Introduction to 802.16 Wireless Systems (aka WiMAX)

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Spring 2009

Outline

- Wireless Metropolitan Area Networks
  - Broadband Wireless Access
- IEEE Standards and IEEE 802
- IEEE 802.16 Working Group
- IEEE 802.16 Air Interface Standard
  - IEEE 802.16:   Air Interface (MAC and 10 - 66 GHz PHY)
  - P802.16a: Amendment, 2-11 GHz (finished)
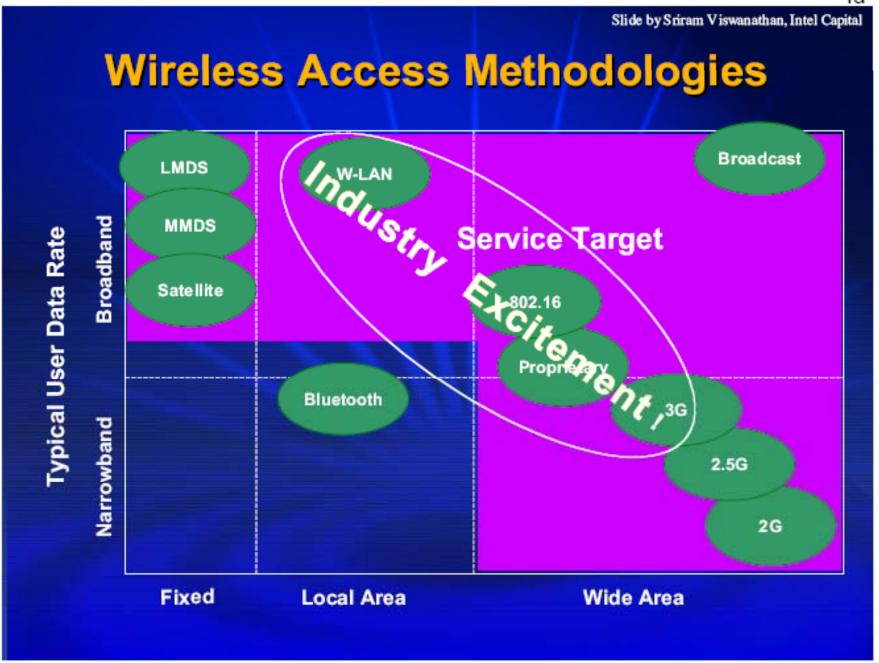   Licensed
                            License-Exempt
  - WiMAX Forum coordinating interoperability testing
  - Interoperability documentation in development

  - P802.16e: Mobile Enhancement
- IEEE Standard 802.16.2 and P802.16.2a
  - Recommended Practice on Coexistence

Broadband Access to Buildings

- The "Last Mile"

  - Fast local connection to network

- Business and residential customers demand it

  - Data

  - Voice

  - Video distribution

  - Real-time videoconferencing

  - etc.

- Network operators demand it

- High-capacity cable/fiber to every user is expensive

  - Construction costs do not follow Moore's Law

802.16a Last Mile Market Segments

- **Market still early stage**
- **Dramatic product improvements since 1st gen**
- **802.16a standard opens door for volume components**
- **Cooperation & promotion amongst vendors is key**

T1 LEVEL SERVICE for ENTERPRISE

FRACTIONAL T1 for SMALL BUSINESS

RESIDENTIAL/SOHO BROADBAND

WIRELESS BACKHAUL for Hotspots

Today's Wireless Performance

	Channel Bandwidth	Maximum Data Rate	Maximum Bps/Hz
802.11a	20 MHz	54 Mbps	~2.7 bps/Hz
802.16a	10, 20 MHz; 3.5, 7, 14 MHz; 3, 6 MHz	70 Mbps*	~5 bps/Hz
EDGE	200 kHz	384 kbps	~1.9 bps/Hz
CDMA2000	1.25 MHz	~2 Mbps	~1.6 bps/Hz

* Assuming a 14 MHz channel and ~ 5 bps/Hz

Centimeter-Wave Bands
for Wireless MAN

International
3.5 GHz
10.5 GHz

U.S.: MMDS & ITFS
2.5-2.7 GHZ

Non-Line-of-Sight

License-Exempt Bands
for Wireless MAN

5.725-5.825 GHz
(U-NII)

2.4 GHz License-Exempt:
Wireless LANs

59-64 GHz

Properties of IEEE Standard 802.16

- **Broad bandwidth**
    - Up to 134 Mbit/s in 28 MHz channel (in 10-66 GHz air interface)
- **Supports multiple services simultaneously with full QoS**
    - Efficiently transport IPv4, IPv6, ATM, Ethernet, etc.
- **Bandwidth on demand (frame by frame)**
- **MAC designed for efficient used of spectrum**
- **Comprehensive, modern, and extensible security**
- **Supports multiple frequency allocations from 2-66 GHz**
    - ODFM and OFDMA for non-line-of-sight applications
- **TDD and FDD**
- **Link adaptation: Adaptive modulation and coding**
    - Subscriber by subscriber, burst by burst, uplink and downlink
- **Point-to-multipoint topology, with mesh extensions**
- **Support for adaptive antennas and space-time coding**
- **Extensions to mobility are coming next.**
- **Is this 4G?**

IEEE 802.16 Projects: 2-11 GHz

- **Air Interface**
  - new PHY based on 802.16 MAC
  - **IEEE Standard 802.16a**
    - Completed in November 2002
    - Approved 29 January 2003; published 1 April 2003
  - Followup interoperability projects
    - **P802.16d**: first meeting Jan 2003; in WG Ballot
  - Followup air interface project: *mobility*
    - **P802.16e**: first meeting Jan 2003; Working Doc in review
- **Coexistence**
  - **IEEE Standard 802.16.2a (Recommended Practice)**
    - In IEEE ballot
    - Completion expected in March 2003

Mesh/Relay nodes: 80216j: in progress

WiMAX Forum

- **WiMAX: Worldwide Interoperability for Microwave Access**
- Mission: *To promote deployment of BWA by using a global standard and certifying interoperability of products and technologies.*
- Principles:
  - Support IEEE 802.16
    - 2-66 GHz
  - Propose access profiles for the IEEE 802.16 standard
  - Guarantee known interoperability level
  - Promote IEEE 802.16 standard to achieve global acceptance
  - Open for everyone to participate
- Developing & submitting baseline test specs

IEEE Standard 802.16:
The WirelessMAN-SC™ Air Interface
Published: 8 April 2002

IEEE Std 802.16-2001~

IEEE Standard for
Local and metropolitan area networks

Part 16: Air Interface for Fixed Broadband Wireless Access Systems

Sponsor

LAN/MAN Standards Committee
of the
IEEE Computer Society

and the
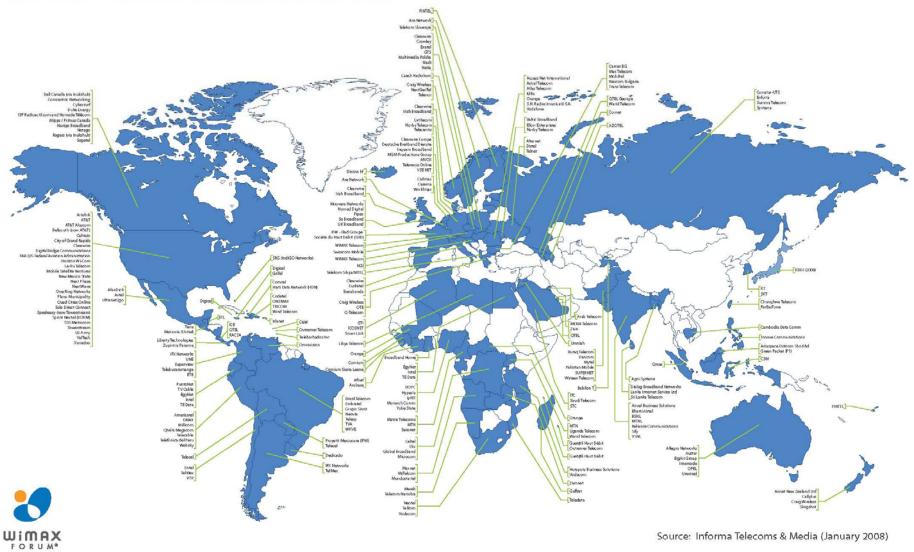**IEEE Microwave Theory and Techniques Society**

