http://WirelessMAN.org

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

IEEE Computer Society
Distinguished Visitors Program
Santa Clara Valley Chapter
Stanford University: 15 January 2003

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Chair, IEEE 802.16 Working Group

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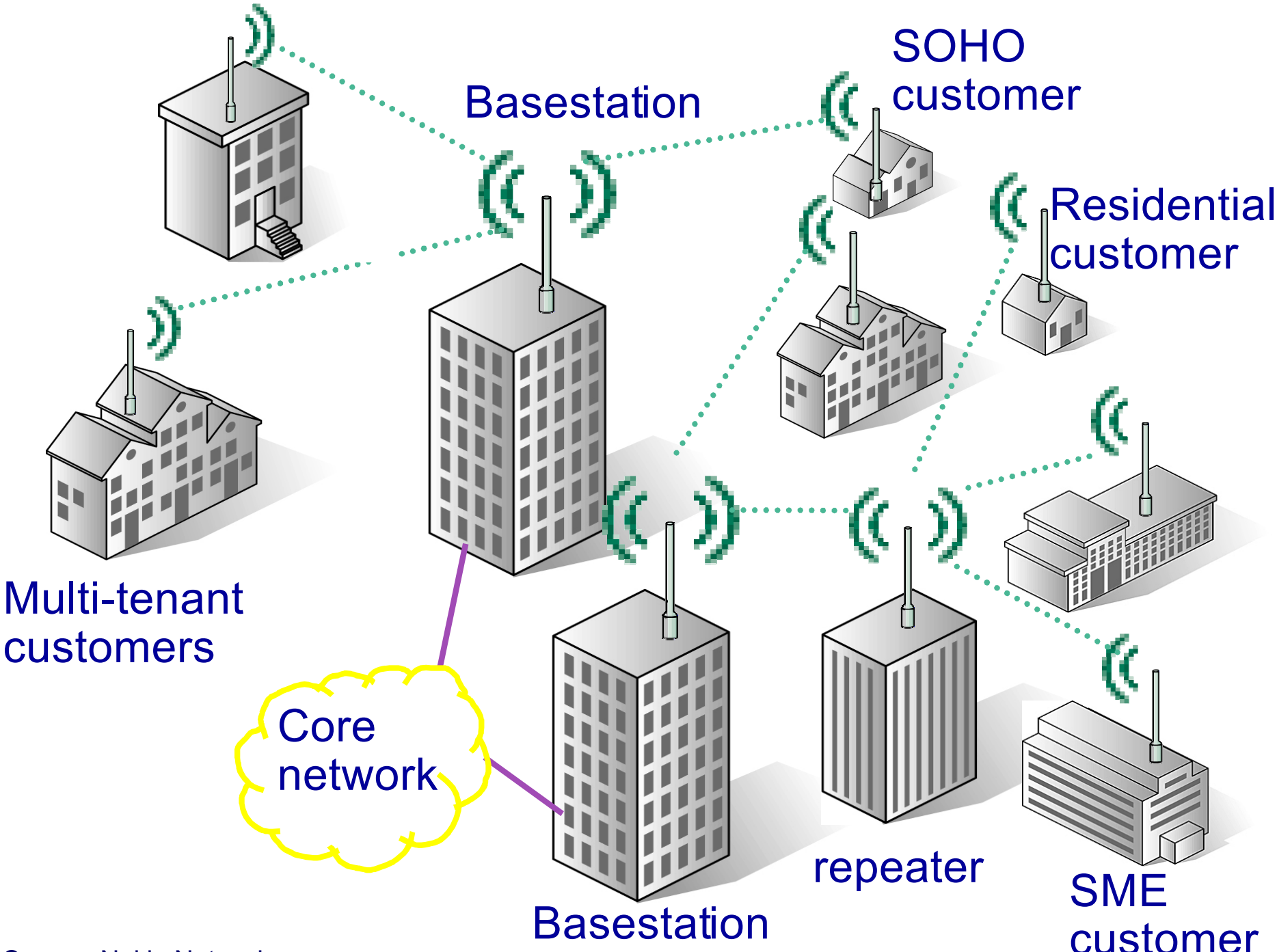
Outline

