Wireless MAN Networks

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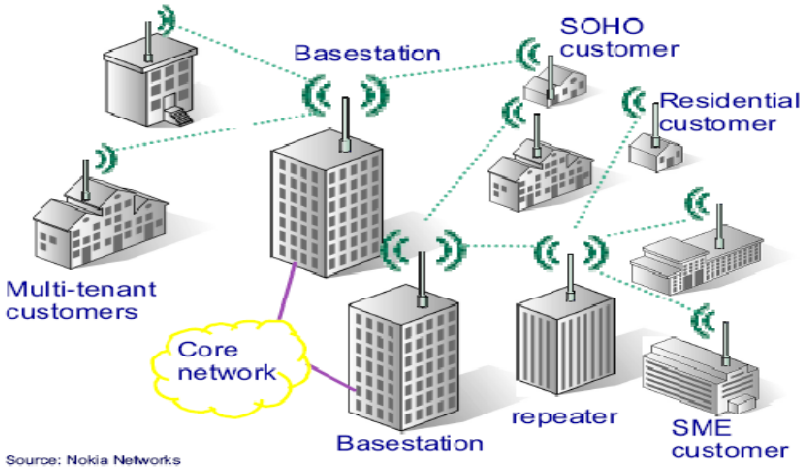
Slides 17

Wireless Networks

- **Wireless Wide Area Networks (WWANs)**
  - **Cellular Networks :**
    - **GSM, cdmaone (IS-95), UMTS, cdma2000 EV-DO**
  - **Satellite Networks:**
    - **Iridium, Globalstar, GPS, etc.**
- **Wireless Metro Area Networks (WMANs)**
  - **IEEE 802.16 WiMAX**
- **Wireless Local Area Networks (WLANs)**
  - **IEEE 802.11, a, b, g, etc. (infrastructure, ad hoc)**
- **Wireless Personal Area Networks (WPANs)**
  - **IEEE 802.15 (Bluetooth), IrDa, Zigbee, 6LowWPAN, proprietary sensors, 802.15.3 WiMedia, etc.**

Wireless MANs

- Wireless Metropolitan Area Networks (WiMANs) : provide wireless connectivity across a geographical area the size of a city



Wireless MANs

- Wireless MANs
  - Broadband data rates for last mile connectivity to businesses, homes and network bridging
  - Wireless alternative to DSL/cable modem/Fiber to the Home) services for last mile broadband access.
  - Triple play service (video, voice, data), Quad play
  - *Potential* Advantages: support for QoS, lower cost than cabling, user mobility in later releases
  - Currently variety of technologies, speeds, cost, coverage range, spectrum, etc.
  - Market is fragmented among technologies
    - Proprietary Solutions
      - Free Space Optical
      - LMDS (Local Multipoint Distribution Systems)
      - MMDS (Multipoint Microwave Distribution Systems)
      - Wireless multi-hop mesh networks (based on 802.11)
    - Standards Based Solutions
      - IEEE 802.16 also called WiMAX, WirelessMAN
      - IEEE 802.11 with multi-hop extension standard 802.11s

Wireless MANs

- Proprietary Solutions
  - Free Space Optical:
    - point to point high data rates (100 Mbps -2.5Gbps) over short distances
    - Unlicensed, uses infrared lasers
    - LOS required – severely effected by weather

  - LMDS (Local Multipoint Distribution Systems)
    - Bulk of deployment focused on backhaul extension of fiber infrastructure and cellular networks
    - Operates in 28, 29 GHz spectrum
    - Range 3-5 miles, weather effects

  - MMDS (Multipoint Microwave Distribution Systems)
    - Operates in 2.5-2.7MHz licensed spectrum
    - Originally intended for wireless cable TV distribution
    - 20MHz spectrum → 99 10Mbps channels
    - Range ~25Km (LOS and NLOS possible)
    - Data rates ~ .5-1 Mbps on 10Mbps channel

  - WLAN equipment with mesh routing, scheduling, flow control
    - Use 802.11a/g equipment to build mesh – need many APs
  - Proprietary equipment seen as a hindrance to market growth

IEEE 802.16/WiMAX Standard

- Worldwide Interoperability for Wireless Microwave Access (WiMAX)
- IEEE 802.16 Broadband Wireless Access Standards Working Group
  - Started in 1998 led by NIST
  - Since July 1999 IEEE 802.16 working group meeting bimonthly
  - Suite of WiMAN standards
  - As in WLAN standard focus is Physical and MAC layers only!
- Parallel to IEEE 802.16, ETSI proposed HiperMAN and HiPERACCESS standards
  - High performance radio metropolitan area network (HiperMAN)
- IEEE 802.16 and HiperMAN have basically converged
  - Same MAC layer and 802.16a OFDM as Physical layer baseline