Approved 6 December 2001

IEEE-SA Standards Board

Abstract: This standard specifies the air interface of fixed (stationary) point-to-multipoint broadband wireless access systems providing multiple services. The medium access control layer is capable of supporting multiple physical layer specifications optimized for the frequency bands of application. The standard includes a particular physical layer specification applicable to systems operating between 10 and 66 GHz.
Keywords: fixed broadband wireless access network, metropolitan area network, microwave, millimeter wave, WirelessMAN™ standards

WiMAX™ Networks Worldwide 2008

WiMAX FORUM®

North America (USA)
- ArialLink
- AT&T
- AT&T Alascom
- Bellsouth (now AT&T)
- Calnain
- City of Grand Rapids
- Clearwire
- DigitalBridge Communications
- FAA (US Federal Aviation Administration)
- Horizon Wi-Com
- La-Ru Telecom
- Mobile Satellite Ventures
- New Mexico State
- Next Phase
- NexWave
- One Ring Networks
- Plano Municipality
- Quad Cities Online
- Solo Direct Connect
- Speakeasy (now Towerstream)
- Sprint Nextel (XOHM)
- TDS Metrocom
- Towerstream
- US Army
- ValTech
- Xanadoo

Canada
- Bell Canada (via Inukshuk)
- Concentric Networking
- Cybersurf
- Dulu Energy
- ESP Radioactif.com and Nomade Telecom
- Mipps / Primus Canada
- Navigo Broadband
- Nertago
- Rogers (via Inukshuk)
- Sogetel

- AlanDick
- Axtel
- UltranetJigo

- Digicel
- BTL
- ICE
- QTEL
- RACSA
- Terra
- Maxavia (Unitel)
- Liberty Technologies
- Zapirtra Panama

- IFX Networks
- UNE
- Supervew
- Telebucaramanga
- ETB
- PuntoNet
- TV Cable
- EgyNet
- Intel
- TE Data

- Americatel
- EMAX
- Millicom
- Qtel & Megacom
- Teleacble
- Telefonica del Peru
- Websky

- Telecel

- Entel
- TelMex
- VTR

Central America / Caribbean
- SRG (IndiGO Networks)
- Digicel
- GoTel
- Comcel
- Haiti Data Network (HDN)
- Codetel
- ONEMAX
- TRICOM
- Wind Telecom
- Intanet
- C&W
- Outremer Telecom
- Telebarbados Inc
- Omnivision

- Brazil Telecom
- Embratel
- Grupo Sinos
- Neovia
- Telespi
- TVA
- WKVE

- Proyetti Mercosure (PM)
- Telecel
- Dedicado
- IFX Networks
- TelMax

Europe
- FINTEL
- Ara Network
- Telekom Slovenje
- Clearwire
- Crowley
- Exatel
- GTS
- Multimedia Polska
- Niask
- Netia
- Czech Radiokom
- Craig Wireless
- NextGenTel
- Telenor
- Clearwire
- Irish Broadband
- Lattlecom
- Norby Telecom
- Telecomis
- Clearwire Europe
- Deutsche Breitband Dienste
- Inquam Broadband
- MGM Productions Group
- MVOX
- Televersa Online
- VSE NET
- Siminn hf
- Clearwire
- Irish Broadband
- Moovera Networks
- Nomad Digital
- Pipex
- So Broadband
- UK Broadband
- IFW - Iliad Groupe
- Société du Haut Débit (SHD)
- WiMAX Telecom
- Swisscom Mobile
- WiMAX Telecom
- NGI
- Telekom Srbija/MTEL
- Clearwire
- Eutelsat
- Iberbanda
- Craig Wireless
- OTE
- Q-Telecom
- Callmax
- Caelsma
- Worldfax
- Baltic Broadband
- Elion Enterprises
- Norby Telecom
- Altenet
- Dial net
- Telnet

Eastern Europe / Russia
- Access Net International
- Astral Telecom
- Atlas Telecom
- Idilis
- Orange
- S.N. Radiocomunicatii S.A.
- Vodafone
- Carrier BG
- Max Telecom
- Mobiltel
- Nexcom Bulgaria
- Trans Telecom
- QTEL Georgia
- World Telecom
- Comet
- AZQTEL
- Comstar-UTS
- Enforta
- Summa Telecom
- Synterra

Africa
- GTI
- ICOSNET
- Smart Link
- Libya Telecom
- Orange
- Comium
- Comium Sierra Leone
- Afisat
- Arabase
- DCPC
- Hyperia
- IpMD
- Monarch Comm
- Yobe State
- Matrix Telecoms
- Saco net
- Broadband Home
- EgyNet
- Intel
- TE Data
- Arab Telecom
- MENA Telecom
- Zain
- QTEL
- Umnish
- Busaq Telecom
- Dancom
- Mytel
- Pakistan Mobile
- SUPER NET
- Wateen Telecom
- Babilon T
- ITC
- Saudi Telecom
- STC
- Orange
- MTN
- Uganda Telecom
- Warid Telecom
- Guanfili Haut Débit
- Outremer Telecom
- Guanfili Haut Débit
- Celtel
- Elix
- Global Broadband
- Microcom
- Maxnet
- MsTelecom
- Mundostarnet
- Hotspots Business Solutions
- Vodacom
- Zamnet
- Gulfsat
- Teledata
- Mweb
- Telecom Namibia
- Neotel
- Telkom
- Vodacom

Middle East / Asia
- Agni Systems
- Dialog Broadband Networks
- Lanka Internet Service Ltd
- Sri Lanka Telecom
- Aircel Business Solutions
- Bharti Airtel
- BSNL
- MTNL
- Reliance Communications
- Sify
- VSNL
- Cambodia Data Comm
- Innove Communications
- Airaspace Datcom Sdn Bhd
- Green Packet (P1)
- CSM
- Omax
- KDDI (2009)
- KT
- SKT
- Chunghwa Telecom
- PanBesTone
- FINTEL

Australia / New Zealand
- Allegro Networks
- Austar
- BigAir Group
- Internode
- OPEL
- Unwired
- Airnet New Zealand Ltd
- Callplus
- Craig Wireless
- Slingshot

