The IEEE 802.16 WirelessMAN™ Standard for Wireless Metropolitan Area Networks

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To inform the Working Group concerning a tutorial on IEEE 802.16 given by the Working Group Chair at the Beijing University of Posts and Telecommunications (22 June 2002 in Beijing, China).

The IEEE 802.16 WirelessMAN™ Standard for Wireless Metropolitan Area Networks

http://WirelessMAN.org

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Presentation Credits

- Some material prepared by:
  - Carl Eklund, Nokia
  - Ken Stanwood, Ensemble Communications

- Many IEEE 802.16 Participants contributed to content of the standard

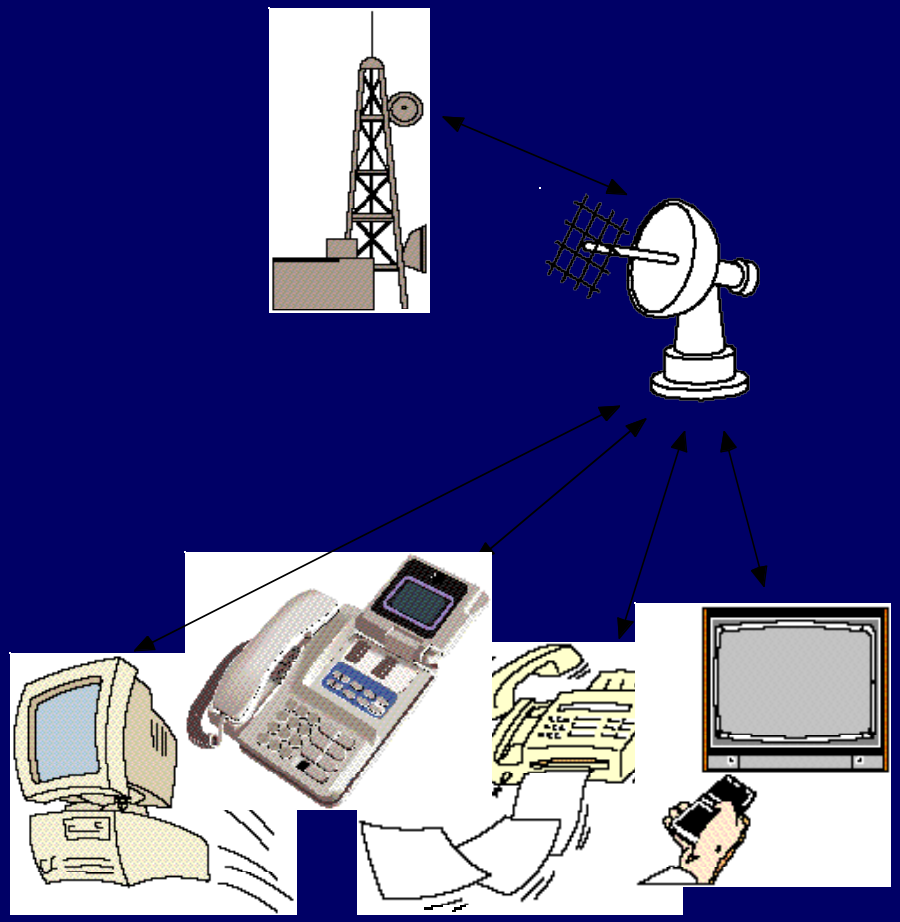
Outline

- 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 (in progress)
    - Licensed
    - License-Exempt
  - MBWA: Mobile Broadband Wireless Access Study Group
- IEEE Standard 802.16.2 and P802.16.2a
  - Recommended Practice on Coexistence

Broadband Access

- The “Last Mile” (or the “First Mile”)
  - Fast local connection to network
  - Data, voice, video
- Every customer wants it
  - Business
  - Residential
- Every operator wants it
  - Not just telephone & cable companies
- High-capacity cabling to every user is expensive

Broadband Wireless Access (BWA)



–fixed (non-mobile) customer premises units

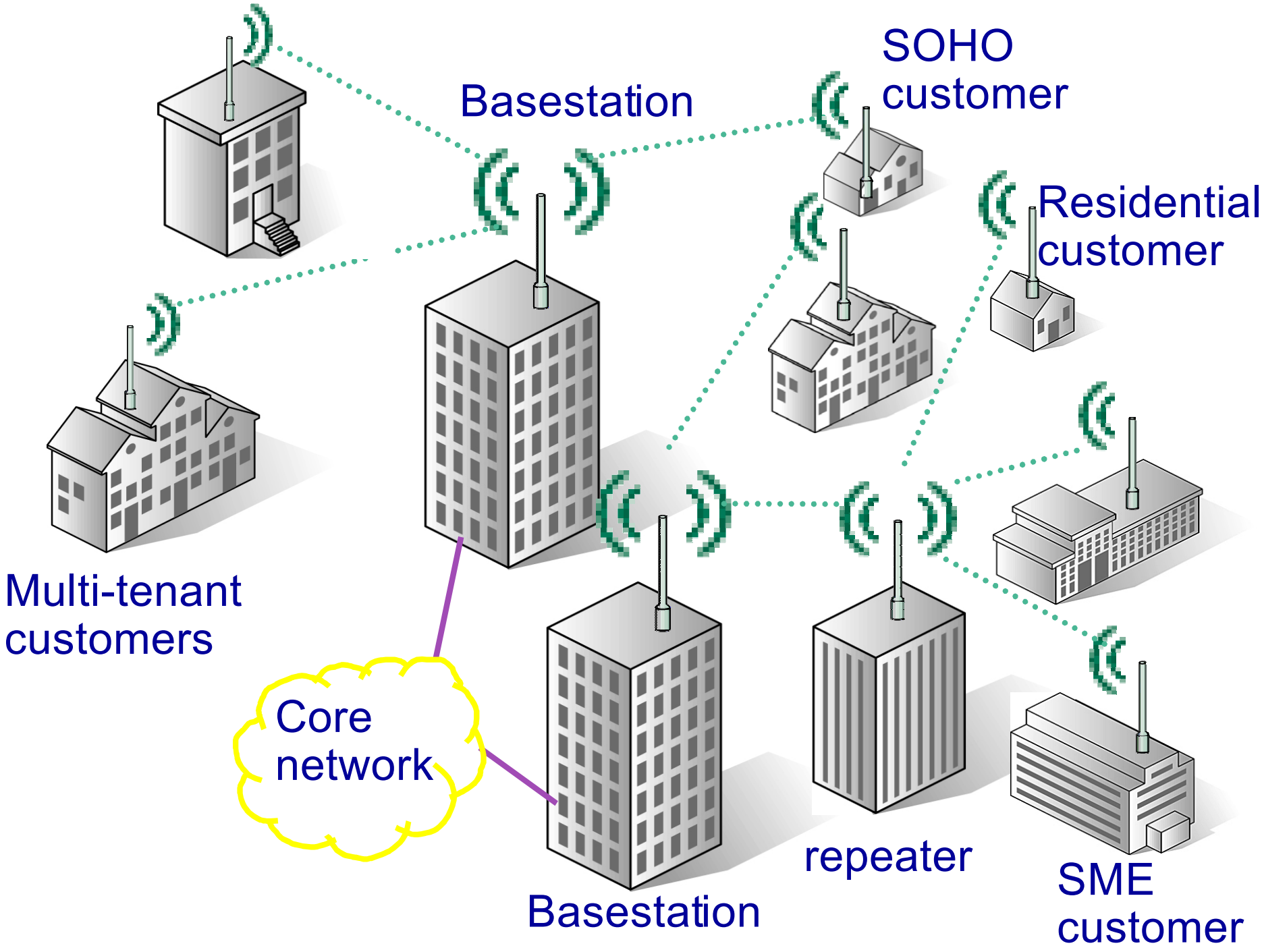
–fixed terrestrial base stations

–broadband data into businesses, homes, etc.
- ATM, TCP/IP, digital video, telephony

–potentially inexpensive and economically competitive with wired broadband

–Millimeter wave bands
  –U.S. spectrum auctions in ‘98 and ‘99
  –Largest spectrum in private hands
  –25 times as large as PCS spectrum cap

–Microwave (centimeter wave) bands
  –3.5 GHz in many countries
  –2.5 GHz in U.S.



Source: Nokia Networks

Summary: WW Spectrum for BWA

PMP Frequency Bands											
Country	10 GHz ETSI	18-24 GHz	24 GHz DEMS	26 GHz ETSI	25-27 GHz	27.5-29.5 GHz	28 GHz Like US	31 GHz	38 GHz US	38 GHz ETSI	38 GHz Other
North America											
USA			X				X	X	X		
Canada			X		X		X		X		
Asia Pacific											
Australia							X	X			
Japan		X			XU						X
Korea					XU						
Malaysia	P										
New Zealand					X						
Philippines	X	X?			X		X				
Singapore						X?	X				
Taiwan				X							X
Thailand						X					
Central& South America											
Argentina	X		X		X		X	X	X		
Bolivia							X				
Brazil	P			P							
Chile					X		X				
Colombia					X		X				
Ecuador						X					
Mexico	X			X							
Paraguay						X					
Peru						X					
Venezuela						X					

CEPT Recommendation for Europe of 40.5-42.5 and 42.5-43.5 GHz not considered

Summary: WW Spectrum for BWA

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Country	10 GHz ETSI	18-24 GHz	24 GHz DEMS	26 GHz ETSI	25-27 GHz	27.5-29.5 GHz	28 GHz Like US	31 GHz	38 GHz US	38 GHz ETSI	38 GHz Other
Europe, Middle East, Africa											
Czechoslovakia						X					
France						T					
Germany				X							
Hungary				X							
Ireland				X							
Israel				P?							
Netherlands				X							
Norway				X							
Poland						X					
Romania							X				
South Africa						X					
Spain				X			X	X			
United Kingdom	X										

CEPT Recommendation for Europe of 40.5-42.5 and 42.5-43.5 GHz not considered

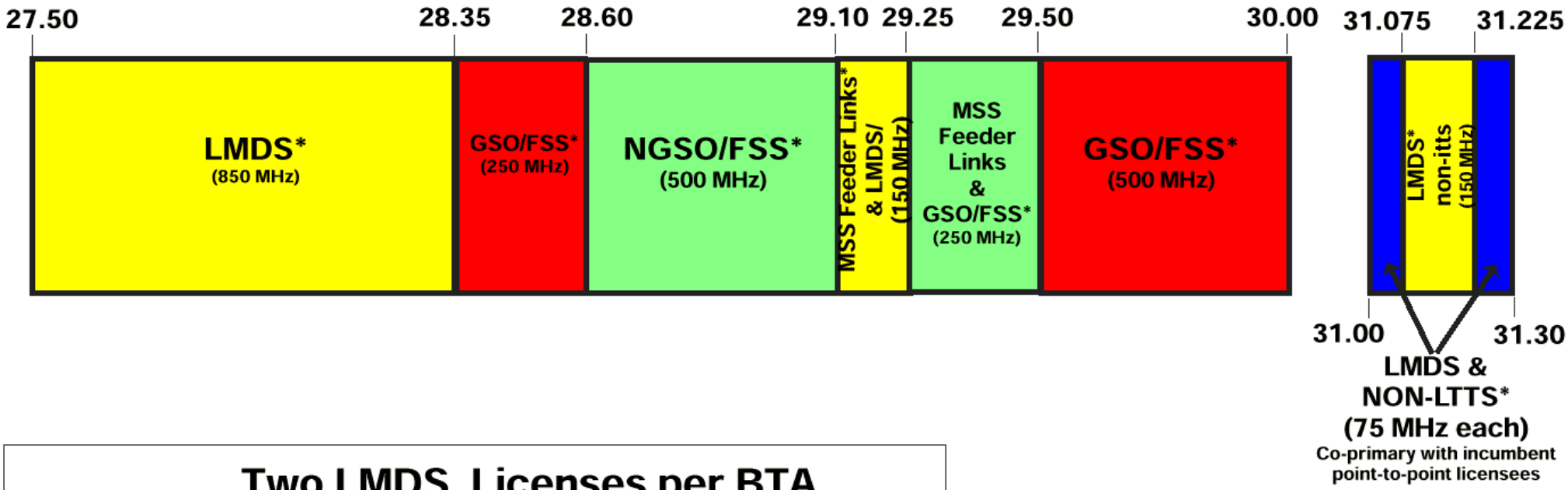
Millimeter-Wave Spectrum (LMDS)

- Around 1 GHz spectrum in many countries
- Line-of-sight propagation
- Hub radius: a few kilometers
- In each 50 MHz, at each hub:
  - –3 Gbit/s
  - – e.g. 64 customer sites at 45Mbit/sec each
  - – up to 5000 sites/hub
- LMDS “A” Block is 23 times larger

LMDS Band Allocation

(Local Multipoint Distribution Service)

28 & 31 GHz Band Plan



Two LMDS Licenses per BTA

Block A - 1150 MHz:
27,500-28,350 MHz
29,100-29,250 MHz
31,075-31,225 MHz

Block B - 150 MHz:
31,000-31,075 MHz
31,225-31,300 MHz

Legend

"*" - Primary Service
FSS - Fixed Satellite Service
GSO - Geostationary Orbit
NON-LTTS - Non-Local Television Transmission Service
MSS - Mobile Satellite Service
NGSO - Non-Geostationary Orbit

