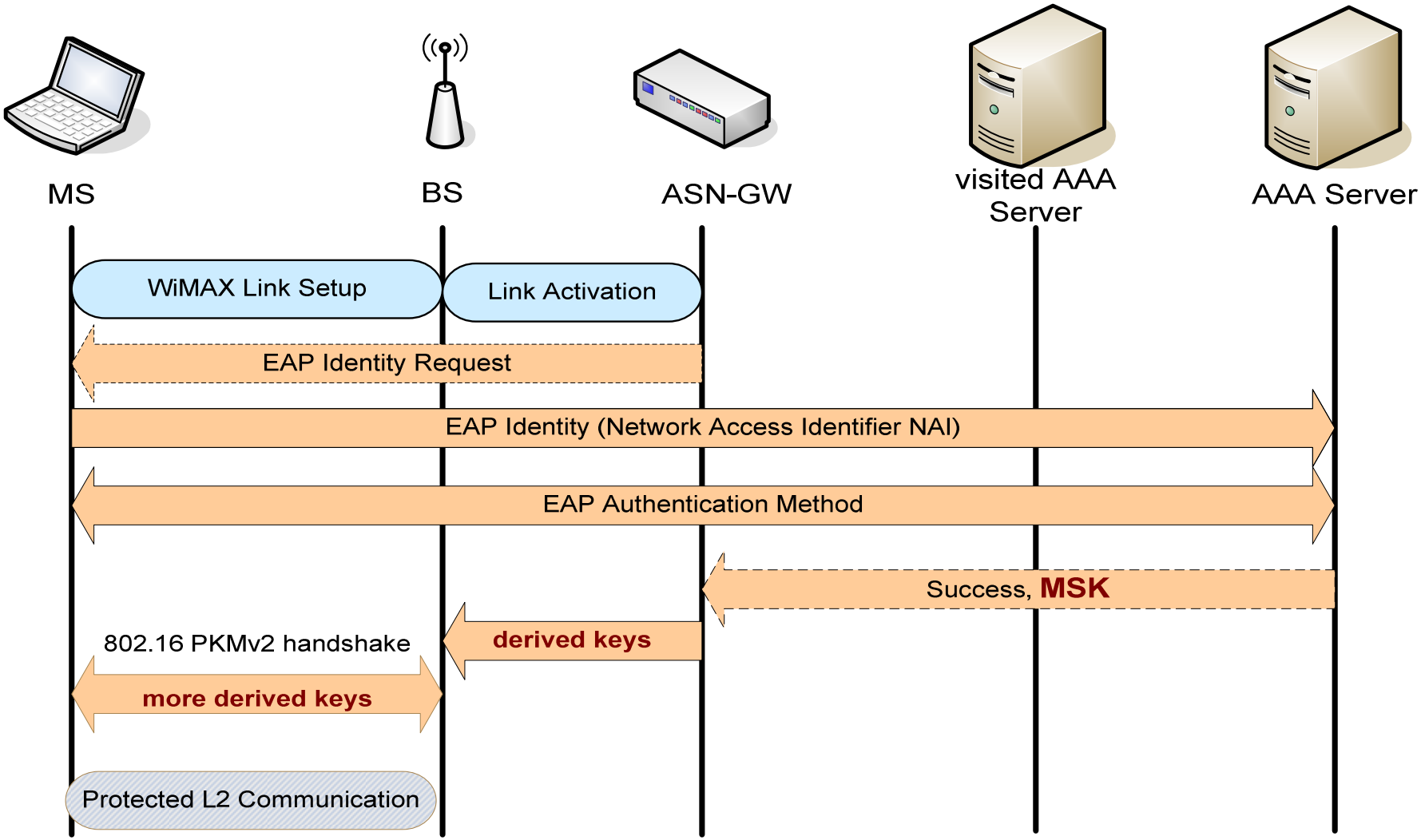
GSM/UMTS

- device auth by verifying mobile phone's IMEI (but not based on cryptographic methods over-the-air)
- subscription auth exclusively based on (U)SIM card

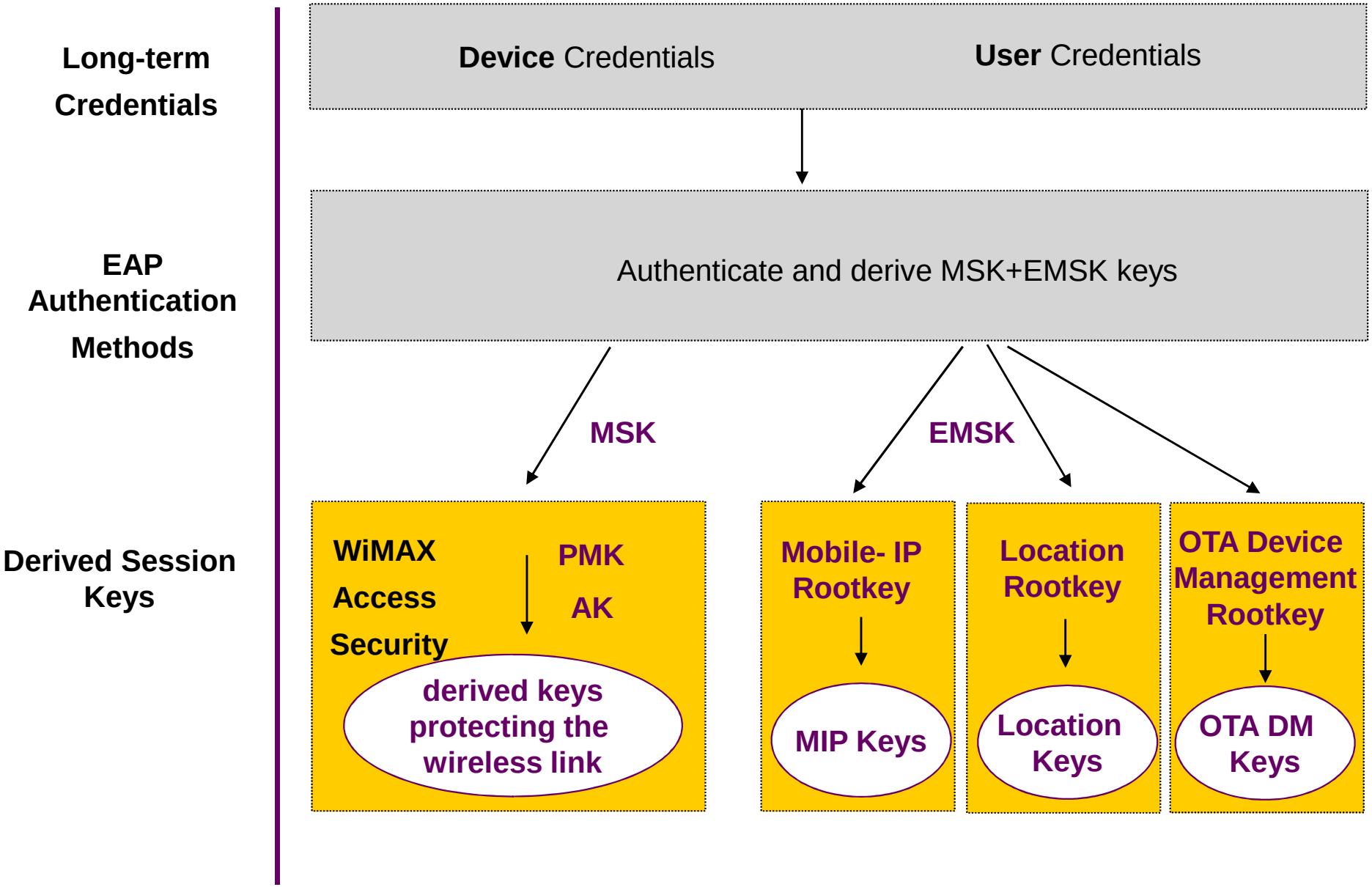
WiMAX Secure Network Access

- Subscription Authentication
  - Network access requires EAP-based authentication (Extensible Authentication Protocol, RFC3748, also possible in Wi-Fi)
  - RADIUS (RFC2865) or Diameter (RFC3588) based AAA infrastructure for authentication with home operator
- Device Authentication
  - Also based on EAP methods and AAA infrastructure
  - Using X.509 Device Certificates
  - Can be executed in addition to subscription authentication or exclusively for initial provisioning of a new subscription over-the-air
- Default EAP methods in WiMAX
  - EAP-TTLSv0 with MS-CHAPv2 (Subscription)
  - EAP-AKA, RFC 4187 (Subscription)
  - EAP-TLS, IETF RFC2716 (Device)
  - other methods are possible but require device support

EAP-based Authentication and Authorization



The WiMAX Key Hierarchy



Identities in WiMAX Network Access

- EAP uses the Network Access Identity (NAI, RFC 4282) as central subscriber identity for network entry and AAA routing: „username@realm“
- The "username" part may be
  - the real subscriber‘s identity
  - a pseudonym whenever identity hiding is used (recommended deployment)
  - a MAC address for device authentication
- The NAI can be „decorated“ for visited network selection and for indicating special needs
  - Over-the-air provisioning
  - Emergency calls

Some NAI Examples

- localmax.com!dirk@wimax.homemax.com (selecting localmax as visited NSP)
- {sm=2} dirk@homemax.com (MS requesting an emergency call)
- A234F6789B12345612345678 9C12345E@homemax.com (my latest pseudonym)

Identity Confidentiality

- Identity confidentiality via pseudonym identities to
  - Prevent exposure over-the-air (that allows collecting/tracking IDs)
  - Prevent that visited NSPs or ASNs collect information about competing (home) NSP‘s subscribers
- Pseudonym format and generation
  - Recommended: 128bit random value as the username part of the NAI used for routing AAA messages to the home CSN (‘outer NAI’)
  - Generated by the MS
  - The real identity is sent within the EAP method (‘inner NAI’)
- Advantages and limitations
  - Independent of the EAP method
  - Requires an EAP method that hides the ‘inner’ identity (e.g. EAP-TTLS)

WiMAX Forum Public-Key Infrastructure

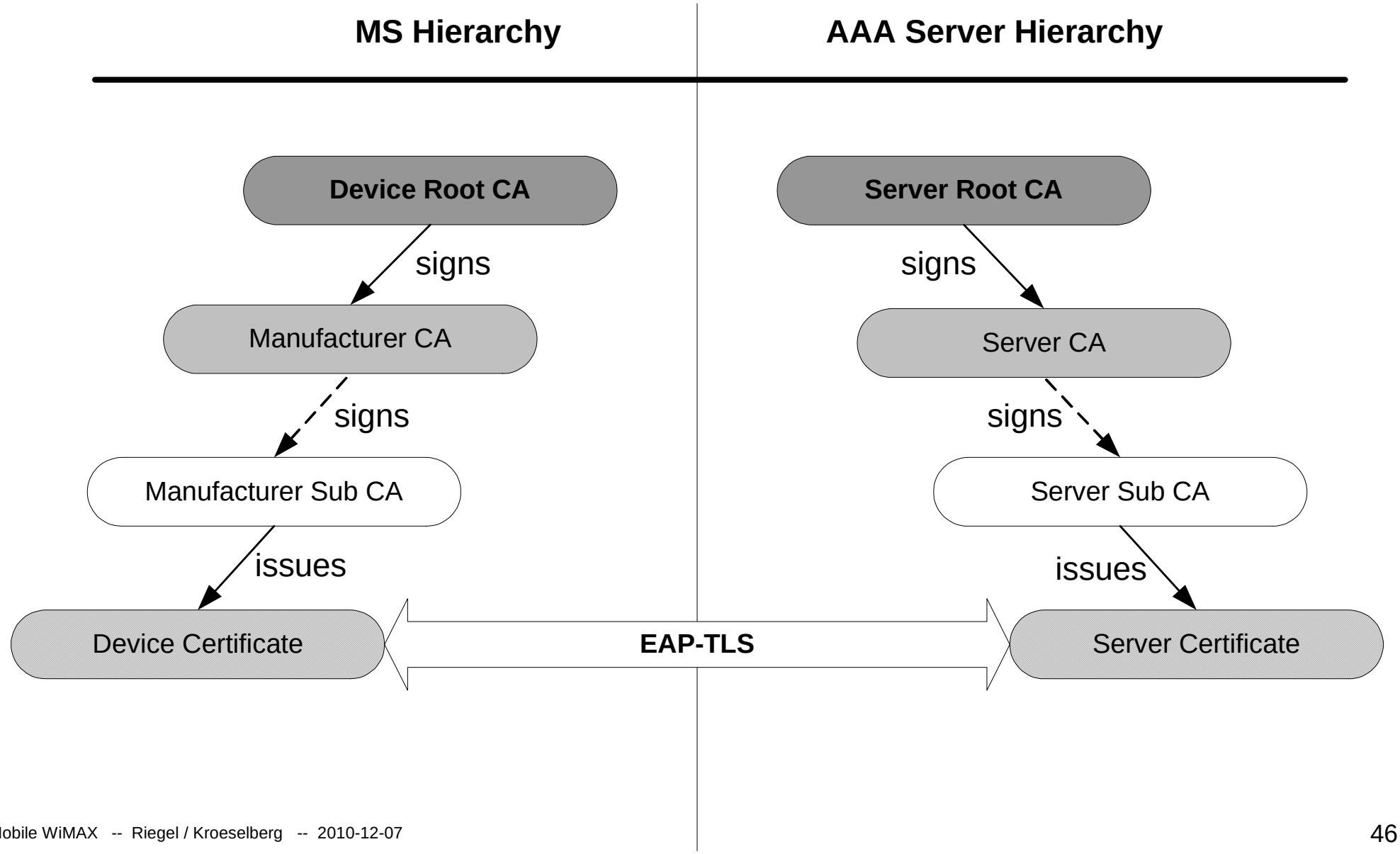
WMF has defined and offers a PKI to leverage device authentication.

This covers

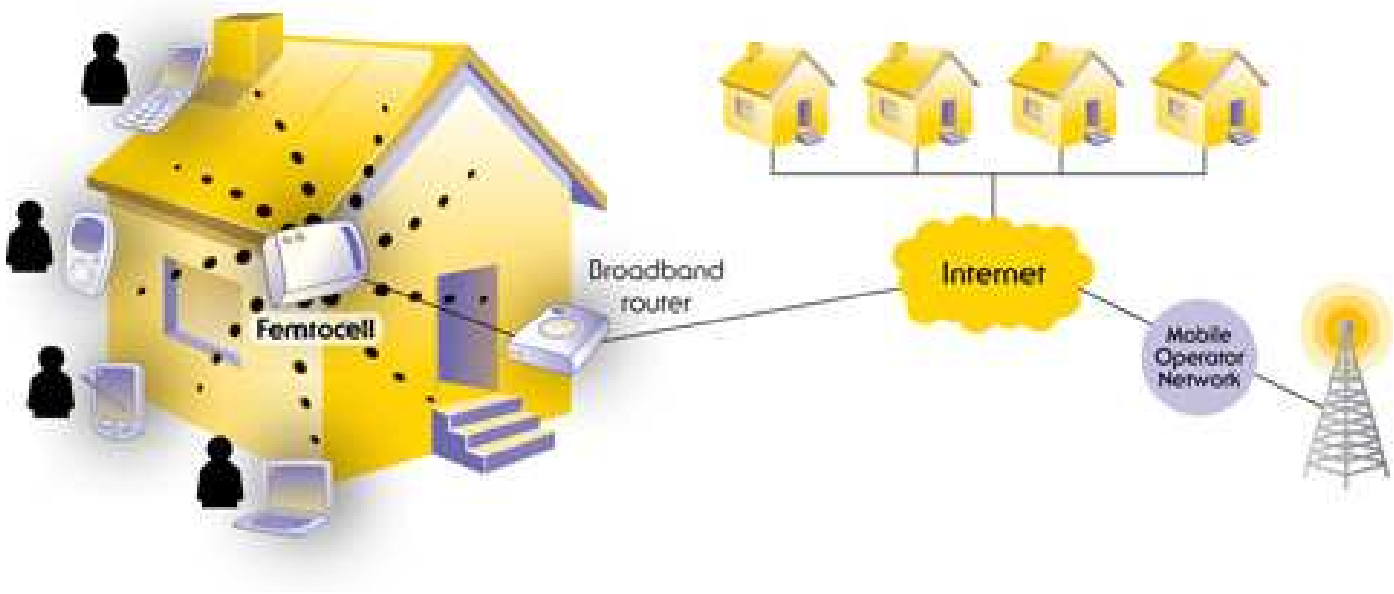
- X.509 Device and Server Certificate profiles
  - WiMAX certificates for device authentication being slightly different from standard TLS certificates e.g. used in Web browsing
- Certificate Revocation
  - Certificate revocation lists (CRL) usage, or
  - Online certificate status checking through OCSP (RFC 2560) that is better suited for mobile devices, creating less load on the wireless link
- Operational and process documents (including pricing)

Root Certificate Authorities are hosted by the WiMAX forum.