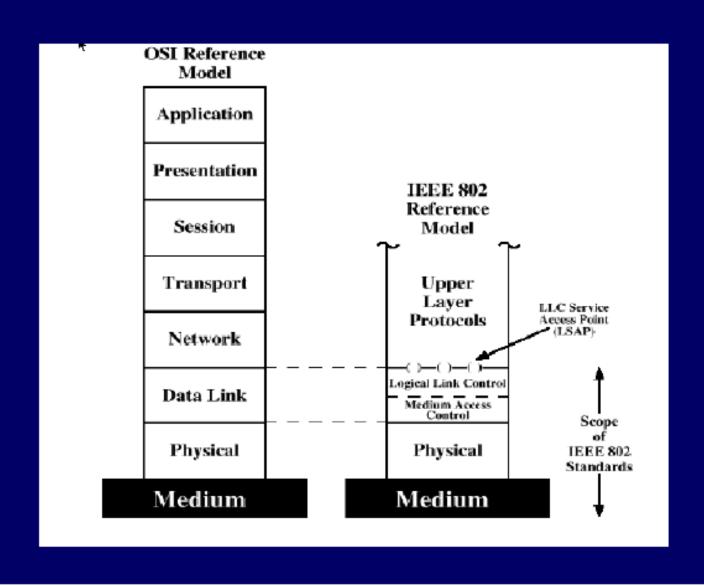## WiMAX Developments in the Middle East and Africa
IEEE Communications Magazine, Feb 2009

Countries	Operators	WiMAX status
Algeria	SLC LaCom Icosnet Algeria Telecom	ISS 2005 Conducted a 802.16d trial in 2006; filed bankruptcy in Nov 2008 ISS summer 2008 Preparing to launch in 2009
Bahrain	Zain Bahrain MENA Telecom	ISS 2007 802.16e commercial launch in 2009
Egypt	Two ISPs - EgyNet and TE Data	ISS 2008 in tourist resorts
Iran	Datak TeleCom, Laser TeleCom, Shatel Telecom Paya Comm. Ltd, Iran Mobin, MTN IranCell, MTCE, RDG	ISS 2007/2008 Awarded provincial licenses in Nov 2008
Iraq	IRAQTEL Kalimat Telecom	ISS 2007 ISS 2008
Jordan	Batelco's UMC Wi-tribe	ISS 2007 ISS 2008
Kuwait	Arab Telecom	ISS 2007
Libya	Libya Telecom and Technology General Post & Telecom Co.	Launch expected in early 2009 Launch mid to late 2009
Lebanon	CedarCom Cerinum	ISS 2006 ISS 2008
Morocco	Wania Meditel	ISS 2007 ISS 2006
Pakistan	Wateen Telecom Mobilink LinkdotNet (ISP) TeleCard (ISP)	Largest network in the country since Dec 2007 covering 22 cities ISS late 2008 in Karachi only ISS 2007 Planning to launch in 2009
Qatar	Wi-tribe Vodafone-Qatar	Planning to launch in 2009 Received license in Sept. 2008
Saudi Arabia	STC ITC Mobily Batelco	ISS 2007 ISS 2006 ISS Fall 2008 Has the license
UAE	Etisalat du	Under customer friendly trial In trial
Yemen	Nexen Petroleum (energy company)	Service restricted to oil fields only

Note: ISS: in service since

TABLE 1: WiMAX availability status.

Point-to-Multipoint
Wireless MAN: not a LAN

- **Base Station (BS) connected to public networks**
- **BS serves Subscriber Stations (SSs)**
  - SS typically serves a building (business or residence)
  - provide SS with first-mile access to public networks

- **Compared to a Wireless LAN:**
  - Multimedia QoS, not only contention-based
  - Many more users
  - Much higher data rates
  - Much longer distances

Scope of 802 Standards
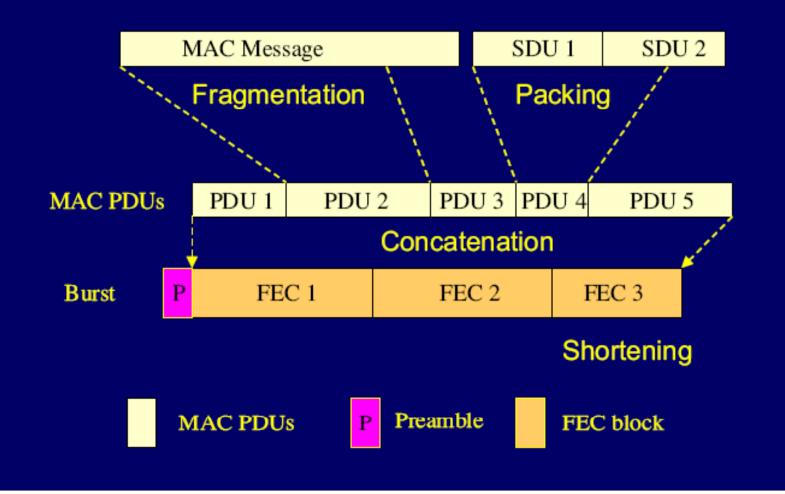
MAC Requirements

- Provide Network Access
- Address the **Wireless** environment
  - e.g., very efficient use of spectrum
- Broadband services
  - Very high bit rates, downlink and uplink
  - A range of QoS requirements
  - Ethernet, IPv4, IPv6, ATM, ...
- Likelihood of terminal being shared
  - Base Station may be heavily loaded
- Security
- Protocol-Independent Engine
  - Convergence layers to ATM, IP, Ethernet, ...
- Support both TDD and FDD in the PHY

802.16 MAC: Overview

- **Point-to-Multipoint**
- **Metropolitan Area Network**
- **Connection-oriented**
- **Supports difficult user environments**
  - High bandwidth, hundreds of users per channel
  - Continuous and burst traffic
  - Very efficient use of spectrum
- **Protocol-Independent core (ATM, IP, Ethernet, …)**
- **Balances between stability of contentionless and efficiency of contention-based operation**
- **Flexible QoS offerings**
  - CBR, rt-VBR, nrt-VBR, BE, with granularity within classes
- **Supports multiple 802.16 PHYs**
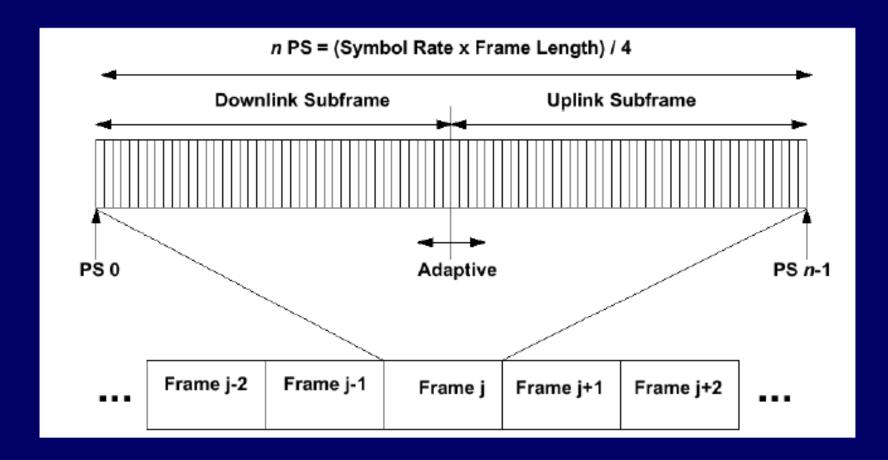
Multiple Access and Duplexing

- On DL, SS addressed in TDM stream
- On UL, SS allotted a variable length TDMA slot

