The IEEE 802.16 WirelessMAN™ Standard for Broadband Wireless Metropolitan Area Networks

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Roger Marks

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Purpose:

To inform the Working Group concerning an address on IEEE 802.16 given by the Working Group Chair at a meeting of T1P1, the Technical Subcommittee of Standards Committee T1 responsible for Wireless/Mobile Services and Systems, in Westminster, CO, USA on 24 July 2002.

The IEEE 802.16 WirelessMAN™ Standard for Broadband Wireless Metropolitan Area Networks

http://WirelessMAN.org

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Chair, IEEE 802.16 Working Group

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

Free IEEE 802 Standards

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

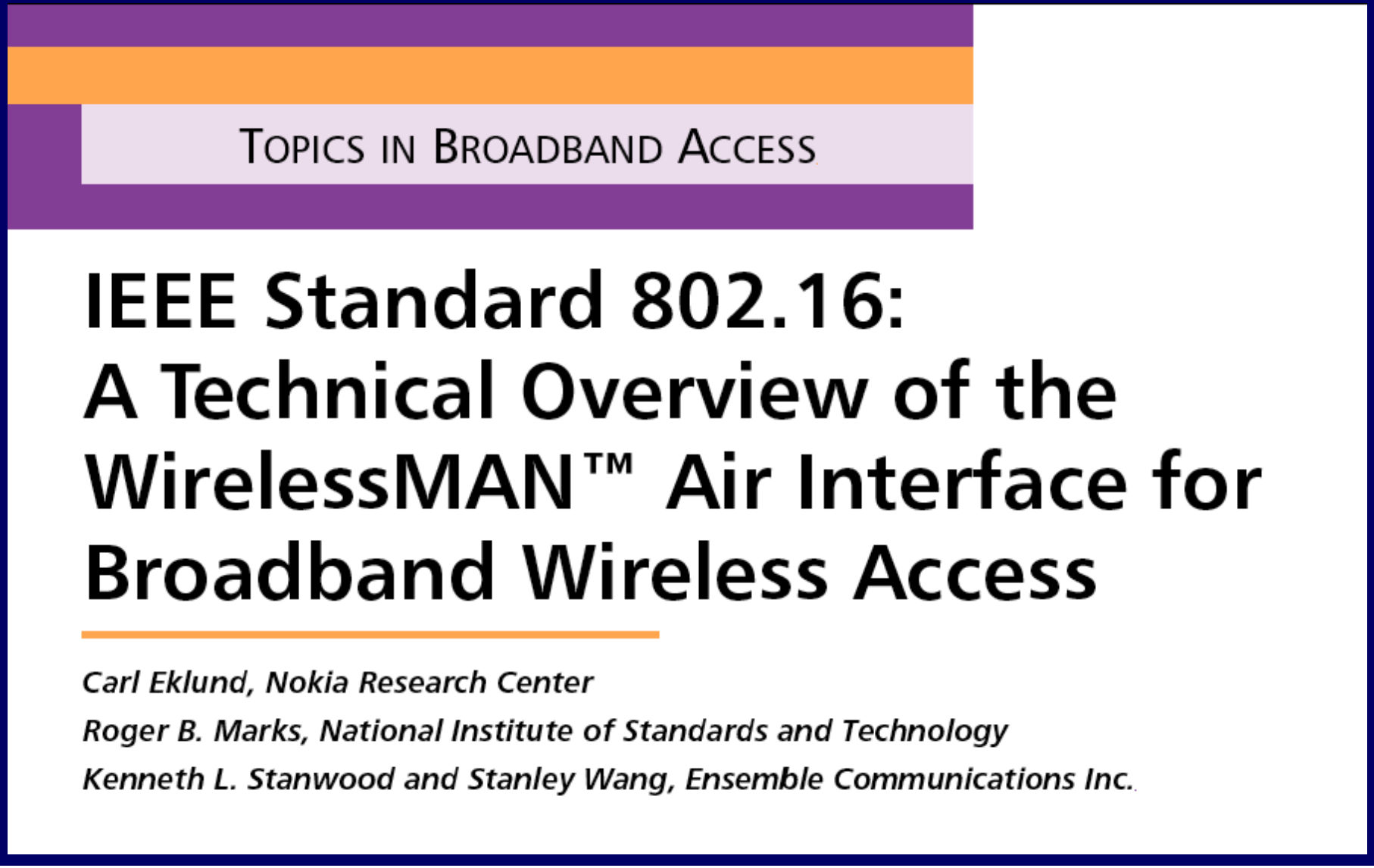
http://WirelessMAN.org

beginning six months after publication

- IEEE Std 802.16.2 is now free
- IEEE Std 802.16 will be free in October 2002

IEEE Standard 802.16: Tutorial

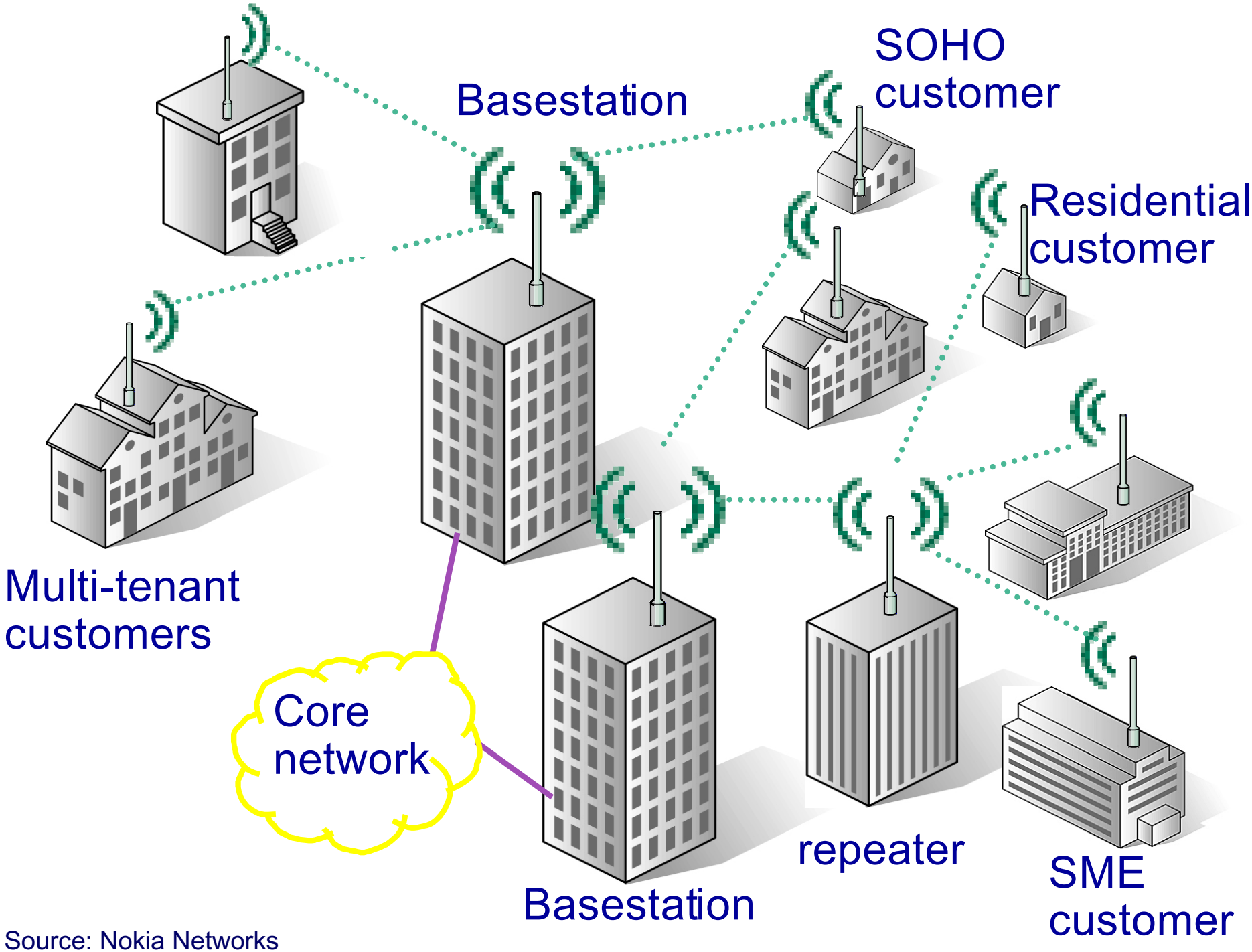
IEEE Communications Magazine, June 2002
(available on 802.16 web site)