WiMAX PKI CA Hierarchy



Femto Overview



- „Femtocells are low-power wireless access points that operate in licensed spectrum to connect standard mobile devices to a mobile operator‘s network using residential DSL or cable broadband connections.“ (text and figure from www.femtoforum.org)
- That is, a Femto CPE device acts as a micro base station. It is connected via standard DSL/Cable to the celluar network operator‘s infrastructure.
- Standardized solutions available for 3GPP/LTE, 3GPP2, WiMAX.

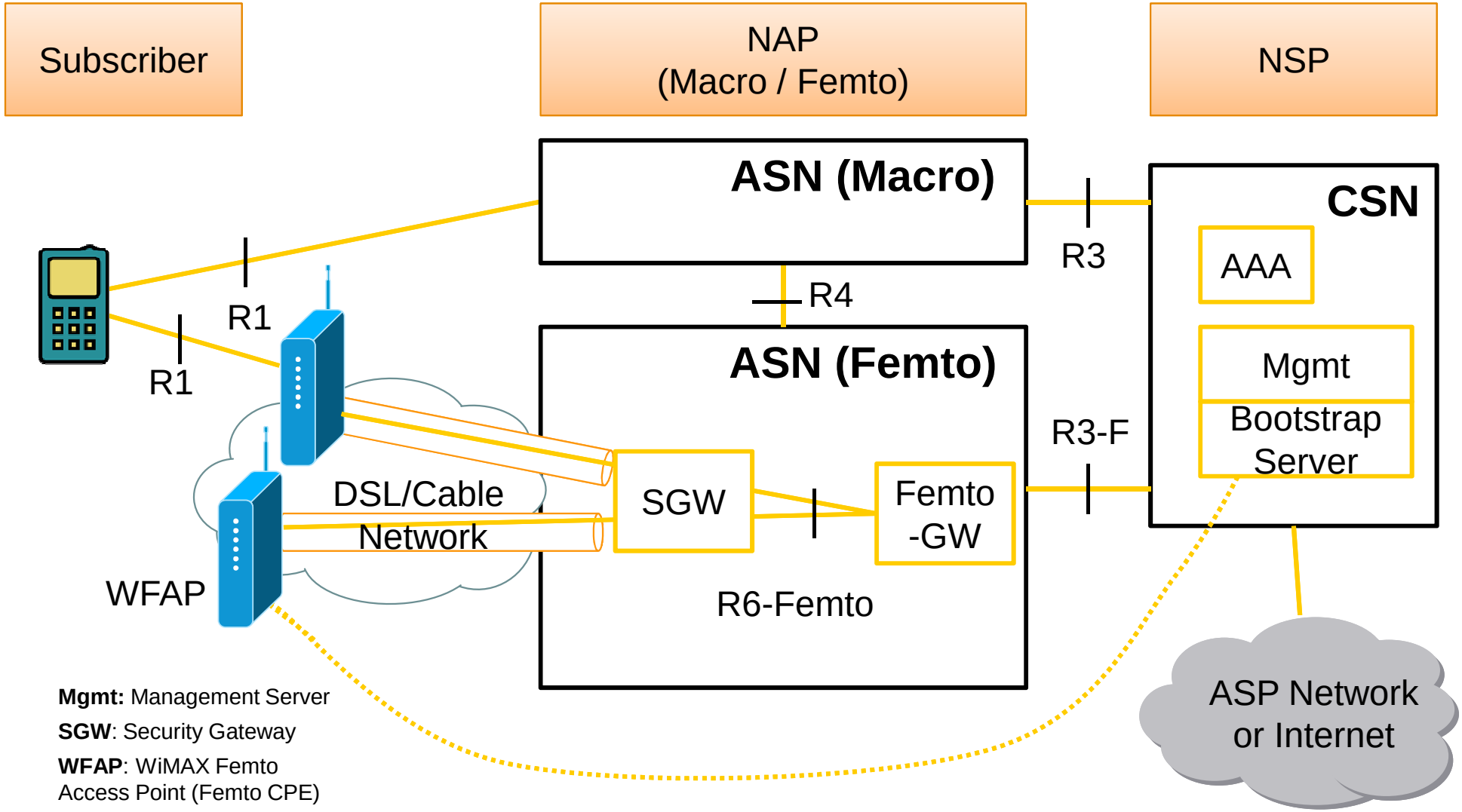
Potential Femto Use Cases

- For the end user:
  - Improve the cellular network‘s coverage indoors or at remote locations
- For the operator:
  - Improved user experience (see above)
  - Offload subscribers and traffic volume from macro (standard) base stations
  - New combined tariff models (fixed+mobile bundles)
  - Hotspots
  - Competitive measure to react to VoIP and WiFi
- But
  - The list of obvious user benefits is rather small
  - That is, the operator has to subsidize the Femto box

WiMAX Femto

- WiMAX Femto support is standardized in the WiMAX Forum Network working group (NWG) as part of Release 1.6
  - technical work finalized during Spring 2010, but final specification not yet publicly released
- Modifications to the radio interface not yet considered. The solution is purely based on network support for regular WiMAX MSes.
  - Saying: WiMAX MSes have no information whether they connect to a regular BS or a Femto-CPE base station.
- Requirements for Femto in WiMAX are roughly similar to those of 3GPP Femto and of the Femto Forum (www.femtoforum.org).
- However, the solution of WiMAX compared to 3GPP is relatively different due to the split between ASN and CSN (access and ISP networks can belong to different business entities like for DSL)

WiMAX Femto Architecture



Mgmt: Management Server

SGW: Security Gateway

WFAP: WiMAX Femto Access Point (Femto CPE)

Architecture Specifics

- Standard (Macro) and Femto-ASN are logically separated; no single ASN has both Femto and macro BSes.
- CSN can be the same for macro and femto ASN, or there can be separate CSNs
- R6 and R3 for Femto are largely based on the standard R6 and R3 reference point functionality (as far as required for Femto)
- WFAP management happens end-to-end between CSN and WFAP

Femto and Location

- Femto boxes will typically not be allowed to be moved (e.g. to a different DSL line or a different country)
- Location verification is required
- Possible solutions: checks in the Femto CPE or network
  - IP address
  - Parameters provided by the DSL operator
  - Information about surrounding base stations (measured and reported by the Femto CPE)
  - Measurements by a built-in GPS module in the Femto CPE
- However, exact checks are problematic
  - Not all of the above information may be available
  - GPS is problematic indoors

Closed Subscriber Groups (CSG) in Femto

- CSG means that only selected MSes or Subscribers can connect to the network through a Femto-CPE
- Examples
  - Home: mobiles of all family members
  - Enterprise: all corporate users at a specific site of the company
  - Hotspot: a subscriber can connect to all Femto CPEs of a specific coffee company, airport etc.
- CSG enforcement has to be part of the access authorization procedures
  - either in the network: Femto-CPE or Femto Gateway
  - or in the MS if the MS is Femto-enabled (the approach in 3GPP)
  - Current WiMAX standards mainly allow to check the MS MAC address during network entry and block access if not authorized

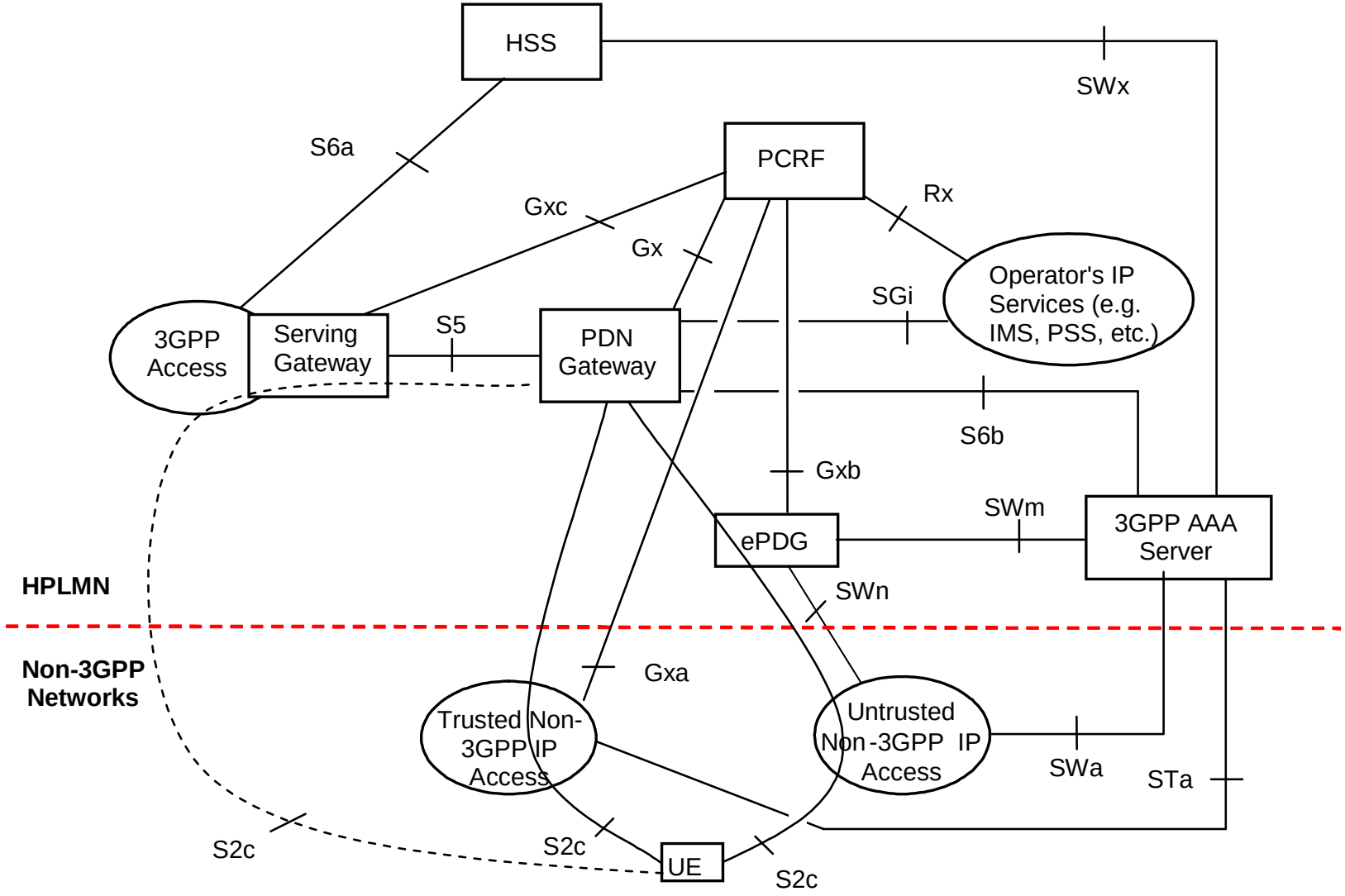
WiMAX Femto Security

- Security Architecture roughly similar to 3GPP Femto
  - WFAP runs mutual authentication with the ASN
  - Additional authorization by the CSN, as the CSN owns the WFAP subscription
  - Protection of control and user data between WFAP and ASN (DSL line considered untrusted)
- Technical solution:
  - IKEv2/IPsec between WFAP and Security Gateway
  - WFAP comes with a Certificate for authentication of the IKEv2 exchange
  - Authorization of WFAP by CSN supported by additional RADIUS / Diameter functionality

Interworking with 3GPP EPS

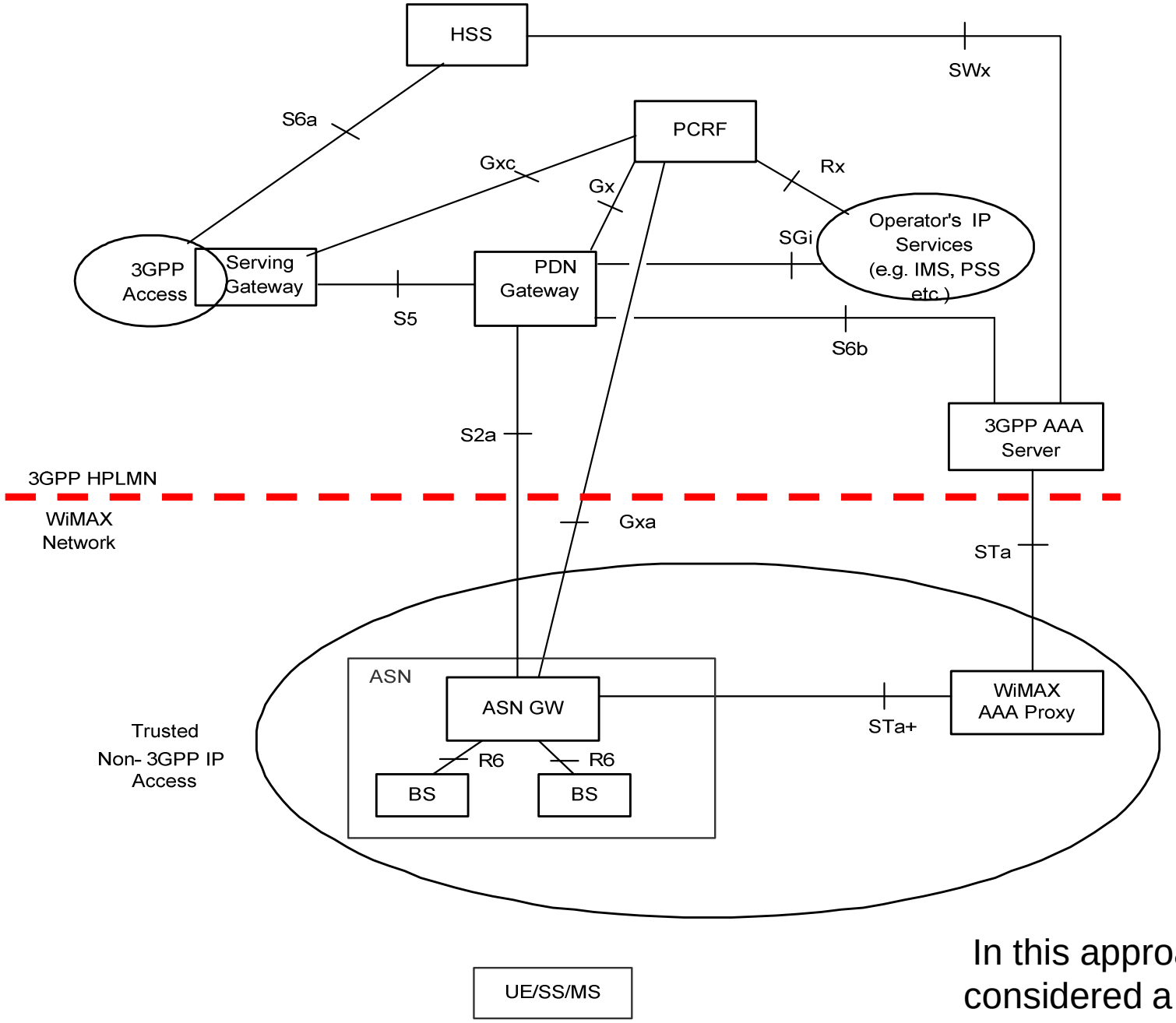
- 3GPP defines a standardized architecture for access to the 3GPP Release 8 (and higher) core network through access other than 3GPP radio technology
  - WiMAX
  - Cdma (mobile cellular networks following the 3GPP2 specifications)
  - WiFi
- Such “non-3GPP” access can either be considered as
  - Trusted, or
  - Untrusted
- The WiMAX Forum interworking specifications consider WiMAX a trusted access
  - Direct connection of an ASN to the 3GPP EPC (evolved packet core) is possible
  - Untrusted access would require a VPN-like solution between the device and the EPC, making user data transparent to the access.