- Time-Division Duplex (TDD)
  - DL & UL time-share the same RF channel
  - Dynamic asymmetry
  - SS does not transmit/receive simultaneously (low cost)
- Frequency-Division Duplex (FDD)
  - Downlink & Uplink on separate RF channels
  - Static asymmetry
  - Half-duplex SSs supported
    - SS does not transmit/receive simultaneously (low cost)
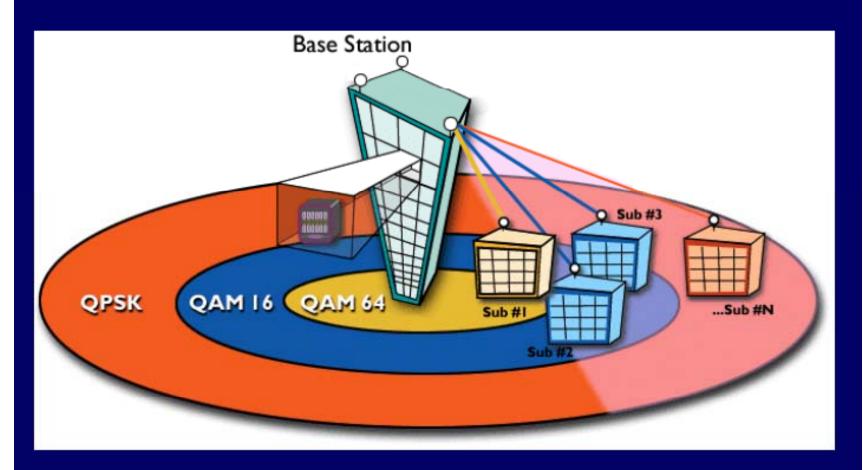
Adaptive PHY
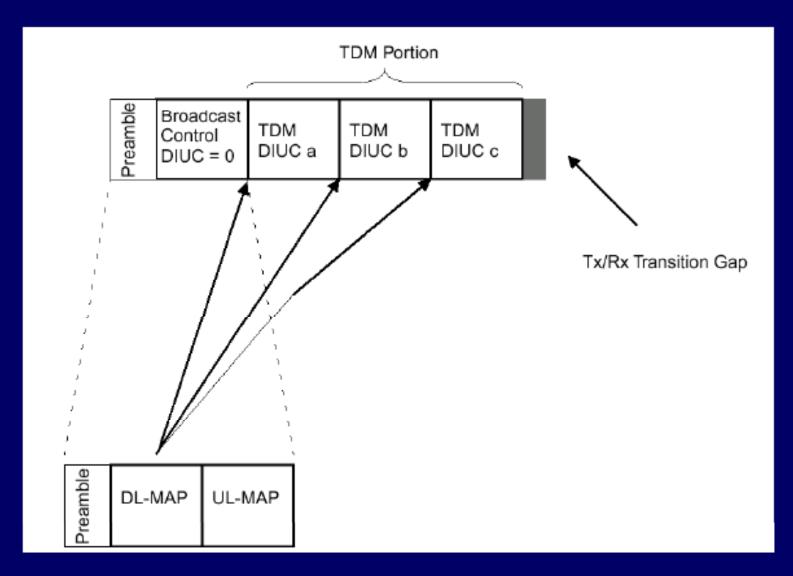
(burst-by-burst adaptivity not shown)

Adaptive Burst Profiles
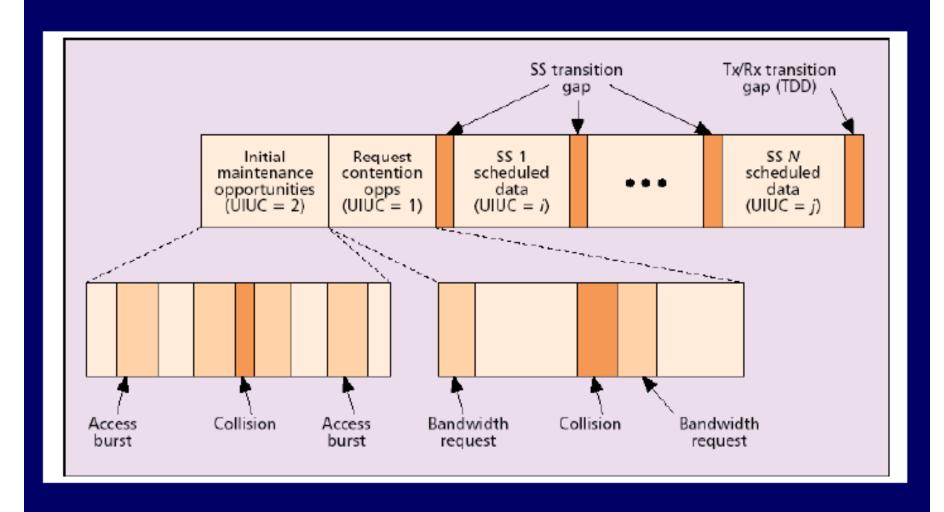
- **Burst profile**
  - Modulation and FEC
- **Dynamically assigned according to link conditions**
  - Burst by burst, per subscriber station
  - Trade-off capacity vs. robustness in *real time*
- **Roughly doubled capacity for the same cell area**
- **Burst profile for downlink broadcast channel is well-known and robust**
  - Other burst profiles can be configured "on the fly"
  - SS capabilities recognized at registration

TDD Downlink Subframe

DIUC: Downlink Interval Usage Code
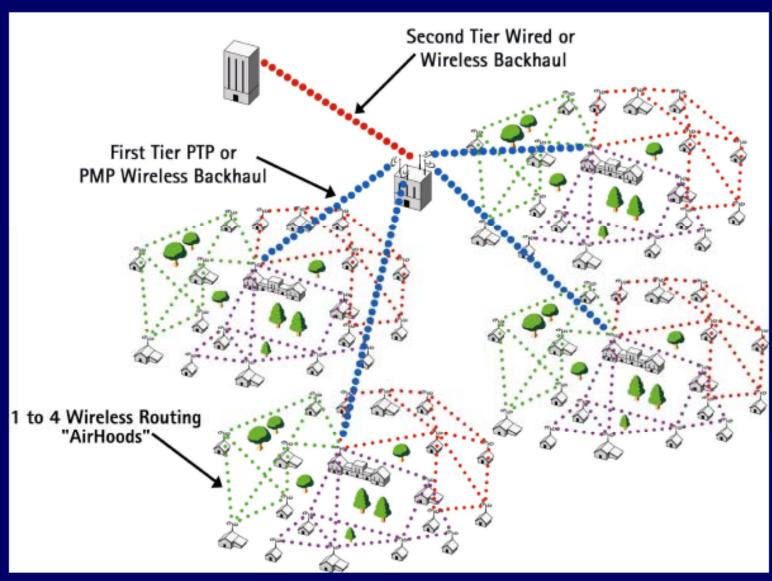
Typical Uplink Subframe (TDD or FDD)

802.16a PHY Alternatives: Different Applications, Bandplans, and Regulatory Environments

- **OFDM (WirelessMAN-OFDM Air Interface)**
  - 256-point FFT with TDMA (TDD/FDD)

- **OFDMA (WirelessMAN-OFDMA Air Interface)**
  - 2048-point FFT with OFDMA (TDD/FDD)

- **Single-Carrier (WirelessMAN-SCa Air Interface)**
  - TDMA (TDD/FDD)
  - BPSK, QPSK, 4-QAM, 16-QAM, 64-QAM, 256-QAM
  - Most vendors will use Frequency-Domain Equalization

Mesh-based WirelessMAN

Second Tier Wired or Wireless Backhaul

First Tier PTP or PMP Wireless Backhaul

1 to 4 Wireless Routing "AirHoods"

Source: Nokia Networks

Free IEEE 802 Standards

- Since May 2001, IEEE 802 standards have been available for free download.
- See:

http://WirelessMAN.org

beginning six months after publication

- IEEE Std 802.16.2 is now free
- IEEE Std 802.16 is now free

IEEE Standard 802.16: Tutorial

IEEE Communications Magazine, June 2002

(available on 802.16 web site)

TOPICS IN BROADBAND ACCESS

IEEE Standard 802.16: A Technical Overview of the WirelessMAN™ Air Interface for Broadband Wireless Access

Carl Eklund, Nokia Research Center

Roger B. Marks, National Institute of Standards and Technology

Kenneth L. Stanwood and Stanley Wang, Ensemble Communications Inc.