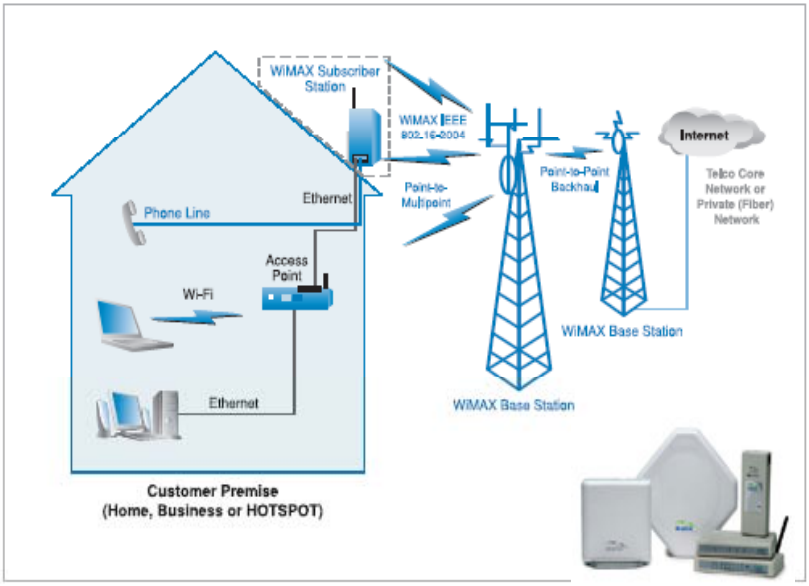
IEEE 802.16/WiMAX Standard

- WiMAX industry alliance (WiMAX Forum) started to promote equipment development and interoperability testing/conformance
- http://www.wimaxforum.org
  - Interoperable multi-vendor fixed/nomadic/mobile/ wireless access networks using microwaves - line of sight not required
  - Define a set of ``profiles '' for interoperability/conformance testing
  - Profile specify the physical layer for a frequency band and various MAC layer parameters
  - Higher Layer protocols
  - End-to-End Network Architectures
  - Interaction with other standard organizations (IETF, 3GPP,etc)

IEEE 802.16 /WiMAX Standard

- IEEE 802.16 developed as a Wireless Metropolitan Area Network (WiMAN) protocol
- Focus wireless alternative to DSL and T1 level services for last mile broadband access and backhaul for other technologies (WiFi, cellular)
- Characteristics of 802.16
  - Point to Multipoint (PMP) and Mesh protocol
  - NLOS wireless broadband services including bandwidth on demand
  - QoS support
  - Security
  - Scope expanded to include mobility and higher data rates
- Focus on both licensed and unlicensed spectrum deployment – supports multiple service providers/licenses in same area
- TDD and FDD duplexing support with flexible channel sizes
- 802.16 Terminology
  - Base Station (BS) is WiMAX cell site/access point
  - Subscriber Station (SS) is customer premise equipment and terminates the wireless link to the user location
  - Mobile Station (MS) is a standalone consumer device equipped with a WiMAX radio

WiMAX Architecture



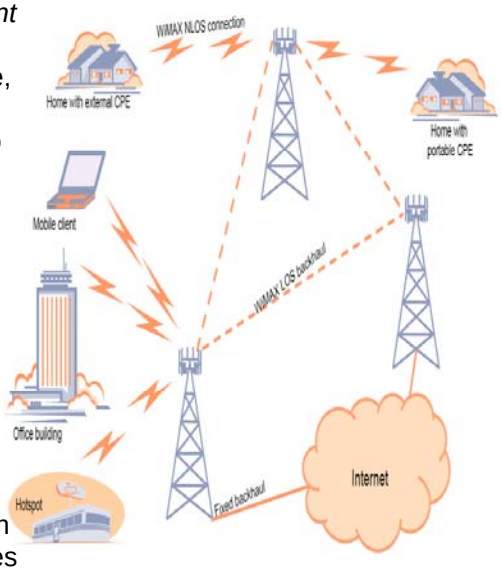
WiMax Service Architectures

WiMax Services Point to Multi-Point

1. Non-LOS, Wi-Fi sort of service, where a small antenna on a computer/ roof top connects to the tower.
2. Mobile service to computer or handset – at vehicular speeds
3. LOS, where a fixed antenna points straight at the WiMax tower from a rooftop or pole. (LOS can provide higher data rates)