EPS Architecture for non-3GPP IWK



(source: 3GPP TS23.402)

EPS-WiMAX Interworking



In this approach, WiMAX is considered a trusted access.

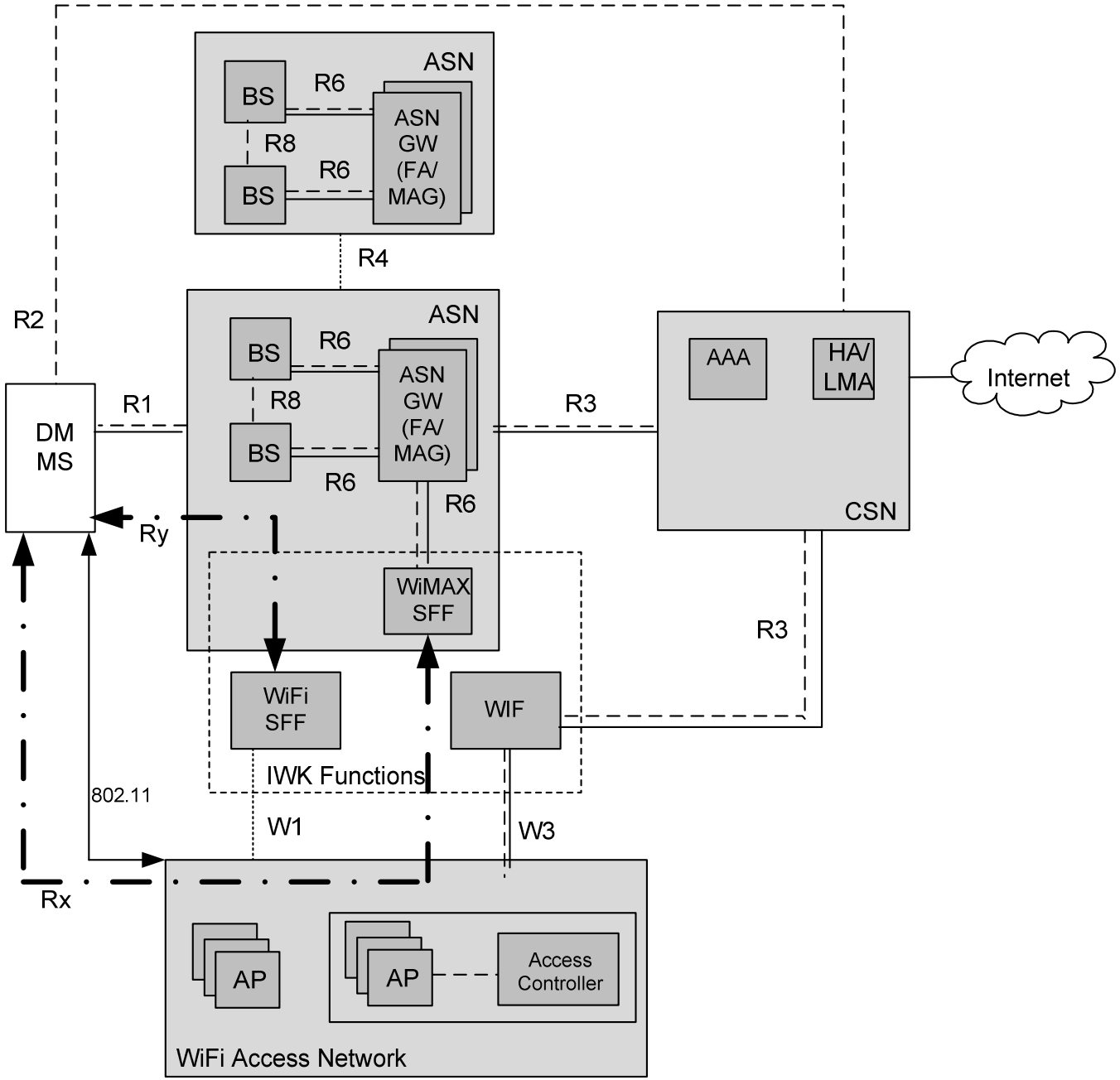
EPS Interworking Aspects

- EPS non-3GPP access supports IP mobility based on Mobile IP
- The EPS specifications use MIP security bootstrapping similar to WiMAX (it was in fact taken over from WiMAX)
  - Same key derivation procedures based on EMSK
  - But partially closer to IETF MIP security architecture than to the one of WiMAX (e.g. PMIP security associations are not per-MS, but per MAG-LMA pair)
- PCC: the EPS assumes PCC according to the 3GPP Release 8 or higher specifications. However, WiMAX up to now only supports PCC according to 3GPP Release 7
  - Work is scheduled to address this gap as part of the Release 2 network architecture during 2011.

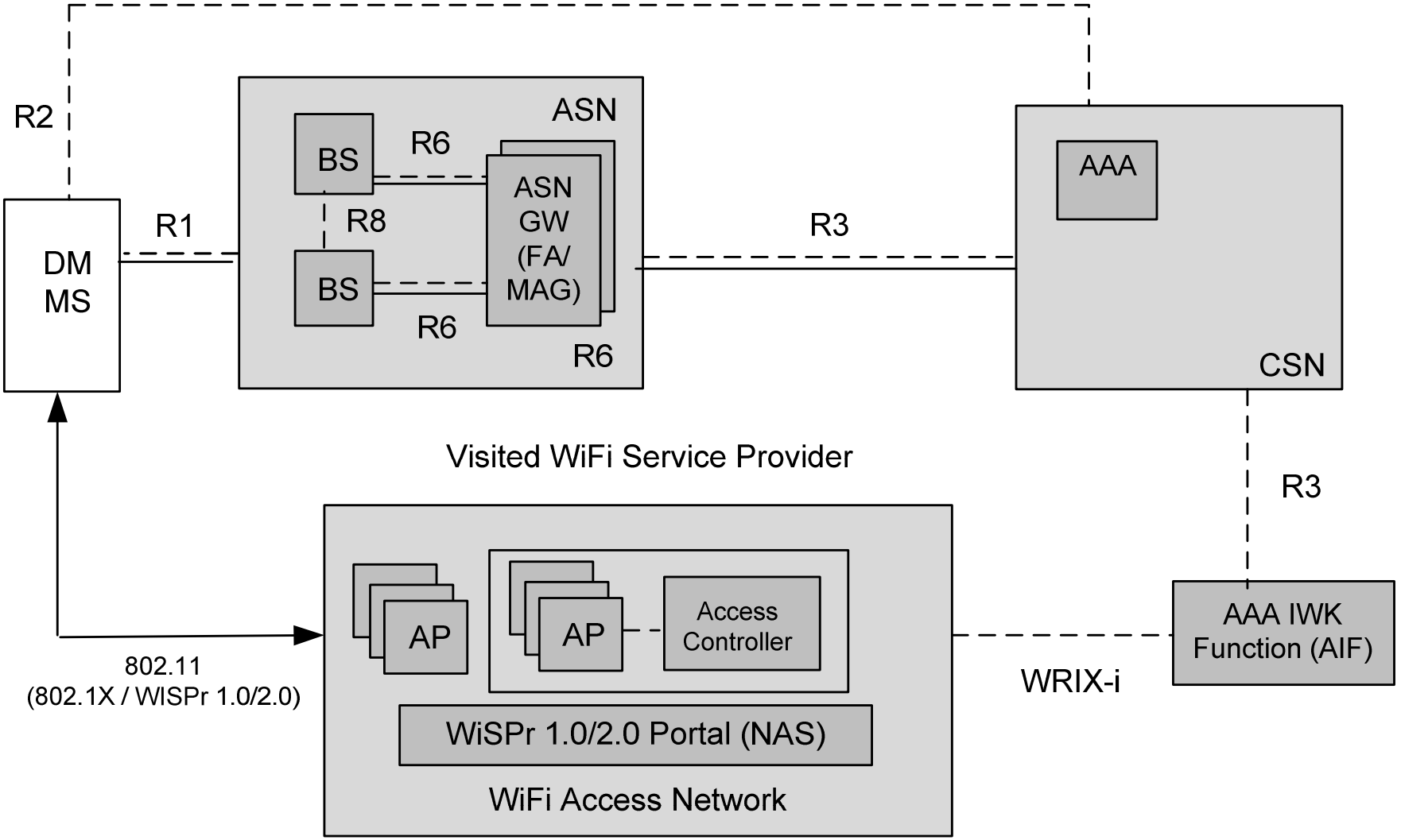
WiMAX – WiFi Interworking and Roaming

- Typically, available WiFi access should be preferred over WiMAX
- Standard improves network support for a terminal moving between WiMAX and WiFi access (e.g. moving in and out of home WiFi, hotspot area etc.)
- Technical approaches:
  - Roaming allows access to WiMAX core through partnering operator‘s WiFi access, or vice versa.
    - AAA backend implementing „both worlds“ is assumed (i.e. WiMAX AAA funtions as well as WiFi roaming support)
    - No integration of WiMAX and WiFi access network
    - Practical for „dual-radio“ devices
  - Interworking allows closer integration with significant impact on the access network
    - Requires new interworking entities to translate control signaling and to perform a kind of „pre-authentication“
    - Required for „single-radio“ devices

WiMAX – WiFi Interworking Architecture

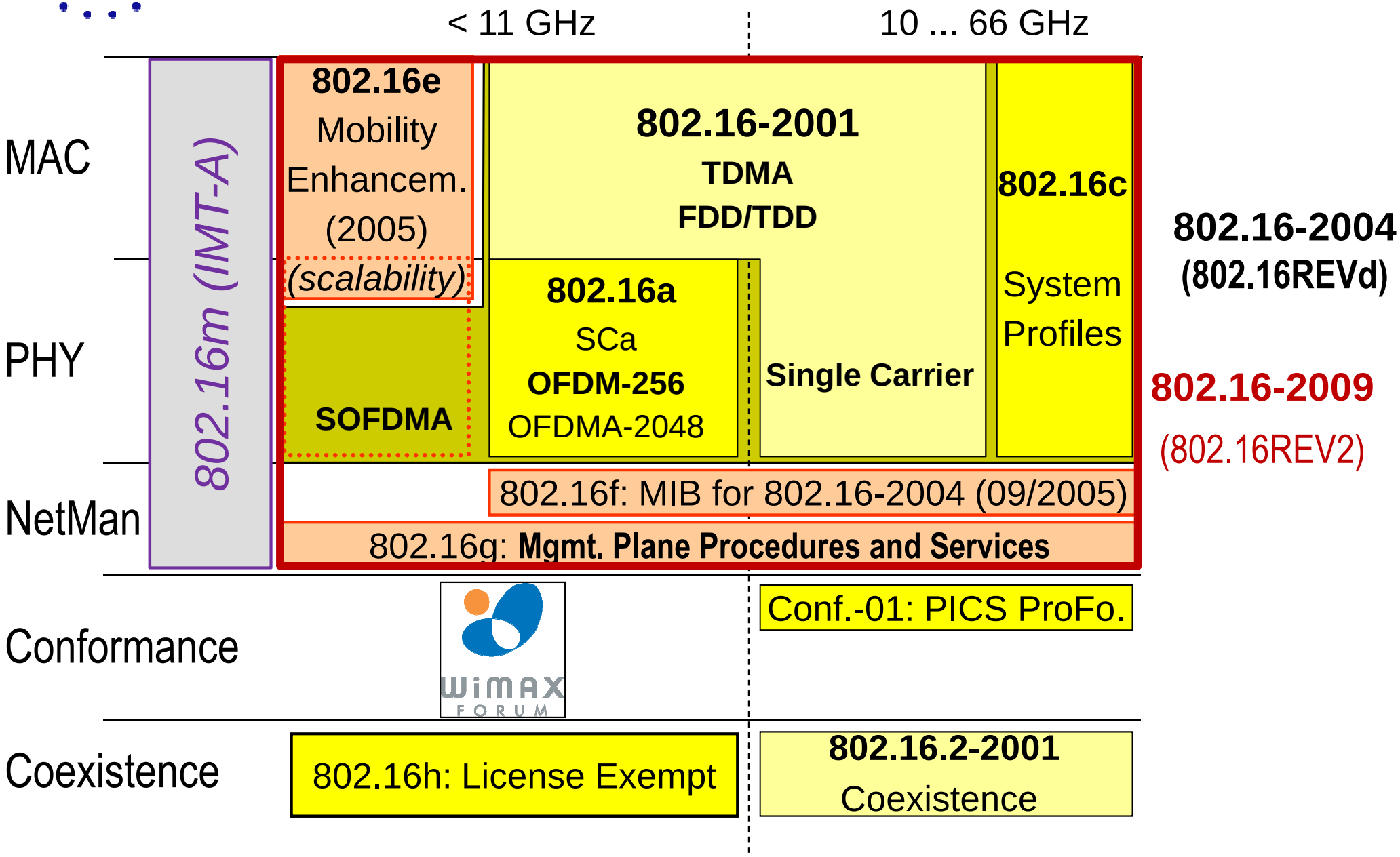


WiMAX – WiFi Roaming Architecture (Example)



4 - Air Interface

IEEE 802.16 Broadband Wireless Access

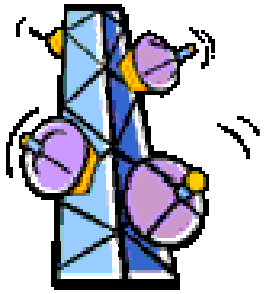


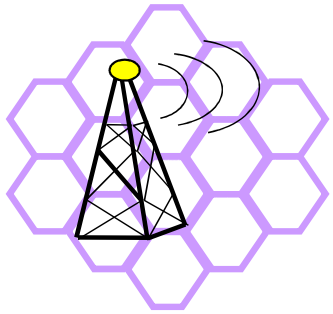
WiMAX Radio Interface Release 1.0

- Physical Layer
  - Physical Layers in IEEE802.16
  - Overview about OFDM and OFDMA
  - Frame Structure
  - Subcarrier Allocation
  - Fractional Frequency Reuse
  - Other aspects

- MAC Layer
  - Overview
  - Convergence Sublayer
  - Protocol Data Transmission
  - Network Entry and Initialization
  - Payload Connection Management and QoS
  - Mobility Support

Physical Layers in IEEE 802.16

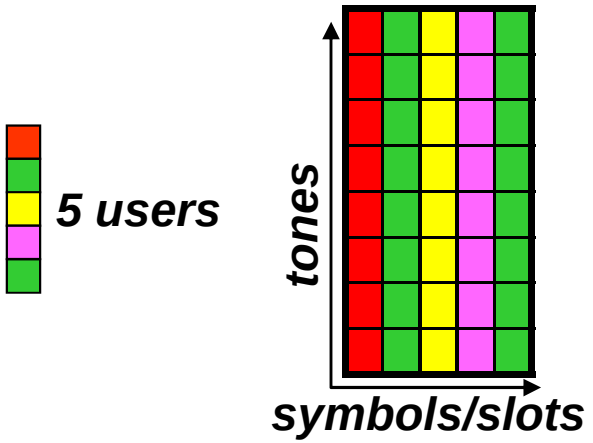


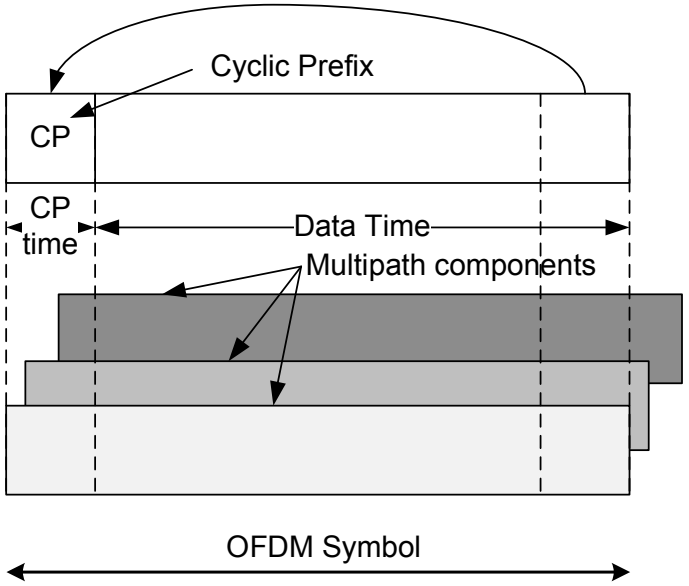


	Feeding	FWA	Cellular
Completed	December 2001	January 2003	June '04/Mobility '05
Spectrum	10 - 66 GHz	< 11 GHz	< 6 GHz
Channel Conditions	Line of Sight Only	Non Line of Sight	Non Line of Sight
Bit Rate	32 – 134 Mbps in 28MHz channel bandwidth	Up to 75 Mbps in 20MHz channel bandwidth	Up to 15 Mbps in 5MHz channel bandwidth
Modulation	Single Carrier QPSK, 16QAM, 64QAM	OFDM 256 sub-carriers QPSK, 16QAM, 64QAM	1x Scalable OFDMA QPSK, 16QAM, 64QAM
Mobility	Fixed	Fixed	Portable Mobile (up to 120 km/h)
Channel Bandwidths	20, 25 and 28 MHz	Scalable 1.5 to 20 MHz	Scalable 1,25 to 20 MHz
Typical Cell Radius	2-5 km	7 to 10 km Max range 50 km	1-5 km