EE 548

WiMAX MAC layer

Spring 2009

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- Supports difficult user environments
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- Supports multiple 802.16 PHYs

Relationship to DOCSIS

- Management
  - Dynamic service "editing" protocol (Add/Change/Delete)
  - Management message payload format
- Security
  - Authentication and Privacy
- Polling categories
- Initial Access
  - Slightly modified allowing terminal capability negotiation

- Core MAC protocol engine is new design for Wireless Metropolitan Area Networks

Definitions

- **Service Data Unit (SDU)**
  - Data units exchanged between adjacent layers
- **Protocol Data Unit (PDU)**
  - Data units exchanged between peer entities
- **Connection and Connection ID**
  - a unidirectional mapping between MAC peers over the airlink (uniquely identified by a CID)
- **Service Flow and Service Flow ID**
  - a unidirectional flow of MAC PDUs on a connection that provides a particular QoS (uniquely identified by a SFID)

Packet Convergence Sublayer

- Initial support for Ethernet, IPv4, and IPv6
- Payload header suppression
  - generic plus IP-specific
- Full QoS support
- Possible future support for:
  - PPP
  - MPLS
  - etc.
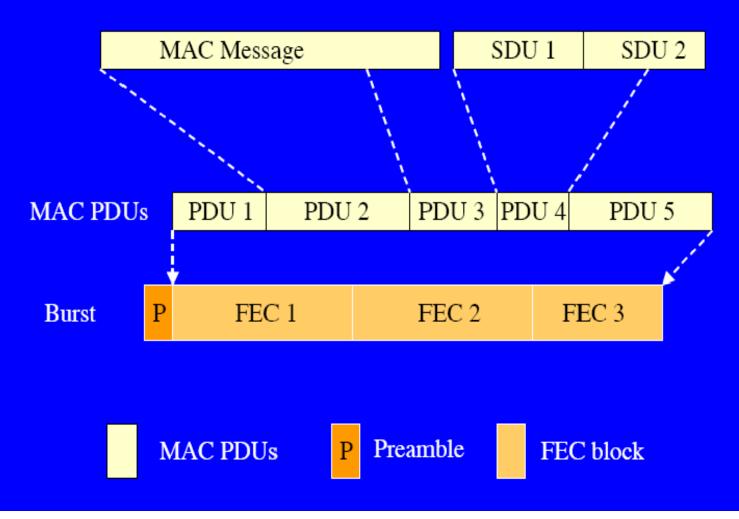
MAC Addressing

- SS has 48-bit IEEE MAC Address
- BS has 48-bit Base Station ID
  - Not a MAC address
  - 24-bit operator indicator
- 16-bit Connection ID (CID)
  - Used in MAC PDUs
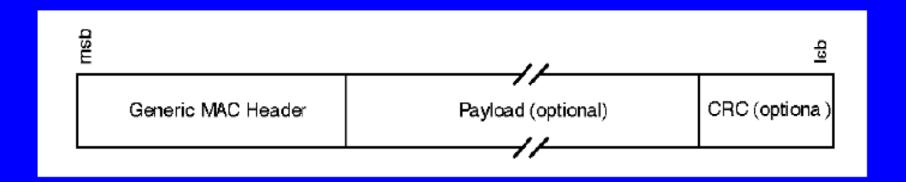
MAC PDU Transmission

- MAC PDUs are transmitted in PHY bursts
- A single PHY burst can contain multiple *Concatenated* MAC PDUs
- The PHY burst can contain multiple FEC blocks
- MAC PDUs may span FEC block boundaries
- The TC layer between the MAC and the PHY allows for capturing the start of the next MAC PDU in case of erroneous FEC blocks

MAC PDU format
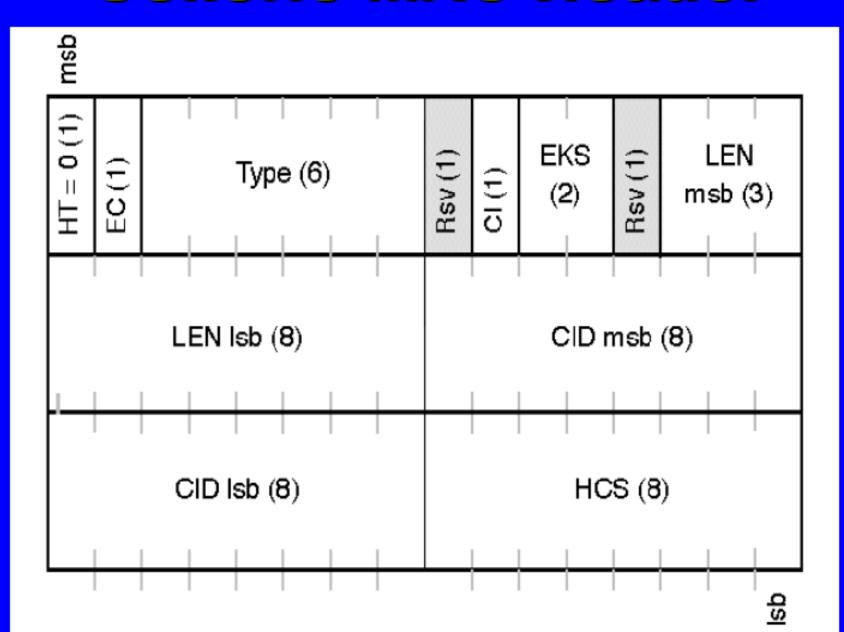
- The Generic MAC header has fixed format
- One or more MAC sub-headers may be part of the payload
- The presence of sub-headers is indicated by a Type field in the Generic MAC header

