Mobile Wi-MAX for Broadband Wireless Internet

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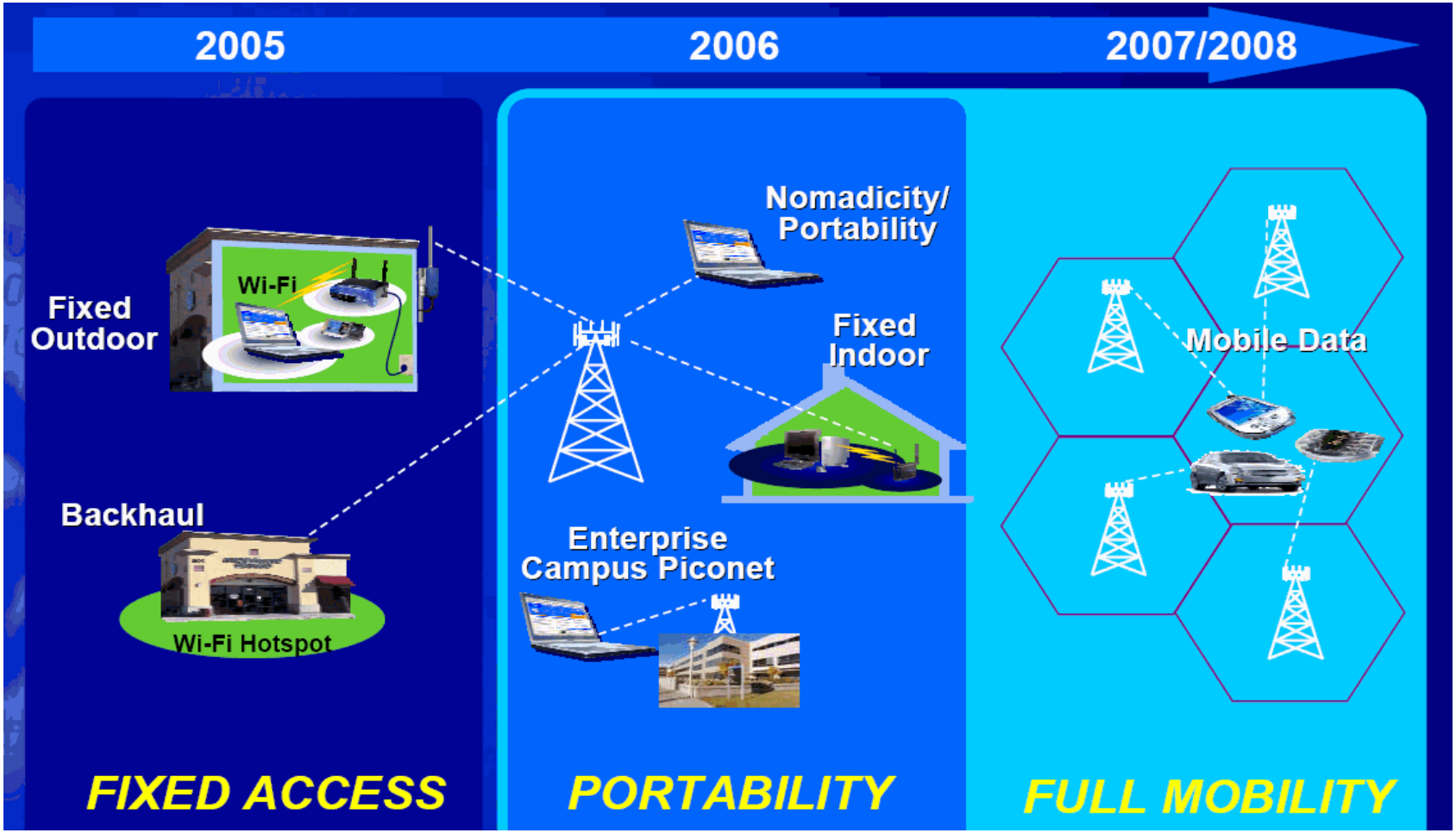
Introduction

- **WiMAX-> Worldwide Interoperability for Microwave Access**
- **Solution to Broadband Wireless Access (BWA)**
  - The standards of the IEEE 802.16 family provide fixed and mobile broadband wireless access (BWA) and promise to deliver multiple high-data-rate services over large areas
  - Promises to revolutionize wireless delivery of broadband services
  - An alternative to DSL and DOCSIS
  - Offers broadband wireless access for long distance
- **Evolution: From 802.16 to 802.16d since 2001 for fixed wireless access**
- **New IEEE 802.16e standard with mobility support**

History and Evolution

- **IEEE 802.16**
  - Released in 2001 for BWA systems operating in the 10-66 GHz range for LOS wireless broadband services
- **IEEE 802.16a**
  - Released in 2003. In the range of 2-11 GHz band for NLOS wireless broadband services
- **IEEE 802.16-2004 - Fixed WiMAX**
  - 802.16d is designed for fixed wireless communications, released in 2004
- **IEEE 802.16e - Mobile WiMAX**
  - Extends the 802.16d standard and provides mobility support in cellular deployments. Ratified in December 2005

Worldwide WiMAX Vision



Source: INTEL RESEARCH AND DEVELOPMENT, 2005. Evolution of WiMAX Beyond Fixed Access Networks [online]. 27 January 2005. http://cfp.mit.edu/events/slides/jan05/Kahn_WiMax.pdf

Motivation for IEEE 802.16e

- **Cellular technologies like 3G, and wireless LAN technologies like Wi-Fi, gave a taste of what high-speed wireless Internet access anytime and anywhere can bring**

- **With mobile WiMAX, the era of personal broadband will truly begin. Why?**
- **A few reasons:**
  - »Provides a Mega-Trend of Convergence Toward Quadruple Play Service (QPS)
  - »IP-Based Mobile Broadband-> Faster, More Affordable, True Mobility

Motivation for IEEE 802.16e (cont)

- **The Mega-Trend of Convergence Toward Quadruple Play Service** (QPS)
  - » Communications moving toward one single converged network
  - » Demand for various types of QPS that combine voice, data, and multimedia with mobility.
  - » Effects of this mega-trend:
  - » Services previously offered by different network systems will be provided by a single next generation network

- **IP-Based Mobile Broadband-> Faster, More Affordable, True Mobility**
  - » IP based-> allows compatibility with existing Internet applications
  - » Mobile access while offering broadband service (offers access when moving at speeds of 120 km or more)
  - » In a unified all IP based network, capital and operating expense are reduced -> Carriers can offer better mobile Internet access at lower costs