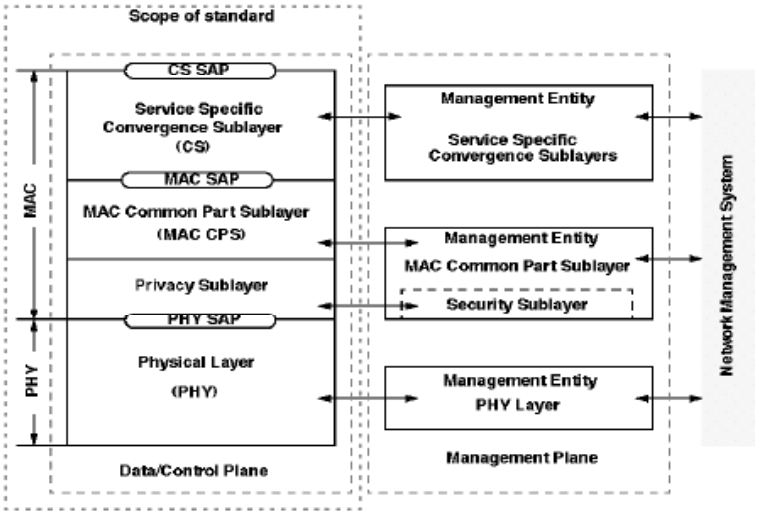
WiMax Services Point to Point

1. Focused LOS antennas – high data rates with longer distances



IEEE 802.16 WiMAX Standards

- Scope of standard is bottom two protocol layers same as other 802 standards



IEEE 802.16 WiMAX Standards

- Suite of standards for WiMANs
  - 802.16 : approved 12/2001 10-66GHz range LOS only
  - 802.16a-2003 : System for 2-11GHz range NLOS
  - 802.16-2004 (802.16d): System for 2-6 GHz range supports nomadic/limited mobility
- In a fashion similar to IEEE 802.11 – multiple physical layers with common MAC layer defined
  - *802.16a* and 802.16d define three physical layers
    - SCa – single carrier
    - OFDM – 256 carriers
    - OFDMA – 2048 carriers (OFDM multiple access) (multiple access by assigning a subset to a user)
- Physical layer standards often called ``WirelessMAN'' standard
  - Most equipment/WIMAX conformance on OFDM 256 carrier 802.15-2004 (802.16d) standard – which is common to ETSI HIPERMAN standard

IEEE 802.16 WiMAX Standards

- Additional important WiMAX standards

- 802.16 Conf/01 – Conf/04
  - Conformance testing aspects
- 802.16e
  - Extension of the IEEE 802.16d standard
  - High speed mobility support (120km/hr) and improved QoS
  - Enables MS to connect and supports vehicle speed mobility
  - Covers MAC and PHY layers for Combined Fixed and Mobile Operation in Licensed Bands.
  - Called ``*Mobile WiMAX*''
- 802.16f
  - Multi-hop mesh network functionality
- 802.16g
  - addresses efficient handover and further improves the QoS support,
- 802.16h
  - Improved coexistence with license exempt operation

Main IEEE 802.16 Standards

Dominant standard

	802.16	802.16a	802.16d	802.16e-2005 Mobile WiMAX
Date Completed	December 2001	January 2003	June 2004	December 2005
Spectrum	10-66 GHz	2-11 GHz	2-11 GHz	2- 6 GHz
Operation	LOS	Non-LOS	Non-LOS	Non-LOS and Mobile
Bit Rate	32-134 Mbps	Up to 75 Mbps	Up to 75 Mbps	Up to 15 Mbps
Omni-directional Cell Radius	1-3 miles	3-5 miles	3-5 miles	1-3 miles

Techniques used in 802.16d

- Orthogonal Frequency Division Multiplexing (OFDM)
  - to reduce multipath effects and provide higher speeds
- Forward error correction as well as ARQ → Hybrid ARQ
  - FEC uses an outer RS block code and an inner convolutional code
- Adaptive modulation and coding
  - adjust the modulation/coding depending on the quality of the radio link, subscriber by subscriber, burst by burst, up and downlink
- Admission control
  - Ensures that new flows do not degrade the quality of established flows
- MAC Layer Scheduling:
  - traffic scheduling to provide QoS traffic classes
- Flexible Channel size - can select among
  - nx1.25Mhz, n x 1.5MHz, n x 1.75 MHz, Max of 20MHz
- TDD and FDD modes supported
- Smart antenna technology supported