- 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

WirelessMAN: Wireless Metropolitan Area Network



Source: Nokia Networks

Properties of IEEE Standard 802.16

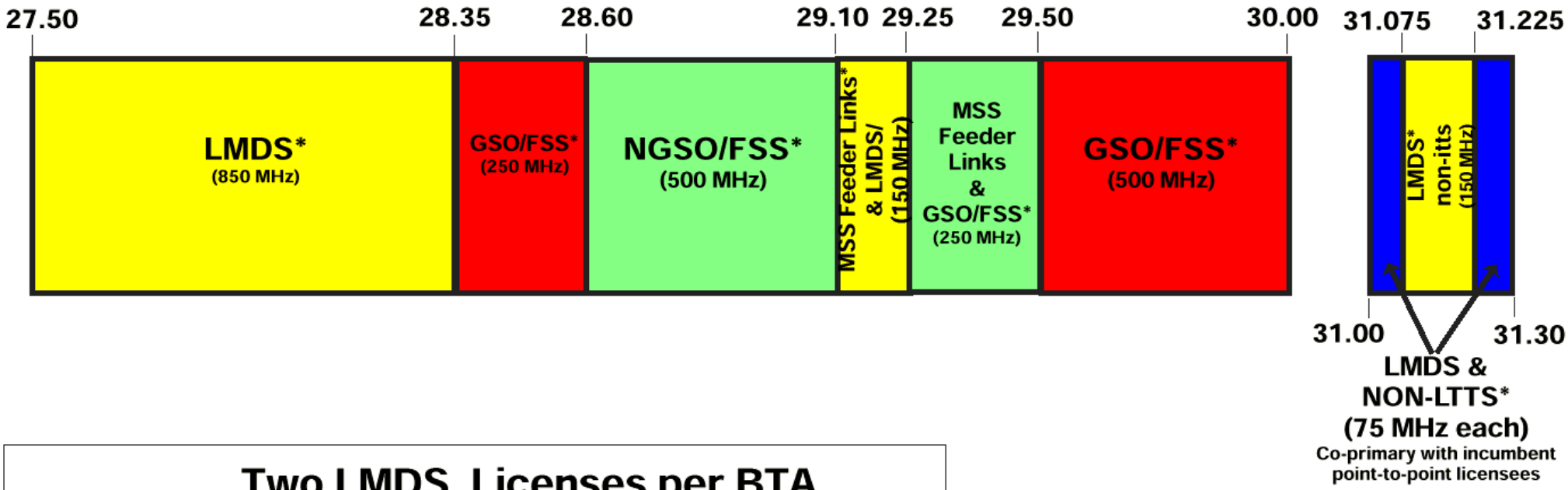
- Broad bandwidth
  - Up to 134 Mbit/s in 28 MHz channel (in 10-66 GHz air interface)
- Supports multiple services simultaneously with full QoS
  - Efficiently transport IPv4, IPv6, ATM, Ethernet, etc.
- Bandwidth on demand (frame by frame)
- MAC designed for effficient used of spectrum
- Comprehensive, 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