Broadband Access to Buildings

- The Last Mile
  - Fast local connection to network
- Business and residential customers want it
  - Data
  - Voice
  - Video distribution
  - Real-time videoconferencing
  - etc.
- High-capacity cable/fiber to every user is expensive
  - Construction costs do not follow Moore s Law

WirelessMAN: Wireless Metropolitan Area Network



Source: Nokia Networks

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 effficient 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?

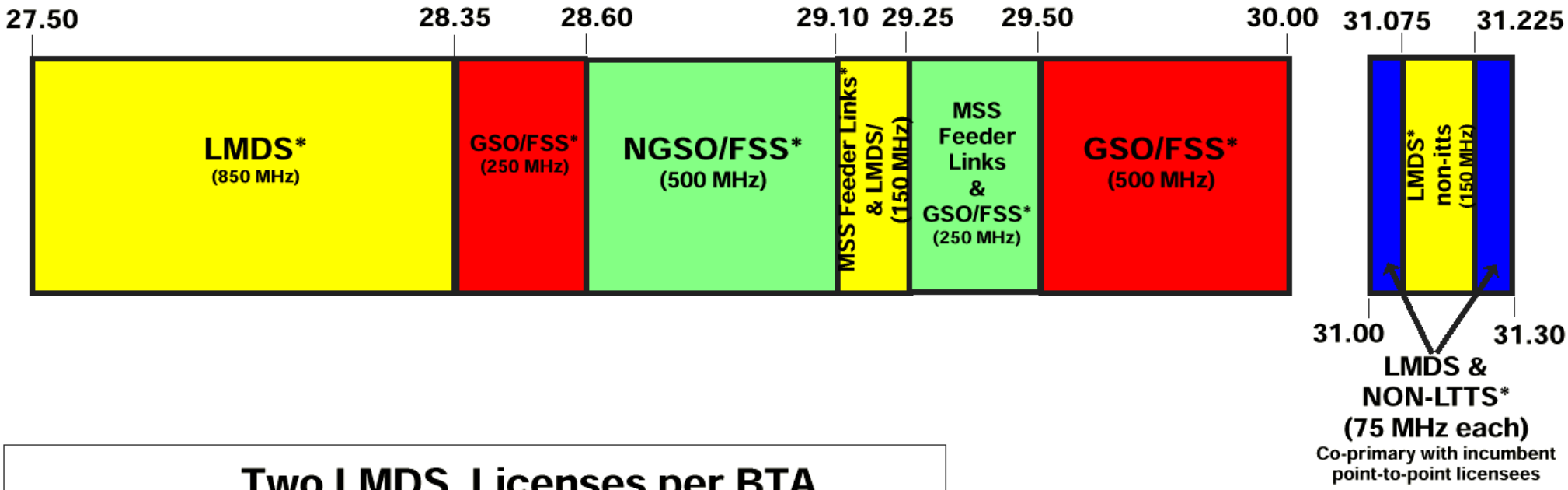
Millimeter-Wave Bands for Wireless MAN

- 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 45 Mbit/sec each
  - up to 5000 sites/hub
- U.S. LMDS allocation includes 26 such 50 MHz blocks!

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
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

802.16 and ETSI

- Over 50 liaison letters between 802.16 and ETSI

- ETSI HIPERACCESS
  - Above 11 GHz
  - ETSI began first, but IEEE finished first
  - 802.16 has encouraged harmonization
  - BRAN is discussing harmonization efforts

- ETSI HIPERMAN
  - Below 11 GHz
  - IEEE began first
  - Signs of healthy cooperation
  - Selected 802.16 MAC/802.16a OFDM PHY as baseline

IEEE 802.16 History

- Project Development: 1998-1999

¥ Meet every two months:

—Session #1: July 1999

—Session #19: May 2002

¥ Future Sessions

—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
[sponsor: IEEE Computer Society]

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 {e.g., Bluetooth=IEEE 802.15.1}
- —802.16: WirelessMAN™
  - ¥Metropolitan Area Networks
    - —*[co-sponsor: IEEE Microwave Theory and Techniques Society]*

Participation in IEEE 802.16

- *Open process and open standards*
- Anyone can participate in meetings
- Anyone can participate outside of 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
    - Producers and Users must both be in voting group

IEEE 802.16 by the Numbers

- 93 Members (peaked at 178)
- 37 Potential Members
- 23 Official Observers
- 800 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 (49)
- FINLAND (4)
- FRANCE (2)
- GERMANY (2)
- GREECE (2)
- ISRAEL (22)
- ITALY (1)
- JAPAN (2)
- KOREA (4)
- SPAIN (1)
- UK (11)
- USA (163)

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
- Flarion
- 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
- RF Magic
- 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
- Unique Broadband Systems
- 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

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 WirelessMAN 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 Standard 802.16: The WirelessMAN-SC“ A ir 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.