IEEE 802.16e-2005 Improvements upon IEEE 802.16-2004

- Adds support for mobility (hard and soft handovers between BS)
- Use of Scalable OFDMA (SOFDMA).- Keep the carrier spacing constant across different channel bandwidths by scaling the Fast Fourier Transform (FFT). The main channel bandwidths are 1.25 MHz, 5 MHz, 10 MHz or 20 MHz
- The allowed FFT subcarrier numbers are 128, 512, 1024, and 2048, therefore the best options for bands are multiples of 1.25 MHz
- Improves NLOS coverage using HARQ and antenna diversity schemes
- Improves capacity and coverage using multiple-input multiple-output (MIMO) technology and Adaptive Antenna Systems (AAS)
- Denser sub-channelization improves indoor penetration
- Enhances security and NLOS by using high performance coding techniques and Low-Density Parity Check

IEEE 802.16e-2005 vs. IEEE 802.16-2004

Main differences between IEEE 802.16e-2005 and IEEE 802.16-2004: Enhancement of PHY/MAC layers to support mobility at vehicular speed

- IEEE 802.16e-2005 offers mobile access while IEEE 802.16-2004 only supports fixed access
- IEEE 802.16e-2005 uses SOFDMA while IEEE 802.16-2004 uses OFDMA256
- IEEE 802.16e-2005 keeps the carrier spacing fixed by scaling the FFT

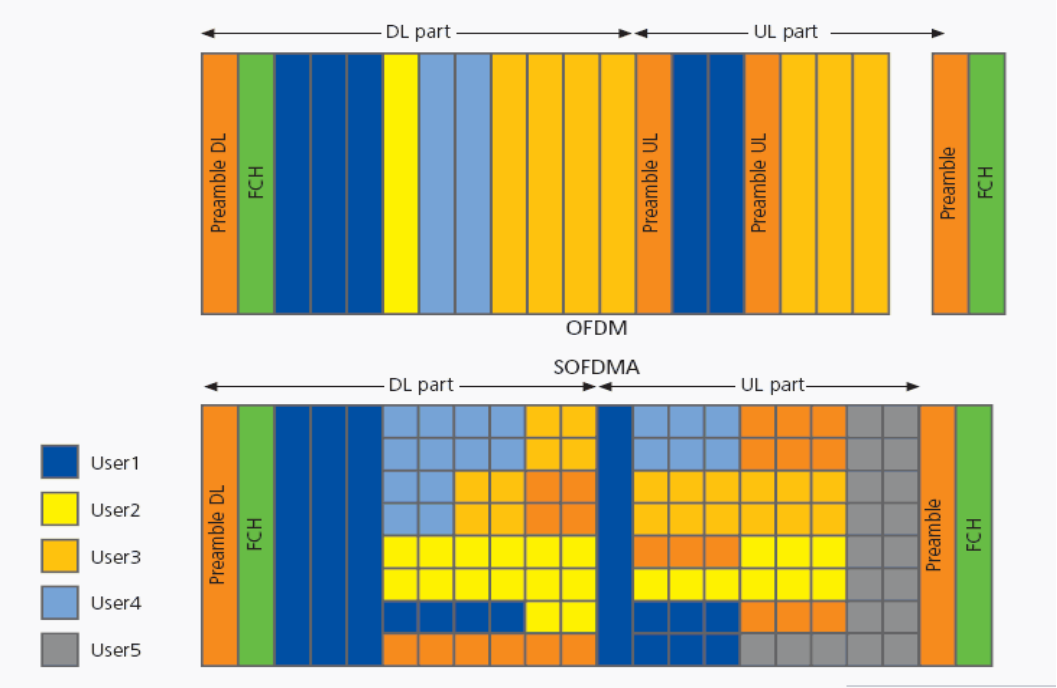


Figure 1: OFDMA Vs SOFDMA Channelization

Source : "Understanding the Radio Technologies of Mobile WiMAX," WiMAX Forum, 2006.

Mobile WiMAX System Profile

- Mobile WiMAX enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture
- Adopt OFDMA for improved multi-path performance in NLOS
- Scalable OFDMA (SOFDMA) is introduced in IEEE 802.16e to support scalable channel bandwidths from 1.25 to 20 MHz
- Release-1 will cover 5, 7, 8.75, and 10 MHz channel bandwidths for licensed worldwide spectrum allocations in the 2.3, 2.5, 3.3, and 3.5 GHz frequency bands
- Mobile WiMAX systems offer scalability in radio access technology and network architecture-> provides great flexibility in network deployment options and service offerings

Features of Mobile WiMAX

- **High Date Rates**

  Peak DL data rates up to 63 Mbps per sector and peak UL data rates up to 28 Mbps per sector in the 10 MHz channel
- **QoS**

  Fundamental characteristic of MAC architecture. MPLS enable end-to-end IP based QoS
- **Scalability**

  Able to scale to function in different channelizations from 1.25 to 20 MHz to comply with varied worldwide requirements
- **Security**

  Flexible key management schemes assures that security is maintained during handovers
- **Mobility**

  Support optimized handover schemes with latencies less than 50 ms

Physical Layer Description

Scalable OFDMA (S-OFDMA)

- IEEE 802.16e-2005 Wireless MAN OFDMA mode is based on the concept of scalable OFDMA
- S-OFDMA supports a wide range of bandwidths
- Scalability is supported by adjusting the Fast Fourier Transform (FFT) size while fixing the sub-carrier frequency spacing at 10.94 kHz
- Resource unit sub-carrier bandwidth and symbol duration is fixed, therefore the impact to higher layers is minimal when scaling the bandwidth

Physical Layer Description – S-OFDMA

The S-OFDMA parameters are listed in Table 1. The system bandwidths for two of the initial planned profiles being developed by the WiMAX Forum Technical Working Group for Release-1 are 5 and 10 MHz

Parameters	Values			
System Channel Bandwidth (MHz)	1.25	5	10	20
Sampling Frequency (Fp in MHz)	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	512	1024	2048
Number of Sub-Channels	2	8	16	32
Sub-Carrier Frequency Spacing	10.94 kHz			
Useful Symbol Time (Tb = 1/f)	91.4 ms			
Guard Time (Tg = Tb/8)	11.4 ms			
OFDMA Symbol Duration (Ts= Tb+Tg)	102.9 ms			
Number of OFDMA Symbols (5 ms Frame)	48			

Table 1: OFDMA Scalability Parameters

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006.