Centimeter-Wave Bands

International
3.5 GHz
10 GHz

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

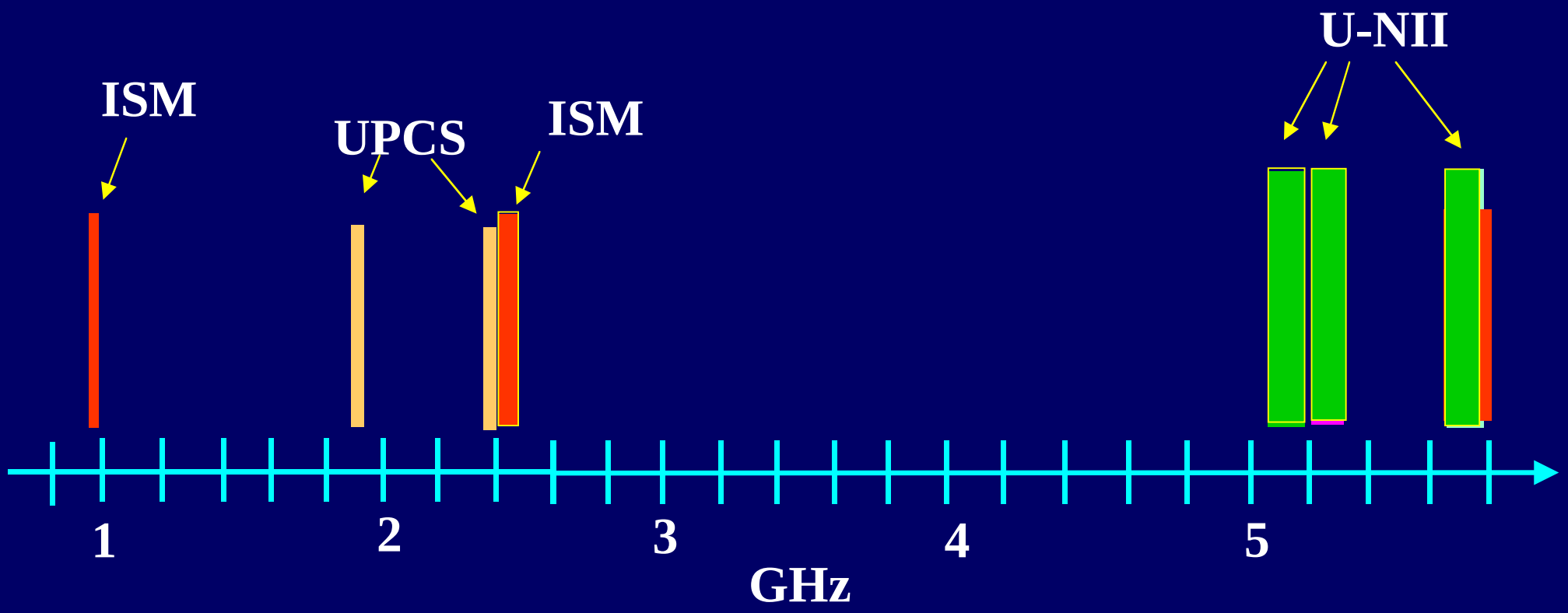
License-Exempt Bands

5.725-5.825 GHz
("U-NII" in U.S.)

2.4 GHz License-Exempt:
Wireless LANs

59-64 GHz

Unlicensed Spectrum in US



ISM: Industry, Science & Medicine

UPCS: Unlicensed Personal Communications Services

U-NII: Unlicensed National Information Infrastructure

License-Exempt Bands

Unlicensed Bands	Spectrum	Typical Applications
ISM: Industrial, Scientific and Medical 902-928 MHz, 2.4-2.4835 GHz & 5.725-5.85 GHz)	234.5 MHz	Cordless Phones, Wireless LANs (WLAN) and Wireless PBXs (WPBX)
UPCS: Unlicensed PCS Asynchronous:1910-1920, 2390-2400 MHz Isochronous: 1920-1930 MHz	 20 MHz 10 MHz	 WLAN WPBX
U-NII: Unlicensed National Information Infrastructure U-NII (5.15-5.25 GHz) U-NII (5.25-5.35 GHz) U-NII (5.725-5.825 GHz)	 100 MHz 100 MHz 100 MHz	 Indoor applications WLAN,WPBX Short outdoor links, campus applications Long outdoor links, Point-To-Point links
Millimeter Wave (59-64 GHz)	5 GHz	Home networking applications

BWA/802.16 Interest within China

"IEEE 802.16a Broadband Wireless Access (BWA) Standard Development and Internet Application": conference sponsored by BUPT and MII on 24 August 2001 in Beijing "on the specific topic of whether to use 802.16a as the Chinese national standard for fixed broadband wireless access at 3.5 GHz" (Prof. Liu Yuan An, Chair)

- 240 people (100 from government; 80 from telecom operators)

BWA in ETSI BRAN

- HIPERACCESS
  - Above 11 GHz
  - HIPERACCESS began before 802.16
  - 802.16 has encouraged harmonization
  - HIPERACCESS is completing its work (summer 2002)
  - BRAN is discussing harmonization efforts
- HIPERMAN
  - Below 11 GHz
  - IEEE went first
  - Signs of healthy cooperation
  - Sselected 802.16 MAC/802.16a OFDM PHY as baseline

IEEE 802.16 History

- IEEE Standards Association, sponsored by:
  - IEEE Computer Society
  - IEEE Microwave Theory and Techniques Society
- Project Development: Summer 1998
- Laid plans in 1998
- IEEE Study Group
  - November 1998-March 1999
- Meet every two months:
  - Session #1: July 1999
  - Session #19: May 2002

IEEE 802.16 Meeting in 2002

- Session #17/Jan 2002: Levi, Finland
- Session #18/Mar 2002: St. Louis, USA
- Session #19/May 2002: Calgary, Canada
- Session #20/July 2002: Vancouver, Canada
- Session #21/Sep 2002: Cheju, Korea
- Session #22/Nov 2002: Hawaii, USA

IEEE 802

The LAN/MAN Standards Committee

Wired:

- 802.3 (Ethernet) {10 Gbit/s approved in June 2002}
- 802.17 (Resilient Packet Ring)

Wireless:

- 802.11: Wireless LAN
  - Local Area Networks
- 802.15: Wireless PAN
  - Personal Area Networks {inc. Bluetooth}
- 802.16: WirelessMAN™
  - Metropolitan Area Networks

Why IEEE 802?

Telecom Standardization

- National
- Political

Datacom Standardization

- Global
- Open
- Industry-Driven
- 802 and IETF set the standards

Who are the Members?

- Telecom Standardization Bodies
  - Governmental Representatives
  - Companies
- IEEE
  - engineers

Free IEEE 802 Standards

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

http://standards.ieee.org/getieee802

beginning six months after publication

- You are welcome to download and read these standards!

Distribution of IEEE 802 Standards

IEEE 802 Process

- Task Groups
- Call for Contributions
  - Specific topics for discussion at next meeting
- Receive and post written contributions
- Discuss and debate at meeting
- Create draft by 75% vote
- Finalized through open IEEE Ballot

IEEE 802 Letter Ballot Response Choices

- Approve
  - May attach non-binding comments.
- Do Not Approve
  - Must attach specific comments on what must be done to the draft to change the vote to “Approve”.
- Abstain

Participation in IEEE 802.16

- Anyone may:
  - Attend and participate in meetings
  - Subscribe to mailing lists and read list archives
  - Post to mailing lists
  - Examine documents
  - Contribute and comment on documents
  - Join the Sponsor Ballot Pool
    - Vote and comment on draft standards
    - Must join the IEEE Standards Association to vote

Philosophy on Participation

- People act in their own interests.
  - Altruism not required.
  - The process channels individual interests for common gain.
    - Within anti-trust laws
- All are are welcome to participate.
  - This will take work.
- All are welcome to not participate
- All are welcome to use the results.

Membership in IEEE 802.16

- Belongs to the individual
  - no formal company participation
- Earned through attendance
  - No membership fee, dues, etc.
- Provides voting rights
- Observer status
  - Participate in a single session
  - Provides access to all documents
    - Same access as members

IEEE 802.16 by the Numbers

- 119 Members (peaked at 178)
- 39 “Potential Members”
- 33 Official Observers
- >750 different individuals have attended a session
- 2.8 Million file downloads in year 2000
- Members and Former Members from
  - 12 countries
  - 144 companies

Countries of 802.16 Members (current and former)

- CANADA (48)
- FINLAND (4)
- FRANCE (2)
- GERMANY (2)
- GREECE (2)
- ISRAEL (22)
- ITALY (1)
- JAPAN (2)
- KOREA (4)
- SPAIN (1)
- UK (11)
- USA (161)

Note: 2 participants from Beijing at Session #17

Companies of 802.16 Members (current & former)

- 3Com Corp.
- Advantech AMT Company
- Agilent Technologies
- Airspan Communications Ltd.
- Akelia Wireless
- Alcatel
- Alvarion Ltd.
- Analog Devices
- Aperto Networks
- ArrayComm, Inc.
- Astute Networks
- AT&T Wireless Services
- BAE Systems
- Barcombe Consulting
- BeamReach Networks, Inc.
- Bell Canada
- Belstar Systems Corp.
- BridgeWave Communications, Inc.
- Broadcom Corp.
- Broadstorm Telecommunications
- Caly Networks
- Canon R&D Center Americas, Inc.
- Carleton University
- Ceragon Networks
- CircuitPath Network Systems
- Clearwire Technologies
- CommAccess Technologies, Inc.
- Communications Consulting
- ComTier
- Concordia University
- Conexant Systems
- Coreon Inc.
- Correlant Communications
- Crosspan
- DENSO International America
- DMC Stratex Networks
- E. A. Robinson Consulting
- Ensemble Communications
- Enterasys Networks
- EPCOS AG
- Escape Communications
- ETRI
- Fujitsu Microelectronics
- Fujitsu Network Comms
- Gabriel Electronics
- Gennum Corporation
- Georgia Institute of Technol
- Global Communications Solns
- GTE Laboratories Incorporated
- Harris Corporation
- Hexagon System Engineering
- HighSpeed Communications
- Hitachi America R&D
- HRL Laboratories
- Hughes Network Systems
- IceFyre Semiconductor
- iCODING Technology Inc.
- IDRIS Communications
- Industry Canada
- Infineon Technologies AG
- InnoWave ECI
- Integrated Device Technology
- Integrity Communications
- Intel
- InterDigital Communications
- Intersil
- Iospan Wireless
- Juniper Networks
- Kostas Associates
- Legend Silicon Corp.
- Lockheed Martin
- Lucent
- Mabuhay Networks
- Malibu Networks
- Marconi
- Marvell Semiconductor
- Media Works
- Meriton Networks
- Mitsubishi Electric Corp.
- Mitsubishi Electronics America
- MostlyTek Ltd.
- Motorola
- National Rural Telephone
- Navini Networks
- nBand Communications
- NEC America, Inc.
- Netro Corporation
- Nextcomm, Inc.
- NIST
- Nokia Networks
- Nortel Networks
- Nottingham Trent University
- NTT
- Oak Wireless
- Omnitel Pronto Italia
- Paul Thompson Associates
- Provigent, Inc.
- Proxim Corporation
- Radia Communications, Inc.
- Radiant Networks PLC
- RADWIN Ltd.
- Rafael
- Rainbow Network Systems
- Raze Technologies
- Red Dot Wireless
- Redline Communications
- RF Solutions
- Ron Meyer Consulting
- Runcom Technologies Ltd.
- SACET
- Samsung
- Saraband Wireless, Inc.
- SP Wireless
- SpaceBridge Networks
- Speedcom Wireless
- Spike Broadband Systems
- Spike Technologies, Inc.
- SPL-ACT Wireless
- Sprint
- SR Telecom Inc.
- StarWave Consulting
- Telaxis
- Telcordia
- Telegen Ltd.
- Teligent, Inc.
- Texas Instruments
- Transcomm Inc.
- Trapeze Networks
- Triton Network Systems
- U S WEST
- University of Sheffield
- Vectrad Networks
- Vyyo Inc.
- WaveIP Ltd.
- Wavesat Telecom
- Wavion
- Wavtrace
- Westwave Comms
- Wi-LAN Inc.
- Widax Corp.
- WinStar
- Wireless Facilities, Inc.
- World Access Inc.
- Xilinx

Patents

- “IEEE standards may include the known use of patent(s), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard.”

- More details on the web site.