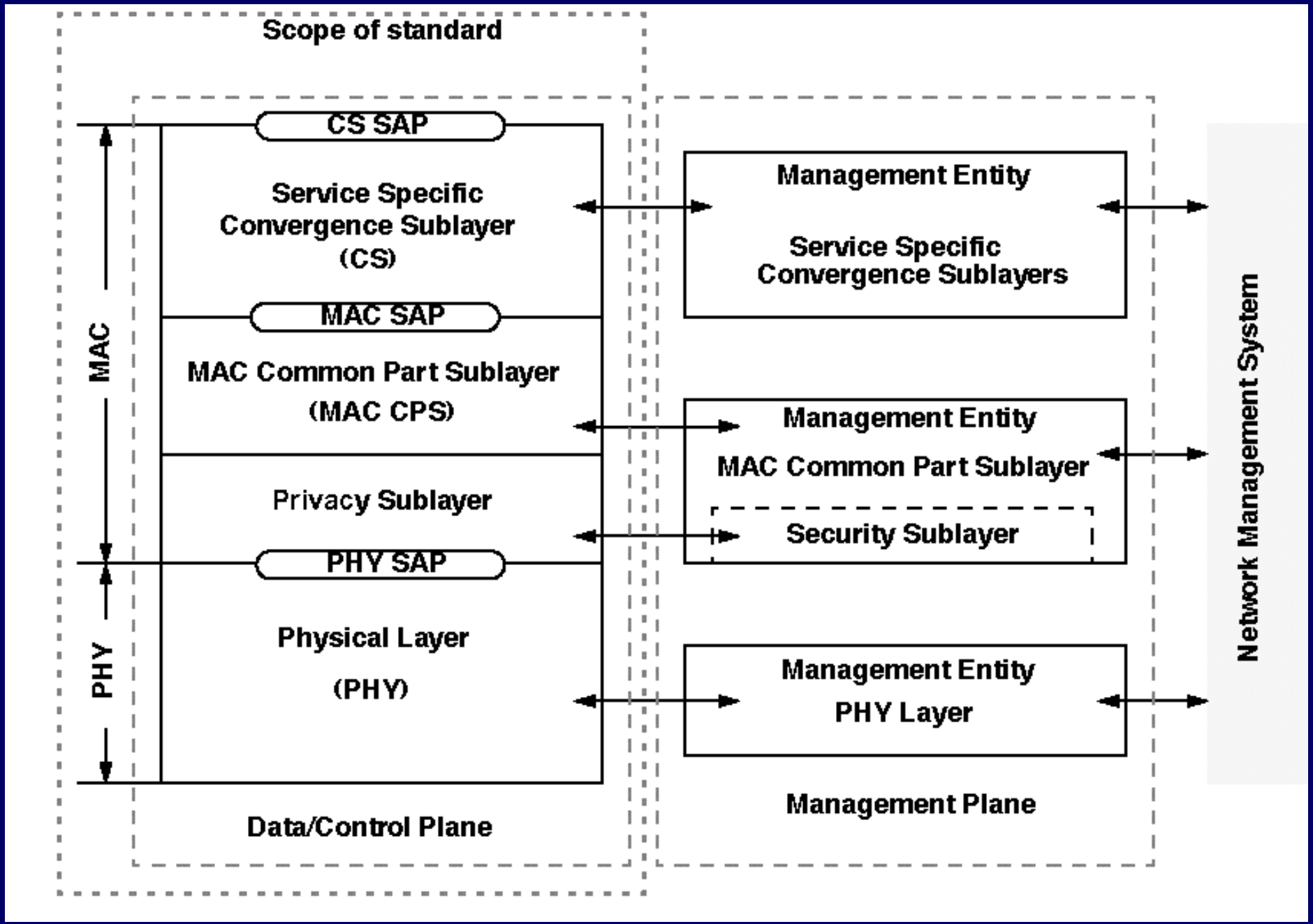
Keywords: fixed broadband wireless access network, metropolitan area network, microwave, millimeter wave, WirelessMAN™ standards

Point-to-Multipoint Wireless MAN: not a LAN

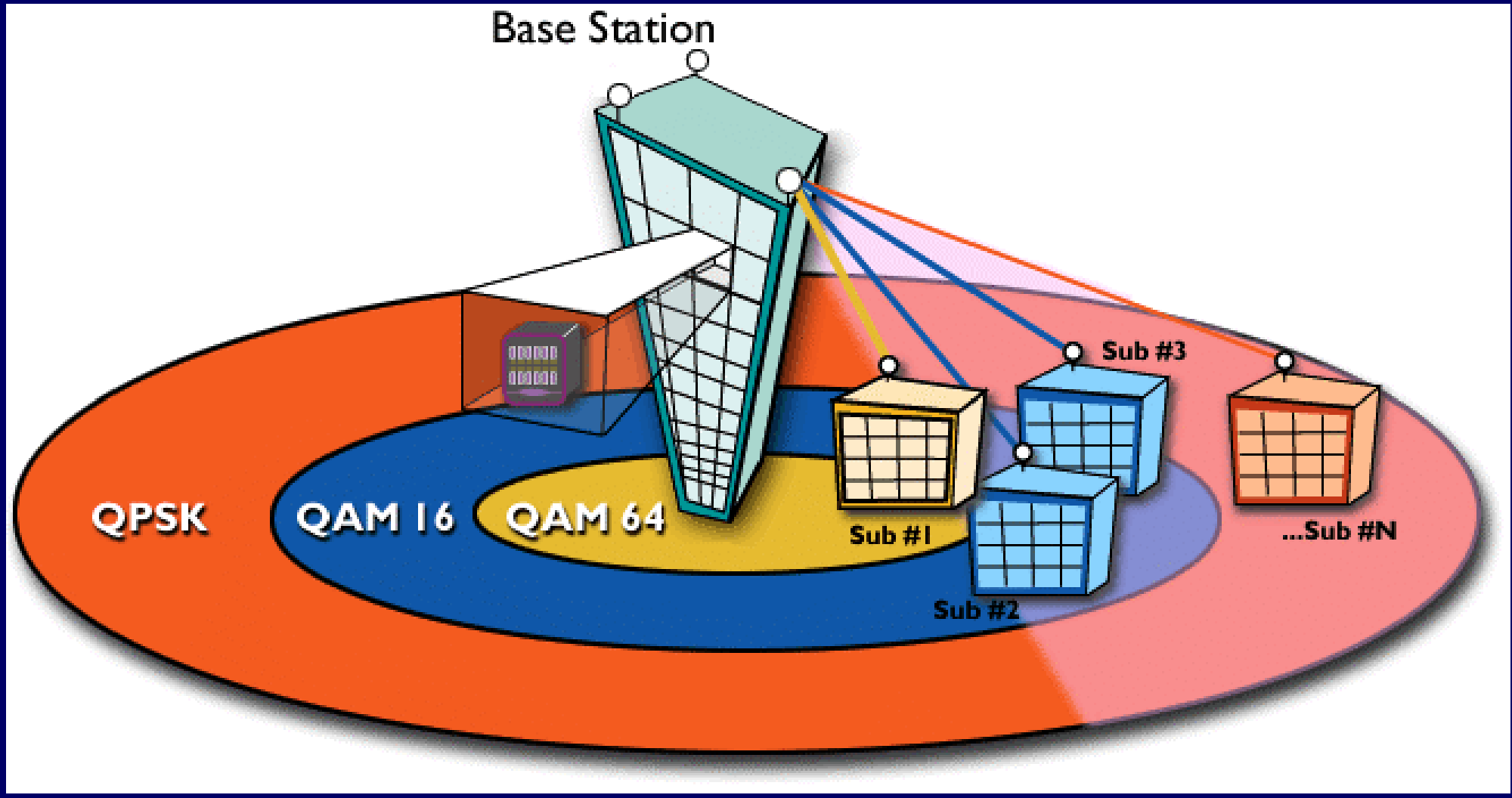
- Base Station (BS) connected to public networks
- BS serves Subscriber Stations (SSs)
  - SS typically serves a building (business or residence)
  - provide SS with first-mile access to public networks

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

Reference Model



Adaptive PHY



(burst-by-burst adaptivity not shown)

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

Baud Rates & Channel Size (10-66 GHz)