TDD Frame Structure

The 802.16e PHY supports TDD and Full and Half-Duplex FDD, however the initial release of Mobile WiMAX certification include only TDD

FDD profiles are being considered by the WiMAX Forum to address specific market opportunities

Even when TDD requires system-wide synchronization, it is preferred over FDD because:

- TDD enables adjustment of the downlink/uplink ratio to efficiently support asymmetric downlink/uplink traffic
- TDD has better support of link adaptation, MIMO and other advanced antenna technologies
- TDD only needs a single channel for both downlink and uplink and provides greater flexibility for adaptation to varied global spectrum allocations

TDD Frame Structure (cont)

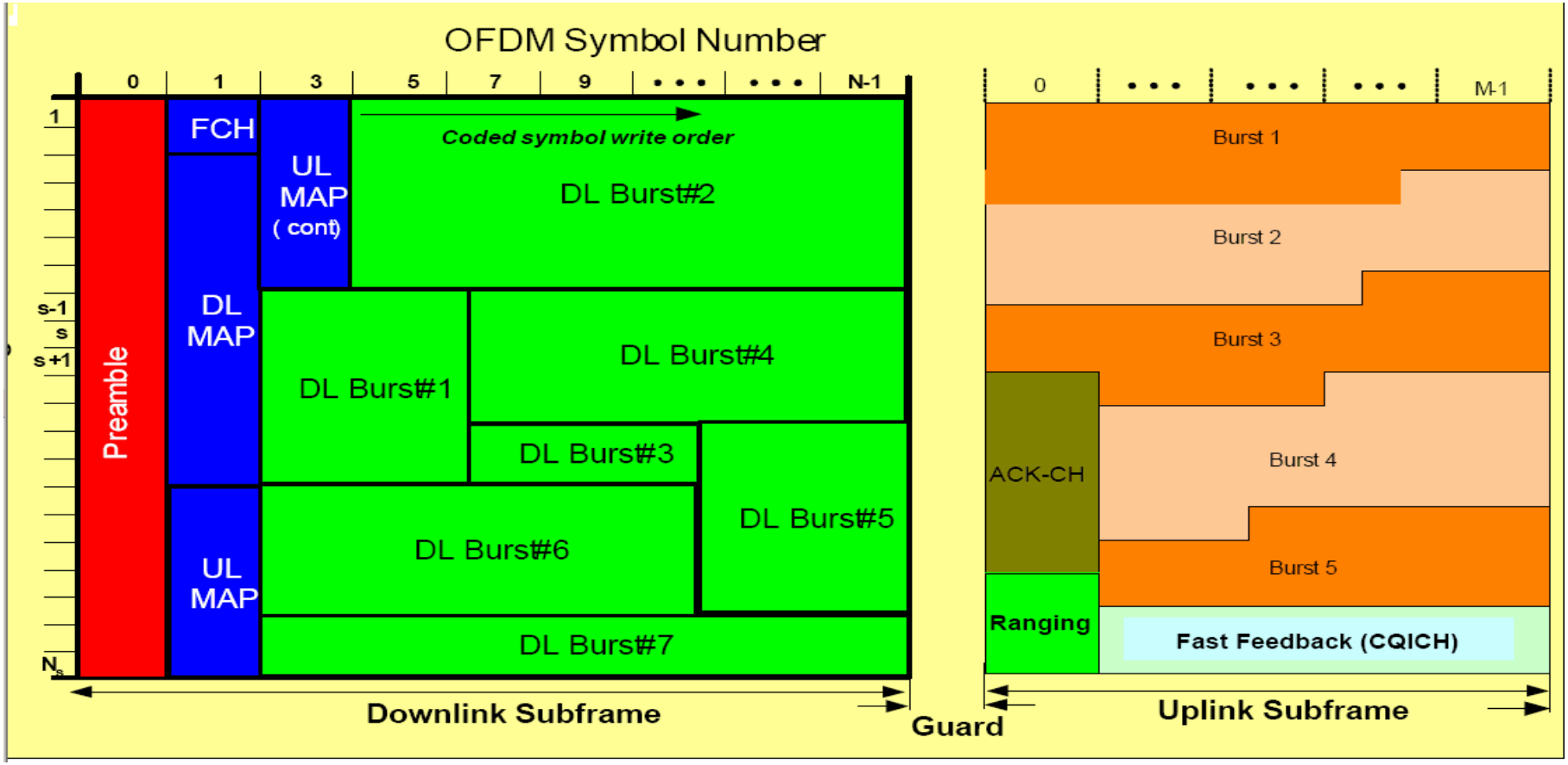


Figure 2: WiMAX OFDMA Frame Structure

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006

Other Advanced Features of PHY Layer

- Adaptive Modulation and Coding (AMC)
- Hybrid Automatic Repeat Request (HARQ)
- Fast Channel Feedback (CQICH)-introduced with Mobile WiMAX to enhance coverage and capacity in mobile applications
- Support for QPSK, 16QAM, and 64QAM (mandatory in DL)
- Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding
- Block Turbo Code and Low Density Parity Check Code (LDPC) – optional

		DL	UL
Modulation		QPSK, 16QAM, 64QAM	QPSK,16QAM, *64QAM*
Code Rate	CC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, *5/6*
	CTC	1/2, 2/3, 3/4, 5/6	1/2, 2/3, *5/6*
	Repetition	x2, x4, x6	x2, x4, x6

Table 2: Supported Code and Modulations

Source: “Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation,” WiMAX Forum, August, 2006

Other Advanced Features of PHY Layer (cont)

- BS scheduler determines data rate or burst profile
- CQI and CQICH retrieves channel-state information
- HARQ uses N channel “Stop and Wait” protocol to provide fast response to packet errors and to improve cell edge coverage
- Incremental Redundancy used to further improve reliability
- A dedicated ACK channel in the UP for HARQ ACK/NACK signaling
- HARQ combined with CQICH and AMC provides robust link adaptation in mobile environments at vehicular speeds in excess of 120 km/hr

MAC Layer Description

- Developed for delivery of voice, data, and video in mobile environments
- MAC layer is base on DOCSIS standard and can support bursty data traffic with high peak rate demand while supporting streaming video and latency-sensitive voice traffic over the same channel
- Resource allocation information is conveyed in the MAP messages at beginning of each frame → scheduler can change the resource allocation on a frame-by- frame basis