Generic MAC Header
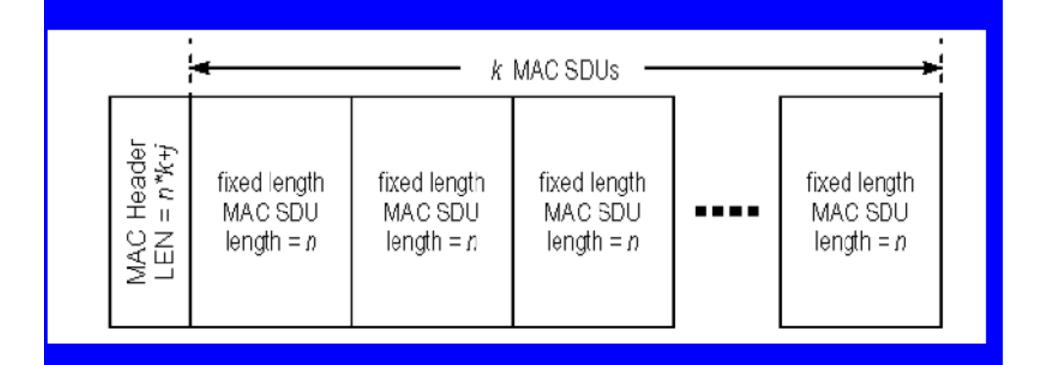
Fragmentation

- Partitioning a MAC SDU into fragments transported in multiple MAC PDUs

- Each connection can be in only a single fragmentation state at any time

- Contents of the fragmentation sub-header:
  - 2-bit Fragmentation Control (FC)
    - Unfragmented, Last fragment, First fragment, Continuing fragment
  - 3-bit Fragmentation Sequence Number (FSN)
    - required to detect missing continuing fragments
    - continuous counter across SDUs
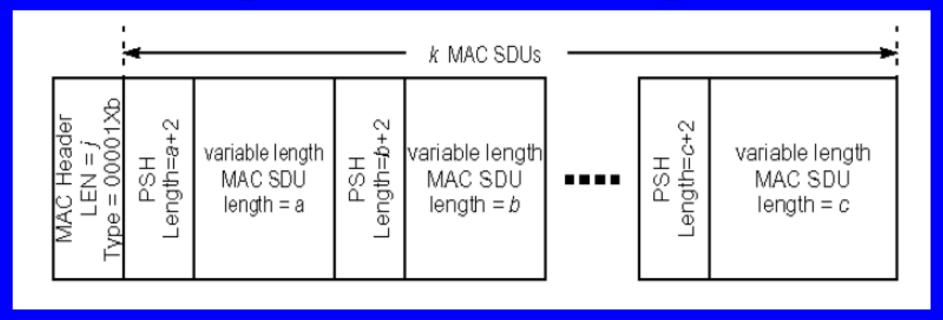
Packing

- The process of combining multiple MAC SDUs (or fragments thereof) into a single MAC PDU
- On connections with variable length MAC SDUs
  - Packed PDU contains a sub-header for each packed SDU (or fragment thereof)
- On connections with fixed length MAC SDUs
  - No packing sub-header needed
- Packing and fragmentation can be combined
- Can, in certain situations, save up to 10% of system bandwidth

Packing Fixed-Length SDUs

Packing Variable-Length SDUs

- 2 Byte Packing Sub-Header before each SDU
  - Length of the SDU: 11 bits
  - fragmentation control (FC): 2 bits
  - fragmentation sequence number (FS): 3 bits

Downlink transmissions

- Two kinds of bursts: TDM and TDMA
- All bursts are identified by a DIUC
  - Downlink Interval Usage Code
- TDMA bursts have resync preamble
  - allows for more flexible scheduling
- Each terminal listens to all bursts at its operational IUC, or at a more robust one, except when told to transmit
- Each burst may contain data for several terminals
- SS must recognize the PDUs with known CIDs
- DL-MAP message signals downlink usage

Downlink Channel Descriptor

- Used for advertising downlink burst profiles
- Burst profile of DL broadcast channel is well-known
- All others are acquired
- Burst profiles can be changed on the fly without interrupting the service
  - Not intended as 'super-adaptive' modulation
- Establishes association between DIUC and actual PHY parameters

Downlink Map Message

- DL-MAP message defines usage of downlink and contains carrier-specific data
- DL-MAP is first message in each frame
- Decoding very time-critical
  - typically done in hardware
- Entries denote instants when the burst profile changes

Uplink Transmissions

- Invited transmissions
- Transmissions in contention slots
  - Bandwidth requests
  - Contention resolved using truncated exponential backoff
- Transmissions in initial ranging slots
  - Ranging Requests (RNG-REQ)
  - Contention resolved using truncated exponential backoff
- Bursts defined by UIUCs
- Transmissions allocated by the UL-MAP message
- All transmissions have synchronization preamble
- Ideally, all data from a single SS is concatenated into a single PHY burst

Uplink Channel Descriptor

- Defines uplink burst profiles
- Sent regularly
- All Uplink Burst profiles are acquired
- Burst profiles can be changed on the fly
- Establishes association between UIUC and actual PHY parameters

Uplink MAP Message

- UL-MAP message defines usage of the uplink
- Contains the "grants"
- Grants addressed to the SS
- Time given in mini-slots
  - unit of uplink bandwidth allocation
  - 2^m physical slots
    - in 10-66 GHz PHY, physical slot is 4 symbols
- Time expressed as arrival time at BS

Classes of Uplink Service

Characteristic of the Service Flow

- Unsolicited Grant Services (UGS)
  - for constant bit-rate (CBR) or CBR-like service flows (SFs) such as T1/E1

- Real-time Polling Services (rtPS)
  - for rt-VBR-like SFs such as MPEG video

- Non-real-time Polling Services (nrtPS)
  - for nrt SFs with better than best effort service such as bandwidth-intensive file transfer

- Best Effort (BE)
  - for best-effort traffic

Uplink Services - UGS

- No explicit bandwidth requests issued by SS
- Prohibited from using any contention requests
- No unicast request opportunity provided
- May include a Grant Management (GM) sub-header containing
  - Slip indicator: indicates that there is an backlog in the buffer due to clock skew or loss of maps
  - Poll-me bit: indicates that the terminal needs to be polled (allows for not polling terminals with UGS-only services).

Uplink Services - rtPS

- Intended for rt-VBR-like service flows such as MPEG video
- Prohibited from using any contention requests
- Terminals polled frequently enough to meet the delay requirements of the SFs
- Bandwidth requested with BW request messages (a special MAC PDU header)
- May use Grant Management sub-header
  - new request can be piggybacked with each transmitted PDU

Uplink Service - nrtPS

- Intended for non-real-time service flows with better than best effort service
  - e.g. bandwidth-intensive file transfer
- Works like rt-polling except that polls are issued less frequently
- Allowed to use contention requests
- May use Grant Management sub-header
  - new request can be piggybacked with each transmitted PDU

Uplink Service - BE

- Generic data
  - e.g. HTTP, SMTP, etc.
- No QoS guarantees
- Allowed to use contention requests
- May use Grant Management sub-header
  - new request can be piggybacked with each transmitted PDU

Request/Grant Scheme

- Self Correcting
  - No acknowledgement
  - All errors are handled in the same way, i.e., periodical aggregate requests
- Bandwidth Requests are always per Connection
- Grants are either per Connection (GPC) or per Subscriber Station (GPSS)
  - Grants (given as durations) are carried in the UL-MAP messages
  - SS needs to convert the time to amount of data using information about the UIUC

GPSS vs. GPC

- Bandwidth Grant per Subscriber Station (GPSS)
  - Base station grants bandwidth to the subscriber station
  - Subscriber station may re-distribute bandwidth among its connections, maintaining QoS and service-level agreements
  - Suitable for many connections per terminal; off-loading base station's work
  - Allows more sophisticated reaction to QoS needs
  - Low overhead but requires intelligent subscriber station
  - Mandatory for P802.16 10-66 GHz PHY
- Bandwidth Grant per Connection (GPC)
  - Base station grants bandwidth to a connection
  - Mostly suitable for few users per subscriber station
  - Higher overhead, but allows simpler subscriber station

Bandwidth Requests

- Come from the Connection

- Several kinds of requests:
    - **Implicit requests (UGS)**
        - No actual messages, negotiated at connection setup
    - **BW request messages**
        - Uses the special BW request header
        - Requests up to 32 KB with a single message
        - Incremental or aggregate, as indicated by MAC header
    - **Piggybacked request (for non-UGS services only)**
        - Presented in GM sub-header and always incremental
        - Up to 32 KB per request for the CID
    - **Poll-Me bit (for UGS services only)**
        - Used by the SS to request a bandwidth poll for non-UGS services