Physical Layer
Overview about OFDM

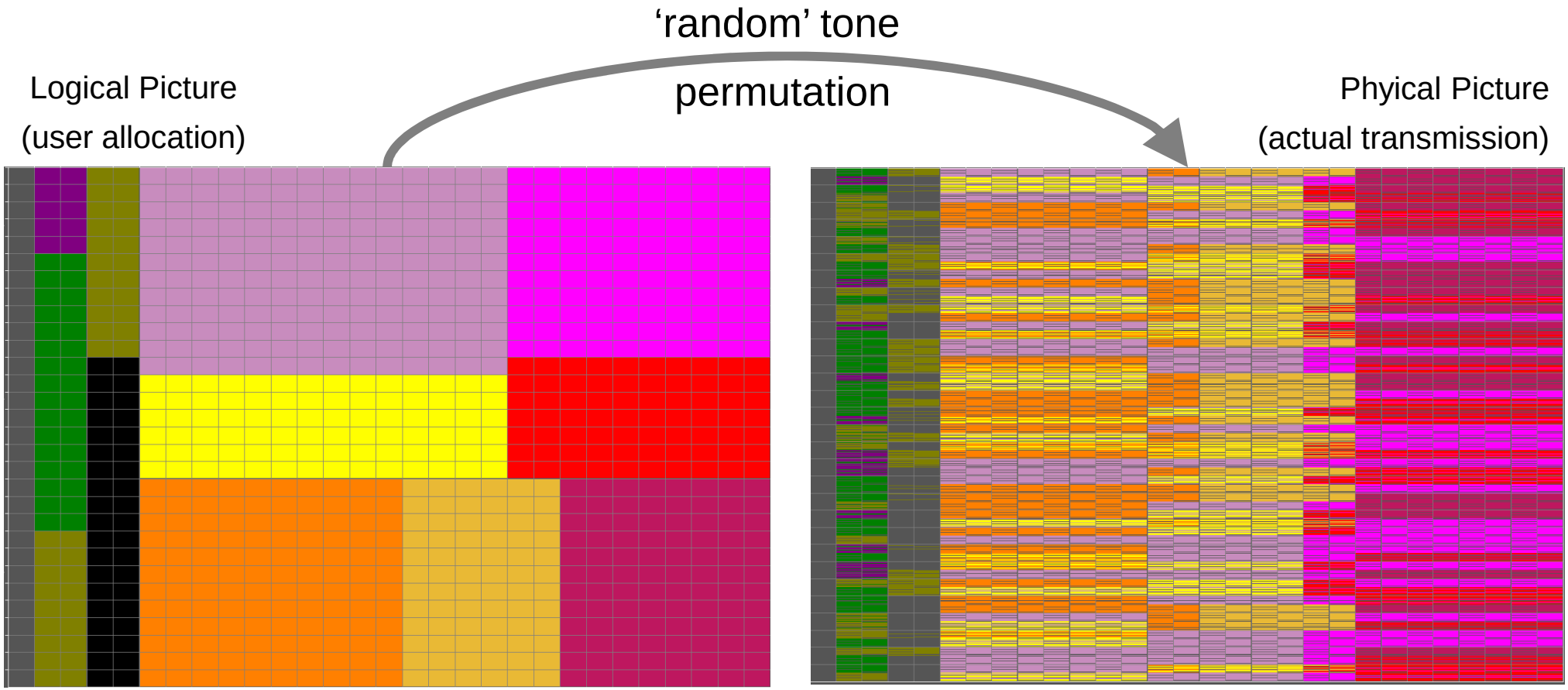
- OFDM: Orthogonal Frequency Devision Multiplex
  - Parallelization of data into orthogonal streams or subchannels
  - Symbol rate much lower than data rate
  - Robust against signal destortions and multipath fading
  - No need for channel equalization
  - Channel delay spread and intersymbol interference alleviated by Cyclic Prefix
  - Drawbacks of OFDM:
    - No frequency reuse = 1
    - No interference averaging
    - Drawbacks addressed by OFDMA





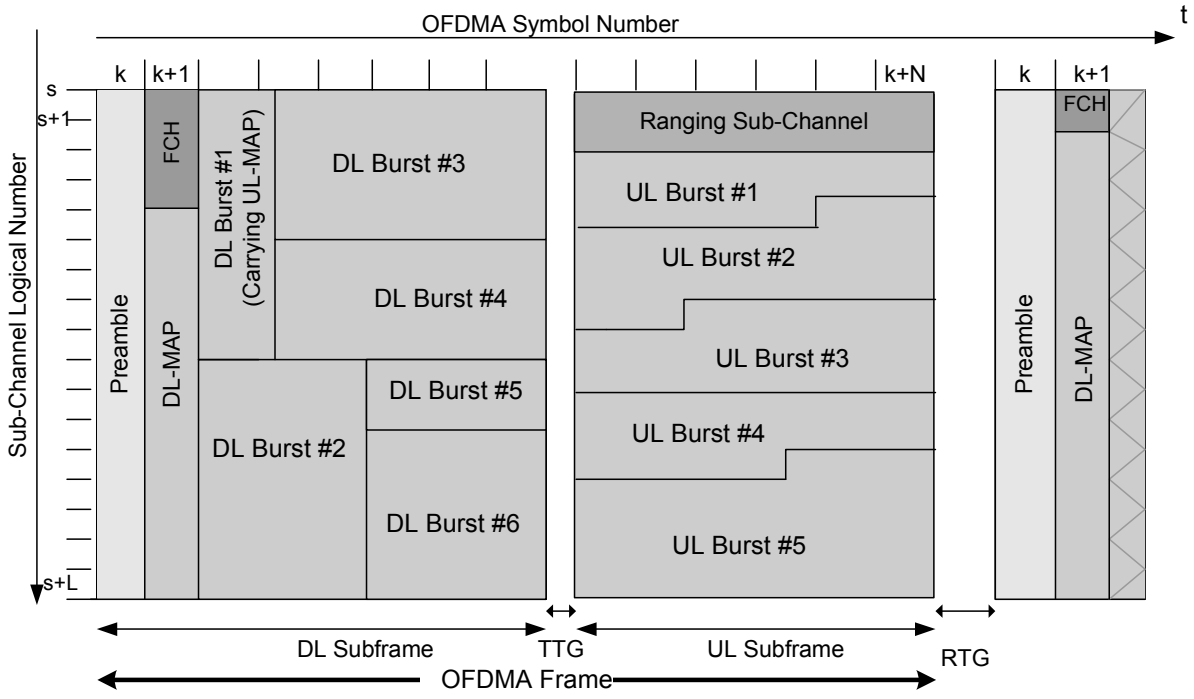
Physical Layer
Overview about OFDMA

- OFDMA: Orthogonal Frequency Devision Multiplex Access
  - Multiple users occupy non-overlapping sets of frequencies (= tones)



Physical Layer
Frame Structure

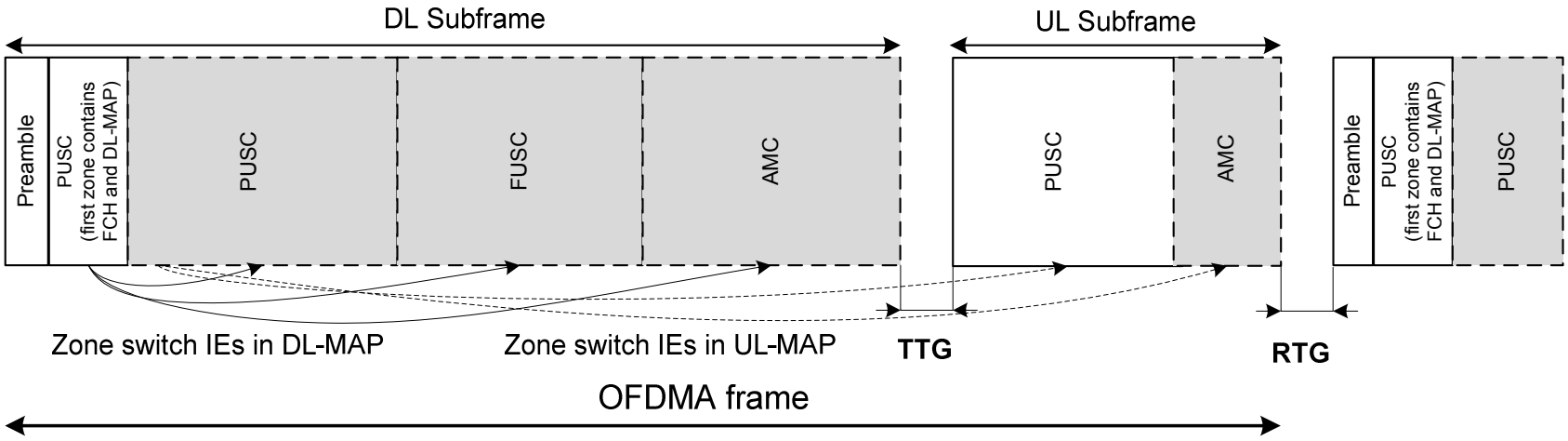
- WiMAX deploys Time Devision Duplex transmission
  - Gaps needed between downlink and uplink transmission
  - Frame level synchronization needed to prevent inter-cell interference
  - BS specitfic preamble used by mobile stations to synchronize



Parameters	Value			
Channel Bandwidth (MHz)	1.25	5	10	20
FFT Size	128	512	1024	2048
Sampling Frequency (MHz)	1.4	5.6	11.2	22.4
Sub-Carrier Frequency Spacing (kHz)	10.94			
Symbol Time (microseconds)	91.4			
Guard Time (microseconds)	11.4			
Frame Size (milliseconds)	5			
Number of OFDM Symbols	48			

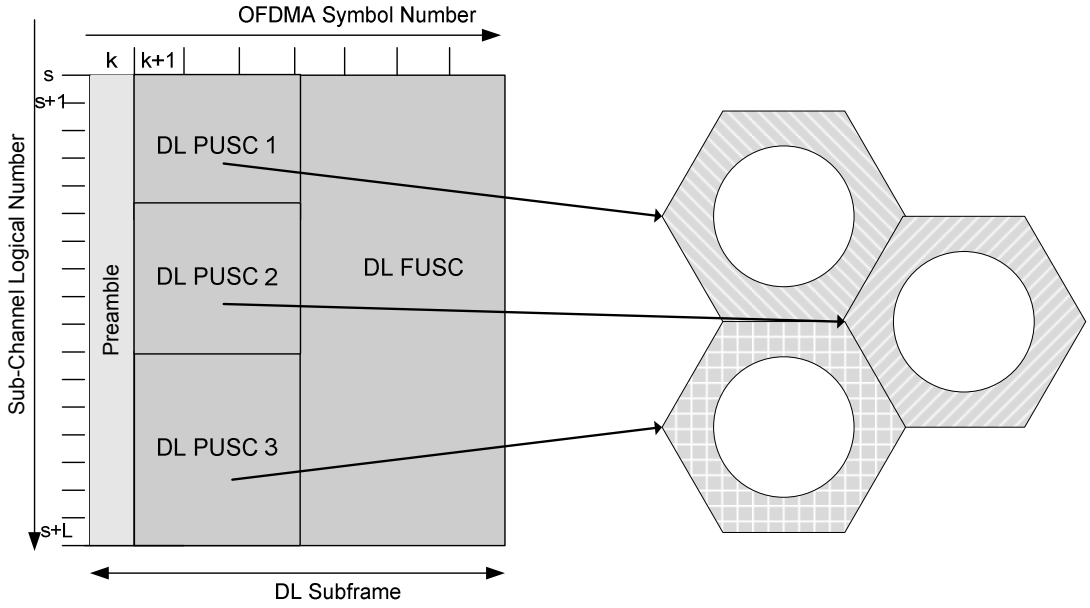
Physical Layer
Subcarrier Allocation

- Distributed subcarrier allocation
  - Subcarriers forming a subchannel are ‘randomly’ distributed
  - *Partially Used SubChannelization (PUSC)* permutation
    - partially used subchannels grouped into sectors of the same cell
  - *Fully Used SubChannelization (FUSC)* permutation
    - applies to whole allocated frequency without segmentation
- Localized subcarrier allocation
  - Adjacent subcarriers build a subchannel
    - Better adjustment of modulation and coding for stationary conditions, e.g.
      - *Advanced Modulation and Coding (AMC)* permutation



Physical Layer
Fractional Frequency Reuse

- Single reuse factor of 1 as well as greater of 1 (e.g. 3) supported by fine grain adjustment of permutation
- Mobile WiMAX supports also fractional frequency reuse
  - Higher reuse factors especially for terminals at the cell edge to reduce interference level at cell edge with low reuse factors
  - Better overall performance for the cost of higher complexity

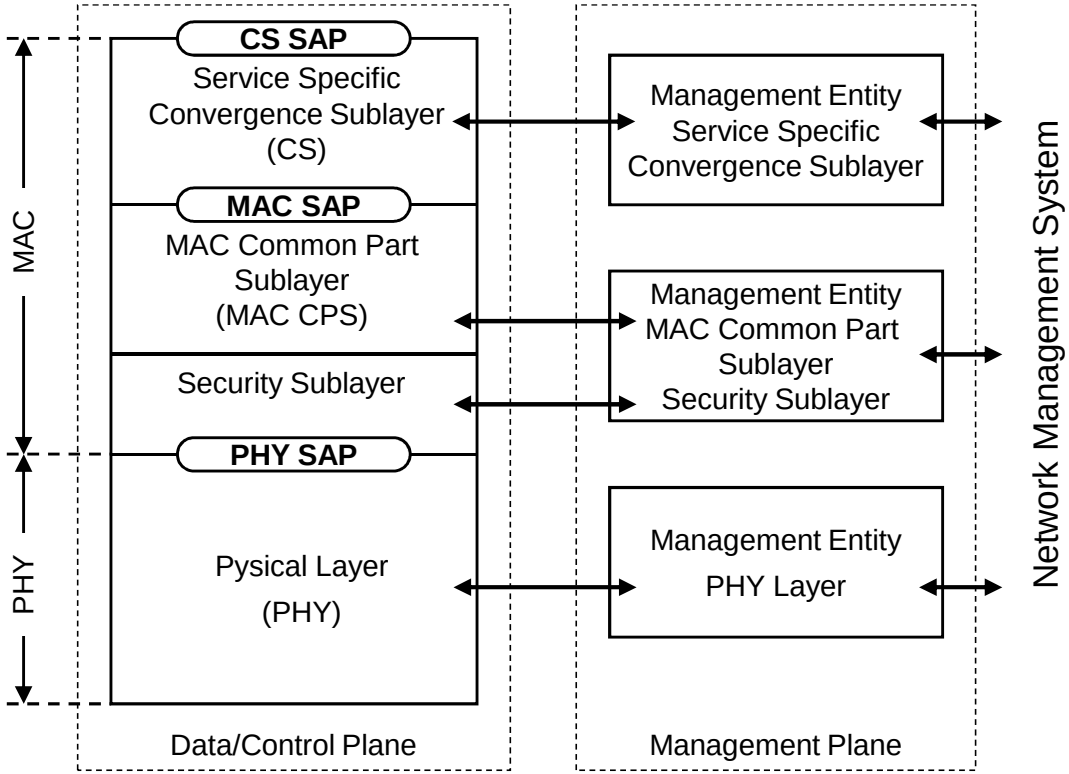


Physical Layer
Other aspects

- Modulation and Coding
  - Randomization, forward-error-correction, interleaver, modulation
    - Randomization (convolutional coding) for increased channel coding
    - Modulation: QPSK, QAM-16, QAM-64
  - Hybrid automatic retransmission request (H-ARQ)
- Multiple Antenna Systems
  - Space-Time Block Coding (STBC)
    - Supports Multiple Input Multiple Output (MIMO) by generating dedicated streams for each of the antennas
  - Cyclic Delay Diversity (CDD)
    - Increasing diversity gain without much additional complexity
  - Spatial multiplexing MIMO
    - Splitting multiple encoded data streams over multiple antennas