Protocol Layer

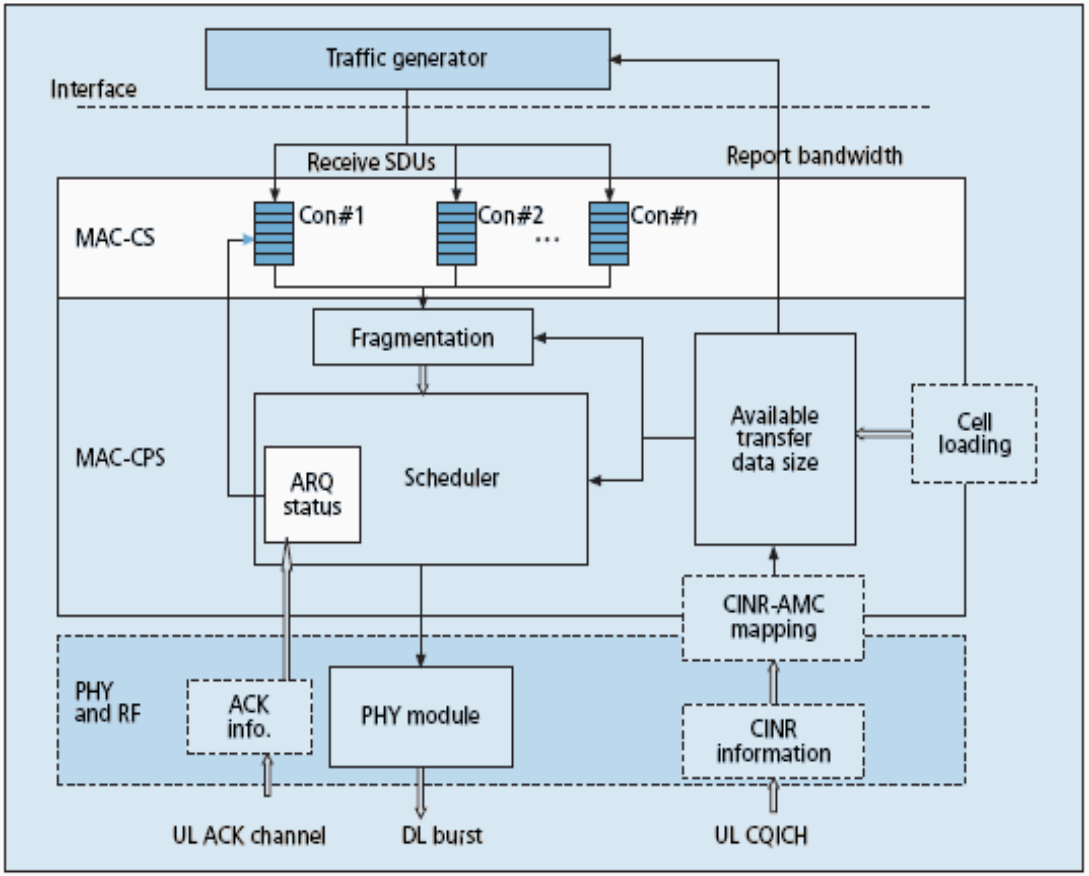


Figure 3: IEEE 802.16e Protocol Layer

- Supports mainly PMP architecture
- Designed to handle applications with different QoS
- All Services are connection-oriented
- Each service is mapped to one connection or multiple connections and it is handled by CS (convergence sub layer) and CPS (common part sublayer1)

Source: Huang, C.Y., et al., *Radio resource management of heterogeneous services in mobile WiMAX systems [Radio Resources Management and Protocol Engineering IEEE 802.16].* Wireless Communications, IEEE, 2007. 14(1): p. 20-26

Service Data Flow

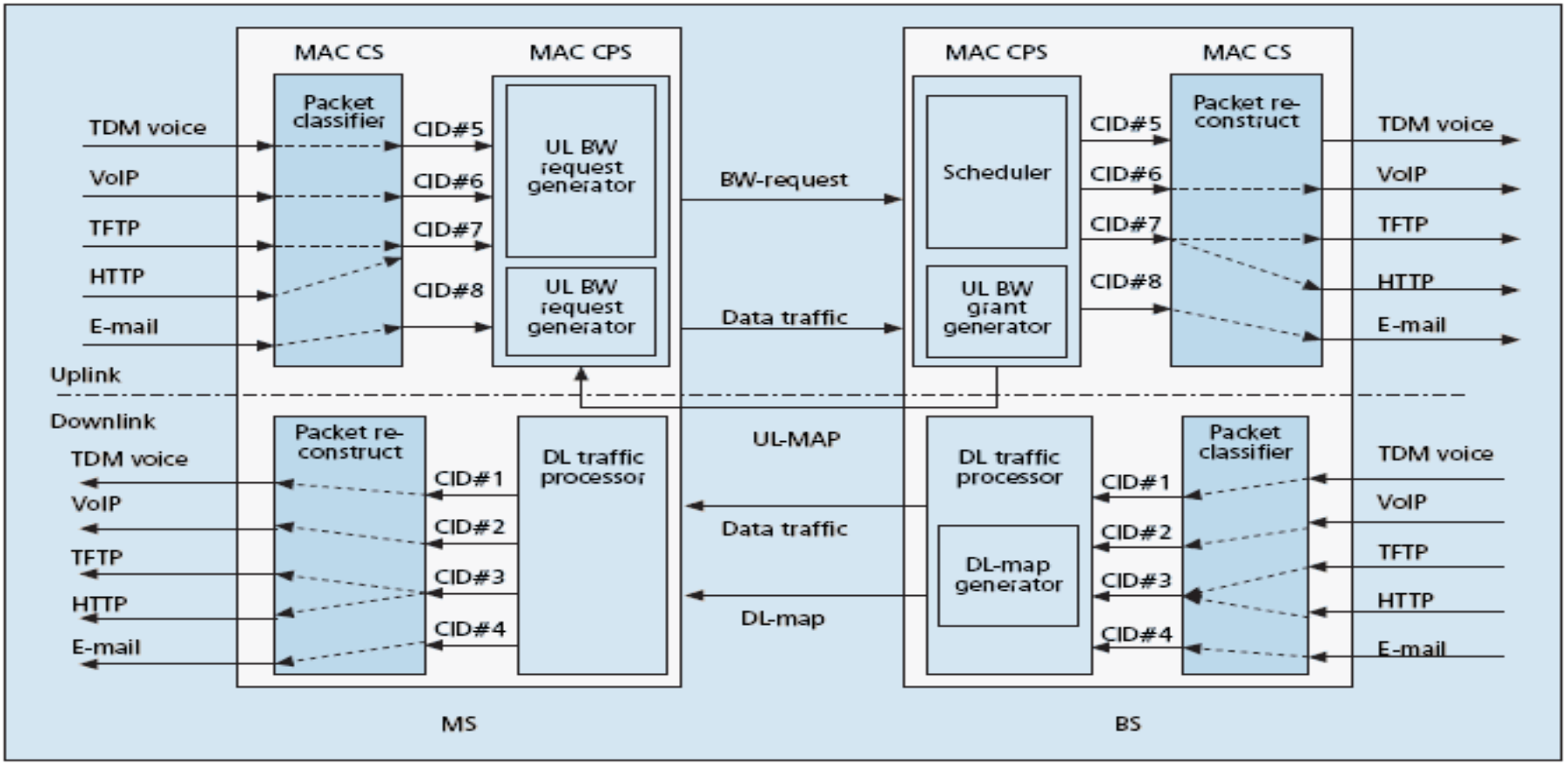


Figure 4: Example of IEEE 802.16e Service Flow

Source: Huang, C.Y., et al., *Radio resource management of heterogeneous services in mobile WiMAX systems [Radio Resources Management and Protocol Engineering for IEEE 802.16].* Wireless Communications, IEEE, 2007. 14(1): p. 20-26