Physical layers for 802.16a/d

	Sca – single carrier	**OFDM**	**OFDMA**
Frequency	2-11 GHz	2-11 GHz	2-11 GHz
Modulation	BPSK, QPSK, 16QAM, 64QAM, 256QAM	BPSK, QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM
No. of subcarriers	N/A	256	2048
Duplexing	TDD, FDD	TDD, FDD	TDD, FDD
Channel Bandwith	1.75-20 MHz	1.75-20 MHz	1.75-20 MHz

OFDM 256 Carrier option is currently available
192 Carriers used for data, 8 pilot channels, 56 guard band

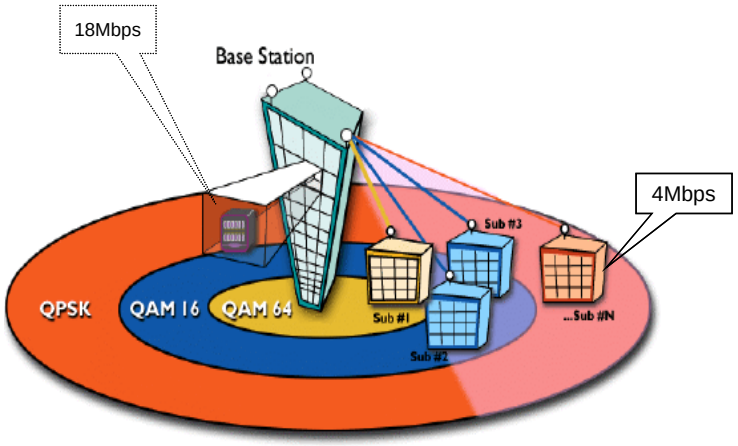
IEEE 802.16d Coding/Modulation

- Table of the maximum data rate in Mbps for the various channel/ coding/modulation options in 802.16d with 256 carrier OFDM physical layer
- Modulation rate used on a set of 256 carriers depends on RSS

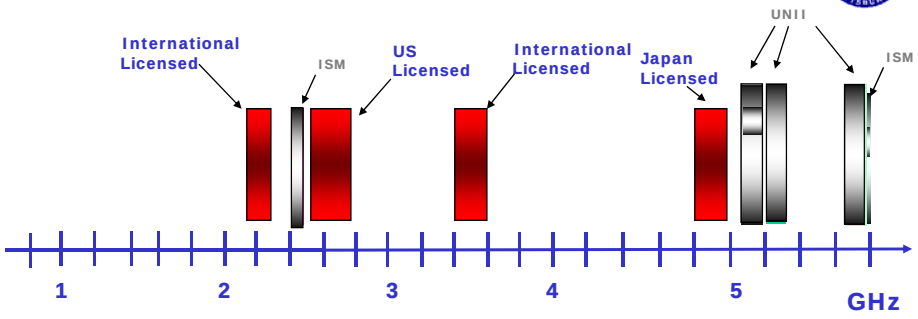
	Modulation FEC Coding					
Channel Bandwidth	**QPSK 1/2**	**QPSK 3/4**	**16 QAM 1/2**	**16QAM 3/4**	**64 QAM 2/3**	**64 QAM 3/4**
1.75 MHz	1.04	2.18	2.91	4.36	5.94	6.55
3.5 MHz	2.08	4.37	5.82	8.73	11.88	13.09
5.0 MHz	3.95	6.00	8.06	12.18	16.30	18.36
7.0 MHz	4.15	8.73	11.64	17.45	23.75	26.18
10.0 MHz	8.31	12.47	16.63	24.94	33.25	37.40
20.0 MHz	16.62	24.94	33.25	49.87	66.49	74.81

802.16d Data Ranges

- Achievable data rate depends on distance to BS, LOS/NLOS, propagation environment – will vary!



802.11/802.16 Spectrum



802.16 has both licensed and license-exempt options

ISM: Industrial, Scientific & Medical Band – Unlicensed band (802.11a,b, g)

UNII: Unlicensed National Information Infrastructure band – Unlicensed band
Licensed band 2.45-2.6 GHz US and 3.4-3.6 GHz International
WiMAX Spectrum Owners Alliance – focuses on Commercialization of licensed spectrum

WiSOA
WiMAX SPECTRUM OWNERS ALLIANCE

Licensed Systems in U.S.