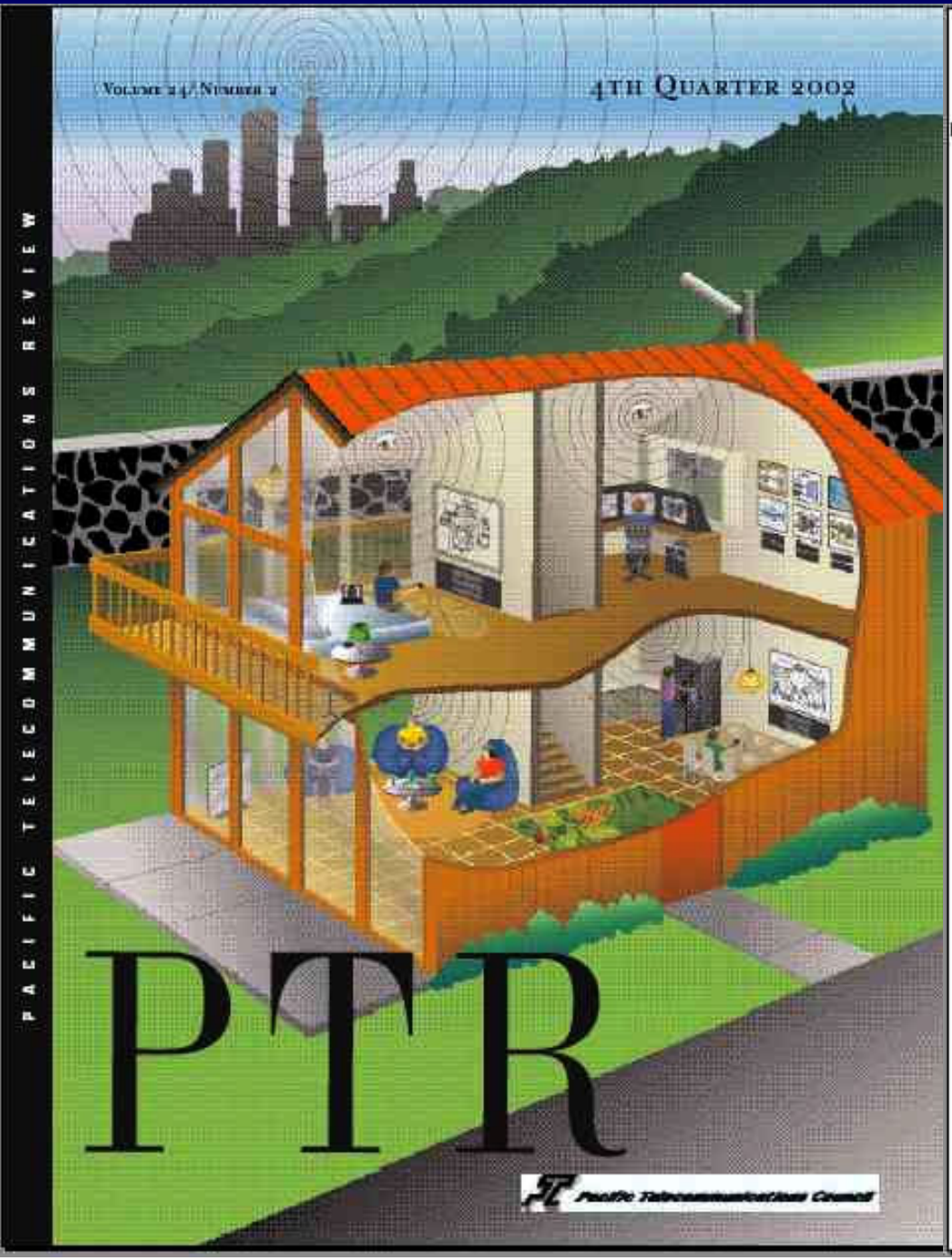
The World Wants Access

- All over the world:
  - Users want access to networks
  - Network operators want access to customers
- Broadband Wireless Access flourishes where:
  - Many users are dissatisfied with their access
  - Network operators need to reach customers

The World Wants Standards

- Standards are at the forefront of world trade
  - World Trade Organization rules accelerating process
  - e.g. Chinese-language MediaView magazine is instituting a monthly column on standards
- In all fields of telecommunications, the world wants standards.
- Broadband Wireless Access is not isolated from this trend.
- Some say that stationary systems don't require standards. But consider:
  - Ethernet
  - DOCSIS

Pacific Telecommunications Council



Contents

The World Wants 802.16 WirelessMAN™ Standards

- Have had attendees from 21 countries (Australia, Canada, China, Finland, France, Germany, Greece, Israel, Italy, Japan, Korea, Netherlands, Norway, Pakistan, Russia, Singapore, Spain, Sweden, Taiwan, UK, USA)
- 2002 meetings in:
  - Finland
  - Korea
  - Canada twice (Vancouver and Calgary)
  - U.S. twice (Hawaii and St. Louis)
- Coordinated European efforts in ETSI

802.16 and ETSI

- Over 50 liaison letters between 802.16 and ETSI
  - (European Telecom Standards Institute)

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

- ETSI HIPERMAN
  - Below 11 GHz
  - IEEE began first
  - Healthy cooperation
  - Harmonized with 802.16a OFDM

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)

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 802

The LAN/MAN Standards Committee

Wired:

- 802.3 (Ethernet)
- 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
- 802.20:
  - Vehicular Mobility (new)

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

IEEE 802 Process

- 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
- Working Group Ballot
- IEEE "Sponsor Ballot"
- Ballot Responses:
  - "Approve" (can include comments)
  - "Disapprove": indicate what needs to be changed to bring about an "Approve" vote

Distribution of IEEE 802 Standards

IEEE 802.16 History

- Project Development: 1998-1999
- Meet every two months:
  - Session #1: July 1999
  - Session #22: Hawaii, Nov 2002
  - Session #23: San Jose, Jan 2003
- Future Sessions
  - Session #24/Mar 2003: Dallas, TX, USA (with 802)
  - Session #25/May 2003: Singapore (with 802.11, etc)
  - Session #26/July 2003: San Francisco (with 802)

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

- 71 Members (peaked at 178)
- ~850 different individuals have attended a session
- 2.8 Million file downloads in year 2000
- Members and Former Members from
  - 12 countries
  - >150 companies

Countries of 802.16 Pre-Registrants This Week

- CANADA (10)
- FINLAND (2)
- FRANCE (1)
- ISRAEL (5)
- JAPAN (2)
- KOREA ( )
- CHINA (1)
- RUSSIA (1)
- UK (4)
- USA (31)

IEEE 802.16 Projects: 10-66 GHz

- Air Interface (MAC and PHY)
  - IEEE Standard 802.16
    - Completed in October 2001
    - Published in April 2002
    - Now free
  - Followup interoperability projects (unusual in 802)
    - 802.16c (Profiles): being published today
    - 1802.16.1 (PICS): in WG ballot; completion expect in April
    - 1802.16.2: (Test Suite Structure & Purposes)
      - Initiated on 11 Dec; WiMAX submitted proposal two days ago
- Coexistence
  - IEEE Standard 802.16.2 (Recommended Practice)
    - Published in September 2001
    - Now free

IEEE 802.16 Projects: 2-11 GHz

- Air Interface
  - new PHY based on 802.16 MAC
  - IEEE Standard 802.16a
    - Completed in November 2002
    - Approval expected this month (January 2003)
  - Followup interoperability projects
    - P802.16d: first meeting this week
  - Followup air interface project: *mobility*
    - P802.16e: first meeting this week
- Coexistence
  - IEEE Standard 802.16.2a (Recommended Practice)
    - In IEEE ballot
    - Completion expected in March 2003

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.