MAC Scheduling Service Properties

Fast Data Scheduler .-

- Scheduler located at each BS to enable rapid response to traffic requirements and channel conditions
- CQICH channel provides fast channel information to enable scheduler to choose appropriate ACM for each allocation
- ACM with HARQ provide robust transmission

Scheduling for DL and UL .- Multiple UL bandwidth request mechanisms: ranging, piggyback and polling support UL bandwidth requests

Dynamic Resource Allocation .- Supports frequency-time resource allocation in both UL and DL on a per-frame basis. The resource allocation is delivered in MAP messages at the beginning of each frame.

QoS Oriented.- Ability to dynamically allocate resources in UL and DL, the scheduler can provide superior QoS for UL and DL traffic

Frequency Selective Scheduling.- Scheduler can operate in different types of sub-channels. Frequency- selective scheduling can allocate users to strongest sub-channels

Mobility Management

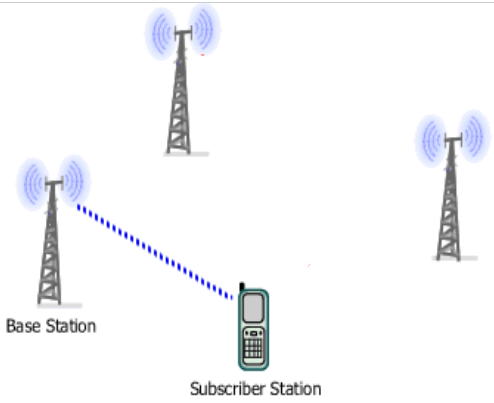
- **Adding support for mobility is one of the most important aspects of 802.16e-2005**
- **Battery life and handoff are two critical issues for mobility management**
- **Battery life.- Supports two modes for power efficient operation**
  - Sleep Mode: MS conducts pre-negotiated periods of absence form the serving base station interface. These periods are characterized by unavailability of the MS to DL or UL traffic
  - Idle Mode: Provides a mechanism for the MS to become periodically available for DL broadcast traffic messaging without registration at a specific base station

Handoff Support

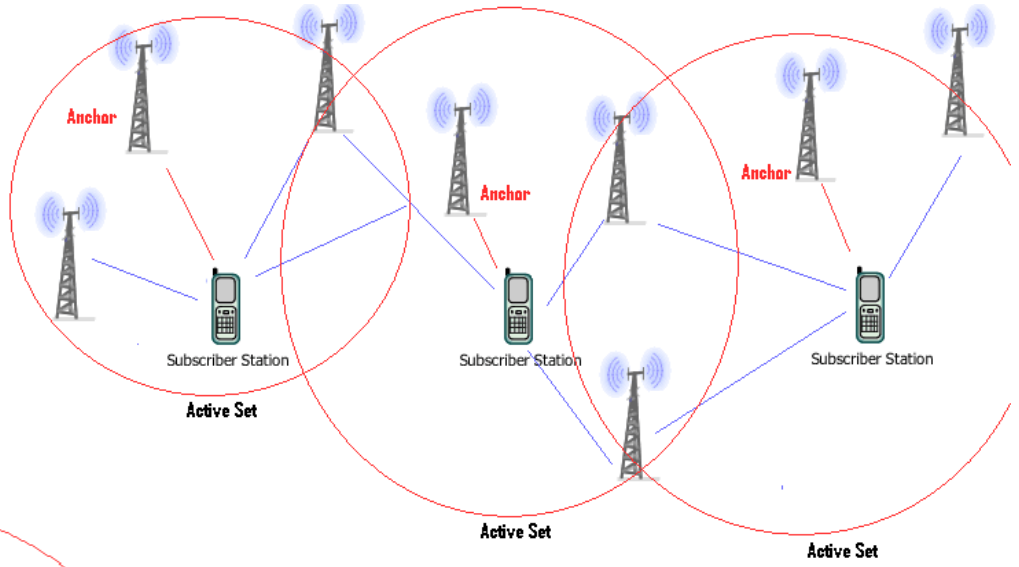
The mobile WiMAX standard supports three physical-layer handoff mechanisms:

- **Hard Handoff** – this is a ‘break before make’ handoff in which the subscriber terminal is disconnected from one base station before connecting to the next base station.
- **Fast base station switching (FBSS) –** the network hands-off the subscriber between base stations while the connection with the core network remains with the original base station,
- **Macro-diversity handover (MDHO) –** the subscriber maintains a simultaneous connection with two or more base stations for a seamless handoff to the base station with the highest quality connection

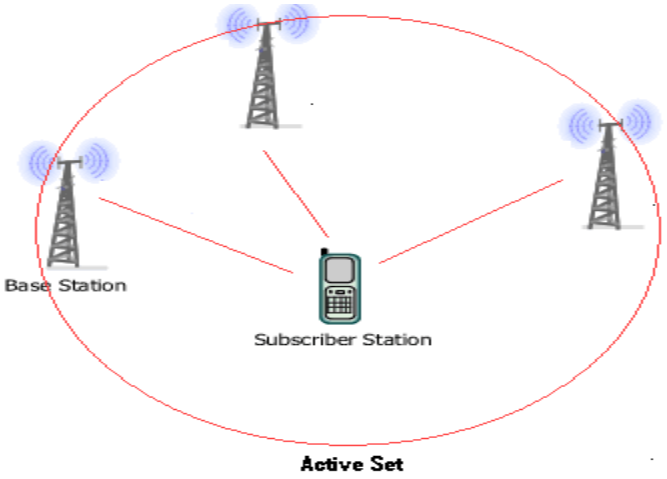
Handoff Mechanisms



Hard Handoff



FBSS Handoff



MDHO Handoff

Quality of Service (QoS) Support

- Meet QoS requirements for a wide range of data services and applications
- In the MAC layer, QoS is provided via service flows as seen in Figure 5.
- The connection-oriented QoS enable the end-to-end QoS control