- U.S.A. has licensed spectrum 2.459 – 2.69 GHz
  - License 22.5 MHz - 8 licenses per geographic service area – operator can acquire multiple licenses
  - Sprint/Nextel and Clearwire own largest number of licenses in the U.S.A.
- Outside U.S.A. 3.5 GHz, 4.8GHz and 10.5 GHz bands used for licensed WIMAX
- Main unlicensed band is U-NII 5.725-5.825 GHz
- TDD and FDD options for every band
  - For example ,
    - TDD used with 5 MHz channels in 2.5 GHz band
    - FDD pair of 2.5 MHz channels (one uplink, one downlink) in 3.5 GHz band
  - TDD cheaper implementation and is recommended more for unlicensed spectrum

IEEE 802.16 MAC Layer

- MAC Layer is independent of physical layer used
- Point to Multipoint
- TDMA Scheduled Uplink/Downlink Frames
- Flexible QoS offerings
- Connection oriented
  - Per Connection QoS
- Integrated Security Sublayer
- Hybrid Selective ARQ
- Adaptive Modulation and Coding selection
  - Increase capacity and vary data rates
  - Burst by burst, per subscriber station
- Adaptive Power Control
- Sleep and Idle Modes for subscriber/mobile stations

MAC Addressing

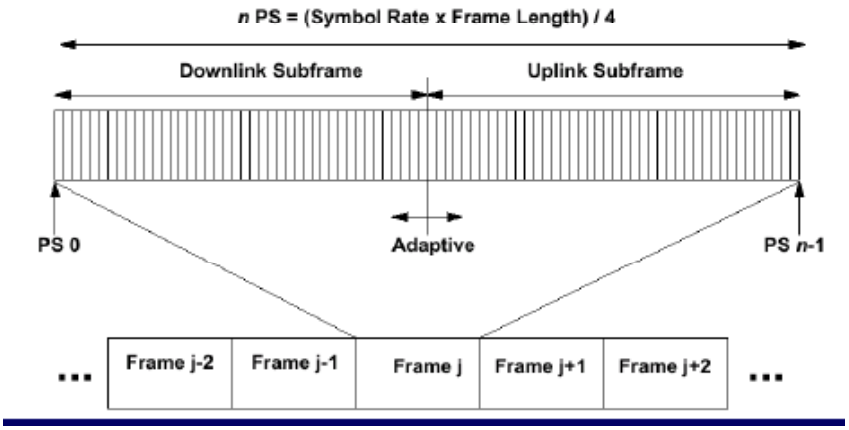
- Subscriber Station/Mobile Station (SS/MS) has a 48 bit IEEE 802 MAC address
- Base Station (BS) has a 48 bit BS ID – 24bits are a network operator indicator
- Each flow to a SS/MS is assigned a 16bit Connection ID (CID) used in the MAC protocol data units and to provide QoS class identifier
  - SS/MS has many simultaneous connections with BS
    - Basic Transport CID – data transfer
    - Management CIDs
      - Ranging CID - synchronize clocks and adjust power
      - Primary Management CID for MAC and PHY management
      - Optional Secondary CID for higher layer management (e.g., DHCP)

Multiple Access

- On DownLink (DL) SS/MS addressed in TDM stream
- On Uplink (UL) SS/MS allotted a variable length TDMA slot
- TDD
  - DL & UL time share the RF channel
  - Dynamic asymmetry
  - SS doesn't transmit receive simultaneously (lowers cost)
- FDD
  - DL & UL separate RF channels
  - Static asymmetry
  - Half Duplex SSs supported (lower cost)
- IUC – Interval Usage Code specifies a modulation, rate and FEC for a time interval on DL or UL
- MAP – MAC layer message used to allocate resources to connections on DL or UL