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

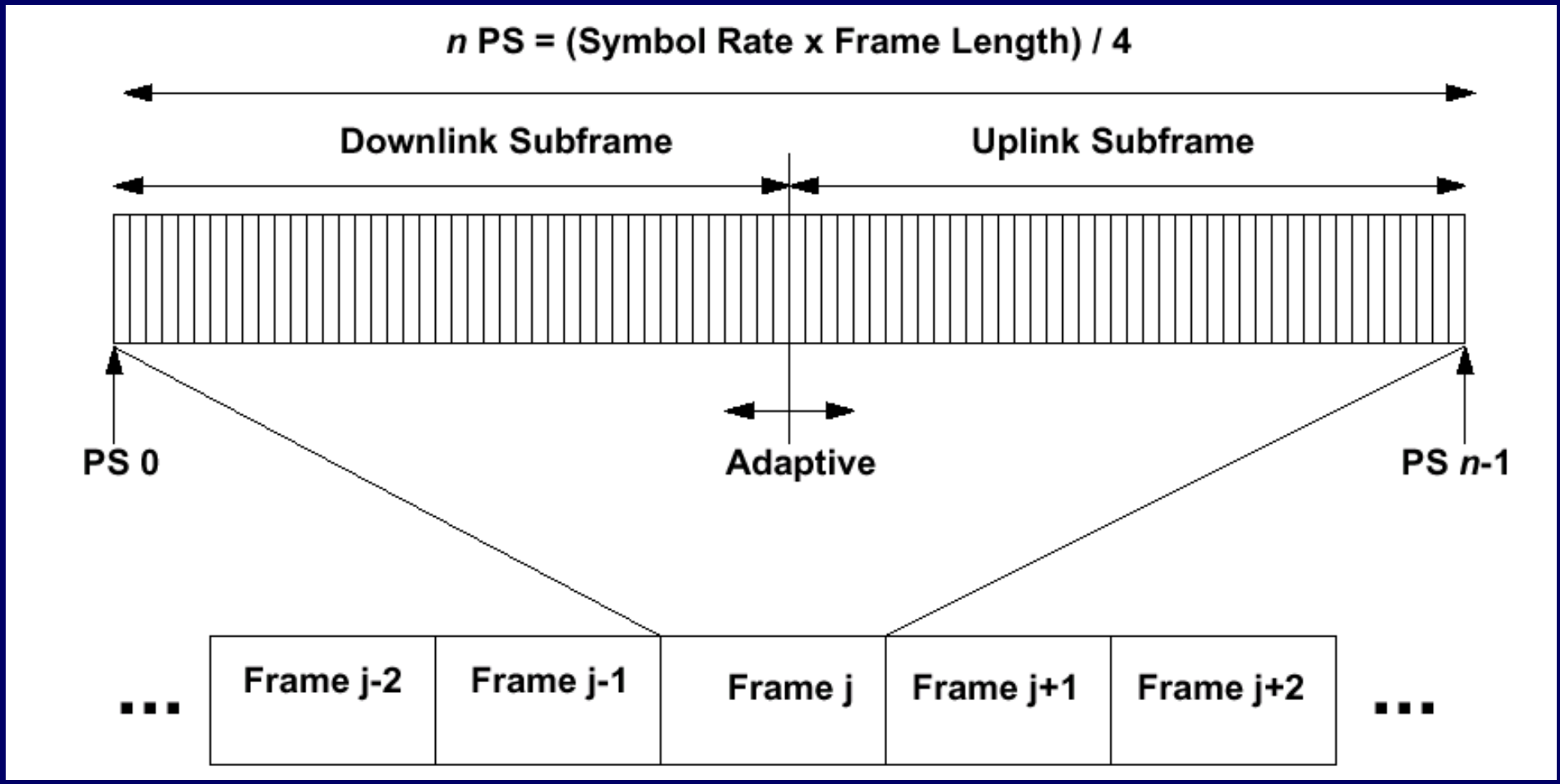
Channel Width (MHz)	Symbol Rate (Msym/s)	QPSK Bit Rate (Mbit/s)	16-QAM Bit Rate (Mbit/s)	64-QAM Bit Rate (Mbit/s)
20	16	32	64	96
25	20	40	80	120
28	22.4	44.8	89.6	134.4

Multiple Access and Duplexing

- On DL, SS addressed in TDM stream
- On UL, SS is 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)

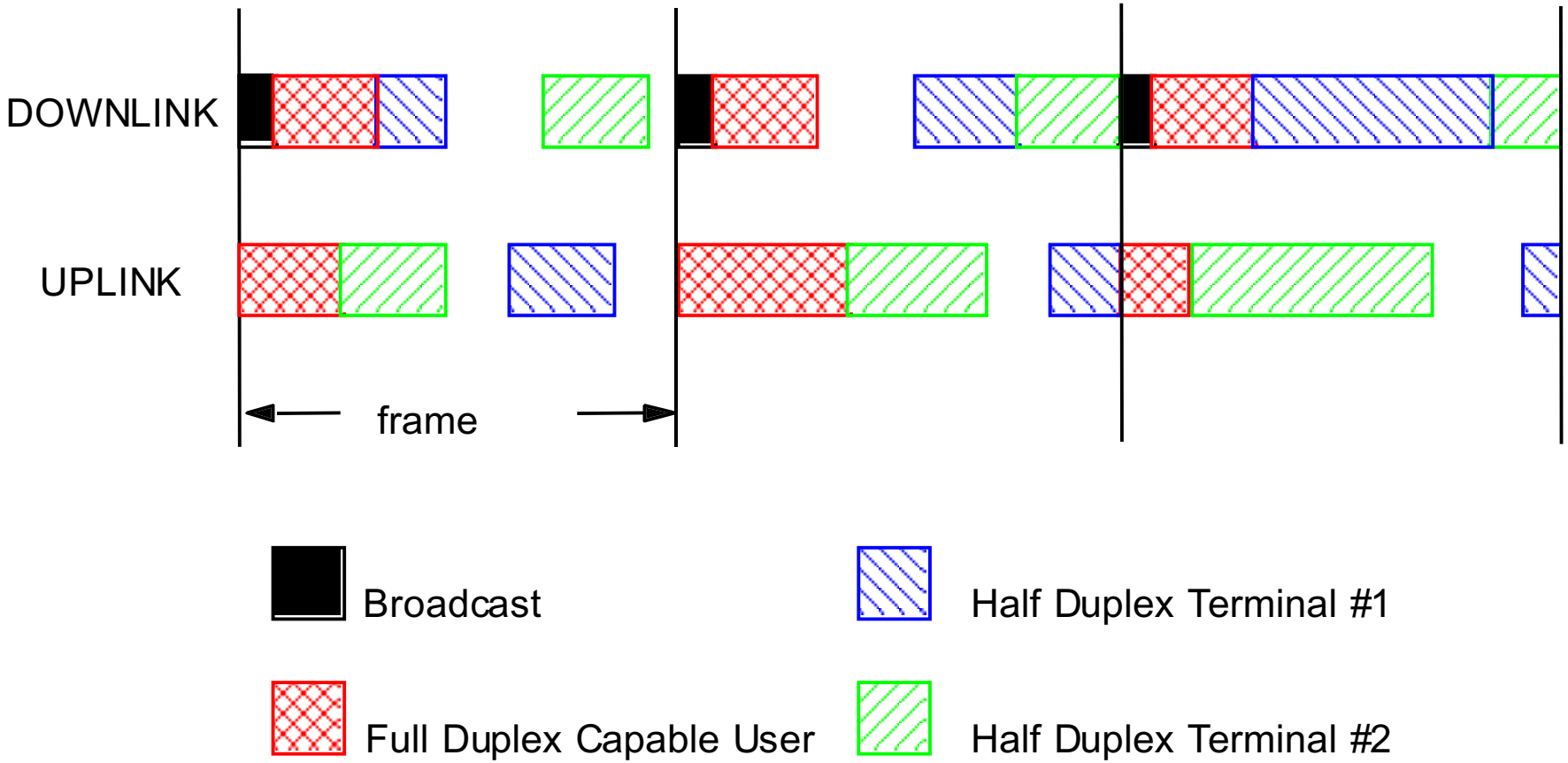
TDD Frame (10-66 GHz)