Maintaining QoS in GPSS

- Semi-distributed approach
- BS sees the requests for each connection; based on this, grants bandwidth (BW) to the SSs (maintaining QoS and fairness)
- SS scheduler maintains QoS among its connections and is responsible to share the BW among the connections (maintaining QoS and fairness)
- Algorithm in BS and SS can be very different; SS may use BW in a way unforeseen by the BS

SS initialization

- Scan for downlink channel and establish synchronization with the BS
- Obtain transmit parameters (from UCD message)
- Perform ranging
- Negotiate basic capabilities
- Authorize SS and perform key exchange
- Perform registration
- Establish IP connectivity
- Establish time of day
- Transfer operational parameters
- Set up connections

Ranging

- For uplink transmissions, times are measured at BS
- At startup, SS sends a RNG-REQ in a ranging window
- BS measures arrival time and signal power; calculates required advance and power adjustment
- BS sends adjustment in RNG-RSP
- SS adjusts advance and power; sends new RNG-REQ
- Loop is continued until power and timing is ok

Registration

- Registration is a form of capability negotiation
- SS sends a list of capabilities and parts of the configuration file to the BS in the REG-REQ message
- BS replies with the REG-RSP message
  - tells which capabilities are supported/allowed
- SS acknowledges the REG-RSP with REG-ACK message

IP connectivity and configuration file download

- IP connectivity established via DHCP
- Configuration file downloaded via TFTP
- contains provisioned information
  - operational parameters
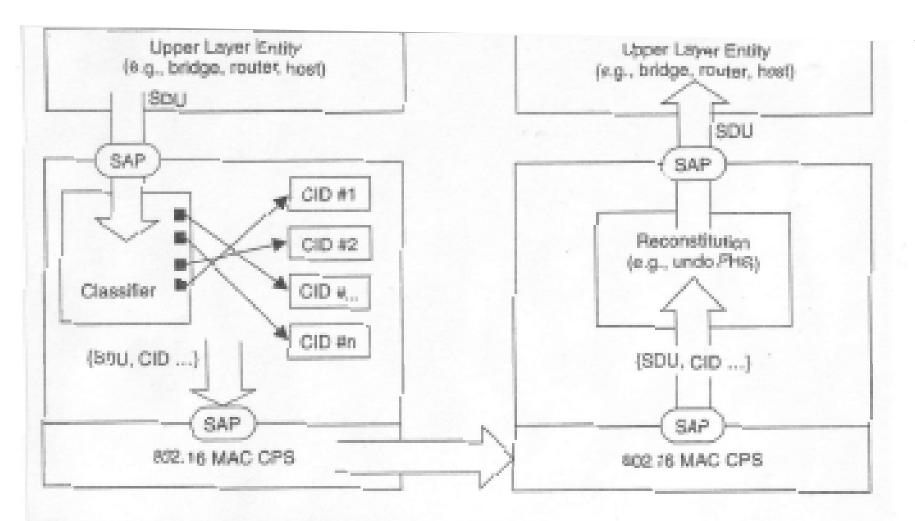
Figure 7.6 Classification and CID mapping. The principle is the same for both ways: BS to SS and SS to BS. (From IEEE Std 802.16-2004 [1]. Copyright IEEE 2004, IEEE. All rights reserved.)

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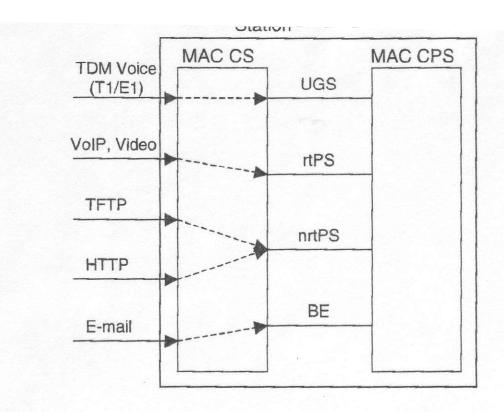
Figure 8.11 Scheduling mechanisms in a station (BS or SS). (From IEEE Std 802.16-2004 [1]. Copyright IEEE 2004, IEEE. All rights reserved.)
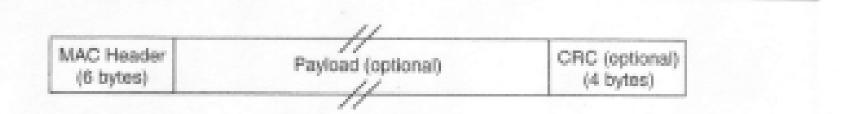
Figure 8.1 General format of a MAC frame or MAC PDU. (From IEEE Std 802.16-2004 [1]. Copyright IEEE 2004, IEEE. All rights reserved.)
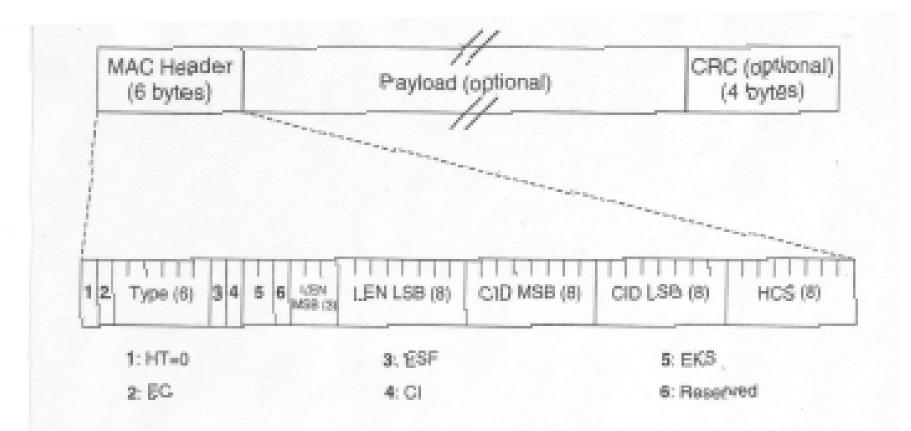
Figure 8.2 Header format of the Generic MAC frame [1]. The number in parentheses is the number of bits in the indicated field

Table 8.1 Some fields of the MAC frame generic header. (From IEEE Std 802.16-2004 [1]. Copyright IEEE 2004. IEEE. All rights reserved.)

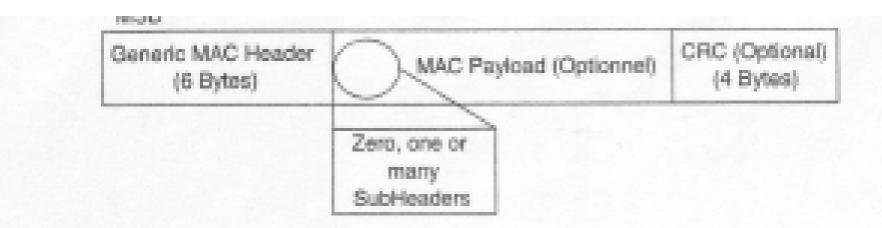| Name	Length (bits)	Description
HT	1	Header Type. Zero for generic MAC header
EC	1	Encryption Control: 0 = payload is not encrypted; 1 = payload is encrypted. For a MAC header without payload, this bit indicates whether it is Type I or II
Type	6	This field indicates the subheaders and special payload types present in the message payload (see below)
ESF	1	Extended Subheader Field. If ESF = 1, the extended subheader is present and follows the generic MAC header immediately (applicable in both the downlink and uplink)
CI	1	CRC Indicator: 1 = CRC is included (see MAC frame format); 0 = no CRC is included
EKS	1	Encryption Key Sequence. The index of the Traffic Encryption Key (TEK) and initialization vector used to encrypt the payload. Evidently, this field is only meaningful if the EC field is set to one
LEN	11	Length. The length in bytes of the MAC PDU including the MAC header and the CRC, if present
CID	16	Connection Identifier (see Chapter 7)
HCS	8	Header Check Sequence. An 8-bit field used to detect errors in the header

| Generic MAC Header (6 Bytes) | ◯ MAC Payload (Optionnel) | CRC (Optional) (4 Bytes) |