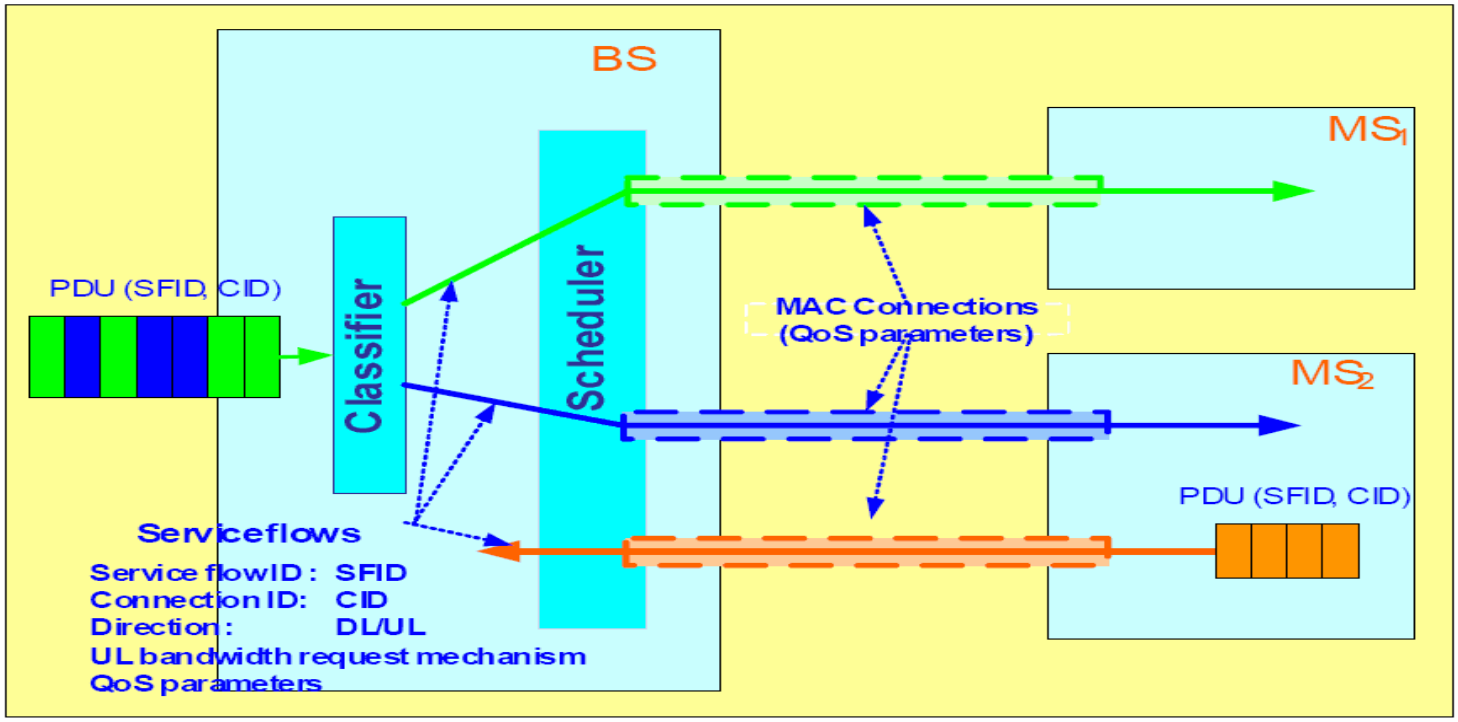


Figure 5: Mobile WiMAX QoS Support

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006

Quality of Service Support (cont)

- **Supports a wide range of data services and applications with varied QoS requirements. These are summarized in Table 3**

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Traffic Priority
ErtPS Extended Real-Time Polling Service	Voice with Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc.	• Maximum Sustained Rate • Traffic Priority

Table 3: Mobile WiMAX Applications and QoS

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006

End-to-End WiMAX Architecture

- **Mobile WiMAX End-to-End Network Architecture is based on All-IP platform**
- **Architecture is based on a packet-switched framework**
- **Advantages of All-IP based Architecture:**
  - Reduced total cost of ownership
  - A common network core is used, no need to maintain packet and circuit core networks

- **Architecture allows modularity and flexibility to accommodate a broad range of deployment options:**
  - Small-scale to large scale WiMAX networks
  - Urban, suburban, and rural radio propagation environments
  - Hierarchical, flat, or mesh topologies, and their variants
  - Co-existence of fixed, nomadic, portable and mobile usage models

End-to-End WiMAX Architecture

- **Support for Services and Applications:**
  - Voice, multimedia services, and emergency services
  - Access to a variety of independent ASP
  - Mobile telephony using VoIP
  - Interfacing with internetworking and media gateways to deliver legacy services over IP to WiMAX access networks

End-to-End WiMAX Architecture

- Internetworking -> key strength of End-to-End Architecture
- Support loosely-coupled internetworking with existing wireless networks such as 3GPP and 3GPP2, or wire line networks such as DSL and MSO with internetworking interfaces based on a standard IETF suite of protocols
- WiMAX Network Reference Model (NRM) -> is logical representation of the network architecture
- Objective: providing unified support for functionality needed in a range of network deployment models and usage scenarios (from fixed-nomadic-portable-simple mobility-to fully mobile subscribers)