Frame duration: 1 ms

Physical Slot (PS) = 4 symbols

Burst FDD Framing

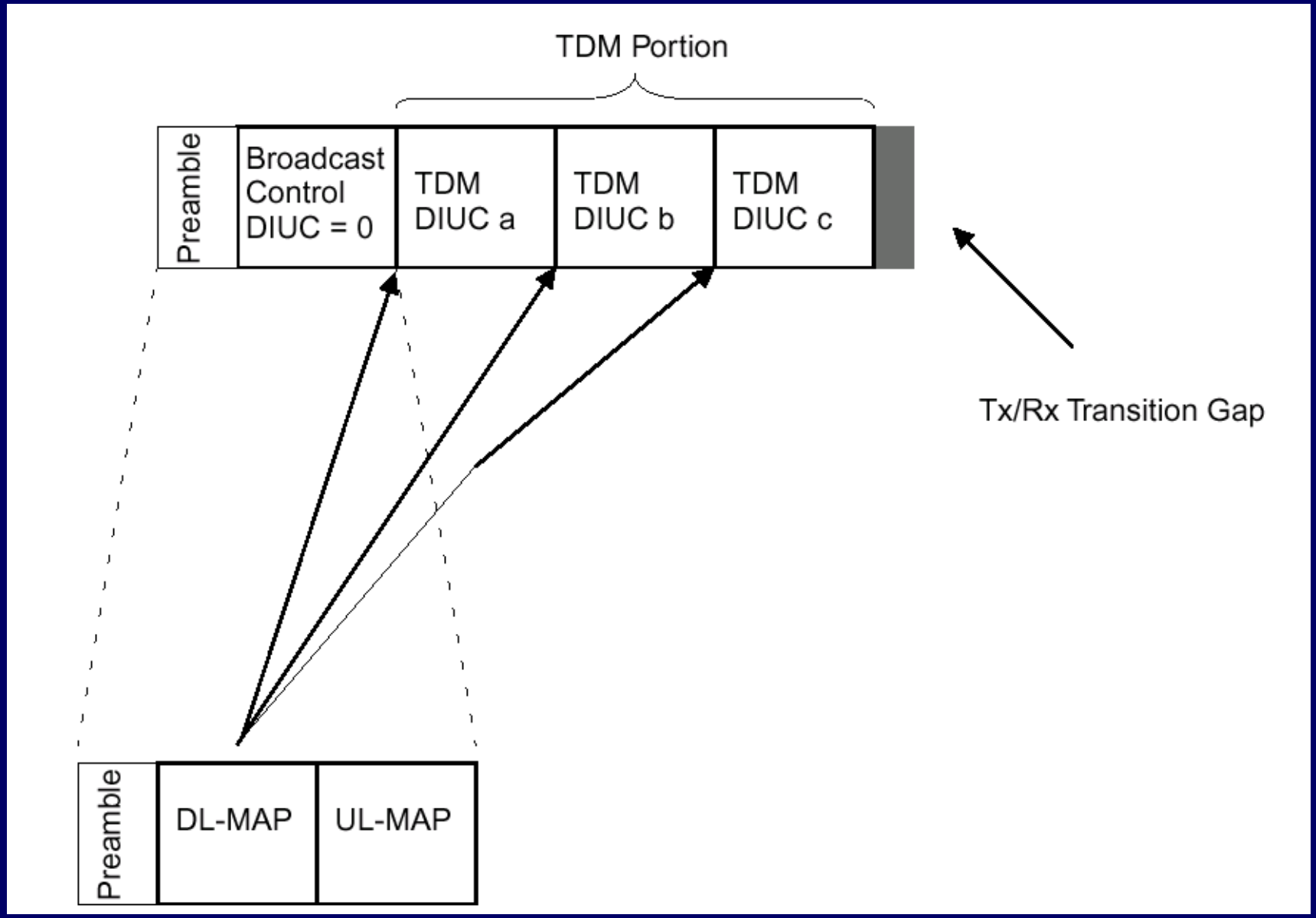


Allows scheduling flexibility

Adaptive Burst Profiles

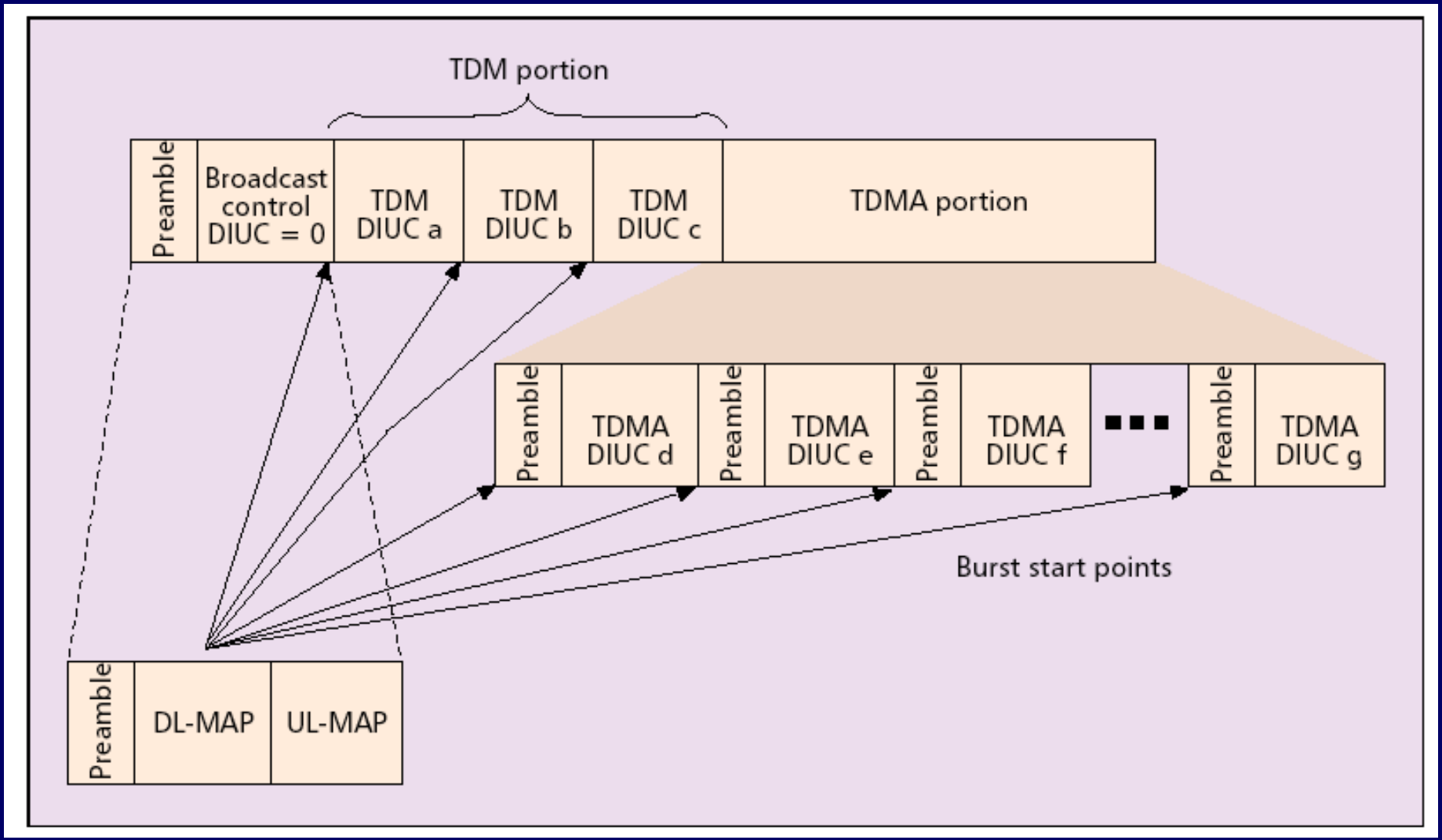
- Burst profile
  - Modulation and FEC
- Dynamically assigned according to link conditions
  - Burst by burst, per subscriber station
  - Trade-off capacity vs. robustness in *real time*
- Roughly doubled capacity for the same cell area
- Burst profile for downlink broadcast channel is well-known and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