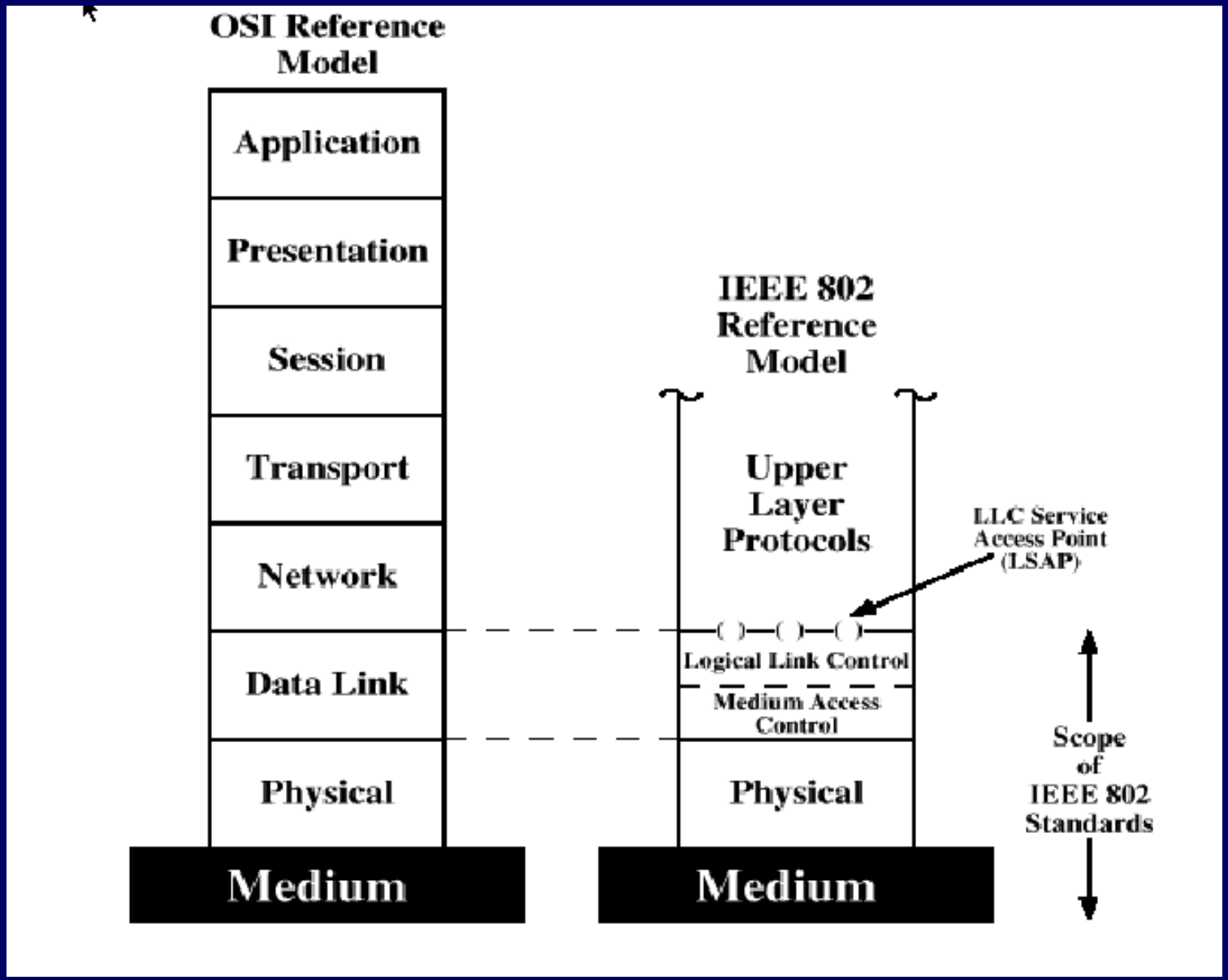
Keywords: fixed broadband wireless access network, metropolitan area network, microwave, millimeter wave, WirelessMAN™ standards