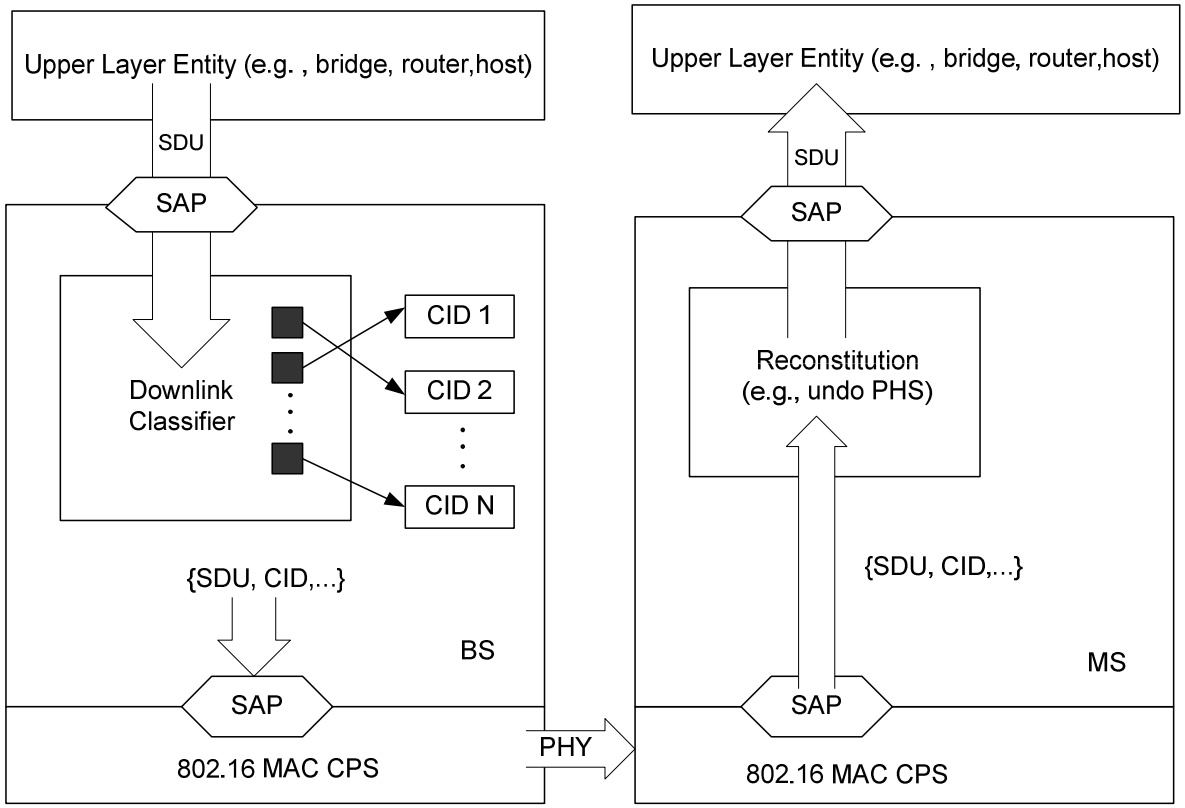
Medium Access Control Layer Overview

- MAC Layer of IEEE802.16 is devided in 3 sublayers
  - Service-specific convergence sublayer
    - Encapsulation of payload
      - ATM, IP, ETH, GPCS
  - MAC common part sublayer
    - Control of access to radio and network
    - Connection establishment and management
    - Management of bandwidth
    - QoS
  - Security sublayer
    - Authentication
    - Privacy
    - Protection to link-level messages



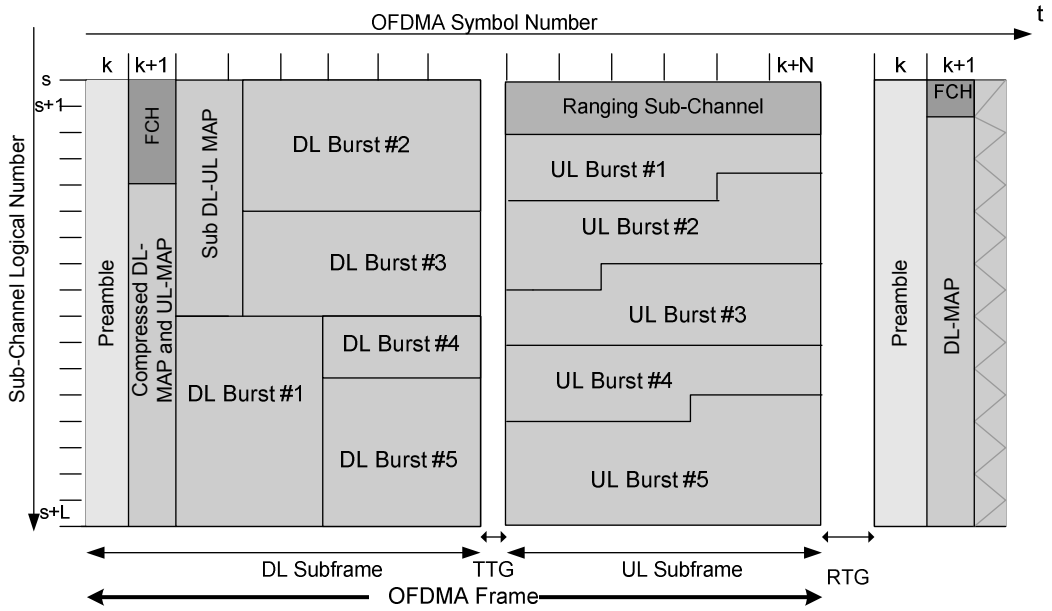
MAC Layer
Convergence Sublayer

- Service specific encapsulation of payload
  - ATM CS
  - Packet CS
    - IP
    - Ethernet
    - GPCS
- Downlink
  - Mapping of Service Data Units (SDUs) into link layer connections
    - Classification and assignment of Connection Identifiers (CIDs)
  - Optional: Packet Header Suppression
  - Optional for IP: ROHC
- Uplink
  - Reconstruction of payload

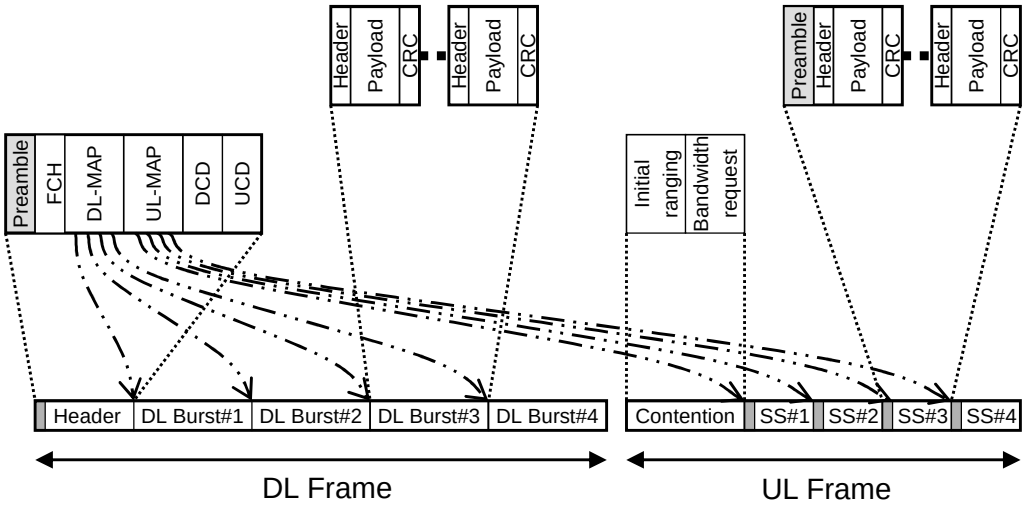


MAC Layer
Protocol Data Transmission

- TDD Frame with compressed DL- and UL-MAP

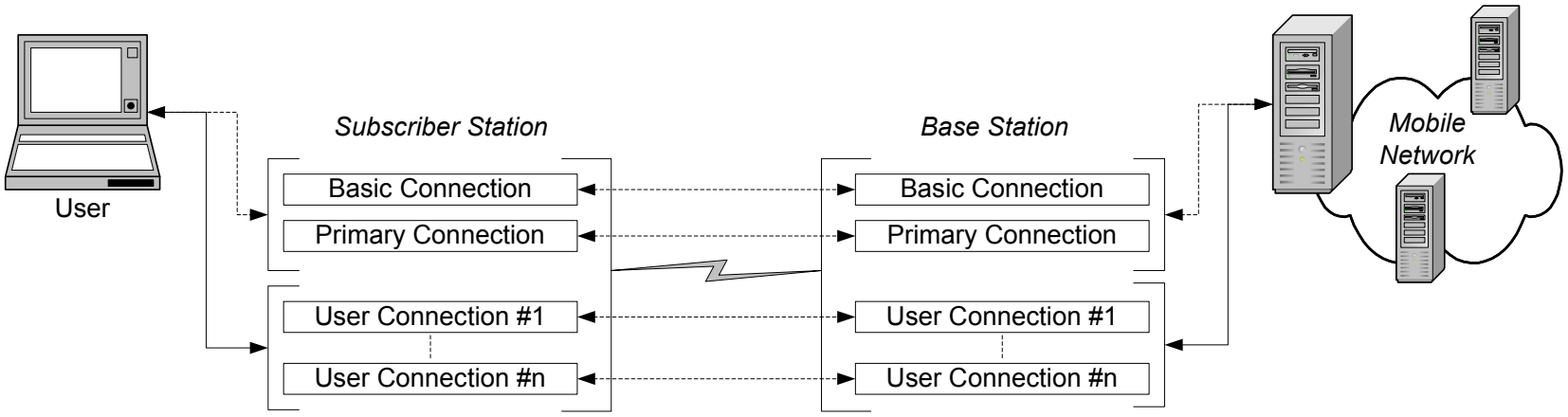


- MAC PDU mapping into DL-Bursts and UL-Bursts



MAC Layer
Connection-oriented Transmission

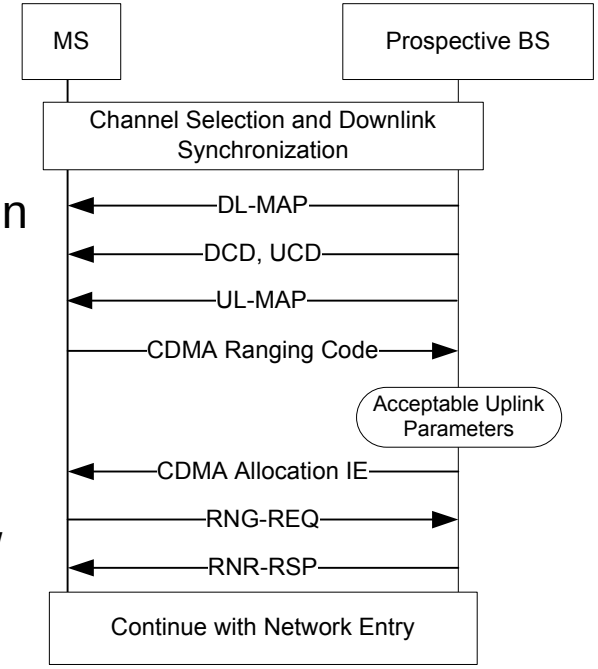
- MAC Layer implements connection-oriented paradigm for transmission over the air

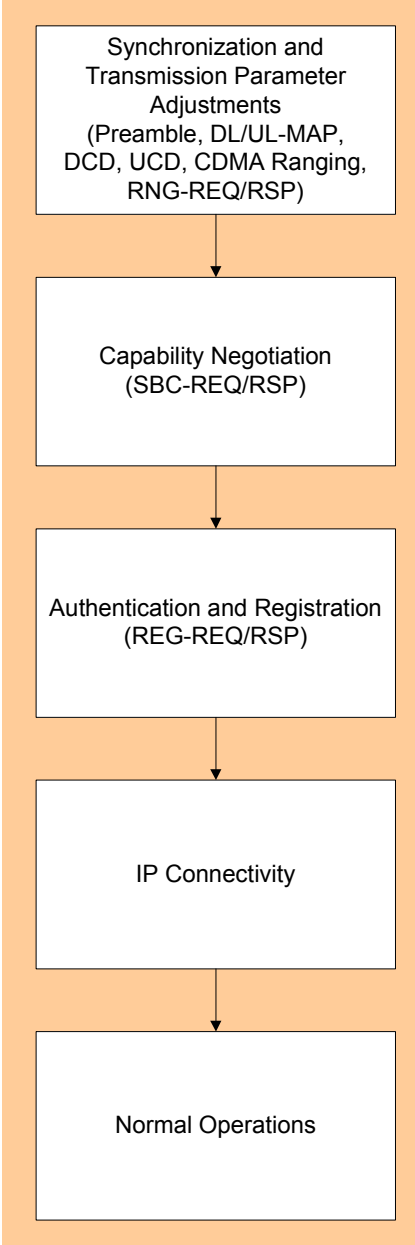


  - Two management connections
    - Third, secondary management connection is not used in Mobile WiMAX
  - Zero or more user connections
  - Managed Quality of Service on a per connection basis

MAC Layer
Network Entry and Initialization

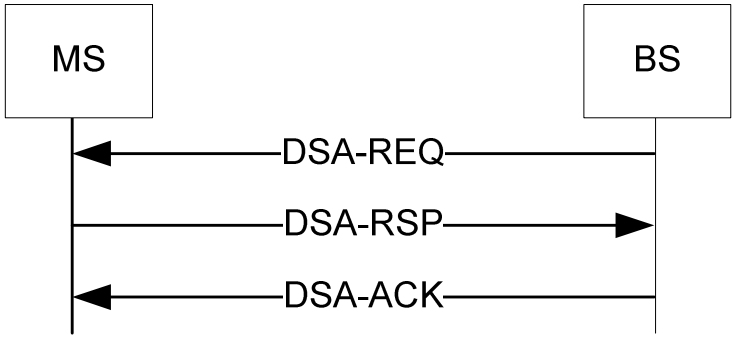
- Synchronization and Transmission Parameter Adjustment
  - Preamble used for determination of downlink parameters
  - Ranging is closed loop process to agree on accepted uplink transmission parameters
  - Once agreed the process is concluded with final RNG-REQ/ RNG-RSP
- Capability Negotiation
  - Further parameters agreed by use of SBC-REQ/SBC-RSP
- Authentication and Registration
  - Exchange of authentication information and start of cyphering suite incl. key management
- IP Connectivity
  - Configuration of the IP connectivity parameters by DHCP