TDD Downlink Subframe



DIUC: Downlink Interval Usage Code

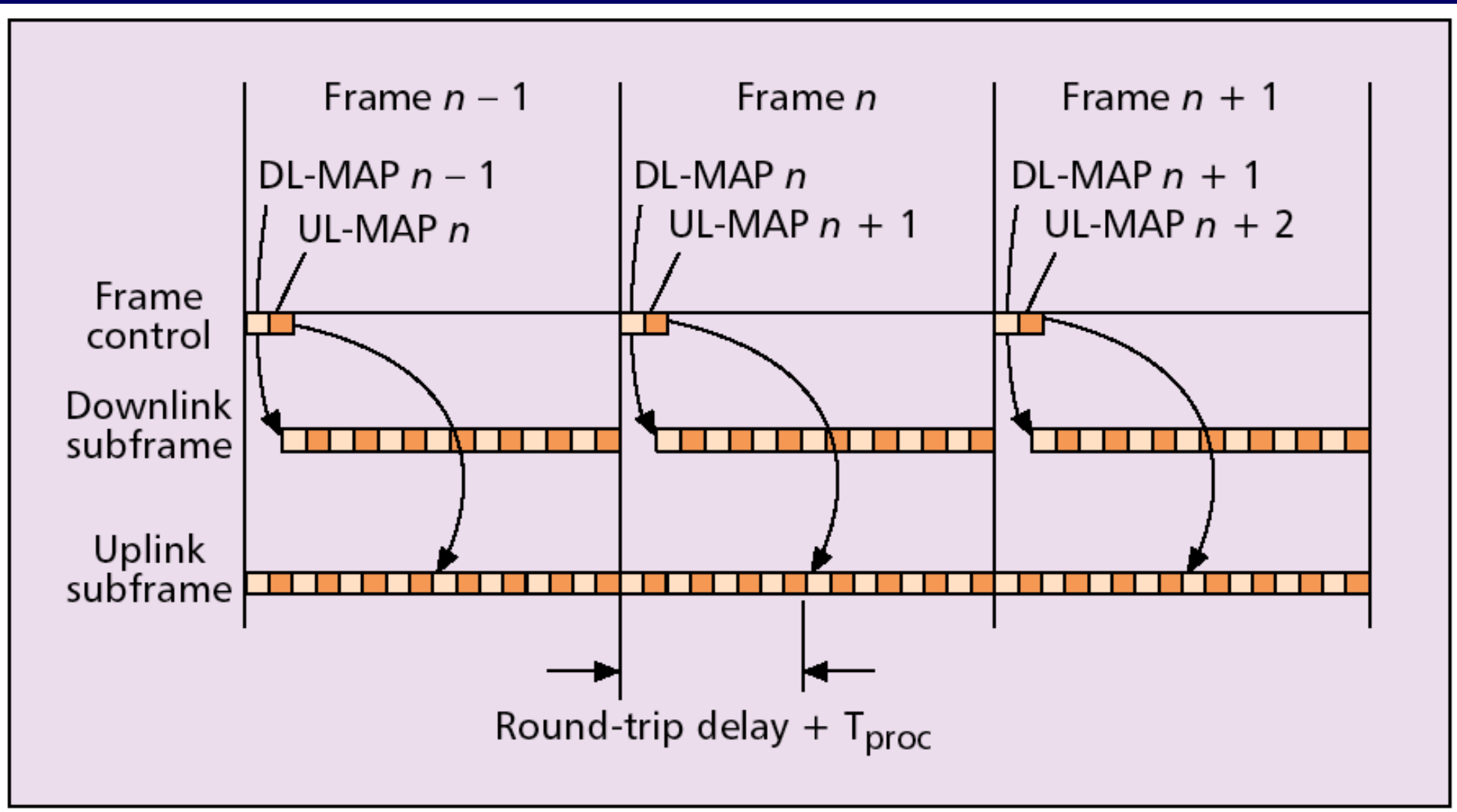
FDD Downlink Subframe



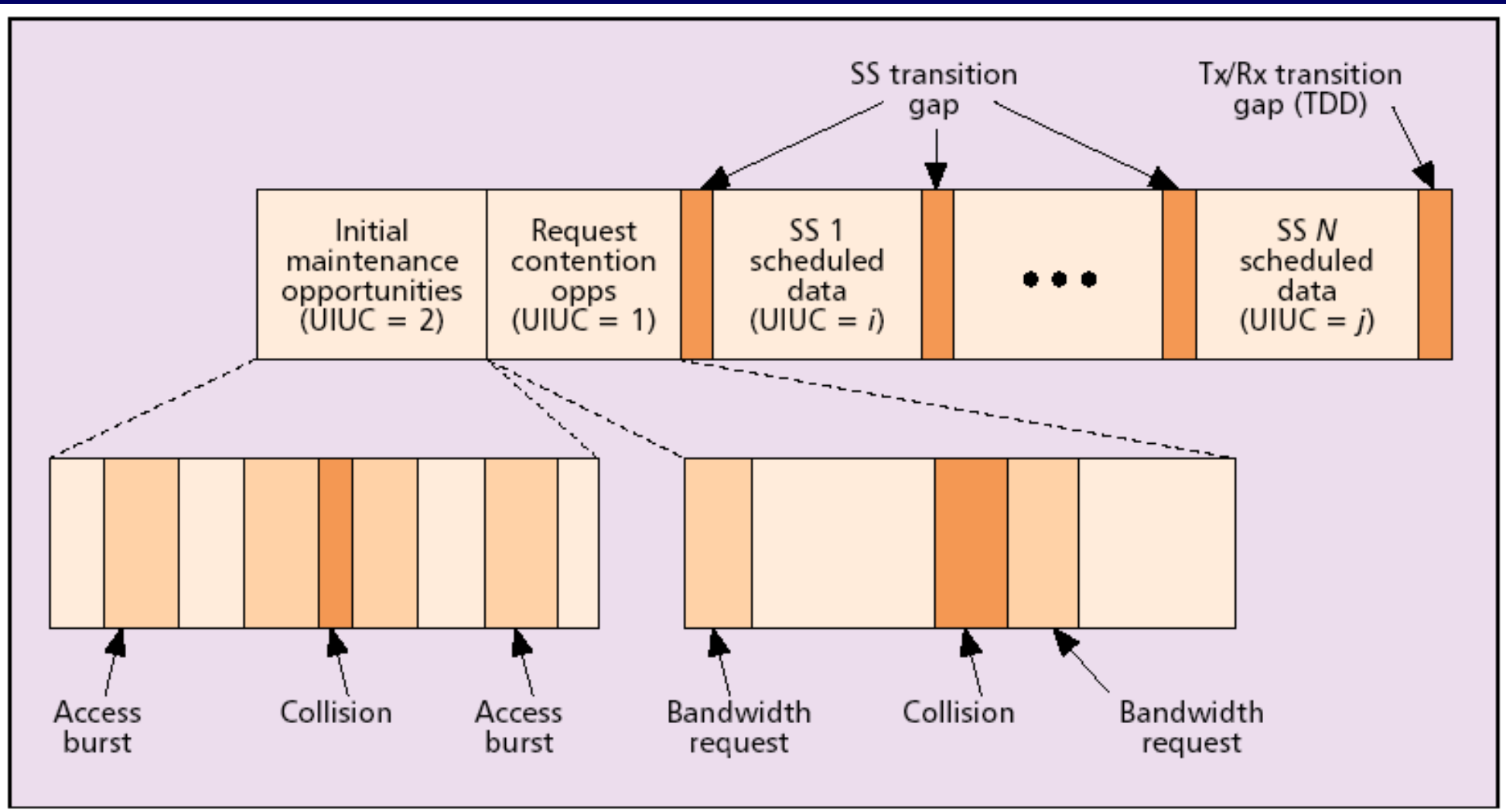
TDMA portion: transmits data to some half-duplex SSs (the ones scheduled to transmit earlier in the frame than they receive)