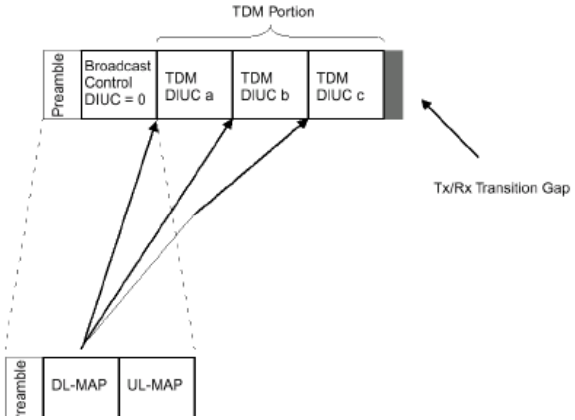
TDD Structure

TDD frames are 5ms durations
adaptively partitioned among up and downlink



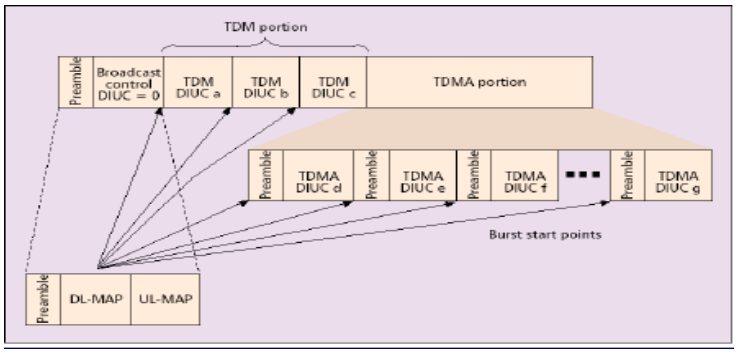
TDD Structure

DL part of frame contains DL-MAP which specifies the modulation and coding for various TDM slots
UL-MAP determines which SS gets slots in UL part of frame and modulation and coding used



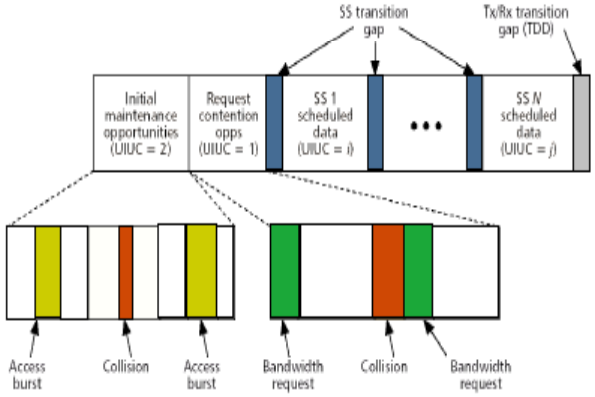
FDD Structure

DL part of frame contains DL-MAP which specifies the modulation and coding for various TDM slots
TDMA portion is for support of half duplex users
UL-MAP determines which SS gets slots in UL part of frame and modulation and coding used

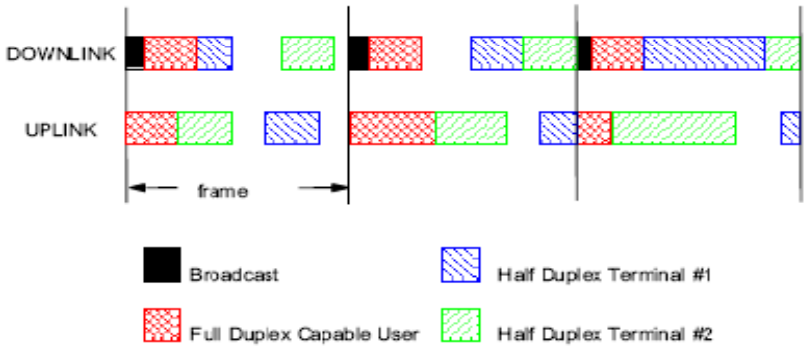


TDD/FDD UL Structure

Contention part for SS to initiate connection followed by TDMA slots



FDD Framing



Allows scheduling flexibility

QoS Services

WiMAX supports QoS classes on the Wireless link

- BS schedules QoS based on connection type not SS
- BS determines the DL and UL MAPs of each frame and DIUC/UIUC of each slot based on QOS classes of each connection and the status of the traffic queues as BS and SS

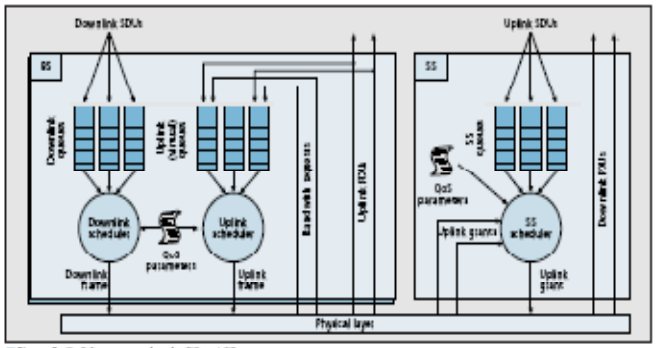


Figure 2. QoS functions within the BS and SSs.