MAC Layer
Payload Connection Management and QoS

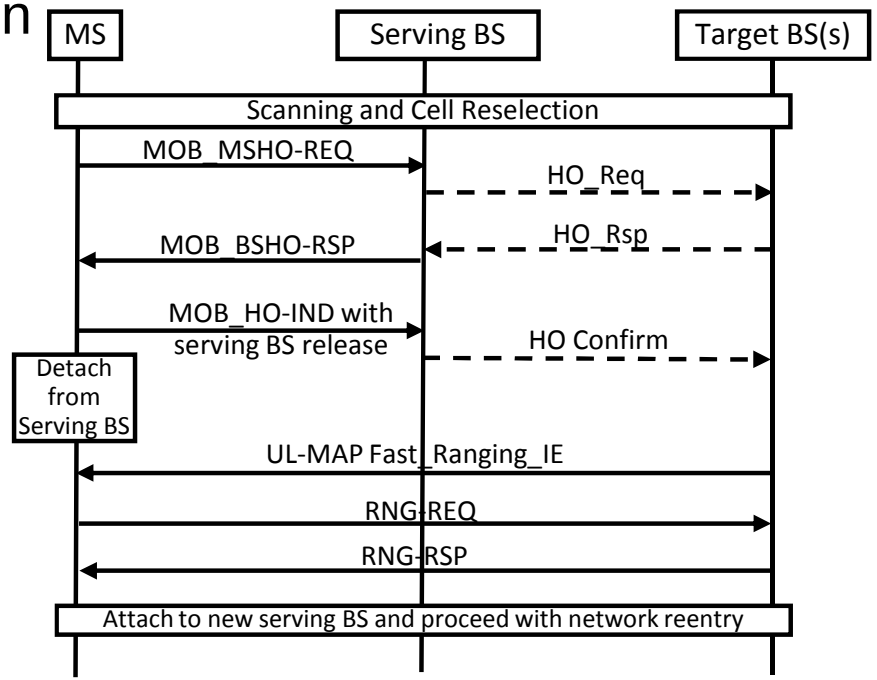
- Connection Setup
  - Connections are unidirectional service-flows with an agreed set of QoS parameters like bandwidth and jitter
  - Identified by 32bit SFID and 16bit CID
  - Either UL or DL
  - 3 Stages: provisioned, admitted, active
  - Set-up either from BS or MS
  - QoS parameters can be changed during lifetime



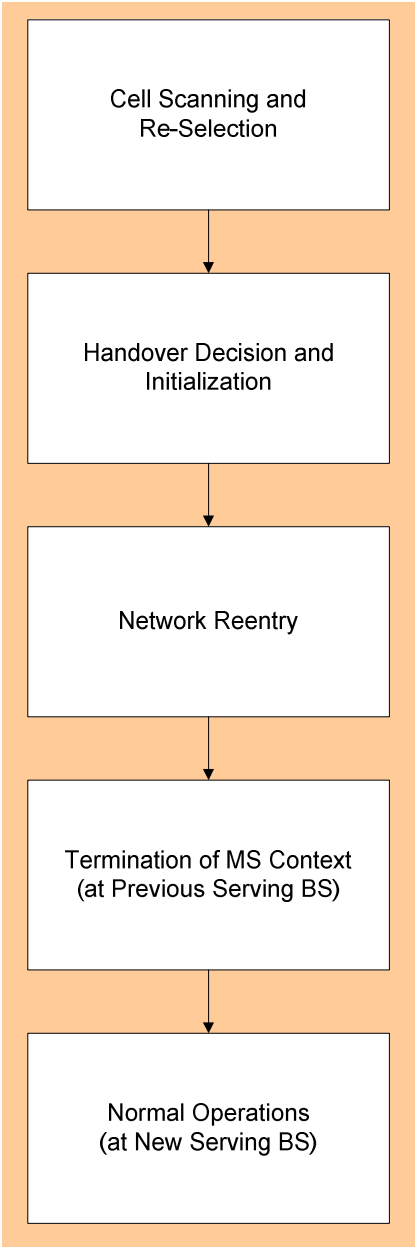
- Scheduling Services
  - Unsolicited Grant Service (UGS)
  - Real-time Polling Service (rtPS)
  - Extended real-time Polling Service (ertPS)
  - Non real-time Polling Service (nrtPS)
  - Best Effort (BE)

MAC Layer
Mobility Support and Handover

- Only hard-handover (break before make)
- Always executed by MS
- Process:
  - Cell Scanning and Reselection
  - Handover Decision and Initialization



  - Network Re-entry
  - Termination of MS Context
- Handover Cancellation



WiMAX Radio Interface
Release 1.5

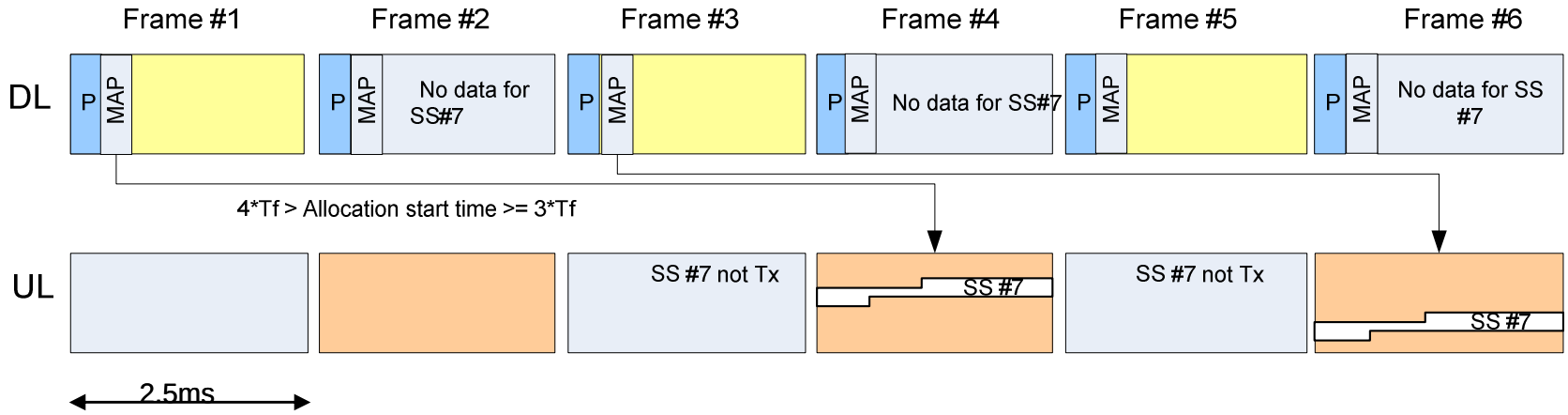
- Enhancements in IEEE802.16-2009
- H-FDD Enhancements in IEEE802.16-2009
- Load Balancing: BS-Controlled Handover
- Persistent Scheduling
- LBS Feature

Enhancements in IEEE802.16-2009

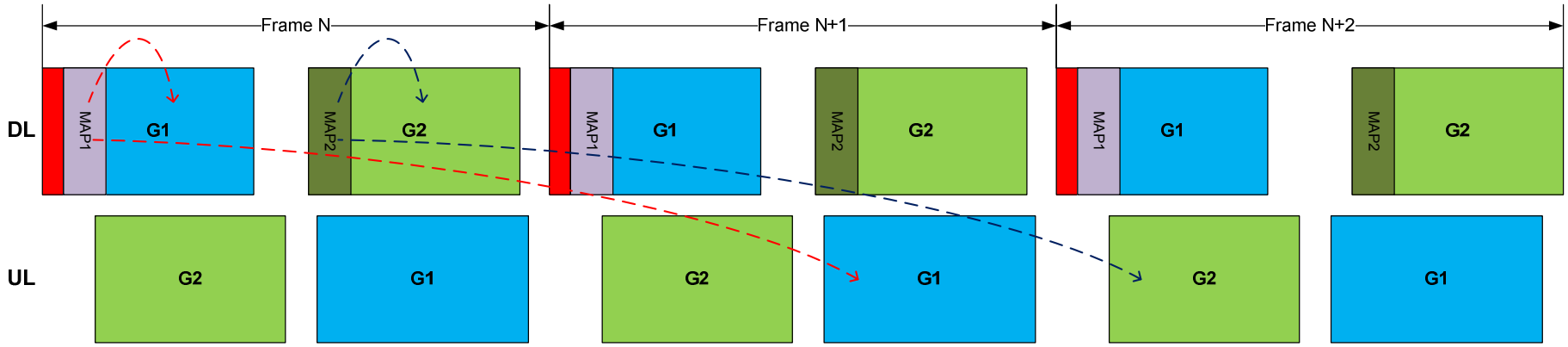
- IEEE802.16-2009 standard created by revising the previous base specification 802.16-2004 and incorporating all ratified amendments such as 802.16e, 802.16f and 802.16g.
- Later amendments such as IEEE802.16j, IEEE802.16h are based on IEEE802.16-2009
- Major changes introduced in IEEE802.16-2009
  - Removal of mesh mode and single carrier PHY mode
  - Additions of new H-FDD frame structure and optimized operations
  - Addition of load balancing and handover enhancements
  - Addition of persistent scheduling for VoIP
  - Addition of LBS information and hooks
  - Addition of WiMAX/WiFi-Bluetooth coexistence mechanisms
  - Bug fixes for MBS and new enhancements
  - Optimization of feedback mechanisms for CL MIMO

FDD: H-FDD Enhancements in IEEE802.16-2009

- H-FDD as specified in 16e is inefficient and require either short frame size (2.5ms frame) or longer latency (5ms frame)

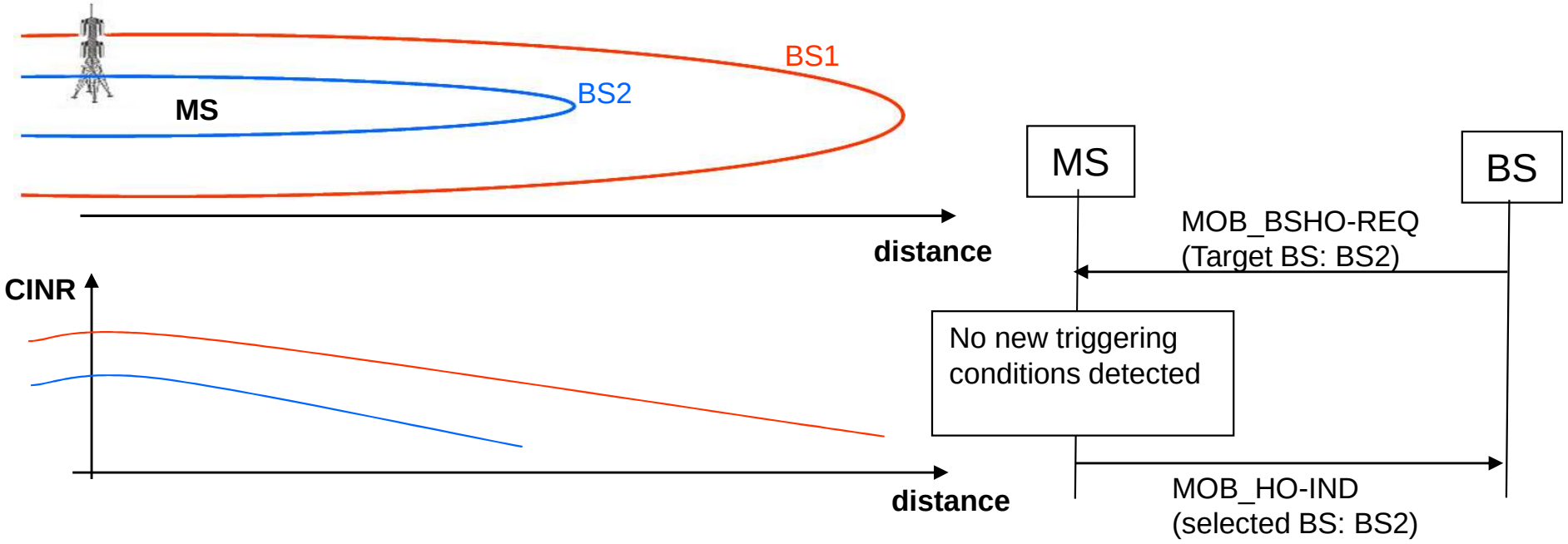


- 802.16-2009 specifies H-FDD using 2 groups of MS in one frame. Each group has its own MAP, FCH and DCD/UCD
  - Possible to optimize MAP (different MCS, repetition) based on MS grouping



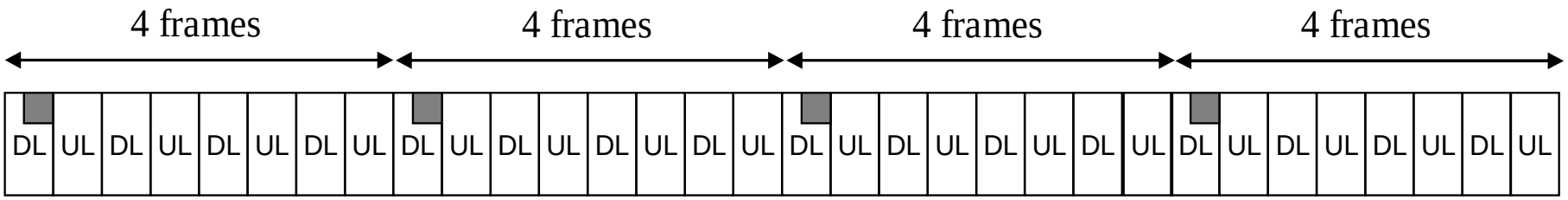
Load Balancing: BS-Controlled HO

- MS shall perform HO toward BS2, unless a new triggering condition specified in Trigger TLV or Neighbor BS Trigger TLV has occurred at MS side for another neighbor cell.
- In case new triggering conditions are detected, MS is allowed to initiate HO to new target cell. This way MS can always initiate handover to the correct cell if HO decision is outdated (e.g. radio channel conditions have changed during handover preparation phase).



Persistent Scheduling

- For periodic type of traffic such as VoIP where the packet arrival is predictable, it is not necessary to send the burst assignment signaling for each packet transmission.
- Burst assignmenst can be sent once at the beginning to persistently assign periodically recurring resource to an MS with a given period.
- Both the assigned resource and MCS are fixed until the persistent allocation is released or overridden.



Enhanced LBS Feature

- The LBS was first introduced in 802.16g by a basic LBS message whith the location information transmitted for each BS in according to IETF RFC 3825.
- The BS uses the new LBS-ADV message to broadcast the LBS information. The message is broadcasted periodically without solicitation.
- This message is sent from the BS to all MSs on a broadcast CID.
- It is up to the BS to decide the broadcast interval
- This message can include (for each BS) the following TLVs:
  - Location information
    - Absolute Position (Long Format) TLV
    - Absolute Position (Short Format) TLV
    - Relative Position TLV
  - Timing information: GPS Time TLV
  - BS frequency accuracy information: Frequency Accuracy TLV

Mobile WiMAX vs. LTE

- Both OFDMA systems
- Comparable Bandwidths

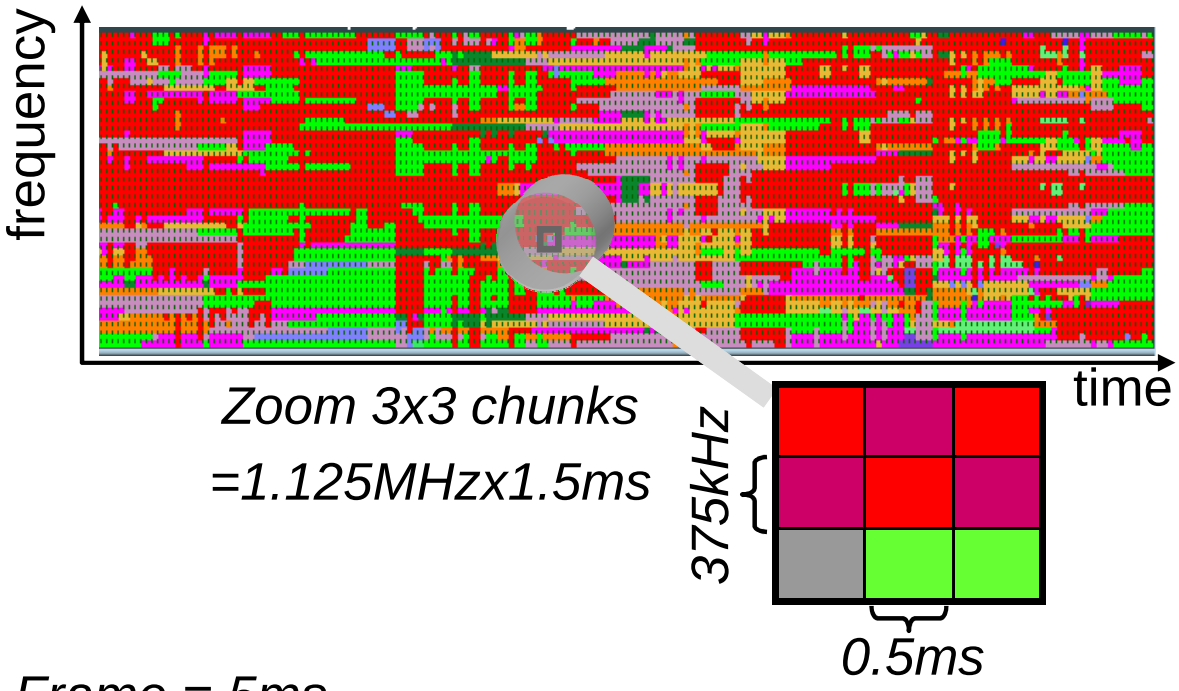
Differences:

- Tone Allocation (➔Efficiency)
  - WiMAX randomly distributes tones across the frequency bands
    - Frequency diversity through averaging peaks and dips
  - LTE uses frequency domain scheduling (always best tones)
    - Better Frequency diversity through avoiding dips and „riding on the peaks“
- TTI / Frame (➔Latency and Efficiency)
  - WiMAX Frame: 5 ms
    - One value for all users (due to frame structure / TDD)
  - LTE Transmission Time Interval: x*0.5ms
    - User specific setting possible (0.5 for delay critical services)

Mobile WiMAX vs. LTE DL Allocation

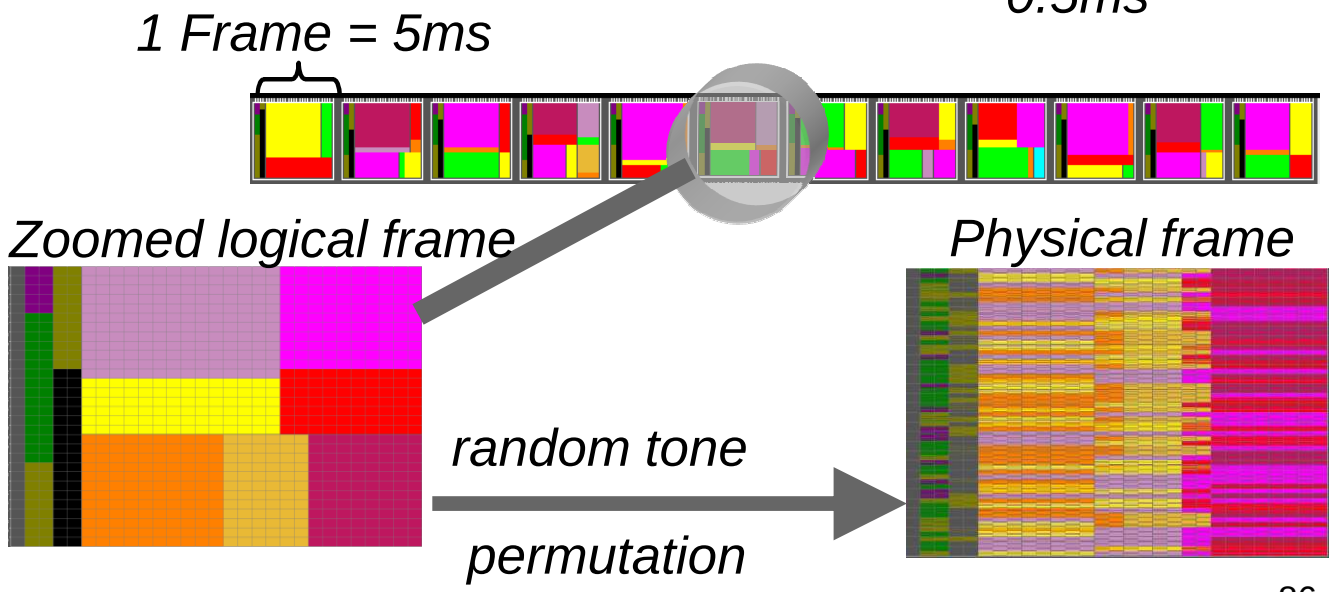
LTE

- Each 375kHz x 0.5ms chunk assigned separately
- …depending on frequency-selective channel



WiMAX

- Logical picture!
- Tones are permuted before transmission
- Similar to Spreading



Mobile WiMAX vs. LTE
Uplink

WiMAX

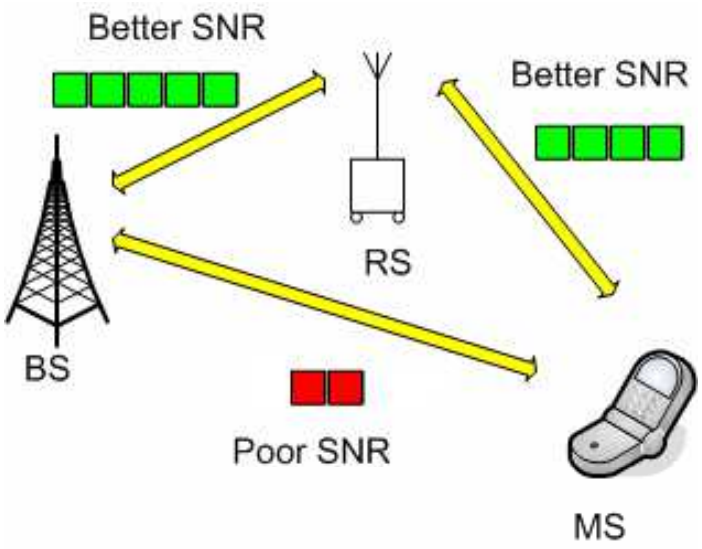
- In principle the same as dowlink (OFDMA with random tone allocation)
- Slightly different frame structure
- Problem: Peak to Average Power Ratio
  ➔ Range
- Synchronization

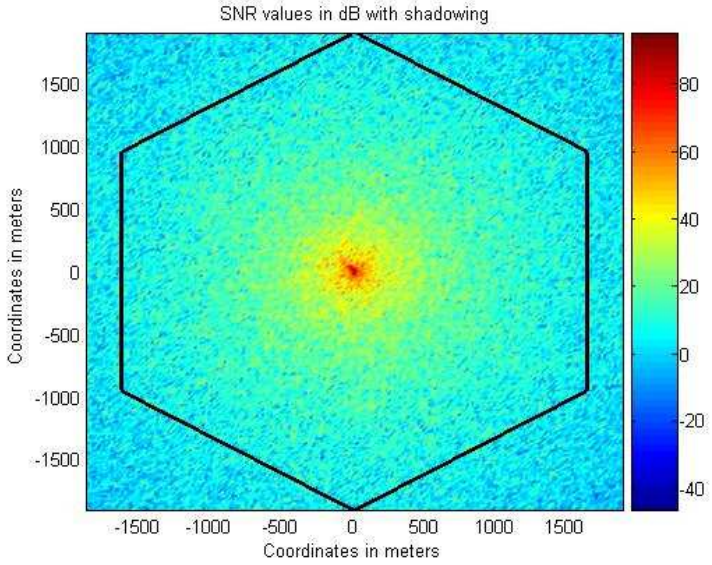
LTE

- Single Carrier FDMA
- In principle very similar to Downlink OFDMA
  - But: chunks of one user have to be adjacent
  - Makes it look like single carrier technique
- Reason: better Peak to Average Power Ratio (➔ Range)
- Removes perfect orthogonality (OFDMA ➔ FDMA)
  - Equalizer required
- Synchronization less demanding

5 - Relay

Radio Relays: Improving Link Quality



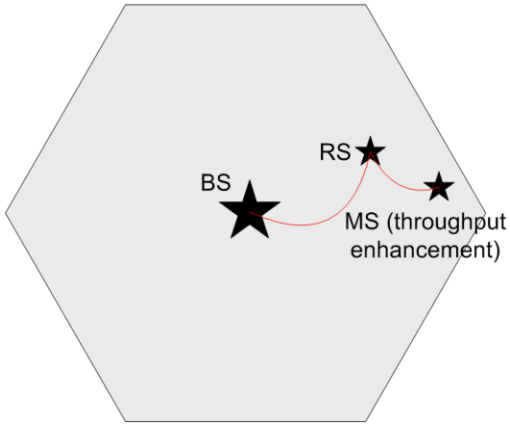


- Relay station helps improve SNR but more radio resource allocation may be needed
  - Tradeoff cell capacity with range (coverage extension)
- With better SNR, higher data rate can be used instead of more robust data rate
  - Relay replaces low SNR link with substantially higher SNR multi-hop links
  - Additional overhead and delay

Radio Relays
Throughput vs. Coverage

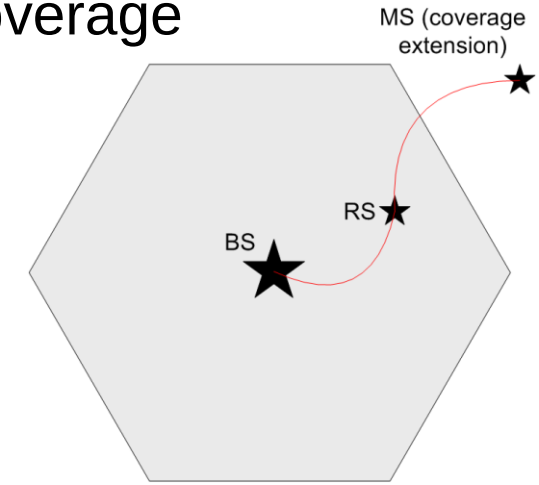
Throughput enhancement

- Target MS located in base station coverage
- Higher average SNR over multiple links
  - Increased link data rate
- Relay station behavior (e.g.):
  - Relay of DL and UL unicast data messages
  - Control messages directly from the base station or (selectively repeated) by RS



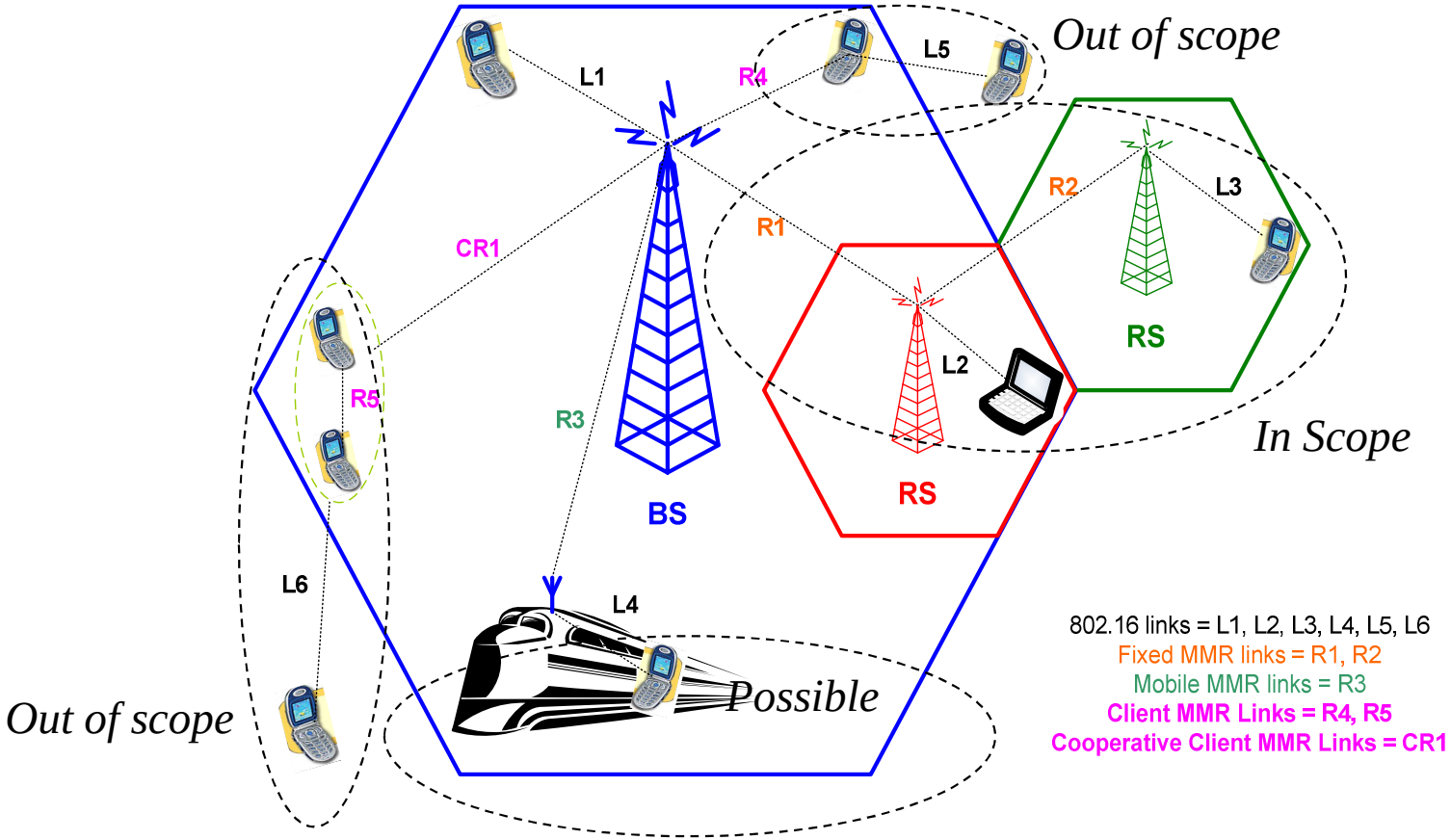
Coverage extension

- Target MS might be located outside of base station coverage
- Extend coverage beyond base station's cell boundary
- Relay station behavior (e.g.):
  - Own preamble
  - Broadcast control messages and unicast data messages
  - Support during network entry procedure



Radio Relays
Mobile Multihop Relays IEEE 802.16j

- IEEE802.16j specifies OFDMA physical layer and medium access control layer enhancements to IEEE Std 802.16 for licensed bands to enable the operation of relay stations. Subscriber station specifications are not changed.



6 - WiMAX 2 / 802.16m

IEEE802.16m - Advanced Features

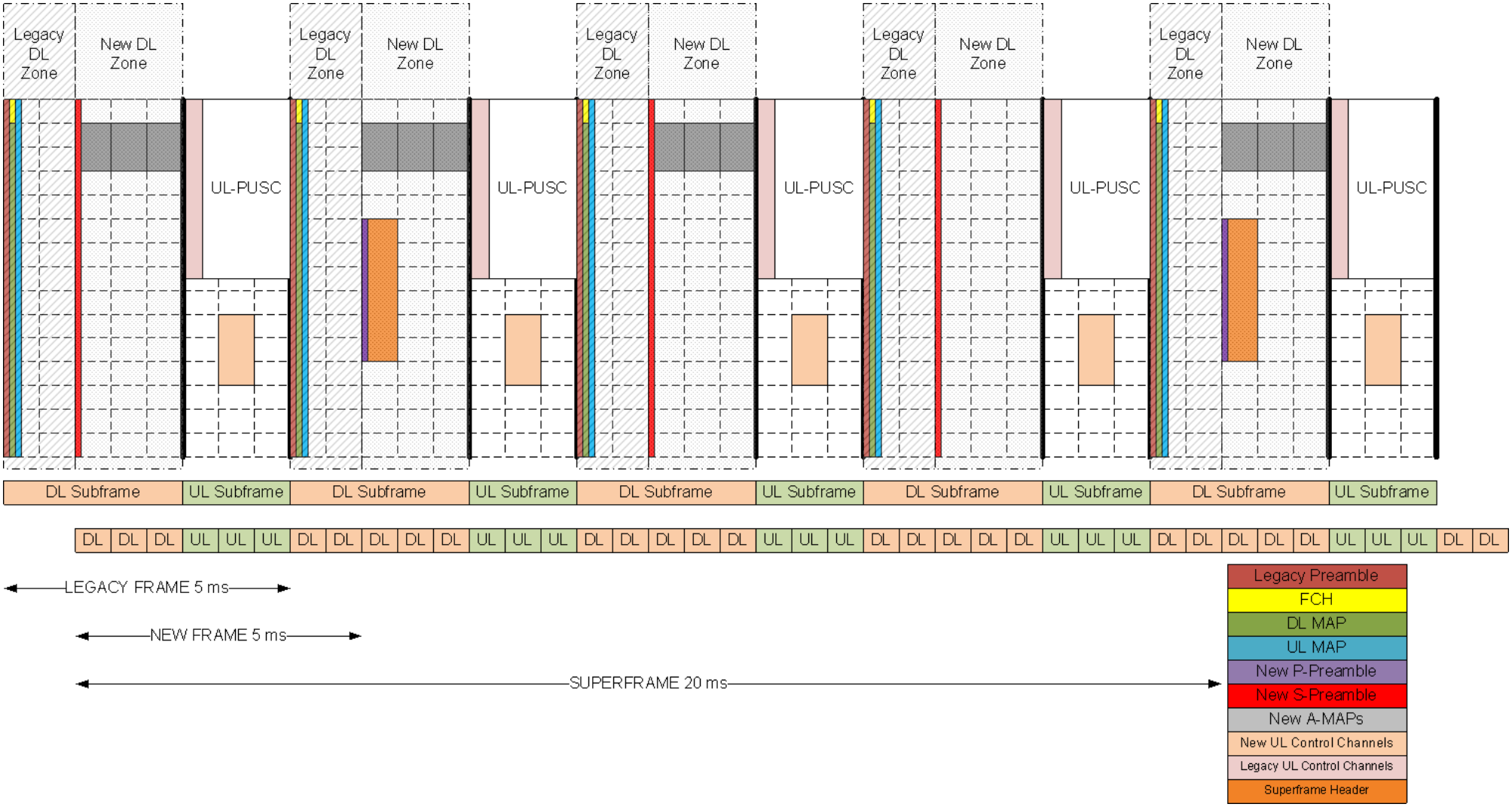
- New subframe-based frame structure
  - Allows for faster air-link transmissions/retransmissions, resulting in significantly shorter user-plane and control plane latencies.
- New subchannelization schemes and more efficient pilot structures in the downlink and uplink
  - Reduction of Layer 1 overhead and to increase spectral efficiency.
- New and improved control channel structures
  - Increased efficiency and reduced latency of resource allocation and transmission as well as system entry/re-entry.
- Multi-carrier operation using a single MAC instantiation
  - For operation in contiguous/non-contiguous RF bands in excess of 20 MHz
- Extended and improved MIMO modes
- Enhanced Multicast and Broadcast Services
  - New E-MBS control channels and subchannelization
- Enhanced GPS-based and Non-GPS-based Location Based Services

IEEE802.16m – Advanced Features, cont.