¥ Need preamble to re-sync (carrier phase)

FDD Uplink Subframe: Minimum Advance



Typical Uplink Subframe (TDD or FDD)



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

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)

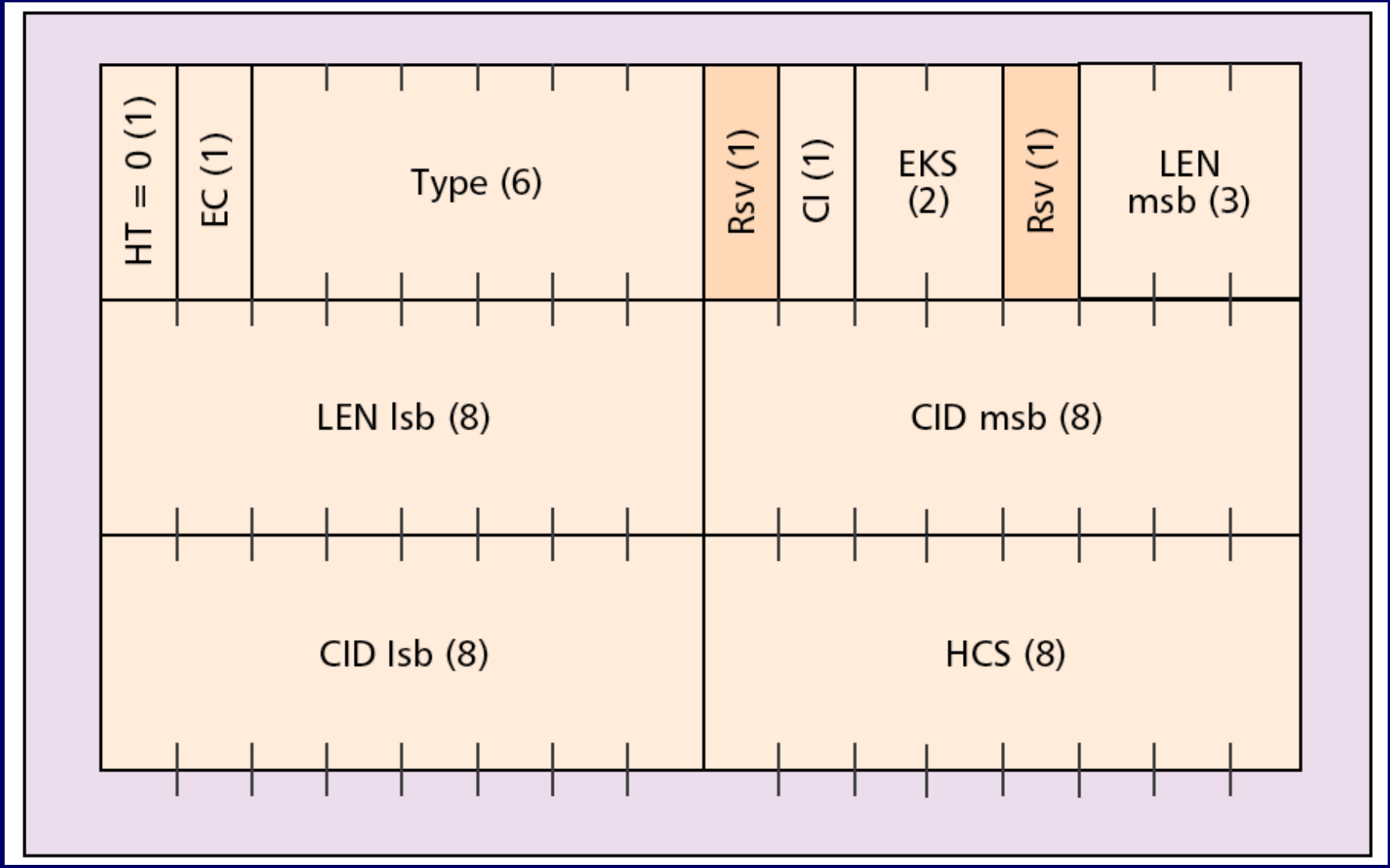
ATM Convergence Sublayer

- 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.

Generic MAC Header



LEN: PDU length, in bytes (2048 max)