Point-to-Multipoint Wireless MAN: not a LAN

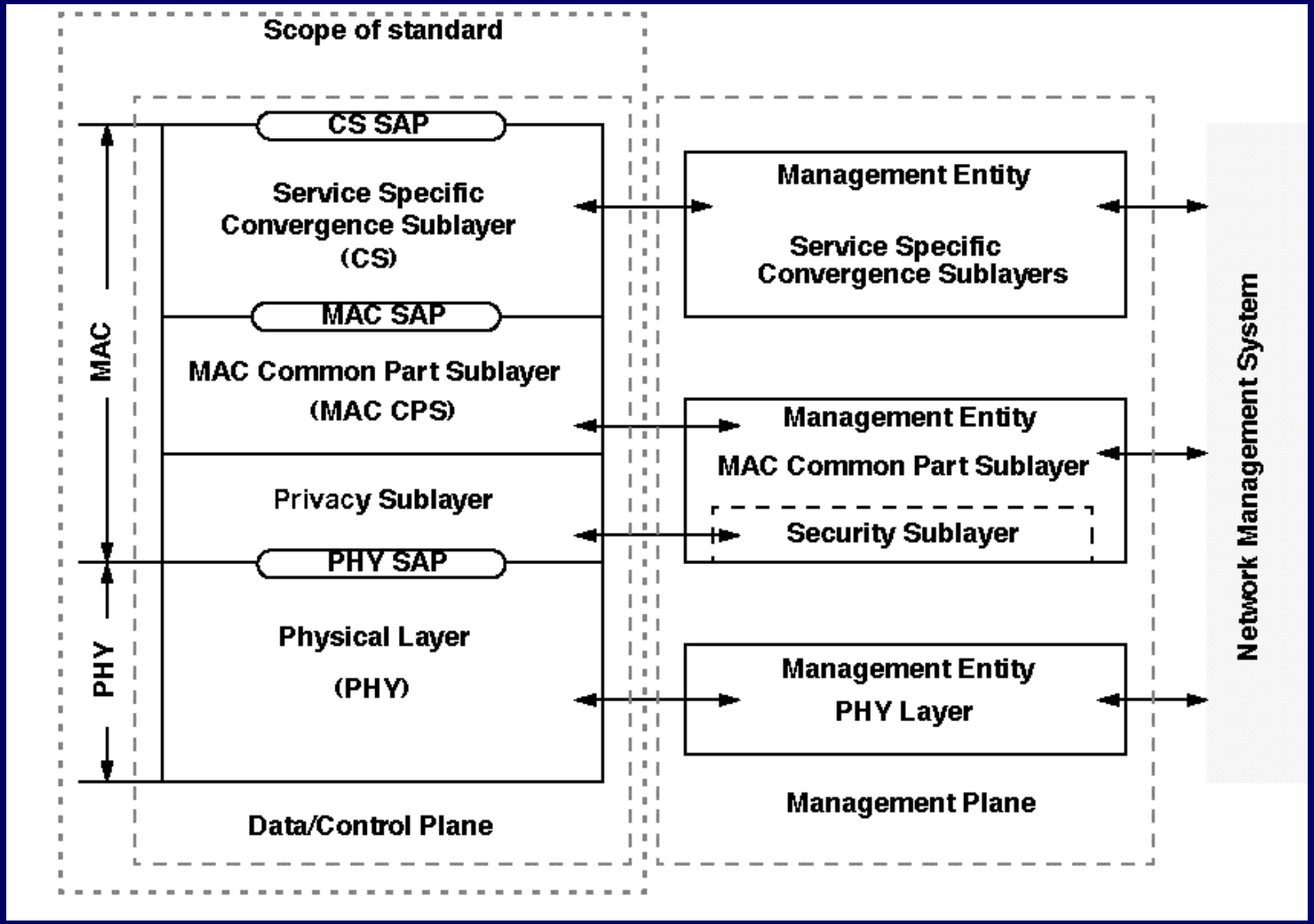
- Base Station (BS) connected to public networks
- BS serves Subscriber Stations (SSs)
  - SS typically serves a building (business or residence)
  - provide SS with first-mile access to public networks