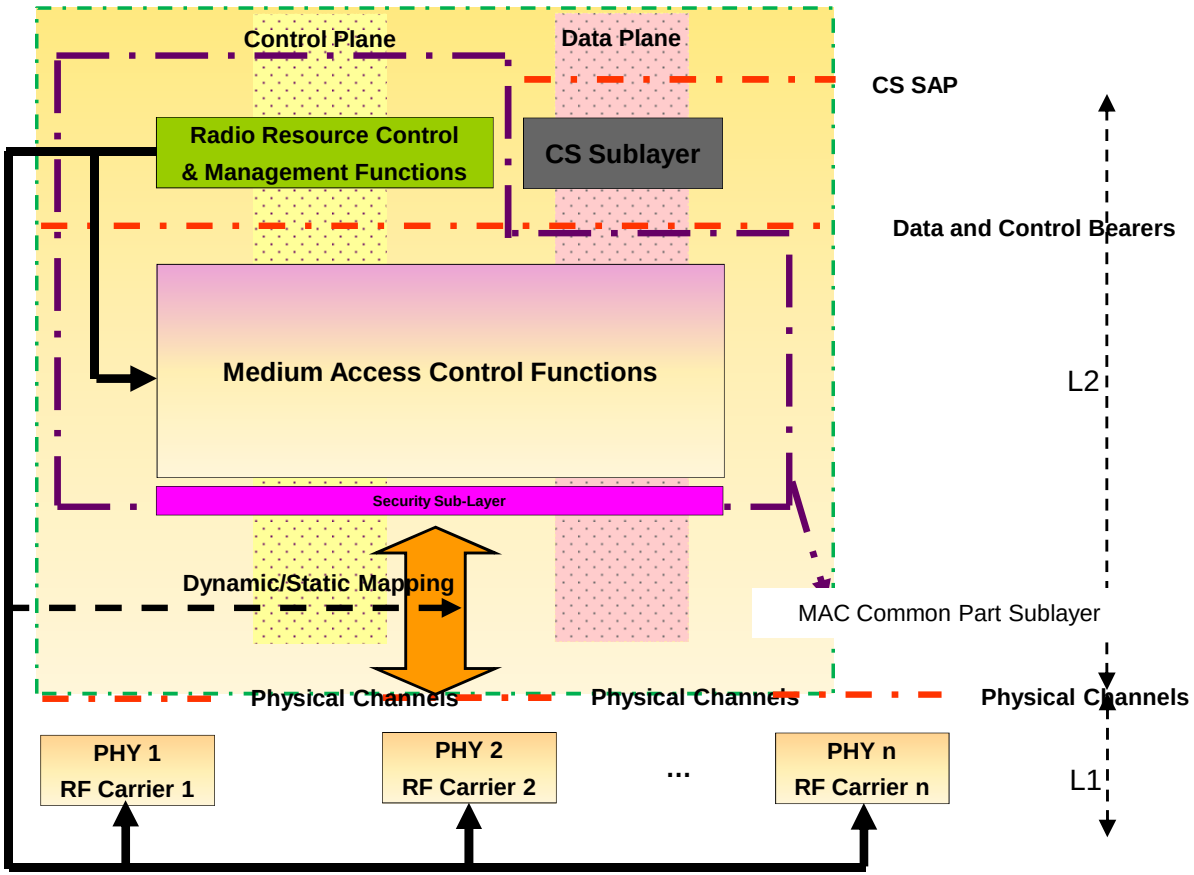
- Support of Femto Cells and Self-Organization and Optimization features
- Increased VoIP capacity
  - New control structure, frame structure, faster HARQ retransmissions, persistent scheduling, group scheduling, and reduced MAC overhead.
- Improved and increased control channel and data channel coverage and link budget
  - Transmit diversity schemes as well as more robust transmission formats and link adaptation.
- Support for multi-hop relay operation with unified access and relay links
- Support for advanced interference mitigation techniques including Multi-BS MIMO, Fractional Frequency Reuse, Closed-loop and Open-loop power control schemes.
- Improved intra-RAT and inter-RAT handover schemes with shorter handoff interruption times
- Improved sleep and idle mode operations
- Improved QoS support

Mixed-Mode Operation of IEEE 802.16m

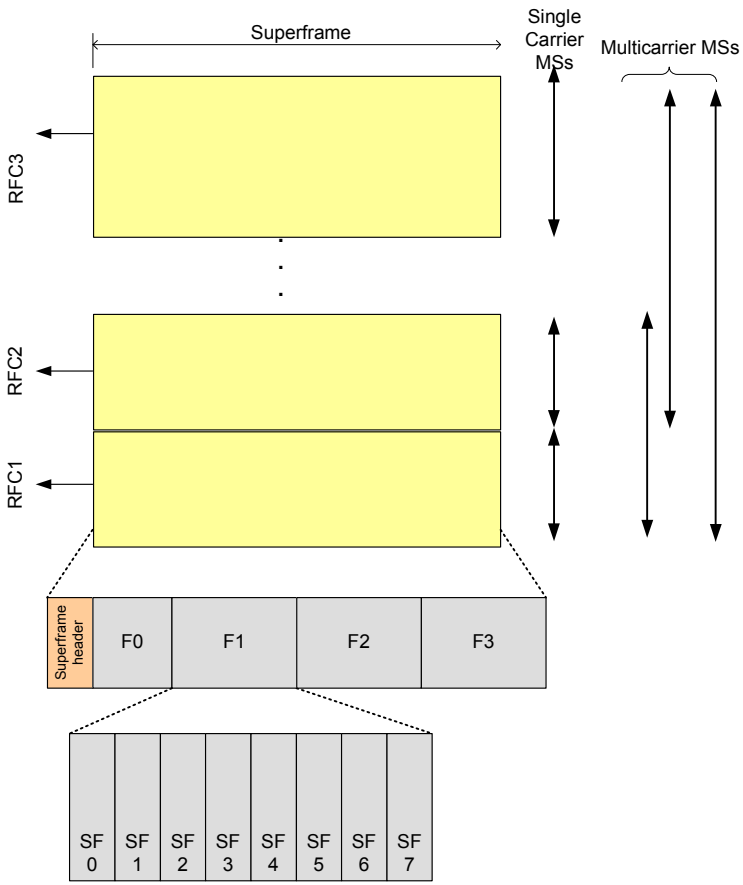
Example



Multi-Carrier Operation



A generalized protocol architecture for support multicarrier operation with single MAC entity



Support of multi-carrier operation in 802.16m basic frame structure

7 - Information Sources

Public access to technical information

- Both IEEE 802.16 and the WiMAX Forum offer public repositories of technical specifications
- However, final specifications
  - appear significantly later compared to when an idea was initially contributed
  - do not say anything about the date where a specific proposal became available to the standards group
  - typically only include a small subset of what had been discussed in the standards group, in their final version

Internal Repositories

- Both IEEE and WMF have internal repositories with all submitted documents
  - Largely for day-to-day standards work
  - Especially including submission dates
  - Typically being the standards group‘s archive and history
- WMF internal documents are open to all members but are not publicly accessible
  - Any membership level is fine for „read-only“ access
  - Requires registration with each WMF work group

Internal Repositories (ctd.)

- IEEE internal archives store all contributions to meetings and require access rights prior to and during the meeting
  - IEEE member + proof of regular meeting participation
  - Contributions are moved to a public archive after each meeting.
- Hence, in general all information from 802.16 is public
- Exception: Draft and final specifications are not available via public access. Final specs are charged for, for a period of six months after finalization (i.e., it is possible to buy them) before being made available free of charge.
  - The current 802.16m specification (Draft-10 of Nov 2010) is still in draft status and therefore not publicly accessible
  - The 802.16-2009 (16e) specification is publicly available. It was finalized already in November 2009: http://standards.ieee.org/getieee802/download/802.16-2009.pdf

IEEE repositories for 802.16

- 802.16 entry page: http://www.wirelessman.org/
- Standards activities overview (projects, groups, commitees) http://www.wirelessman.org/tgs.html
- Technical contributions related to 802.16m http://www.wirelessman.org/tgm/index.html
- Technical contributions related to 802.16e http://www.wirelessman.org/tge/index.html

- Final and draft standards repository: http://www.wirelessman.org/published.html (drafts not public, requires login)

WiMAX Forum Public Repositories

www.wimaxforum.org

Public information

- Working groups (WGs) overview of WMF: http://www.wimaxforum.org/about/technical-activities-and-working-groups
- General document repository (specs, whitepapers, market information etc): http://www.wimaxforum.org/about/technical-activities-and-working-groups
- Technical specifications: http://www.wimaxforum.org/resources/documents/technical

WMF Requirements Documents

- WMF develops general requirements within the **Service Provider WG** (SPWG)
- Requirements documents come with a certain release, but resulting specifications are not necessarily developed within the same release of NWG or TWG (some requirements may never be addressed by actual specifications)
- Requirements documents are part of the T-X1 series documents
  - Radio requirements T-21 series, e.g. for Release 1: WMF-T21-001-R010v01 Rel 1.0 Mobility Profile Requirements
  - Network requirements T-31 series, e.g. for Release 1: WMF-T31-001-R010v01 Network Requirements Release_1.0
- All requirements documents can be found in the SPWG repository: http://members.wimaxforum.org/apps/org/workgroup/spwg/documents.php?folder_id=685
  However, this requires member login, so most of the requirements documents are currently restricted.
- After all, technical relevance is limited: These documents typically do not include solutions.

WMF Radio Profile Specifications

- WMF develops Mobile Radio Specifications and Mobile System Profiles (MSP) based on the IEEE 802.16 specifications in the **Technical WG** (TWG)
  - Mobile Standard Reference: WMF-T23-004-R010v02-SRD
  - Release 1 MSP: WMF-T23-001-R010v09-MSP
  - Release 1.5 MSP common (FDD + TDD) part: WMF-T23-001-R015v01_MSP-Common-Part
  - Release 1.5 MSP FDD specifics: WMF-T23-003-R015v01_MSP-FDD
  - Release 1.5 MSP TDD specifics: WMF-T23-002-R015v01_MSP-TDD
  - Release 1.5 Mobile Radio spec: WMF-T23-005-R015v04-RSP
- Notes:
  - The radio interface releases are not well aligned with the network specification (NWG) releases. As an example, a network feature defined as part of the Release 1.5 network specifications can work with a Release 1 radio interface profile, or Rel1.5, or both.
  - Maintenance of the radio profile and network interface specifications is different. As an example the network specifications after approval will typically not be extended by new features. All new features go into subsequent releases. This is not true for radio profiles.

WMF Roaming Specifications

- WMF developed a limited set of roaming documents addressing inter-operator (inter-CSN) aspects through the **Global Roaming WG** (GRWG)
- However, participation in this group has been very limited and is dormant for more than a year now, so impact of those documents is rather small
- Work is interesting in the area of roaming exchange providers and focuses on AAA protocol aspects.
- See http://www.wimaxforum.org/resources/documents/technical and pick „View by Category“ / „Roaming“.

WMF Network Specifications

- **Network Work Group** (NWG) Stage-2 documents: WMF-T-32 series
  http://www.wimaxforum.org/resources/documents/technical/T32
  - Release 1: WMF-T32-00X-R010v04 (Feb 2009)
    Split into five parts, merged in later releases
  - Release 1.5: WMF-T32-XXX-R015vYY (Nov 2009)
    Latest public release, adds a document on lawful interception (mainly relevant for U.S. market)
  - Release 1.6: will be WMF-T32-XXX-R016vYY, publication expected soon (Jan '11?)
- Notes:
  - Stage-2 specs received less attention than stage-3 -> **less relevant**
  - Many of the Release 1 documents are public since **March 2007** already, but have been replaced by newer versions with maintenance updates
  - On the web page, switch to Rel1.5 documents at the bottom!

WMF Network Specifications

- Most relevant: NWG Stage-3 documents: WMF-T-33 series
  http://www.wimaxforum.org/resources/documents/technical/T33
  - Release 1.0: WMF-T33-00X-R010vYY (Feb 2009)
    Core architecture, Prepaid Accounting and two documents with minor extensions to the core architecture
  - Release 1.5: WMF-T33-XXX-R015vYY (Nov 2009)
    Latest public release, adds many new features, core spec + 15 additional documents. Most relevant is WMF-T33-001-R015v01_Network-Stage3-Base.pdf
  - Release 1.6: will be WMF-T33-XXX-R016vYY, publication expected soon (Jan '11?)

WMF Network Specifications

- WiMAX Forum PKI (Public Key Infrastructure)
  - A set of technical documents developed as part of the NWG Release 1
  - Made a WMF-global set of specifications later on
  - Restricted to members (but were public documents earlier on like the certificate profile that was originally published in April 2008).
  - This repository also contains information related to WiMAX operator ID assignments.
  - See: http://members.wimaxforum.org/kws/x509_certificates

Further related References

- 3GPP EPS interworking with non-3GPP access: TS33.402 v9.1.0
  http://www.3gpp.org/ftp/Specs/archive/33_series/33.402/33402-910.zip
- 3GPP TS 23.203, “Technical Specification Group Services and System Aspects; Policy and Charging Control Architecture (Release 7)”, Version 7.8.0, September 2008 (see http://www.3gpp.org/ftp/Specs/archive/)
- 3GPP TS 23.228, “Technical Specification Group Services and System Aspects; IP Multimedia Subsystem (IMS); Stage 2 (Release 7)”, Version 7.13.0, September 2008. (see http://www.3gpp.org/ftp/Specs/archive/)
- EAP: IETF RFC3748
  http://www.rfc-editor.org/rfc/rfc3748.txt
- RADIUS: IETF RFC2865
  http://www.ietf.org/rfc/rfc2865.txt
- Diameter: IETF RFC3588
  http://www.ietf.org/rfc/rfc3588.txt

Time for Questions!

Advertisements!

- **Introduces the fundamentals of Mobile WiMAX deployments**
- **Explains the rationale behind the Mobile WiMAX network and radio specifications enabling designers to make use of all applicable features**
- **Sets out the major building blocks of the topic and acts as a general reference for developers**
- **Utilizes the latest Release 1.5 network and radio specifications of the WiMAX Forum**
- **Written by expert authors who have actively contributed to the design of the fundamental concepts adopted in the standardized specifications**

www.twitter.com/wbcomms

www.wiley.com/go/commstech