End-to-End WiMAX Architecture

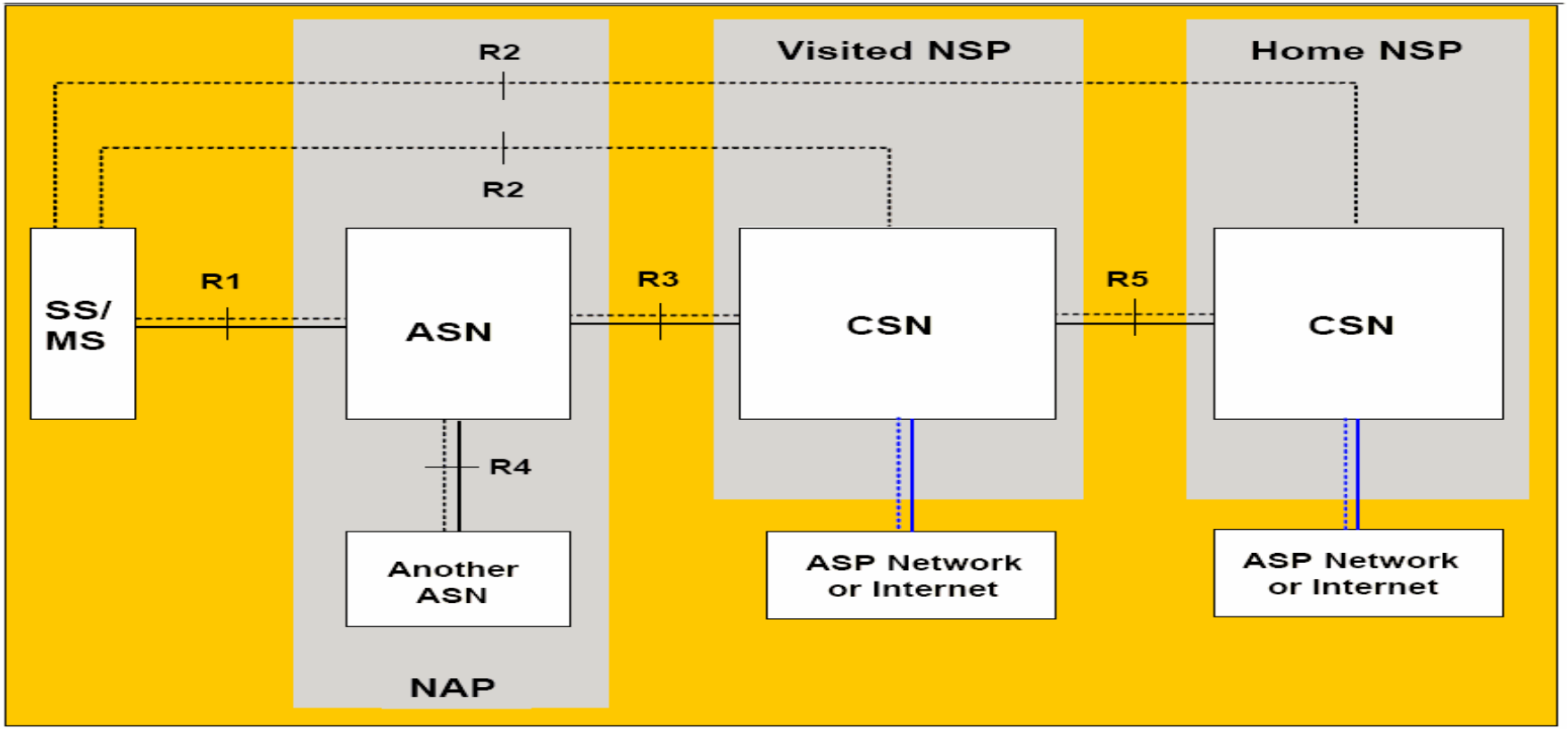


Figure 6: WiMAX Network Reference Model

Source: “Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation,” WiMAX Forum, August, 2006

End-to-End WiMAX Architecture

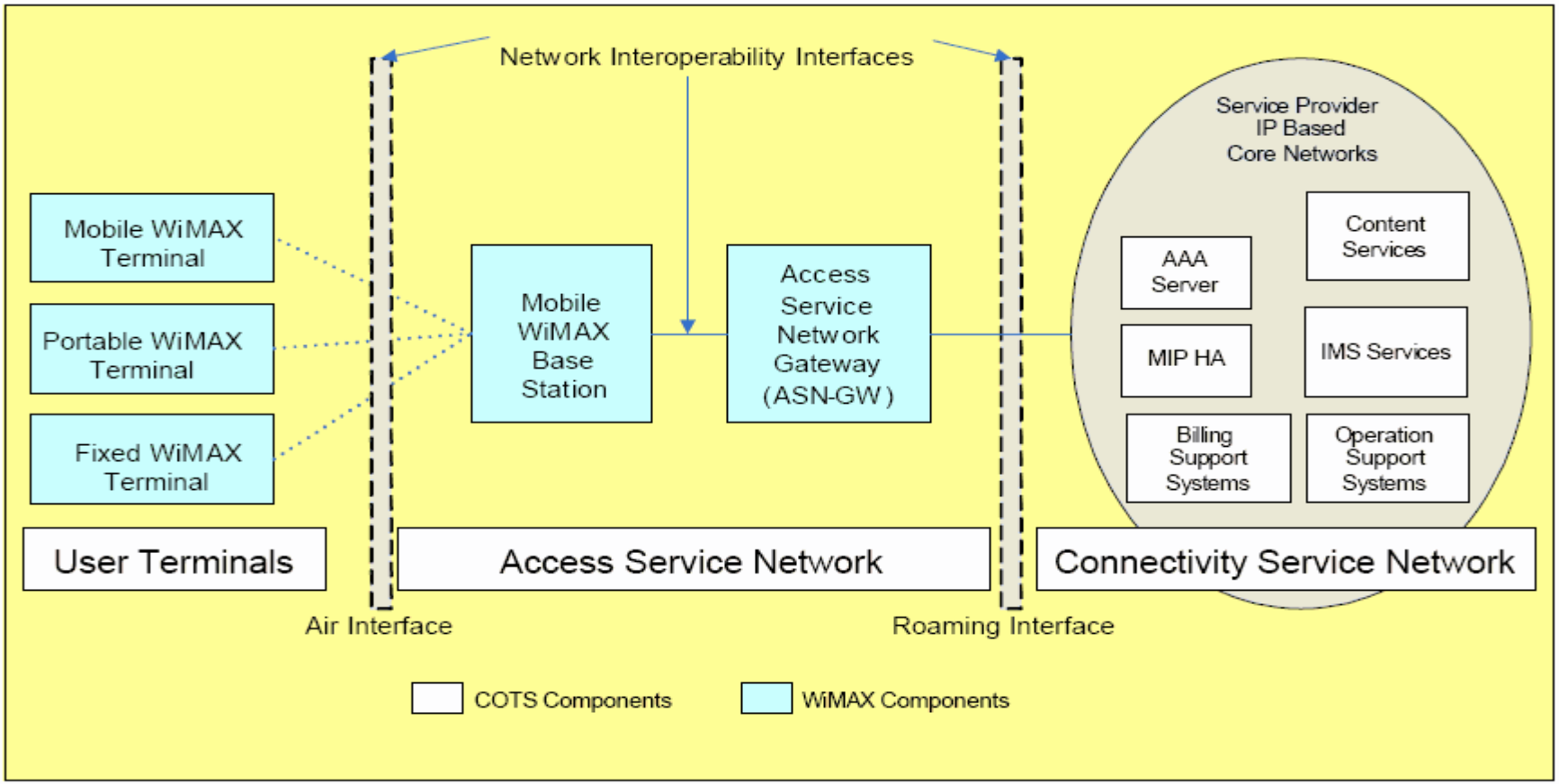


Figure 7: WiMAX Network IP-based Architecture

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006

Major Features of End-to-End WiMAX Architecture

- **Security-** Architecture based on a security framework that applies across internetworking deployment models and usage scenarios, e.g. Use of MS initiated/terminated security mechanisms such as VPN's, standard IPSec address management mechanisms between MS /SS and its home or visited NSP