- 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



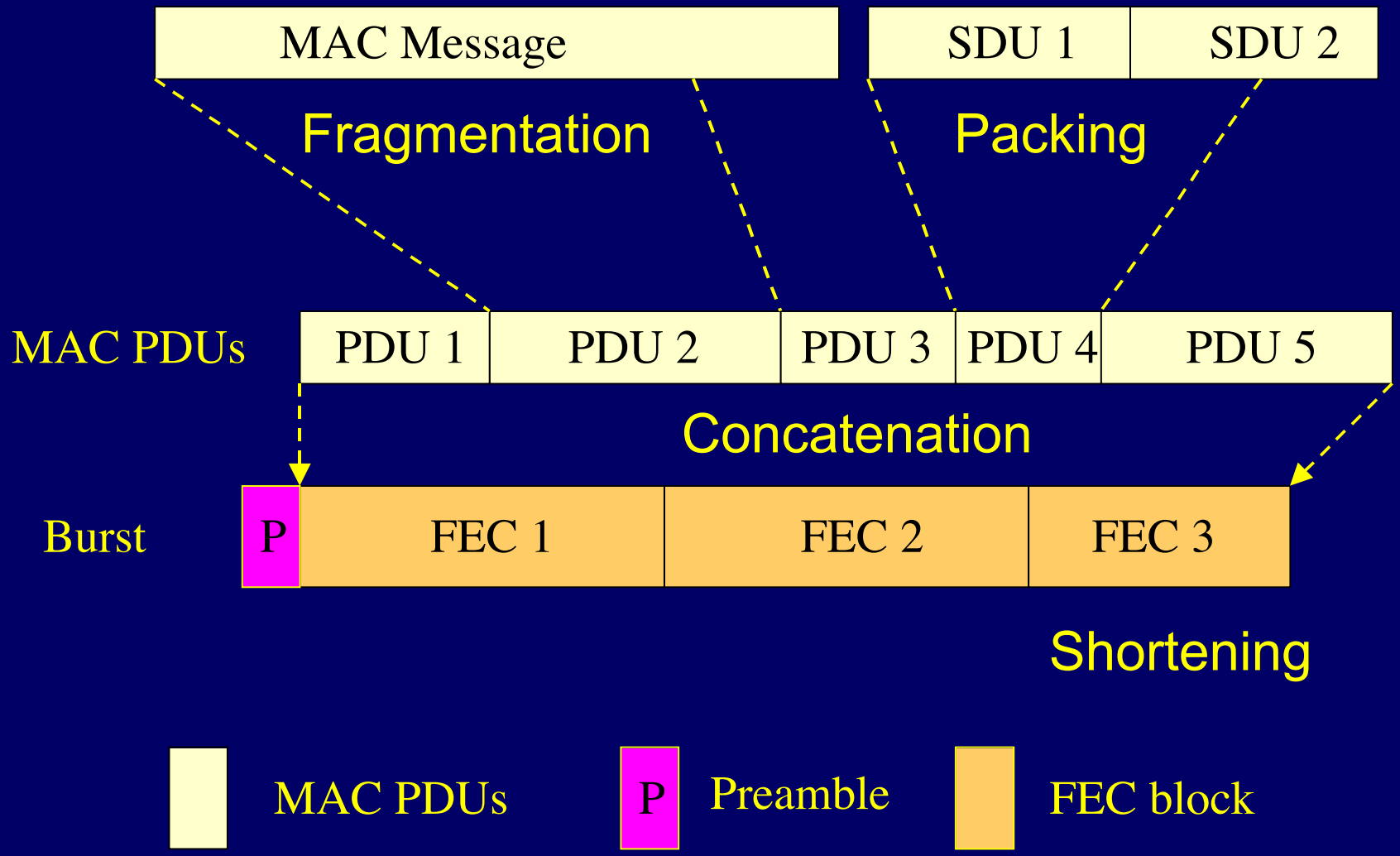
802.16 Reference Model



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

MAC PDU Transmission