Classes of QoS Service

1. Unsolicited Grant Services (UGS)
   - For constant bit rate (CBR) or CBR like emulation (e.g., leased T1/E1 service)
   - Specified fixed throughput, delay , delay jitter
2. Enhanced Real Time Polling Services (ertPS)
   - For real time services that generate variable size packets in periodic or quasi-periodic fashion (VoIP with VAD, Interactive multi-player gaming)
   - Specified delay jitter and delay requirements
3. Real Time Polling Services (rtPS)
   - For rt-variable bit rate (rt-VBR) flows such as streaming video
   - Specified peak and mean throughput, delay and delay jitter
4. Non-Real Time Polling Services (nrtPS)
   - For non-rt flows that need better than best effort service such as file transfer
5. Best Effort (BE)
   - No QoS guarantees – web browsing, email, etc.

IEEE 802.16 Security

- Security is a sublayer of the MAC in the standard
- Security Mechanisms
  - Authentication and Registration
    - PKI at the BS with X.509 digital certificates installed by manufacturers in SSs
    - Downloaded to BS with manufacturers public key
  - Access Control
    - (similar to WiFi - WPA)
    - MAC/IP address filtering
    - VPN at higher layers, passwords, etc.
  - Privacy
    - DES with 128 bit key (triple DES)
    - Newer Releases move to AES
    - PKI for key distribution
    - Key refreshed based on activity - max usage 20 hours

802.16 Management

- How does SS/MS joins a network?
  - SS/MS scans channels for strongest signal and synchronizes by looking at preamble
  - Reads DCD, UCD, DL-MAP, UL-MAP to get parameter settings
  - SS/MS sends a RNG-REQ message in the contention period of frame – contains MAC address, requested profile, IP version, etc.
  - BS sends SS/MS a RNG –RSP message
    - Contains status, timing adjustment, power offset, frequency adjustment, assigned Basic CID, primary management CID, MAC address, DL DIUC, frame # in which RNG-REQ received, modulations supported, max transmit power, bandwidth allocation, mode, MIMO parameters, multicast polling, etc
  - BS and SS/MS then do a security exchange

MAC Layer Management Messages

Type	Name	Description	Connection
0	UCD	Uplink Channel Descriptor	Broadcast
1	DCD	Downlink Channel Descriptor	Broadcast
2	DL MAP	Downlink Access definition	Broadcast
3	UL MAP	Uplink Access definition	Broadcast
4	RNG_REQ	Ranging Request	Initial or Basic
5	RNG_RSP	Ranging Response	Initial or Bsic
6	REG_REQ	Registration Request	Primary
7	REG_RSP	Registration Response	Primary
50	MOB_SLP_REQ	Mobile Sleep request	Basic
51	MOB_SLP_RSP	Mobile Sleep response	Basic
54	MOB_SCN-REQ	Scanning interval allocation request	Basic
55	MOB_SCN_RSP	Scanning interval allocation response	Basic
62	MBS MAP	Multicast Broadcast Services MAP	Broadcast

WiMax Network Design

- **Factors are**
  - **Coverage Planning**
    - **Adequate Received Signal Strength throughout geographic coverage area**
    - **RF Interference**
    - May have different data rate zones
  - **Capacity Requirements**
    - **Need to provide enough data capacity – may need additional radio channels or base stations – frequency planning just like cellular/WLAN networks**
  - **Infrastructure Placement:**
    - Site physical structure that houses or supports the base station must be RF friendly and have power.
    - Must be able to connect to backhaul network

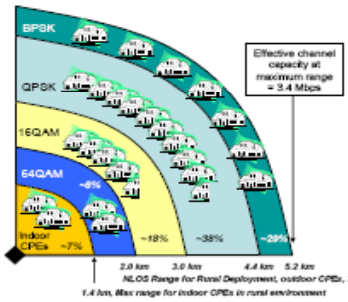


Figure 12: Distribution with Indoor CPEs for a 3.5 GHz Rural Area Deployment

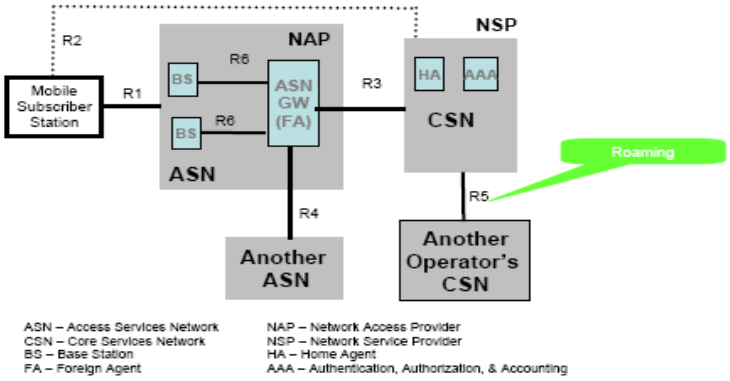
802.16e (Mobile WiMAX)