IEEE 802.16 Projects

- Air Interface (PHYs with common MAC)
  - 802.16: 10-66 GHz
    - Completed in October 2001
    - Published in April 2002
    - Interoperability test documents in development
      - Profiles; PICS; Test Purposes; Abstract Test Suites
  - 802.16a: 2-11 GHz
    - Licensed and license-exempt bands only
    - Balloting since November 2001
    - Completion expected in October 2002
  - Mobile Broadband Wireless Access Study Group
- Coexistence
  - IEEE 802.16.2 (10-66 GHz)
    - Published in September 2001
  - P802.16.2a: amendment
    - with 2-11 GHz licensed
    - Completion expected in March 2003

IEEE 802.16 Project Structure

Air Interface (Standard)	Coexistence (Recommended Practice)
IEEE Standard 802.16 (published) MAC 10-66 GHz PHY	IEEE Standard 802.16.2 (published) 10-66 GHz
P802.16a 2-11 GHz PHY MAC enhancements in ballot Completion: October 2002	P802.16.2a 2-11 GHz in development Completion: March 2003

IEEE Standard 802.16: The WirelessMAN-SC™ Air Interface

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

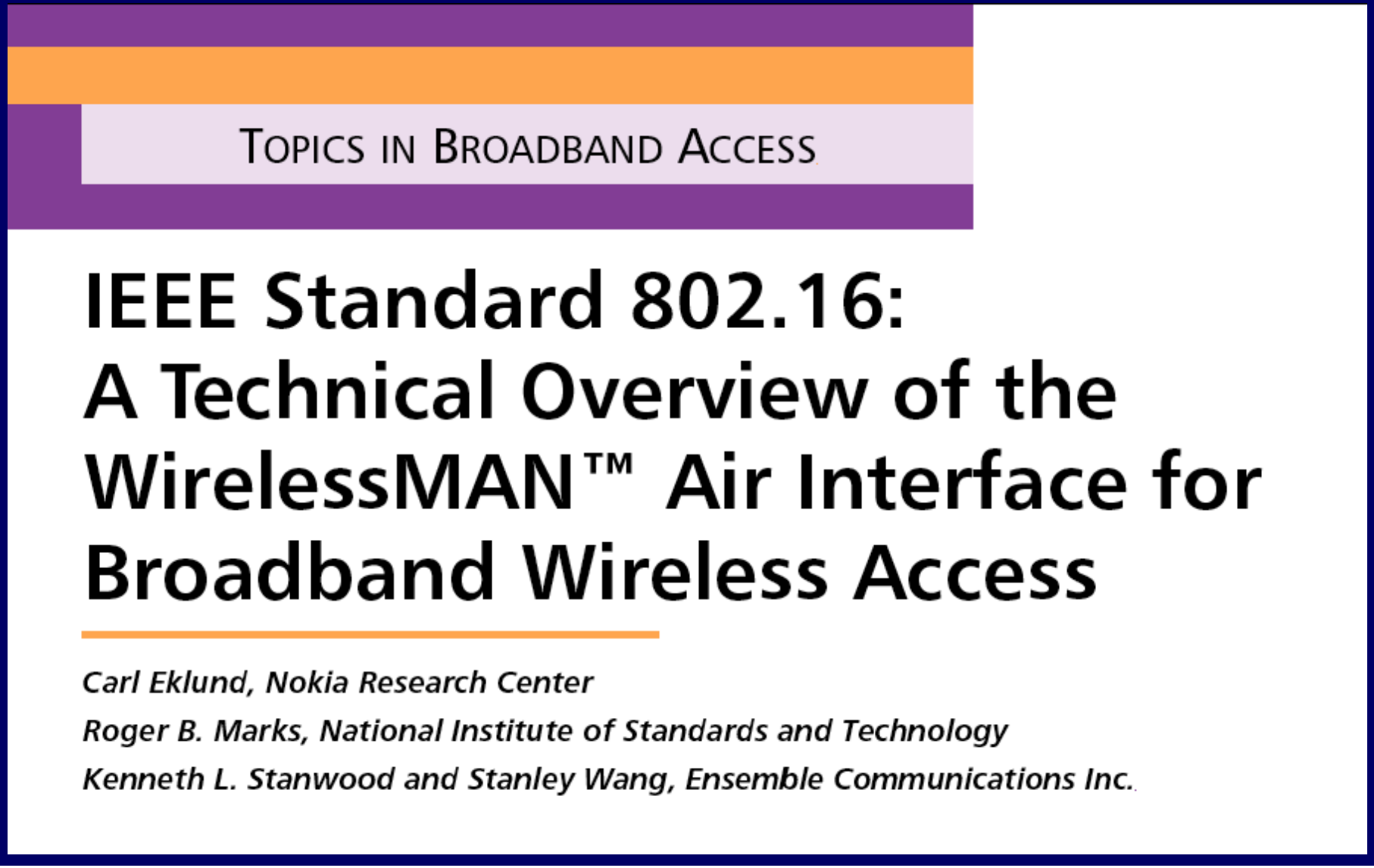
Approved 6 December 2001

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

IEEE Standard 802.16: Tutorial

IEEE Communications Magazine, June 2002
(available on 802.16 web site)



IEEE Std 802.16: Scope

Specifies the air interface, including the medium access control layer (MAC) and physical layer (PHY), of fixed 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 the application. The standard includes a particular physical layer specification broadly applicable to systems operating between 10 and 66 GHz.

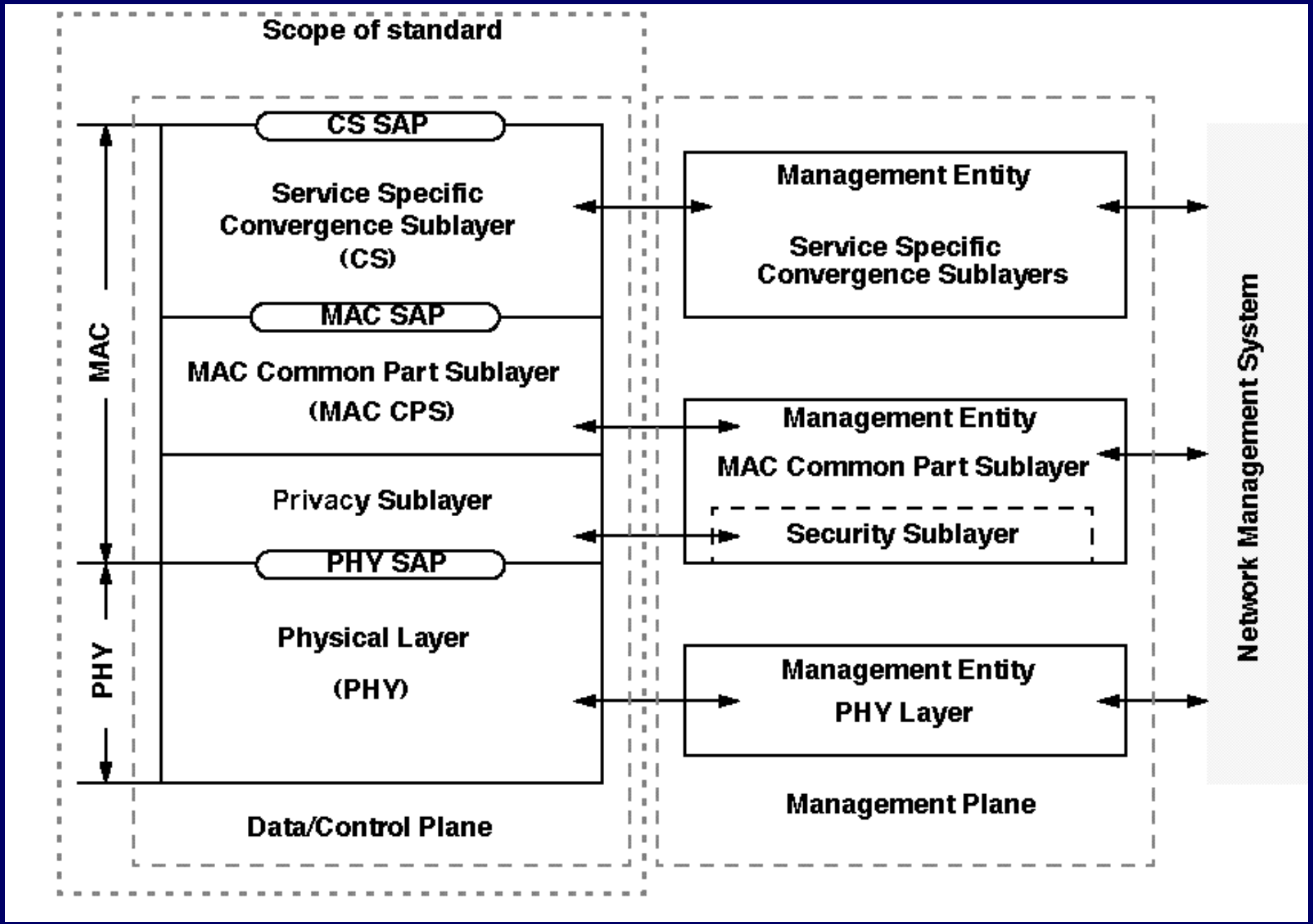
Point-to-Multipoint Wireless MAN: not a LAN

- 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
- Multiple services, with different QoS priority
- Compared to a Wireless LAN:
  - Multimedia QoS, not only contention-based
  - Many more users
  - Much higher data rates
  - Much longer distances

IEEE Std 802.16: History

- July-September, 1999: Functional Requirements
- November 1999: 35 Proposals
- January 2000: 2 Consolidated Proposals
  - 1 MAC proposal based on DOCSIS
  - 1 not
- May 2000: Plan to Merge 2 Proposals
- August 2000: Rev. 0
- until February 2001: Working Group Review
  - formal comment process
- February-August 2001: WG Letter Ballot
- August-October 2001: IEEE Sponsor Ballot
- 6 December 2001: Approved
- 8 April 2002: Published

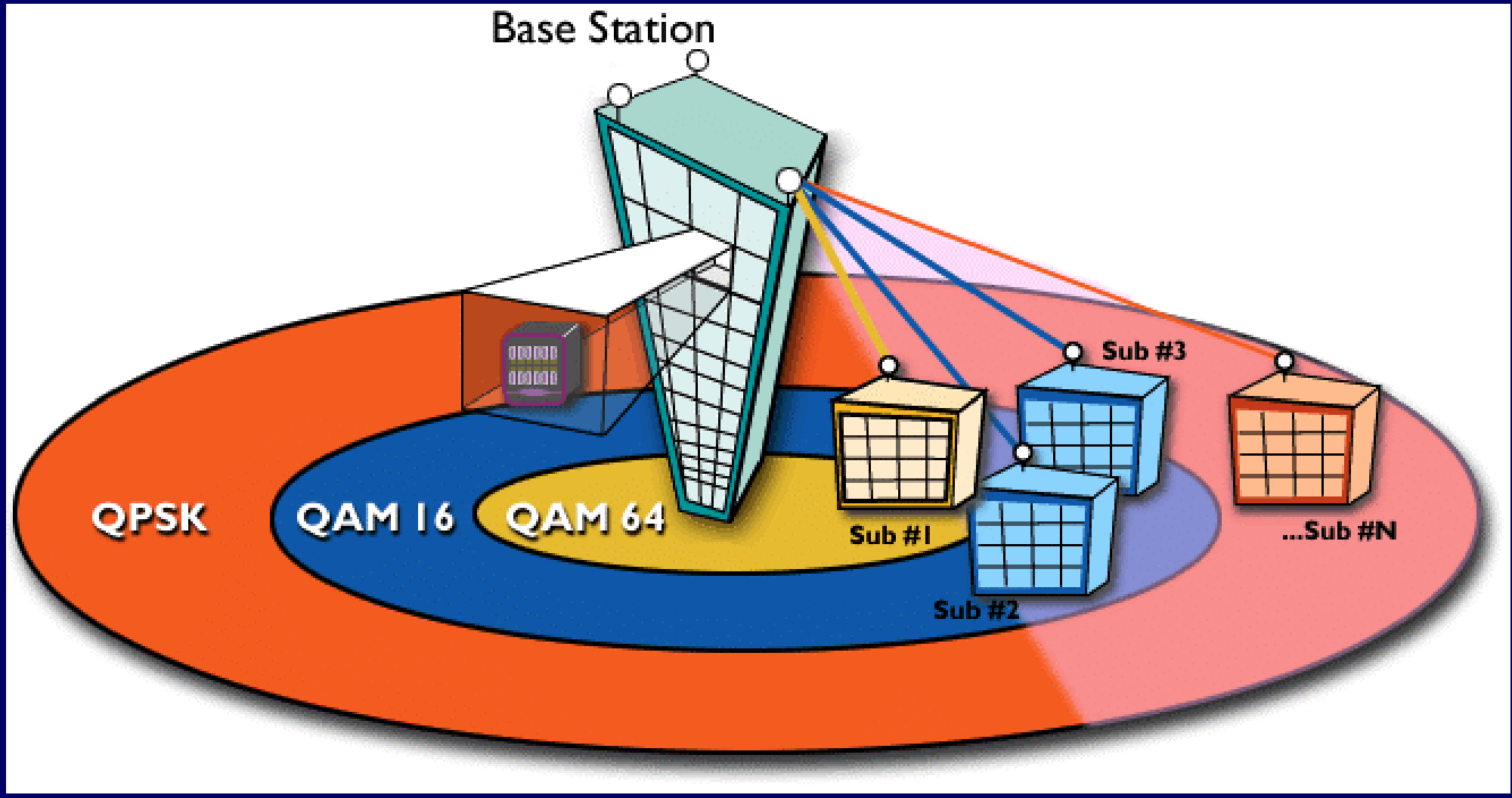
Reference Model



PHY Considerations

- Line of Sight (because of 10-66 GHz)
  - Negligible multi-path ⇒ Large channels
- Broadband Channels
  - Wide channels (20, 25, or 28 MHz)
  - High capacity – Downlink AND Uplink
- Multiple Access
  - TDM/TDMA
  - High rate burst modems
- Adaptive Burst Profiles on Uplink and Downlink
- Multiple duplex schemes
  - Time-Division Duplex (TDD)
  - Frequency-Division Duplex (FDD) [including Burst FDD]
    - Support for Half-Duplex Terminals

Adaptive PHY



(burst-by-burst adaptivity not shown)

Definitions

- BS
  - Base Station
- SS
  - Subscriber Station
- Downlink (DL)
  - BS to SS
- Uplink (UL)
  - SS to BS

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

Modulation

- Single Carrier QAM, Gray coded
  - QPSK
  - 16QAM
    - Mandatory for Downlink, Optional for Uplink
  - 64QAM
    - Optional for both Downlink & Uplink
- Preambles based on 16 symbol CAZAC sequences

FEC

- Reed Solomon
  - RS GF(256), t = 0…16
- For most critical communications, RS is concatenated with a BCC
  - No interleaving, suitable for burst
  - BCC is a rate 2/3 block code based on a tail-bite termination of the $(7,5)_8$ Convolutional Code for every 16 data bits
- Shortening allowed
- Turbo Product Codes (TPC) are optional