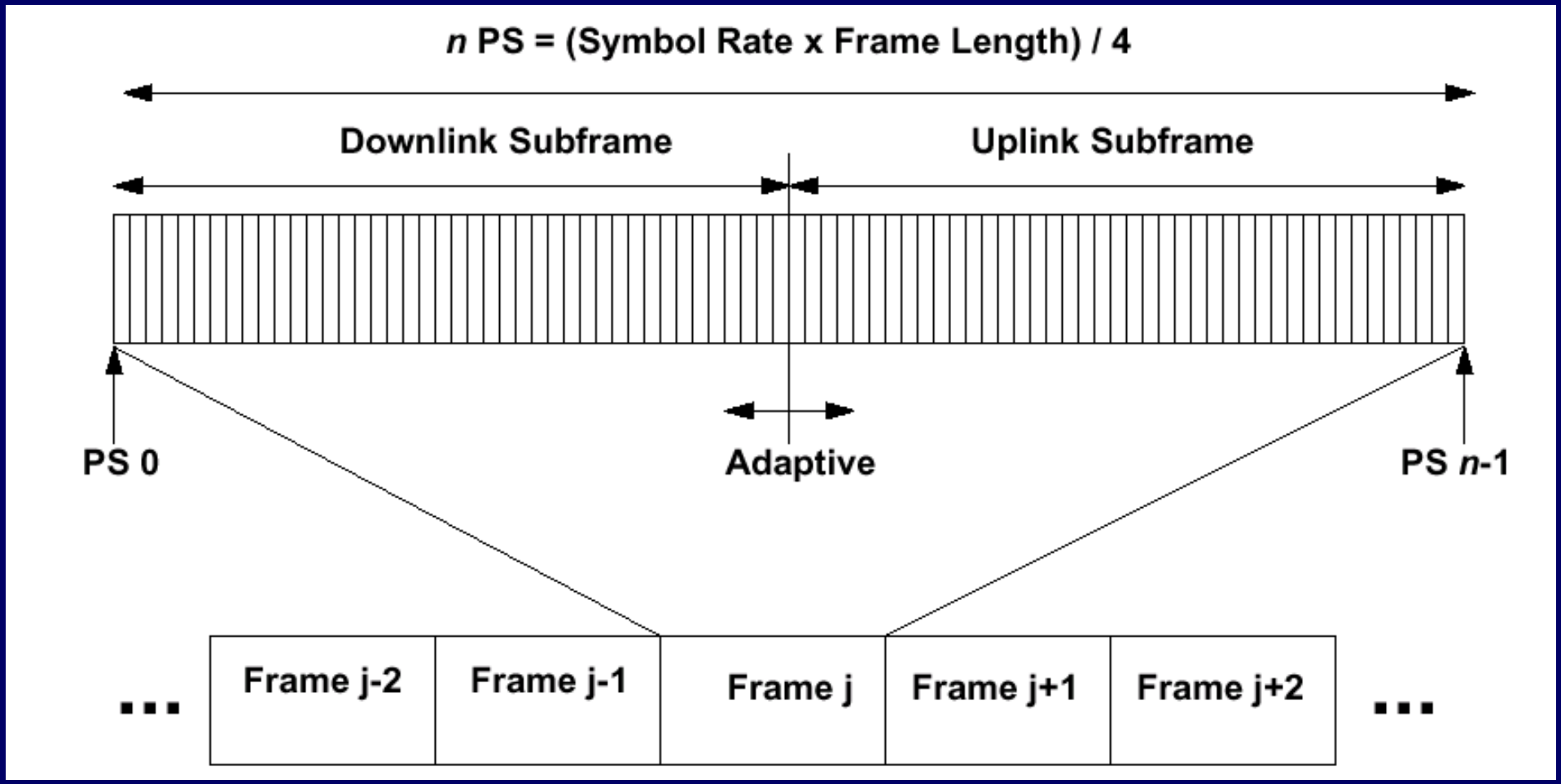


Multiple Access and Duplexing

- 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)

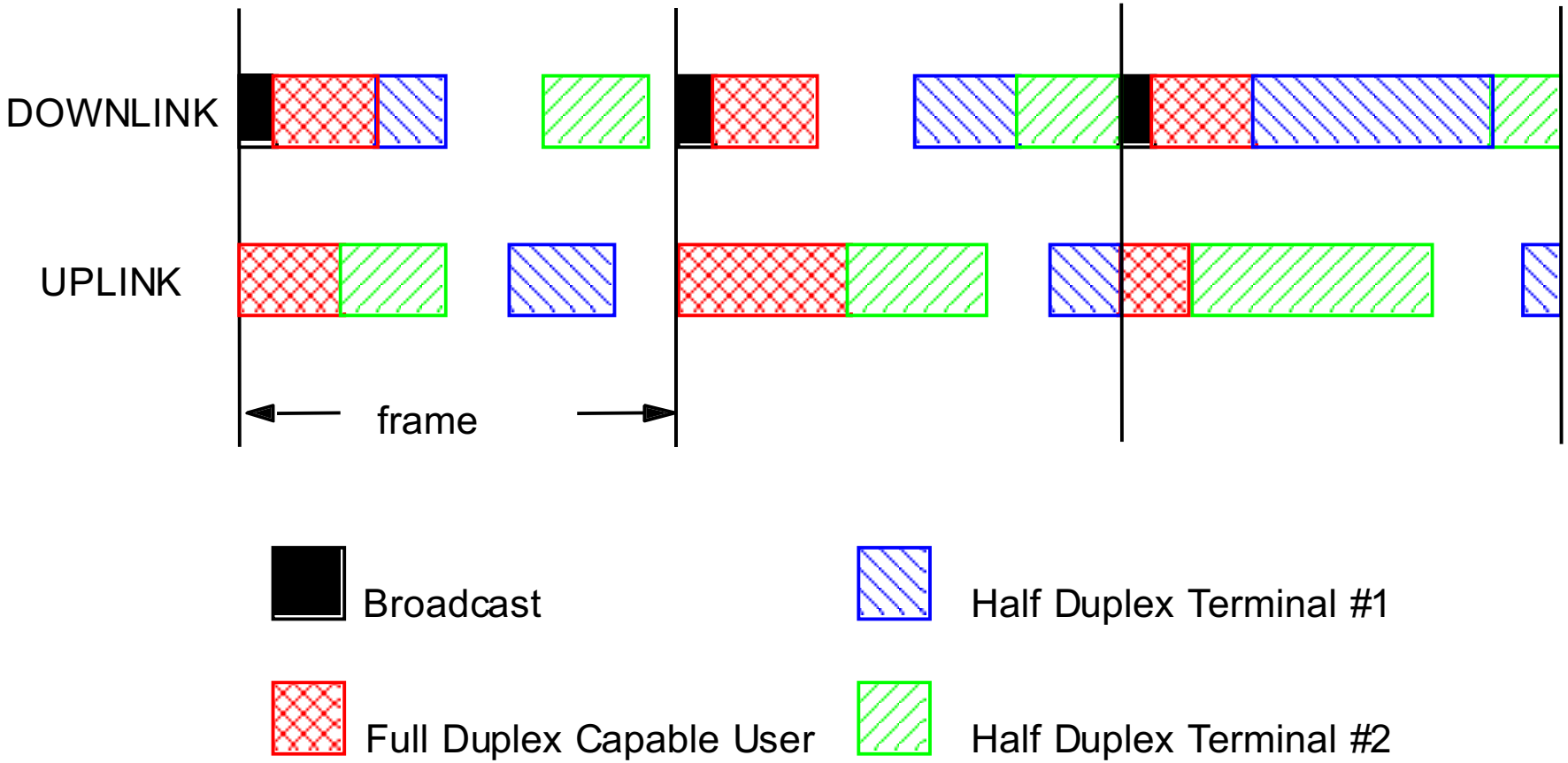
TDD Frame (10-66 GHz)