CID: Connection ID

EKS: Encryption Key Sequence

HT: Header Type

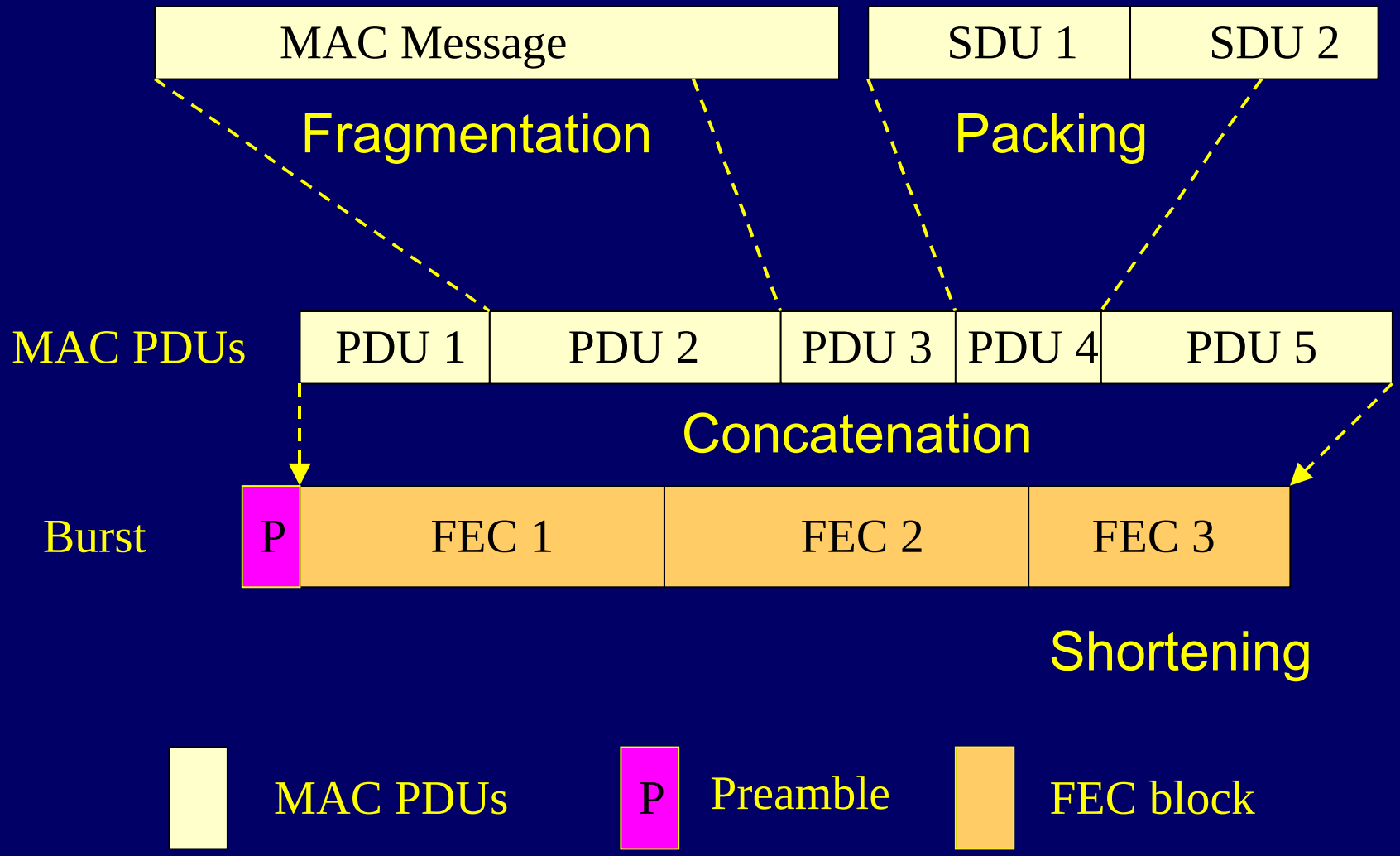
EC: Encryption Control

CI: CRC Indicator

Type: subheaders, etc.

HCS: Header Check Sequence

MAC PDU Transmission



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

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

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

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

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)

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)

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

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

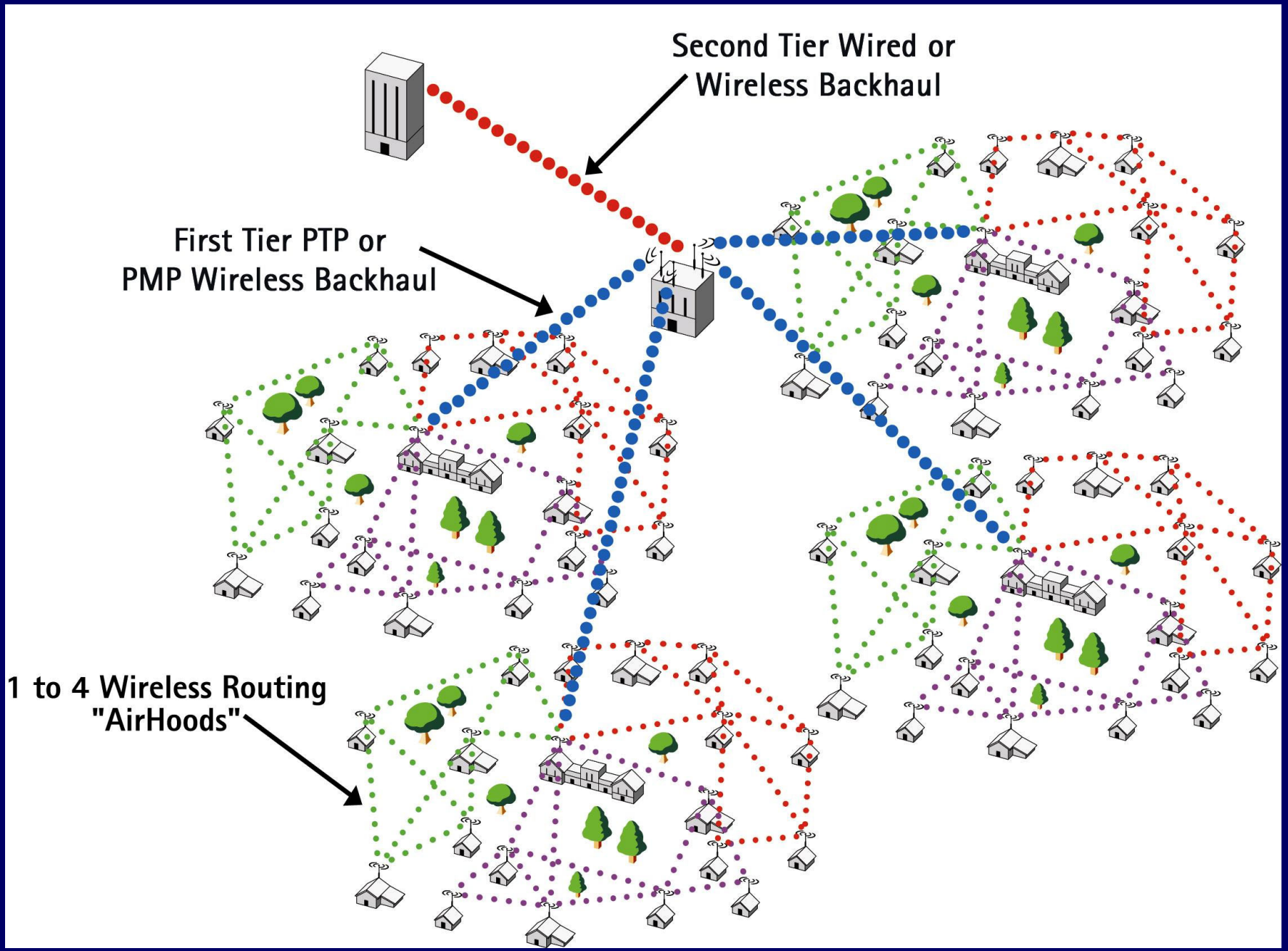
802.16a PHY Alternatives: Different Applications, Bandplans, and Regulatory Environments

- ¥ 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
- ¥ Advanced Antenna System (AAS) support
- ¥ Mesh Mode
  - —Optional topology for license-exempt operation only (TDD only)
  - —Subscriber-to-Subscriber communications
  - —Complex topology and messaging, but:
    - ¥ addresses license-exempt interference
    - ¥ scales well

Mesh-based WirelessMAN



Source: Nokia Networks

Mobililty Enhancements

- March 2002: 802.16 Working Group formed Mobile Broadband Wireless Access Study Group (Mark Klerer, Chair)
- July 2002:
  - 802.16 (with affirmation of IEEE 802) established a Study Group on Mobile WirelessMAN to investigate mobility enhancements to 802.16
  - IEEE 802 chartered an Executive Committee Study Group on Mobile Broadband Wireless Access (Mark Klerer, Chair); could lead to a new, separate project for mobile BWA at vehicular speeds

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

802.16 Summary

- The IEEE 802.16 WirelessMAN Air Interface, addresses worldwide needs
- The outcome is due to successful cooperation between industry worldwide.
- The 802.16 MAC is flexible and powerful enough to support PHY variants in any spectrum allocation.
- 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.
- Interoperability tests are coming.
- Mobility is the next major enhancement.

Conclusion

IEEE 802.16 standards are:

¥ open in development and application

¥ 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