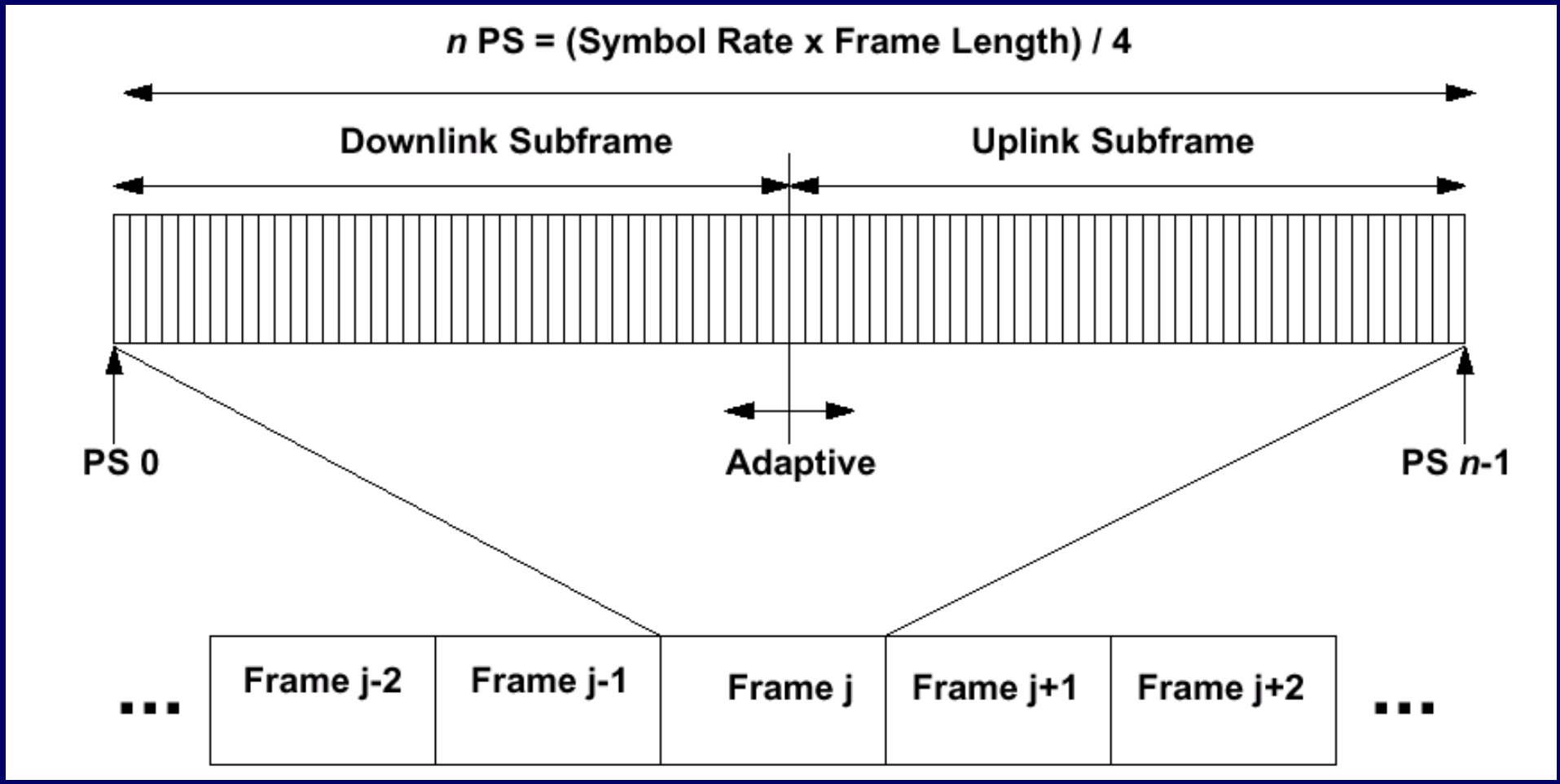
Duplex Scheme Support

- On DL, SS addressed in TDM stream
- On UL, SS is allotted a variable length time slot for transmission
- 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)

Framing Structure

- Frame length: 1 ms
- Allocation process is done in terms of PSs
  - PS = Physical Slot = 4 Modulation Symbols
  - Depending on modulation, a PS contains 1, 2, or 3 bytes

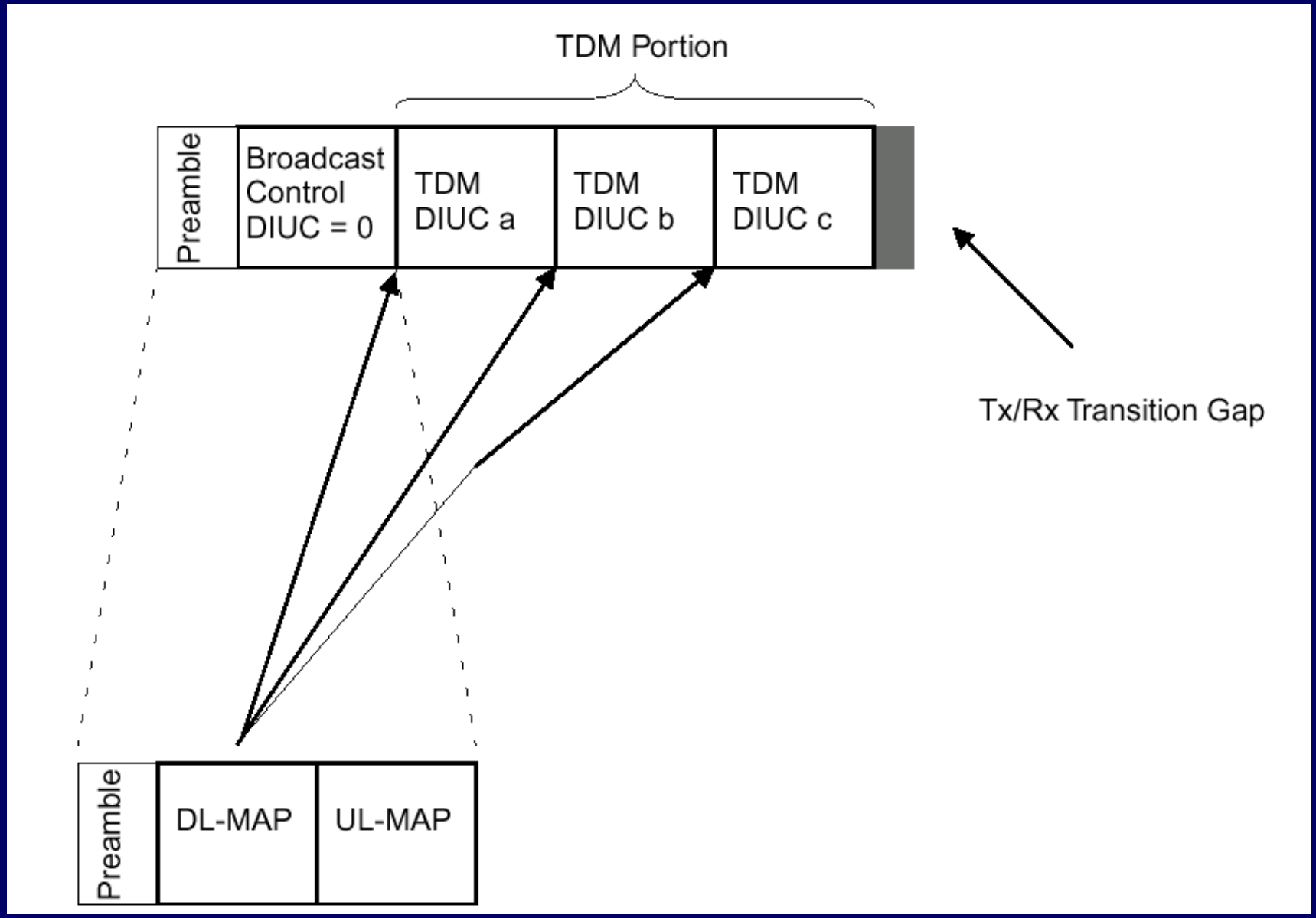
TDD Frame (10-66 GHz)