- **Mobility and Handovers –** Extensive capability to support mobility and handovers, include:
  - Inter-technology handovers –e.g., to Wi-Fi, 3GPP, DSL…
  - Support IPv4 or IPv6 based mobility management
  - Support roaming between NSPs
  - Utilize mechanisms to support handovers at up to vehicular speed

Major Features of End-to-End WiMAX Architecture

- **Scalability, Extensibility, Coverage and Operator Selection**
  - Enable users to select from available NAPs and NSPs
  - Enable ASN and CSN system designs to easily scale upward or downward in terms of range, coverage and capacity
  - Accommodate a variety of ASN topologies
  - Support incremental infrastructure deployment
  - Support the integration of BS of varying coverage and capacity-e.g. pico, micro, and macro BS
  - Support a variety of online and offline client provisioning, enrollment and management schemes based on open, broadly deployable IP-based industry standards
  - Accommodation of Over-The-Air (OTA) services for MS terminal software upgrades

Major Features of End-to-End WiMAX Architecture

- **Multi-Vendor Interoperability**
  - Support of interoperability between equipment from different manufacturers within an ASN and across ASNs
  - Architecture framework supports a variety of CS such as Ethernet CS, IPv4 CS and IPv6 CS
- **Quality of Service**
  - Enables flexible support of simultaneous use of a diverse set of IP services. Architecture supports:
    - »Differentiated levels of QoS
    - »Admission Control
    - »Bandwidth management

Spectrum Considerations

- The initial system performance profiles for IEEE 802.16e-2005 air interface standard are in the licensed 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands
- The 2.3 GHz band has been allocated in South Korea for WiBro services based on Mobile WiMAX technology
- The 2.5 to 2.7 GHz band is available for mobile and fixed wireless services in United States
- Sprint is in the process of deploying WiMAX across United States. With Xohm, Sprint will be the first U.S. carrier to implement a fourth-generation network
- Major wireless players that are partnering on the Xohm project include Intel Corp., Motorola Inc., Nokia, Samsung and Google Inc

Roadmap for WiMAX Technology

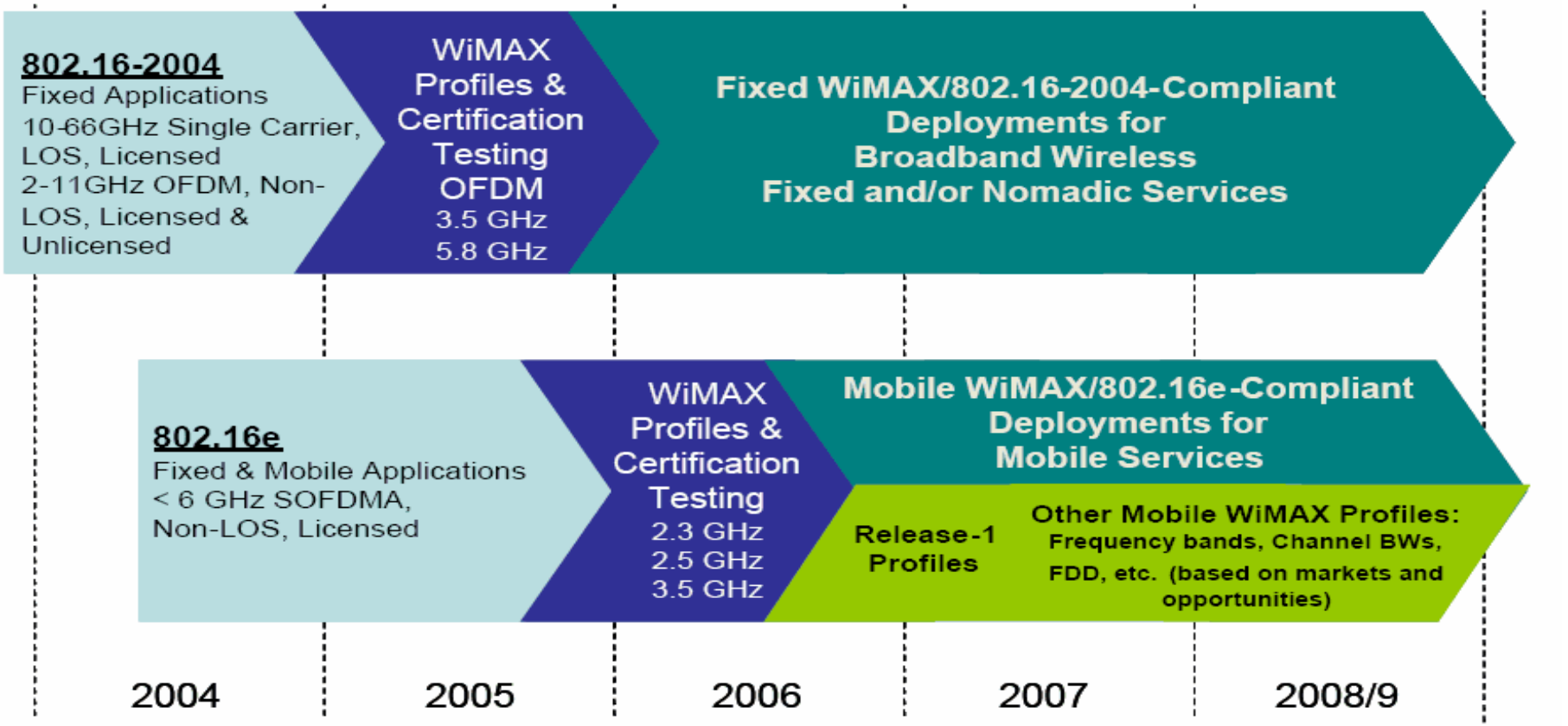


Figure 8: Roadmap for WiMAX Technology

Source: "Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation," WiMAX Forum, August, 2006

Conclusions

- Offers a wide range of services including QPS over a converged IP-based network
- Compelling Solution for high performance, low cost broadband wireless services
- Based on open standard interfaces developed with close 400 companies that are contributing to system specifications and laying a foundation for worldwide adoption
- WiMAX Forum® forecasts 133 million WiMAX users by 2012 globally

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