- Modifies 802.16a/d to support vehicular speed mobility
  - asymmetric data rates uses 2*x*2 MIMO and OFDM or OFDMA of 802.16d
- 802.16e – specifies Layer 1 and 2 only
  - Higher layer functions (handoff, signaling, etc.) part of WiMAXForum
- In US 802.6e supported by 3.5, 5 and 10 MHz wide channels

	Modulation FEC Coding					
Channel Bandwidth	**QPSK 1/2**	**QPSK 3/4**	**16 QAM 1/2**	**16QAM 3/4**	**64 QAM 2/3**	**64 QAM 5/6**
5.0 MHz	3.17/1.63	4.75/2.45	6.34/3.26	9.5/4.9	12.67/6.53	15.84/8.16
10.0 MHz	6.34/3.36	9.5/5.04	12.67/6.72	19/10	25.34/13.44	31.68/16.8

Downlink/Uplink data rates in Mbps

WiMAX Forum Reference Architecture



- NAPs – provide radio access infrastructure
- NSP – provide IP connectivity and end-to-end services
- Uses Mobile IP with HA and FA for mobility support
- R1-R6 are interface standard reference points

WiMAX Architecture

- BS provides 802.16 PHY and MAC services
- ASN Gateway provides
  - DHCP, location and paging management
  - Relay traffic to Connectivity Service Networks
  - Foreign Agent for Mobile IP (like VLR in cellular networks)
- NSP provides
  - End to End connectivity , QOS
  - Home Agent for Mobile IP (like HLR in cellular networks)
  - AAA server for authentication, accounting, authorization

WiMAX Mobility Management

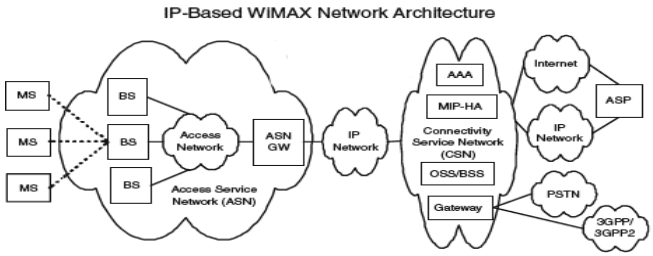
- BS allocates time for each MS to measure signals from neighboring BSs and provides relevant information (scanning interval, frequencies of neighboring BSs)
- Levels of Association
  - Level 0: Scan/Association without coordination
    - MS performs contention based ranging to BS with largest SINR if successful, receives RNG-RSP
  - Level 1: Scan/Association with coordination
    - Serving BS tells MS ranging code and transmission interval for each neighbor BS
    - MS performs unicast ranging – if successful receives RNG-RSP
  - Level 2: Network assisted association reporting
    - Same as Level 1 except
    - Neighboring BSs send their response to serving BS
    - Serving BS aggregates response and send one message to MS

WiMAX Mobility Management

- Handoff/Handover supported
  - Hard handover
    - MS goes through sequence of Level 0 associations
  - Fast BS Switching (FBSS)
    - Mobile maintains valid connections with all BSs in Active set
    - MS communicates only through one BS (Anchor BS)
    - When necessary MS reports the new anchor
  - Macro Diversity Handover (MDHO)
    - MS sends packets to all members of a diversity set
      - → Anchor uses selection diversity to select the best copy
    - MS receives packets from all members of diversity set
      - → Multiple copies are combined as MS

WiMAX Mobility Management

- Where to put handoff function?
  - WiMAX Forum has ASN profiles specifying different options
    - Profile A: Centralized approach
      - » ASN-GW provides handoff control, layer 3 rerouting, load balancing,
      - » ASN-GW does handoff decision and radio control, BS does radio assignment
    - Profile B: Distributed solution
      - » Incorporate functionality of ASN GW in every BS – unified platform
    - Profile C:
      - » BS does radio resource management/control and radio assignment
      - » ASN-GW does handoff control for layer 3 rerouting



WiMAX Summary

- IEEE 802.16 and WiMAX Forum standardization of wireless MANS
- Suite of standards
  - Licensed and Un-licensed options
  - Common MAC layer with different physical layers
  - OFDMA, MIMO, Hybrid ARQ, QoS support
  - Integrated Security sublayer
  - Support quad play → advantage over DSL, Cable modem and FTTH?
- Rollouts
  - Currently deployed primarily in emerging countries where cabling/telecom infrastructure poor