Frame duration: 1 ms

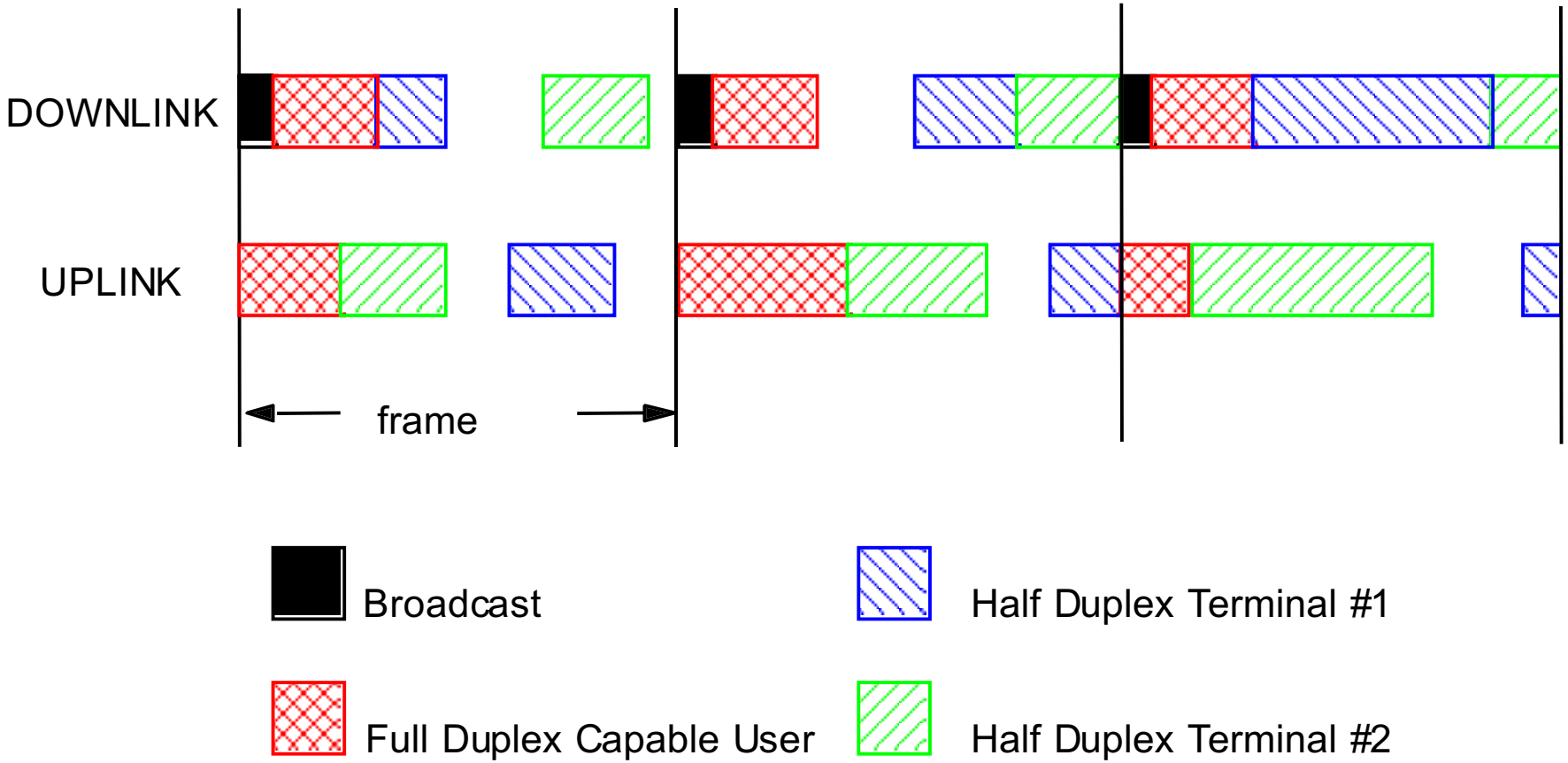
Physical Slot (PS) = 4 symbols

TDD Downlink Subframe



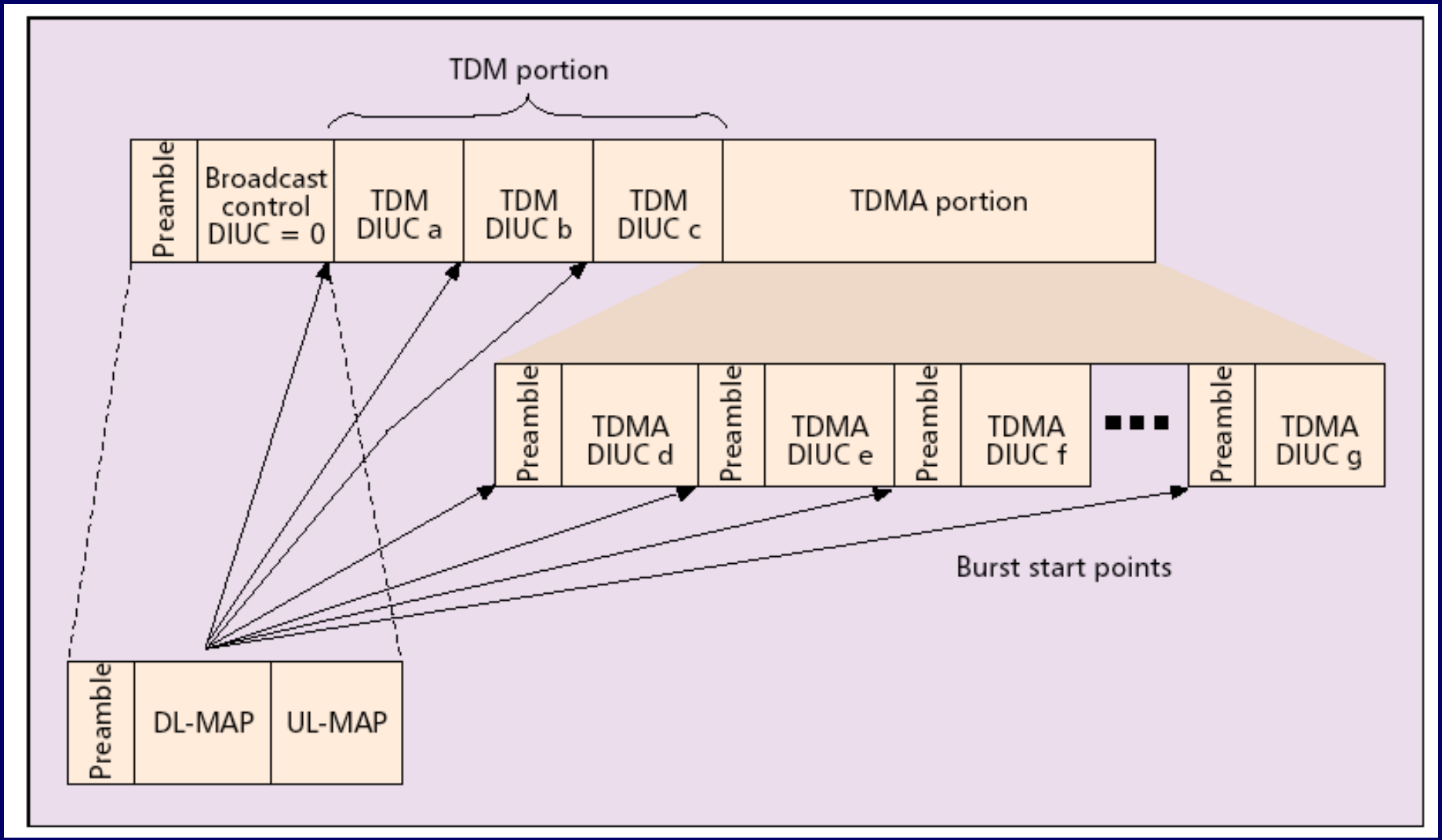
DIUC: Downlink Interval Usage Code

Burst FDD Framing



Allows scheduling flexibility

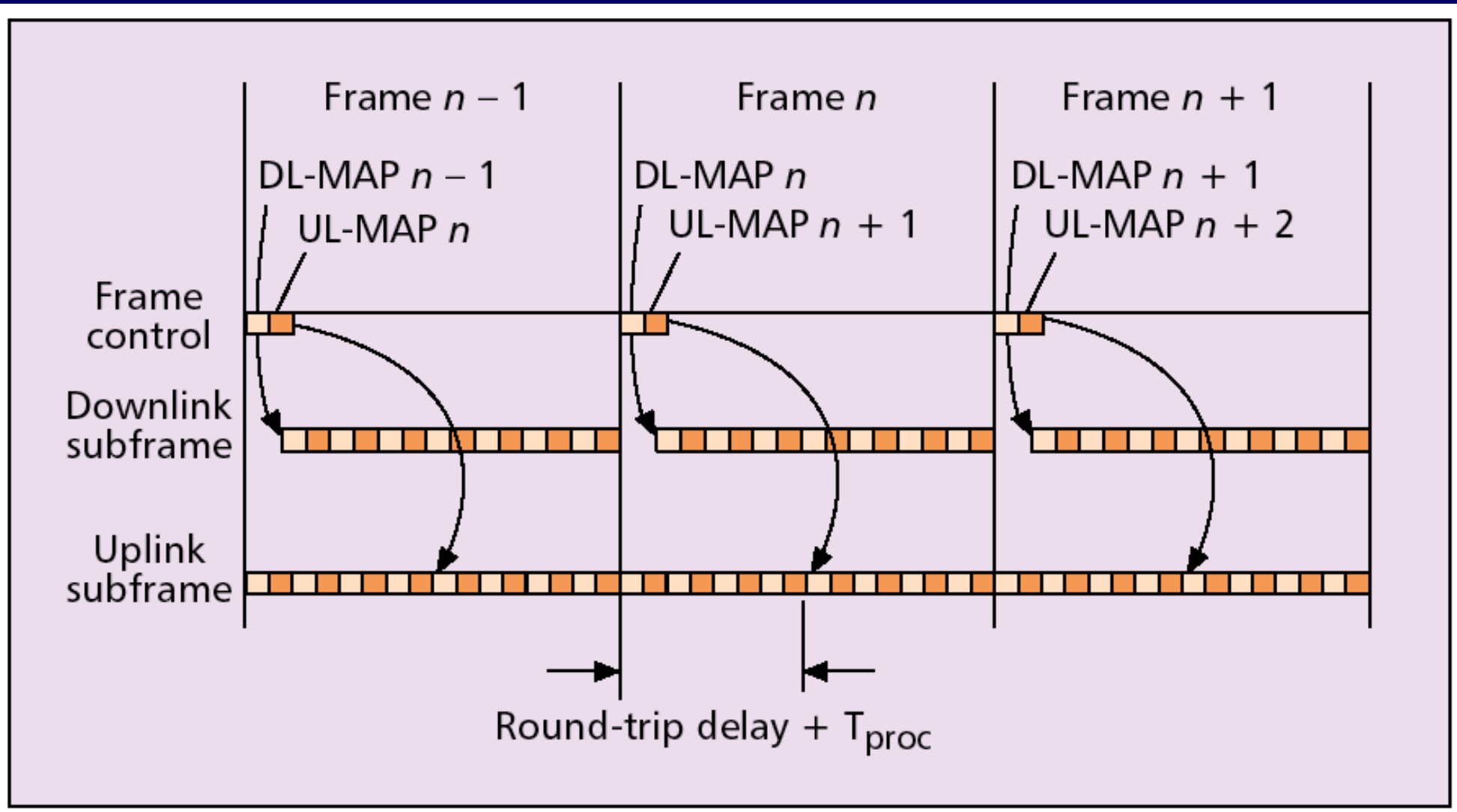
FDD Downlink Subframe



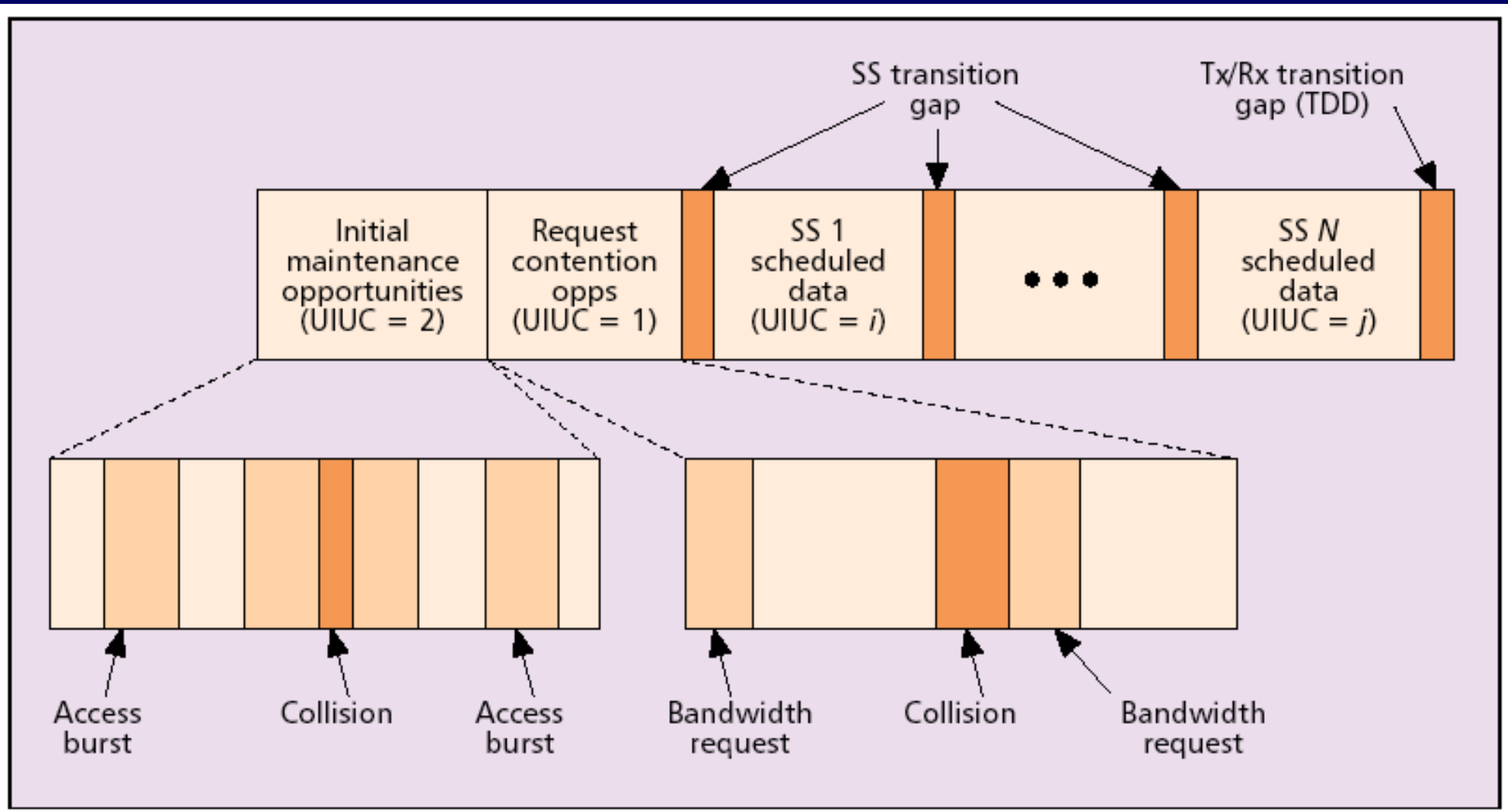
TDMA portion: transmits data to some half-duplex SSs (the ones scheduled to transmit earlier in the frame than they receive)

- Need preamble to re-sync (carrier phase)

FDD Uplink Subframe: Minimum Advance



Typical Uplink Subframe (TDD or FDD)



Baud Rates & Channel Size (10-66 GHz)

- Flexible plan - allows equipment manufactures to choose according to spectrum requirements

Channel Width (MHz)	Symbol Rate (Msym/s)	QPSK Bit Rate (Mbit/s)	16-QAM Bit Rate (Mbit/s)	64-QAM Bit Rate (Mbit/s)
20	16	32	64	96
25	20	40	80	120
28	22.4	44.8	89.6	134.4

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 PHY alternatives
  - Adaptive mod, TDD/FDD; single-carrier, OFDM/OFDMA, etc.

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

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)

ATM Convergence Sublayer

- Support for:
  - VP (Virtual Path) switched connections
  - VC (Virtual Channel) switched connections
- Support for end-to-end signaling of dynamically created connections:
  - SVCs
  - soft PVCs
- ATM header suppression
- Full QoS support