Zero, one or many SubHeaders

Figure 8.3 Generic MAC frame may have one or many subheaders

| 1 | 2 | Type (3) | HC MSB (11) | HC LSB (8) | CID MSB (8) | CID LSB (8) | HCS (8) |

1: HT=1　　　　2 : EC=0　　　HC : Header Content

Figure 8.4 Header format without payload Type I. (Based on Reference [2].)
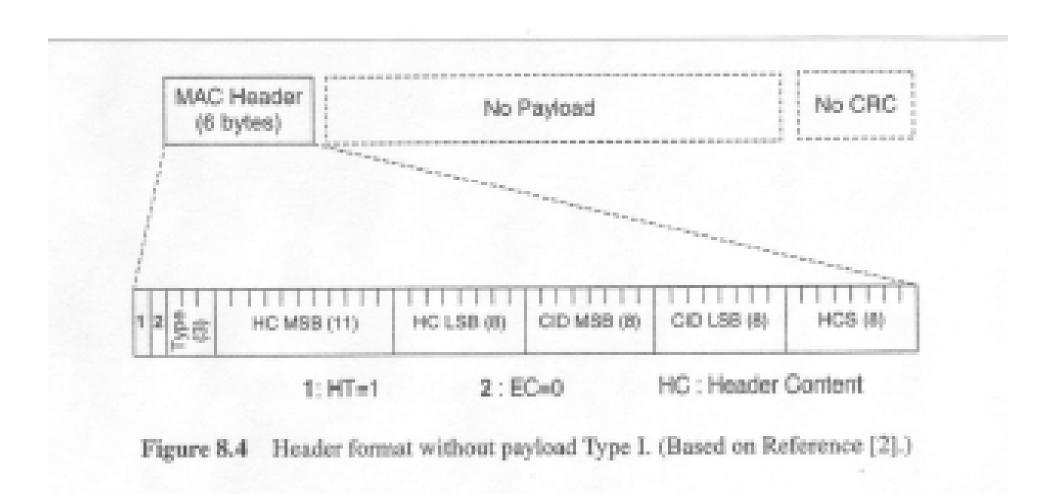
Table 8.3 Some fields of the MAC header without payload Type I. (Based on Reference [2].)

| Name	Length (bits)	Description
HT	1	Header Type. One for the header without payload
EC	1	For a MAC header without payload, this bit indicates whether it is Type I or II
Type	3	Indicates the type of header without payload (see below)
Header content	19	Header content, function of the Type field value
CID	16	Connection IDentifier
HCS	8	Header Check Sequence (same as for the generic MAC header)
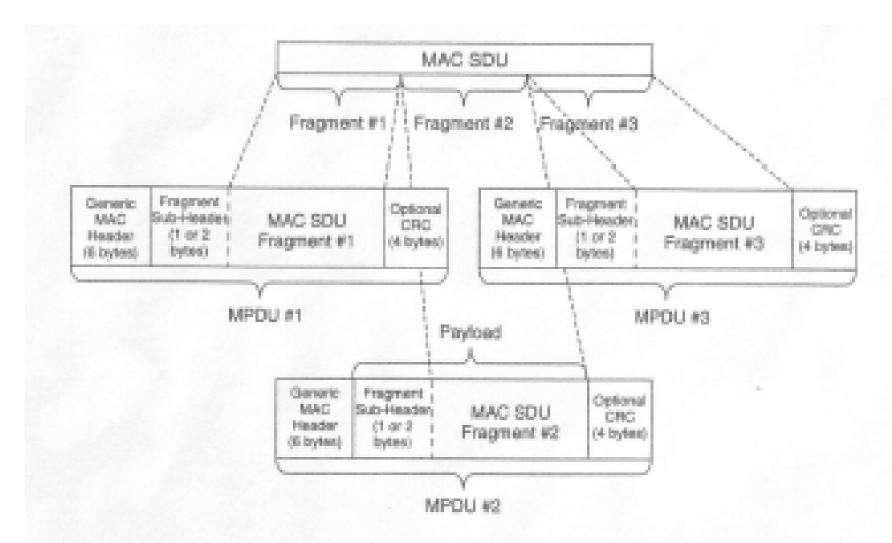
Figure 8.5 Illustration of the fragmentation of an MAC SDU giving three MAC PDUs (or MAC frames)

Generic MAC Header (6 bytes)	Packing Sub-Header (2 or 3 bytes)	MAC SDU	Packing Sub-Header (2 or 3 bytes)	MAC SDU	....	Optional CRC (4 bytes)

Figure 8.6 Illustration of the *packing* of MAC SDUs in one MAC PDU
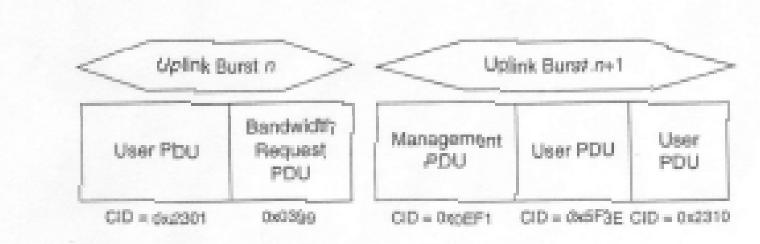
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Figure 8.7 Illustration of the concatenation for an uplink burst transmission. (From IEEE Std 802.16-2004 [1]. Copyright IEEE 2004. IEEE. All rights reserved.)
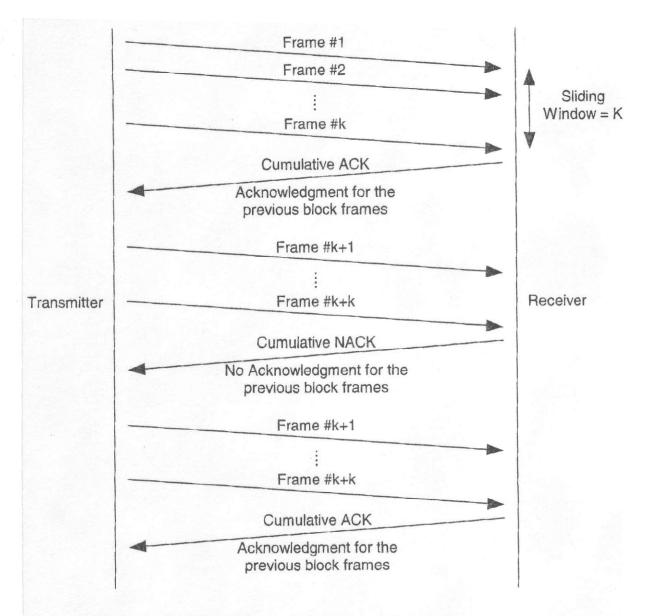
Figure 8.9 Illustration of the cumulative ARQ process