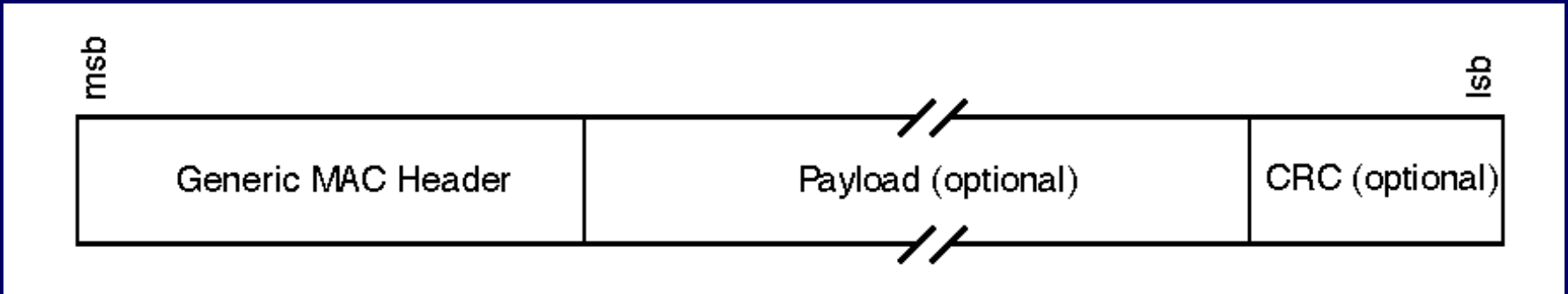
Packet Convergence Sublayer

- 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

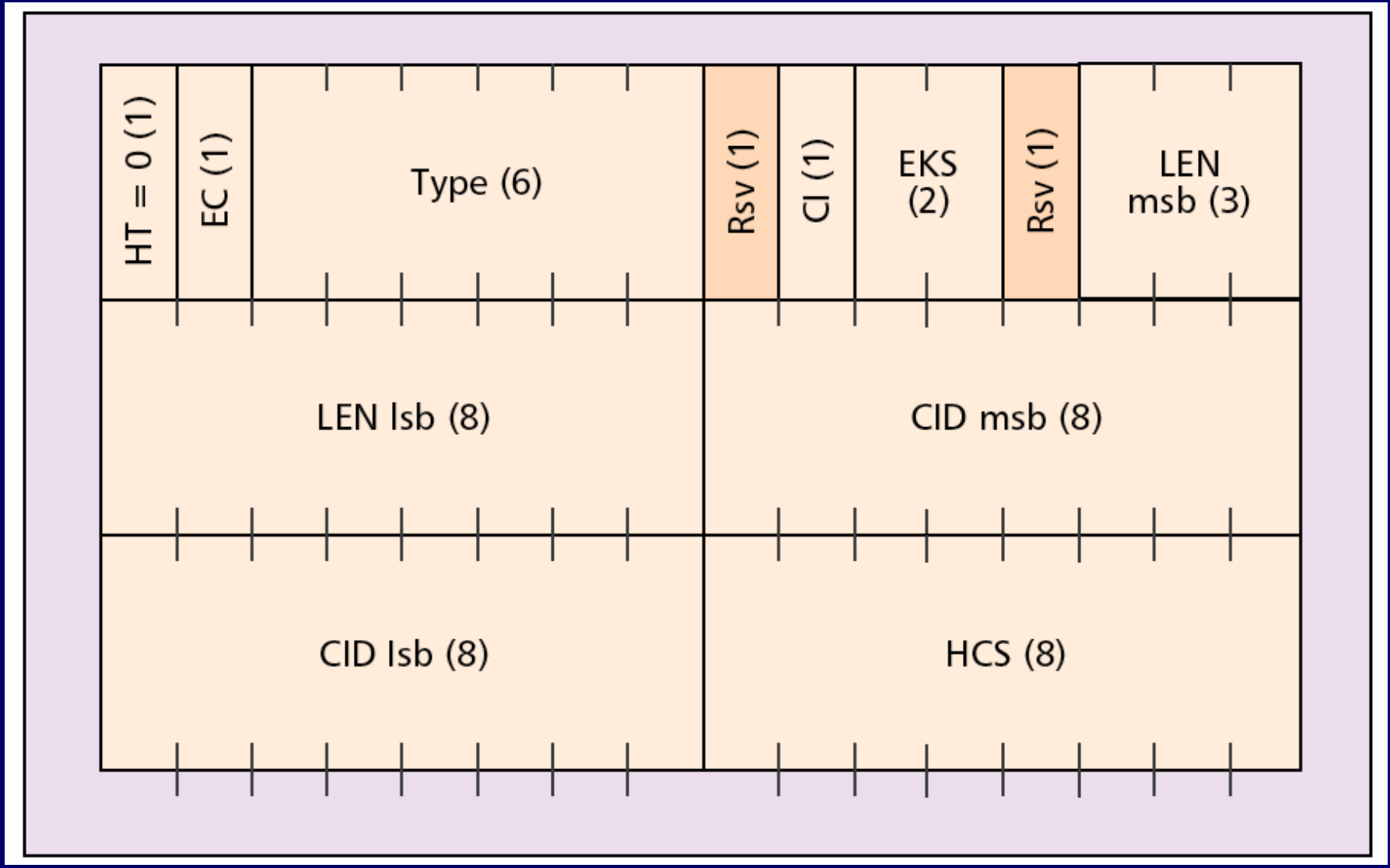
- SS has 48-bit IEEE MAC Address
- BS has 48-bit Base Station ID
  - Not a MAC address
  - 24-bit operator indicator
- 16-bit Connection ID (CID)
  - Used in MAC PDUs

MAC PDU 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



LEN: PDU length, in bytes (2048 max)

CID: Connection ID

EKS: Encryption Key Sequence

HT: Header Type

EC: Encryption Control

CI: CRC Indicator

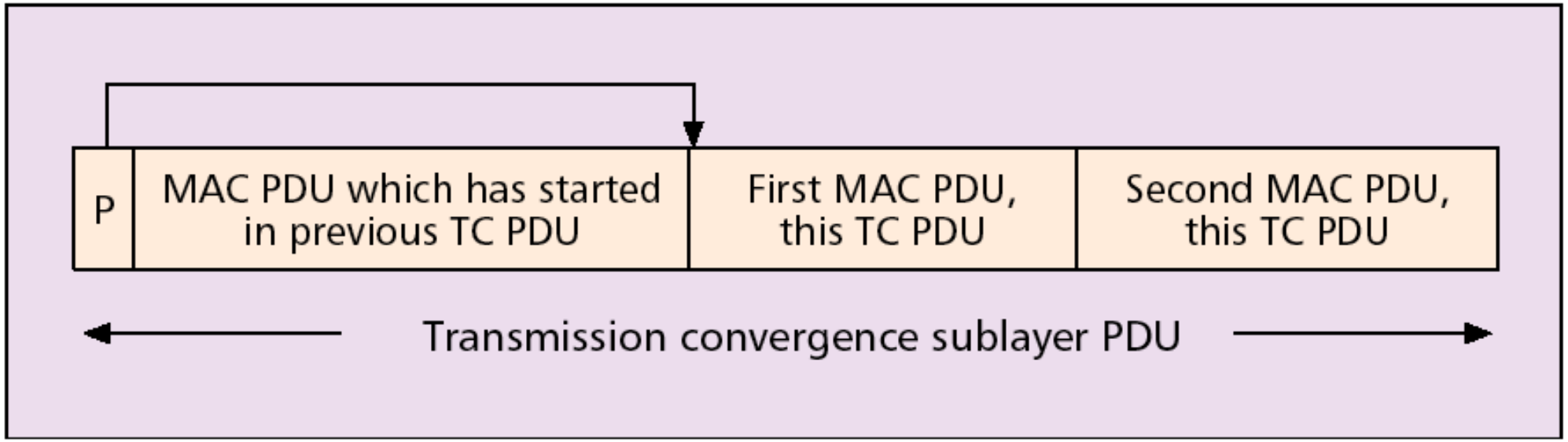
Type: subheaders, etc.

HCS: Header Check Sequence

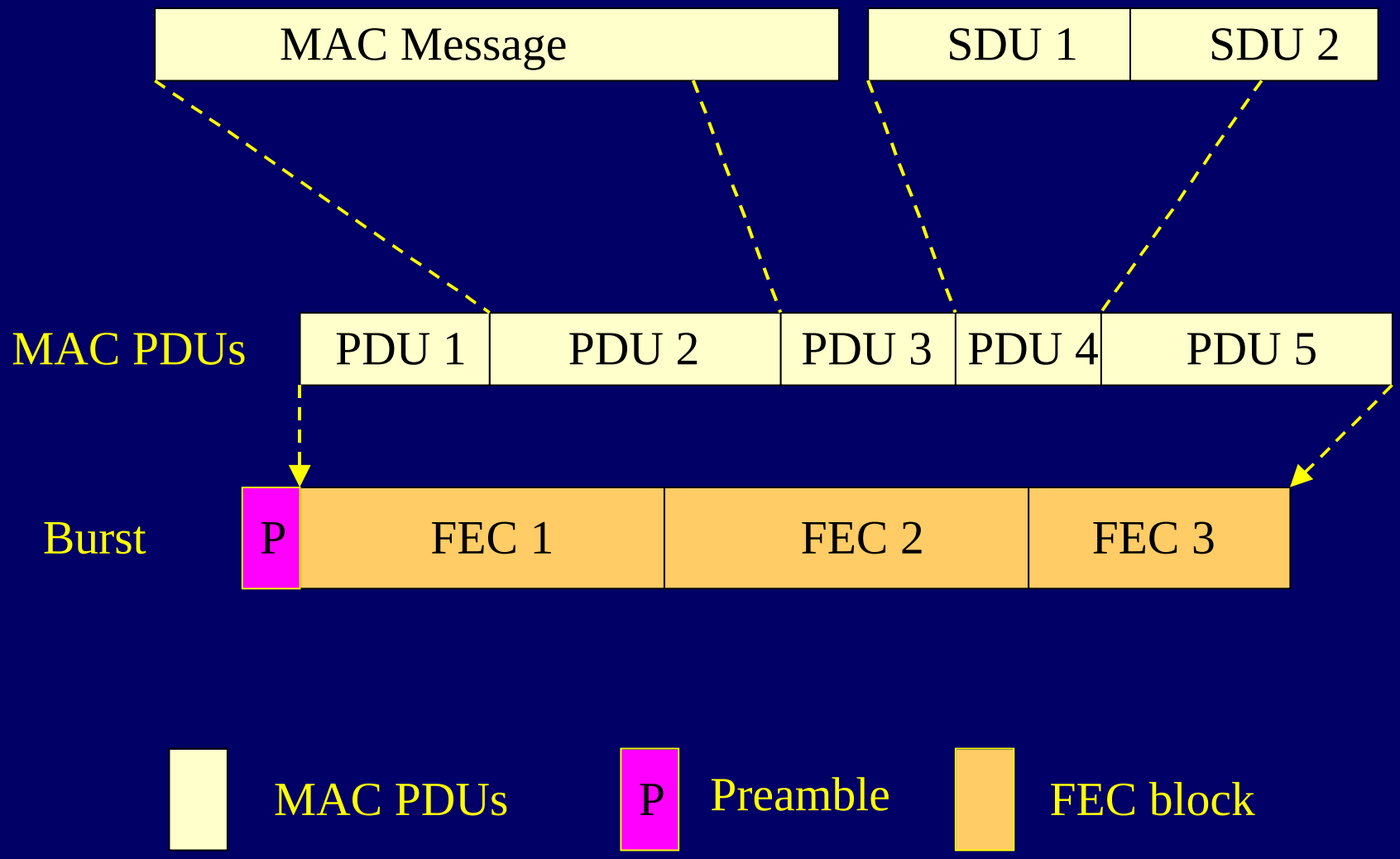
MAC PDU Transmission

- 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

Transmission Convergence Sublayer PDU Format



MAC PDU Transmission



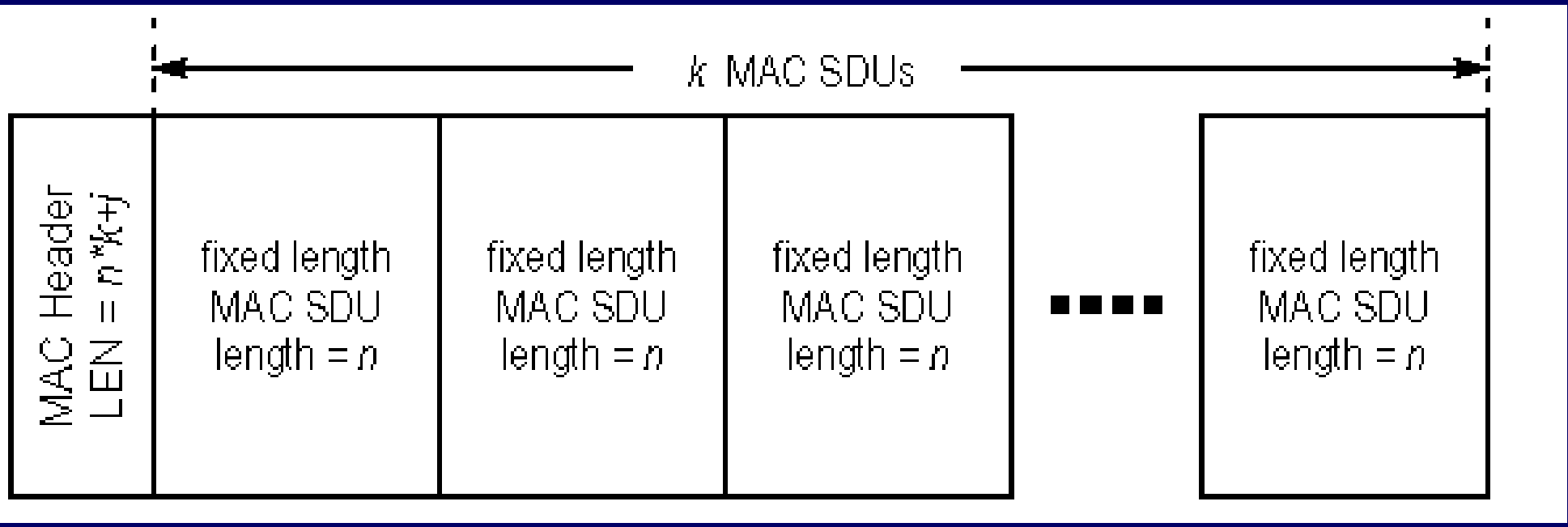
Fragmentation

- 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

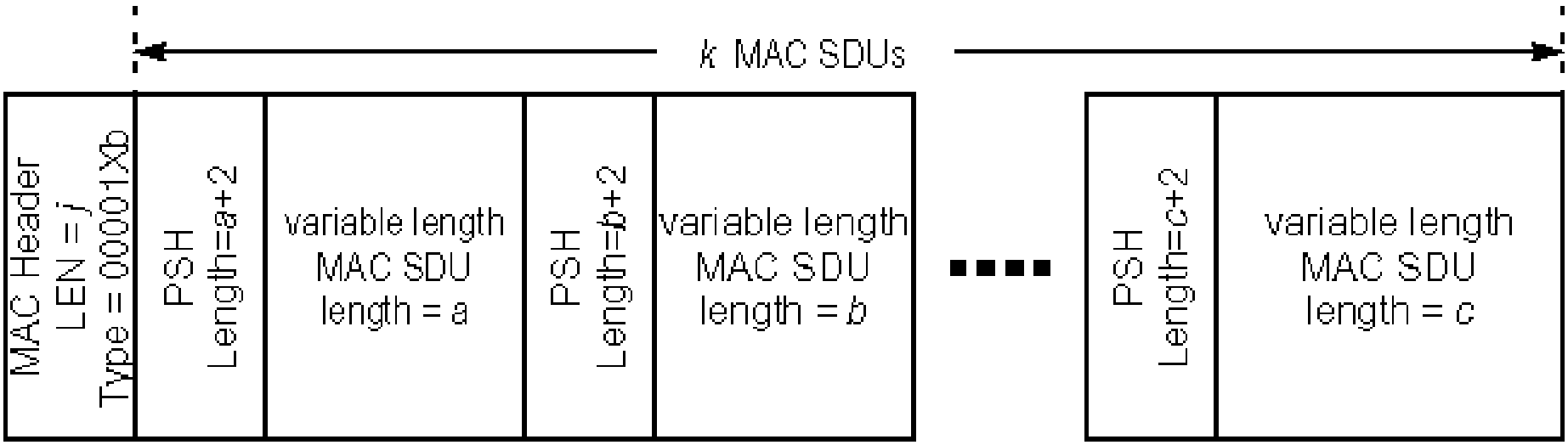
Packing

- 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

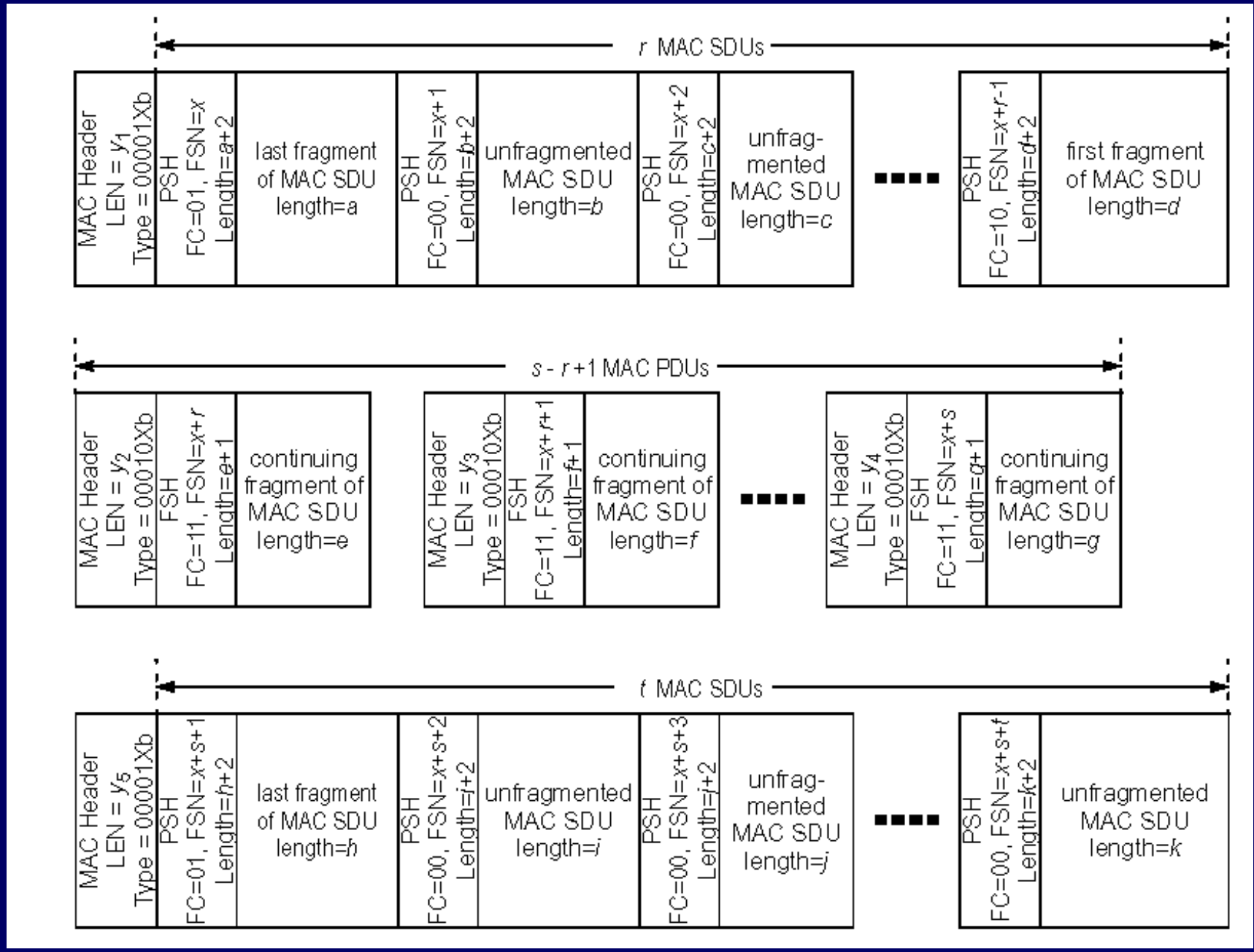


Packing Variable-Length SDUs



- 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

Packing with Fragmentation



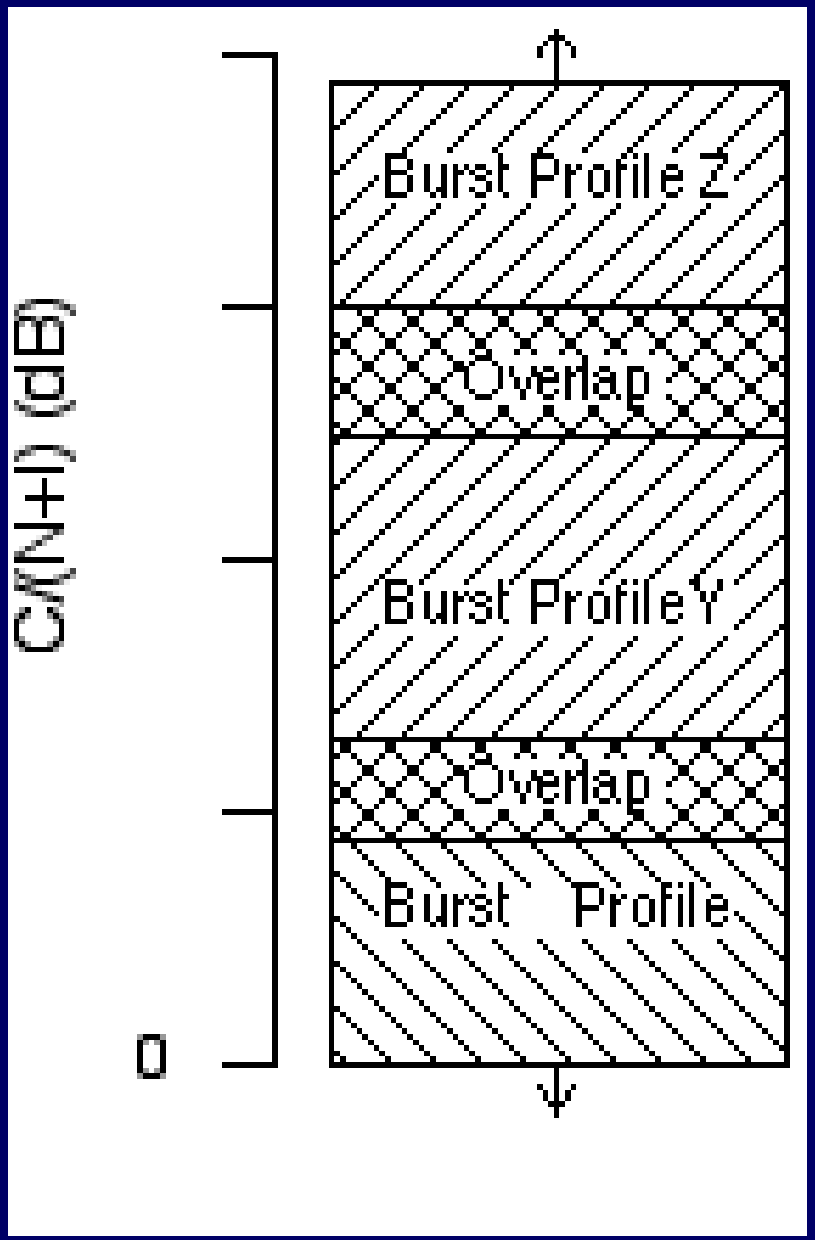
Downlink transmissions

- 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

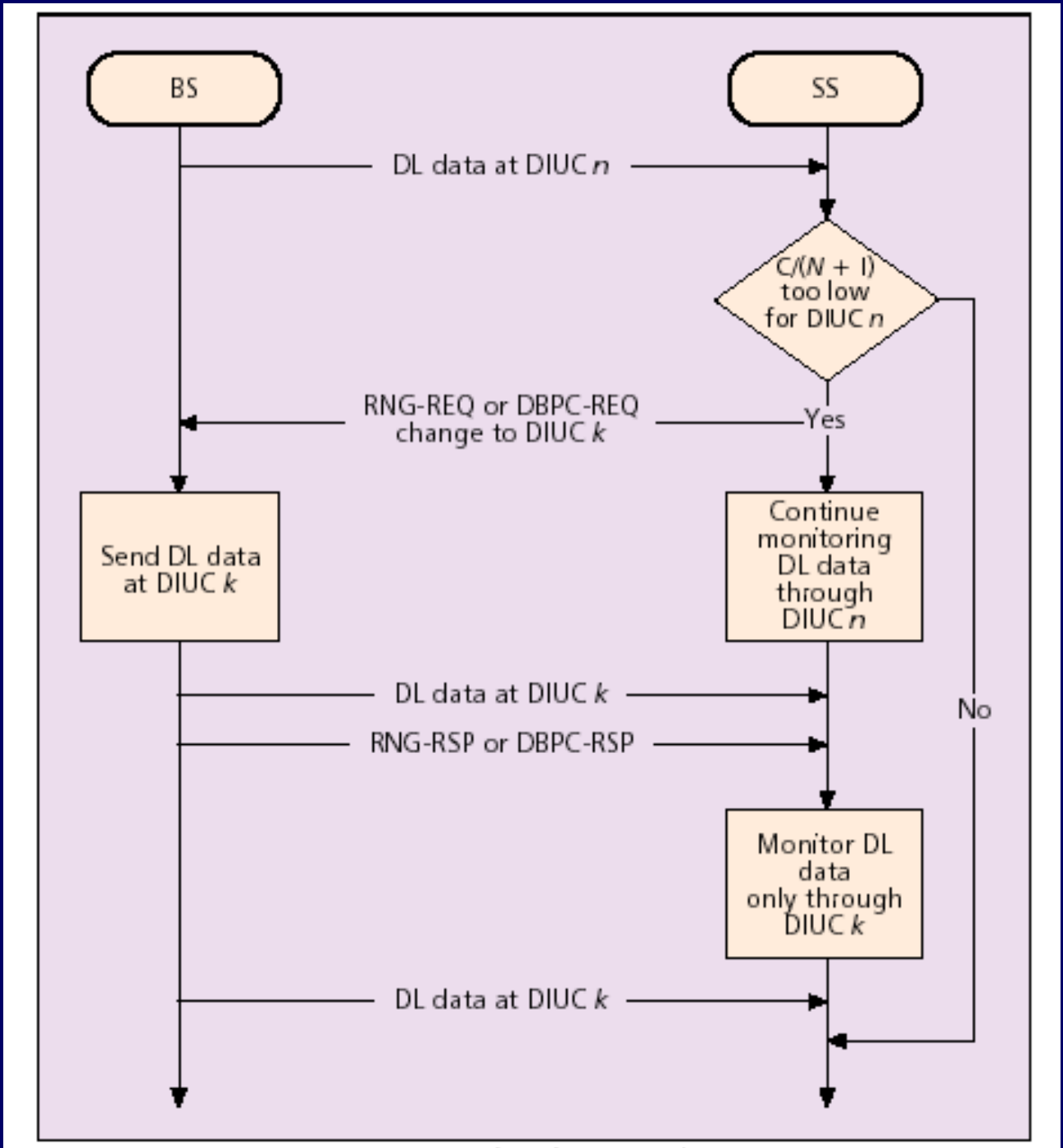
- Used for advertising downlink burst profiles
- Burst profile of DL broadcast channel is well-known
- All others are acquired
- Burst profiles can be changed on the fly without interrupting the service
  - Not intended as 'super-adaptive' modulation
- Establishes association between DIUC and actual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

Burst profiles

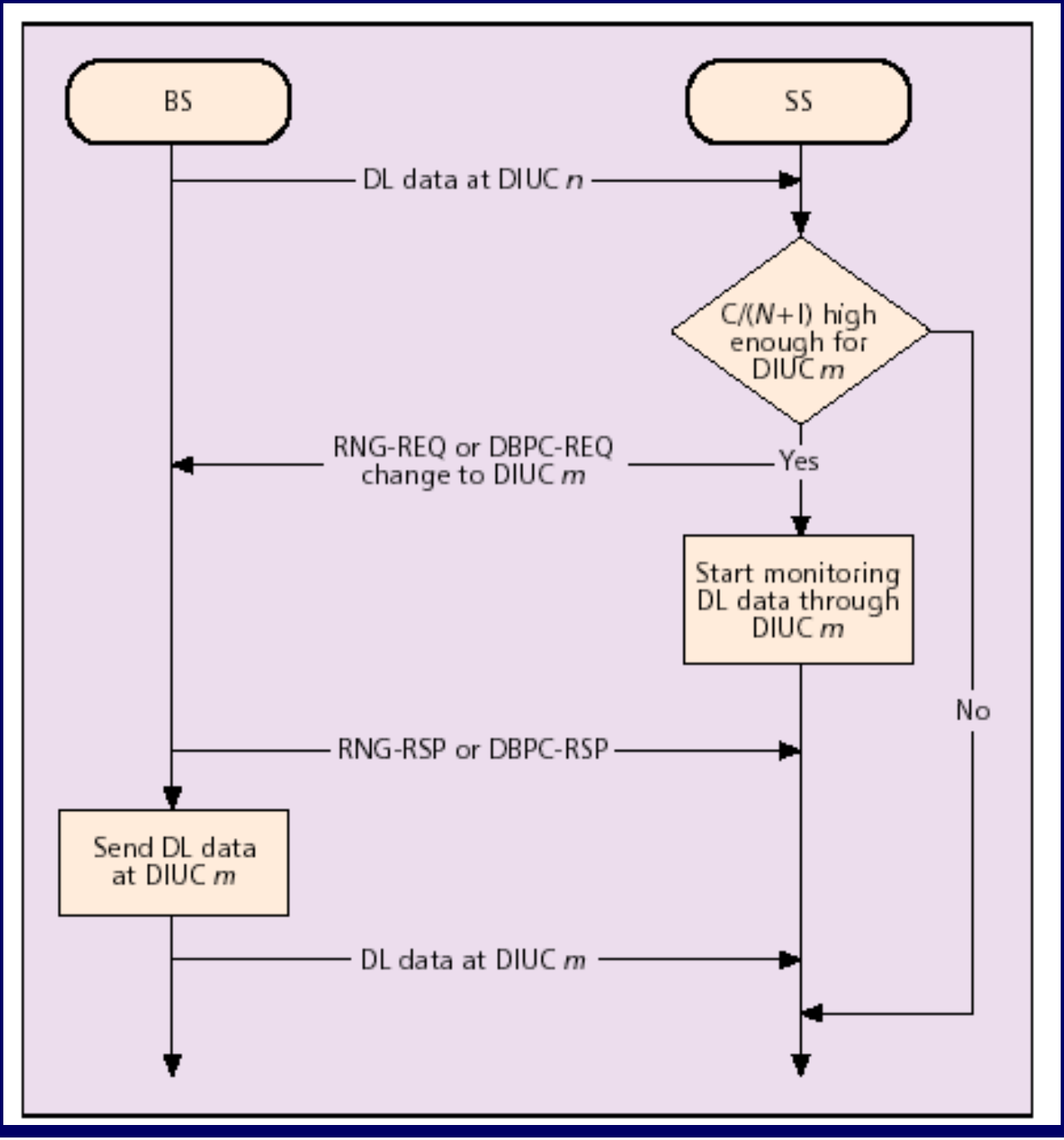


- Each burst profile has mandatory exit threshold and minimum entry threshold
- SS allowed to request a less robust DIUC once above the minimum entry level
- SS must request fall back to more robust DIUC once at mandatory exit threshold
- Requests to change DIUC done with DBPC-REQ or RNG-REQ messages

Transition to more robust burst profile



Transition to less robust burst profile



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

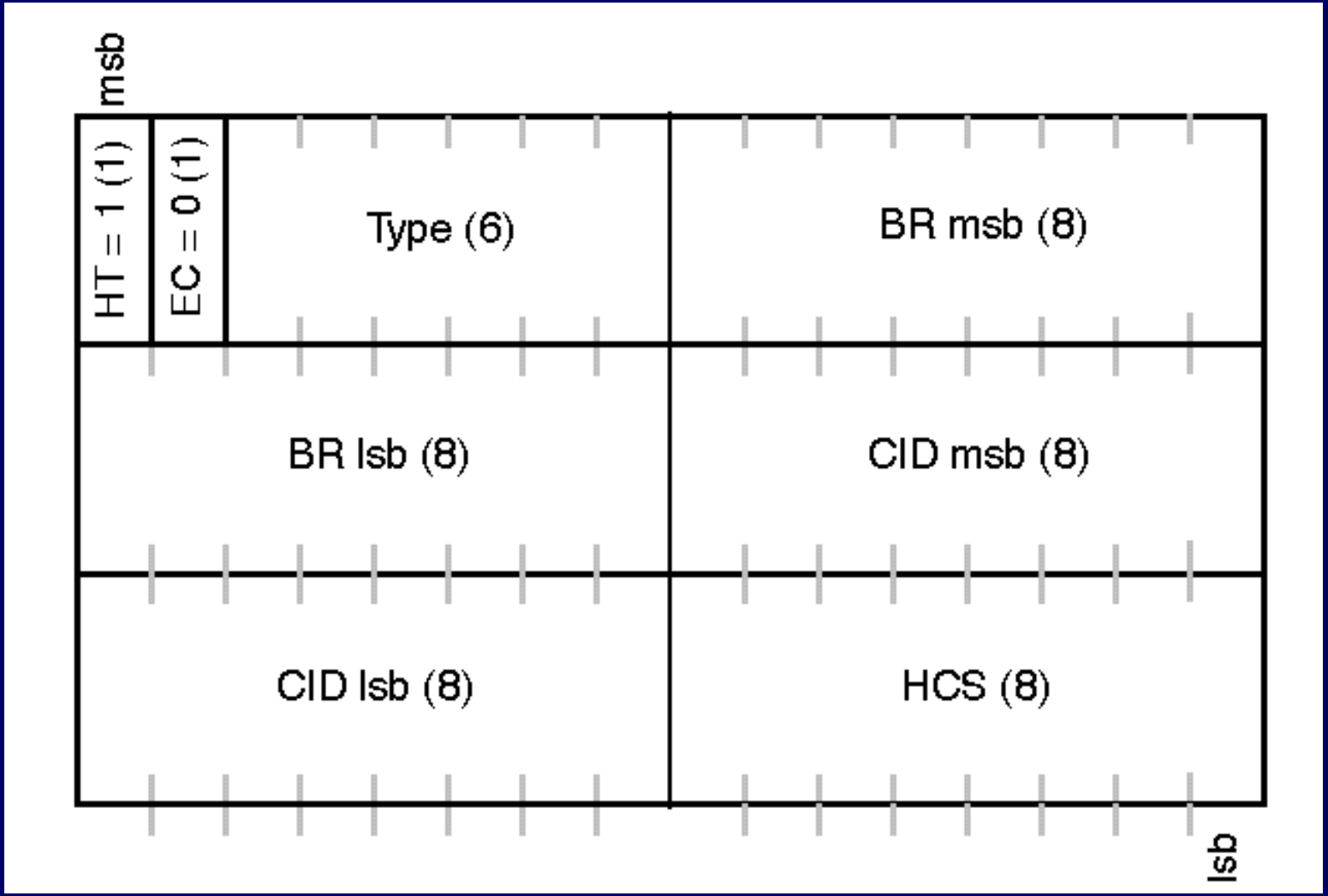
GPSS vs. GPC

- 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

BW Request Message



BR: Bandwidth req, in bytes (64k max)

CID: Connection ID

EKS: Encryption Key Sequence

HT: Header Type

EC: Encryption Control

Type: subheaders, etc.

HCS: Header Check Sequence

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

Initial Connection Setup

- BS passes Service Flow Encodings to the SS in multiple DSA-REQ messages
- SS replies with DSA-RSP messages
- Service Flow Encodings contain either
  - full definition of service attributes (omitting defaultable items if desired)
  - service class name
    - ASCII string which is known at the BS and which indirectly specifies a set of QoS Parameters

Privacy and Encryption

- Secures over-the-air transmissions
- Protocol descends from BPI+ (from DOCSIS)
- Designed to allow new/multiple encryption algorithms
- Authentication
  - X.509 certificates with RSA
  - Strong authentication of SSs (prevents theft of service)
  - Prevents cloning
- Data encryption
  - Currently 56-bit DES in CBC (cypher block chaining) mode
  - Initialization Vector (IV) based on frame number
- Message authentication
  - Most important MAC management messages authenticated with one-way hashing (HMAC with SHA-1)

Security Associations

- A set of privacy information
  - shared by a BS and one or more of its client SSs in order to support secured communications
    - Note possibility of multicast SAs
  - includes Traffic Encryption Keys (TEKs) and CBC IVs
- Security Association Establishment
  - Primary SA established during initial registration
  - other SAs may be provisioned or dynamically created within the BS

SS Authorization

- Authentication and Authorization
  - SS manufacturer's X.509 certificate binds the SS's public key to its other identifying information
  - Trust relation assumed between equipment manufacturer and network operator
  - Possibility to accommodate "root authority" if required
- Authorization Key Update Protocol
  - The SS is responsible for maintaining valid keys
  - Two active AKs with overlapping lifetimes at all times
  - Reauthorization process done periodically
  - AK lifetime (7 days) & grace time timer (1 hr)

Traffic Encryption Key Management

- Authoriztion Key (AK) established with RSA
- Key Encryption Key (symmetric) derived from AK
- Traffic Encryption Keys (TEK) exhanged with symmetric algorithm negotiated at SA establishment (currently only 3-DES supported)
- Two sets of overlapping keying material maintained
- No explicit key acknowledgements
- Key synchronization maintained by 2-bit key sequence number in the MAC PDU header

Data Encryption

- DES in CBC mode with IV derived from the frame number
- Hooks defined for other stronger algorithms, e.g. AES
- Two simultaneous keys with overlapping and offset lifetimes allow for uninterrupted service
- Key sequence number carried in MAC header
- Only MAC PDU payload (including sub-headers) is encrypted
- Management messages are unencrypted

Interoperability Testing for WirelessMAN-SC™ (10-66 GHz)

- IEEE P802.16c (Detailed System Profiles)
  - in ballot; tobe complete in September 2002
  - specifies particular combinations of options
  - used as basis of compliance and interoperability testing
    - MAC Profiles: ATM and Packet
    - PHY Profiles: 25 & 28 MHz; TDD & FDD
- Test Protocols
  - PICS (initiating effort; final in early 2003)
  - Test Suite Structure & Test Purposes (to follow)

Amendment Project
IEEE P802.16a

Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz

IEEE P802.16a Status

- In ballot since November 2001
  - currently balloting Draft 4
  - expect completion of final draft in October 2002

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
- License-exempt: WirelessMAN-OFDM™ and TDD specified (WirelessHUMAN™)

Key 802.16a MAC Features

- OFDM/OFDMA Support
- ARQ
- Dynamic Frequency Selection (DFS)
  - license-exempt
- Optional Advanced Antenna System (AAS) support
- Mesh Mode
  - Optional topology for license-exempt operation only
  - Subscriber-to-Subscriber communications
  - TDD only

Mobile Broadband Wireless Access

- Working Group 802.16 formed Mobile Broadband Wireless Access Study Group in March 2002
- Seems to be going in two directions:
  - Enhance IEEE Std 802.16 to provide nomadic operation, portability, and limited mobility
  - Consider a new, separate project for mobile BWA at vehicular speeds

IEEE 802.16.2

Recommended Practice for Coexistence of Fixed Broadband Wireless Access Systems (10-66 GHz)

Publ: Sept. . 2001

802.16.2a:

amendment project for 2-11 GHz

IEEE 802.16.2 (published Sept. 2001)

IEEE Std 802.16.2-2001

IEEE Recommended Practice for
Local and metropolitan area networks

Coexistence of 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 July 2001

IEEE-SA Standards Board

Abstract: This IEEE recommended practice provides guidelines for minimizing interference in fixed broadband wireless access (BWA) systems operating in the frequency range 10 to 66 GHz, with particular focus on the range 23.5 to 43.5 GHz. It analyzes coexistence scenarios and provides guidance for system design, deployment, coordination, and frequency usage.
Keywords: coexistence, fixed broadband wireless access (BWA), interference, local multipoint distribution service (LMDS), millimeter wave, multipoint, point-to-multipoint, radio, wireless metropolitan area network (WirelessMAN™) standard

802.16.2 Summary

- This Recommended Practice provides guidelines for minimizing interference in fixed broadband wireless access systems. Pertinent coexistence issues are addressed, and recommended engineering practices provide guidance for system design, deployment, coordination and frequency usage. This document covers frequencies of 10 - 66 GHz frequencies in general, but it is focused on 23.5 - 43.5 GHz. If followed by manufacturers and operators, it should allow a wide range of equipment to coexist in a shared environment with acceptable mutual interference.
- 11 Specific Recommendations

802.16.2 Philosophy

Resolving coexistence issues is an important factor for the fixed BWA industry. Recommendations are provided for consideration by operators, manufacturers and administrations to promote coexistence. Practical implementation within the scope of the current recommendations will assume that some portion of the frequency spectrum (at the edge of the authorized bandwidth) may not be able to be utilized. As well, there may be locations within the service area that cannot be used for deployment. Coexistence will rely heavily on the good-faith collaboration between spectrum holders for economical solutions to be implemented.

P802.16.2a Status

- 2-11 GHz coexistence
- More extensive coexistence with point-to-point
- To begin ballot in July 2002
- Completion by early 2002

How to Participate

- Attend meetings

- Read reflector
- Read documents
- Submit documents & comments
- Join sponsor ballot pool

Sponsor Ballot

- Any member of IEEE Standards Association may vote on draft standards
  - IEEE-SA costs US$10 on top of IEEE membership
- Great opportunity
  - Influence important results
  - Free access to valuable documents
- For IEEE 802.16, sign up at

  http://WirelessMAN.org

What's Next ?

- Complete 2-11 GHz work
- Enhance 10-66 GHz spec
  - Interoperability test protocols
    - 802.16c (profiles) is in ballot
    - PICS and test protocols coming soon
- New enhancements
  - Mobility, repeaters, etc.
- Build a basis for 4G wireless

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 above 11 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

Summary

- The IEEE 802.16 WirelessMAN Air Interface, addresses worldwide needs for standard Wireless Metropolitan Area Networks.
- The outcome is due to successful cooperation between industry leaders.
- The 802.16 MAC is flexible and powerful enough to support any PHY variant in any spectrum in any market.
- The 802.16 Air Interface provides great opportunities for vendor differentiation, at both the base station and subscriber station, without compromising interoperability.
- Expansion to 2-11 GHz will soon be complete.

Conclusion

IEEE 802.16 standards are:

- addressed at worldwide markets
- engineered as optimized technical solutions
- moving toward interoperability assurance
- being enhanced for expanded opportunities

I thank you for your interest in IEEE 802.16 and welcome your participation in the development or use of IEEE 802.16 standards.

IEEE 802.16 Resources

IEEE 802.16 Working Group on Broadband Wireless Access

info, documents, tutorials, email lists, etc:

http://WirelessMAN.org