Frame duration: 1 ms

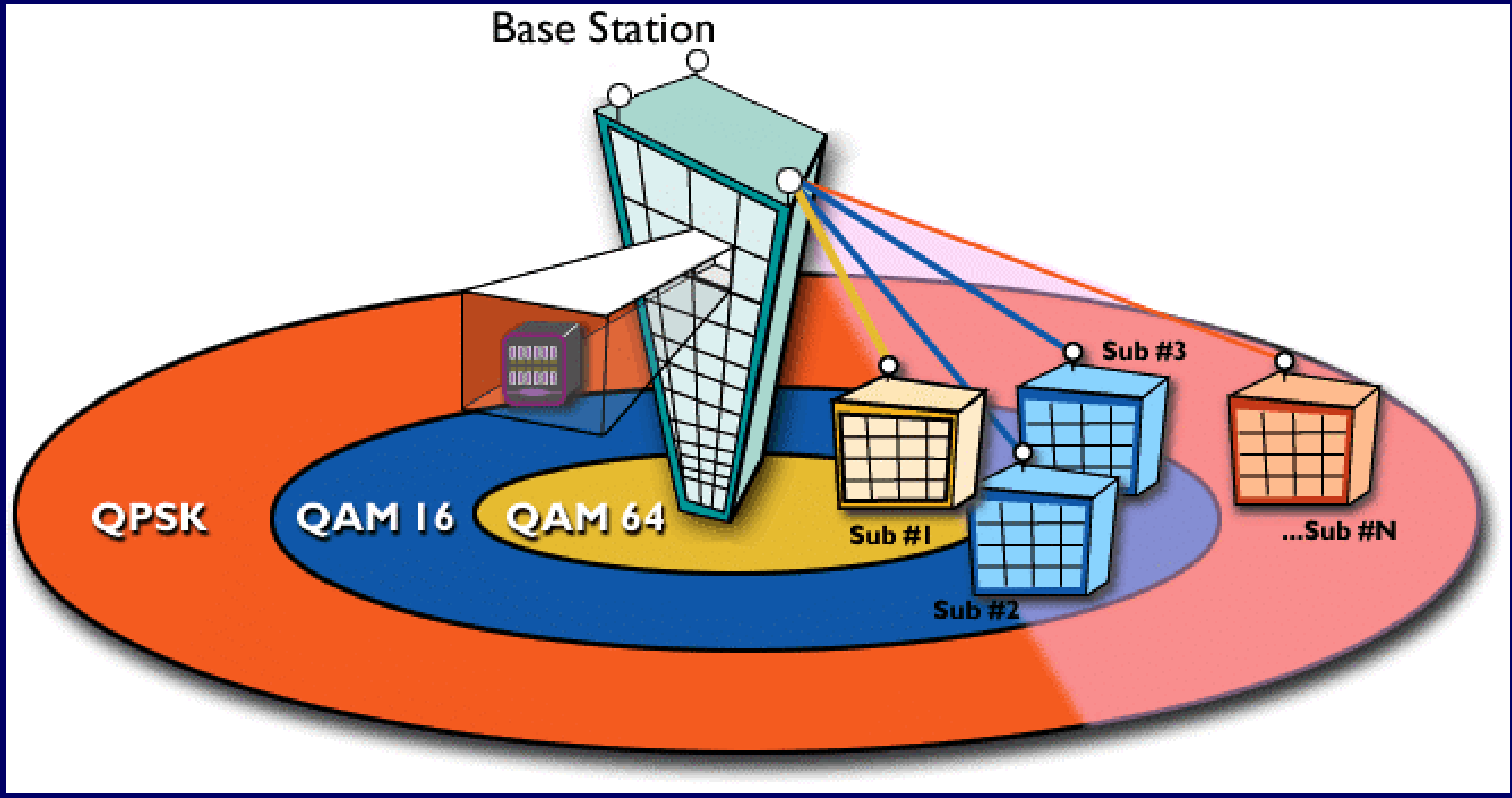
Physical Slot (PS) = 4 symbols

Burst FDD Framing



Allows scheduling flexibility

Adaptive PHY

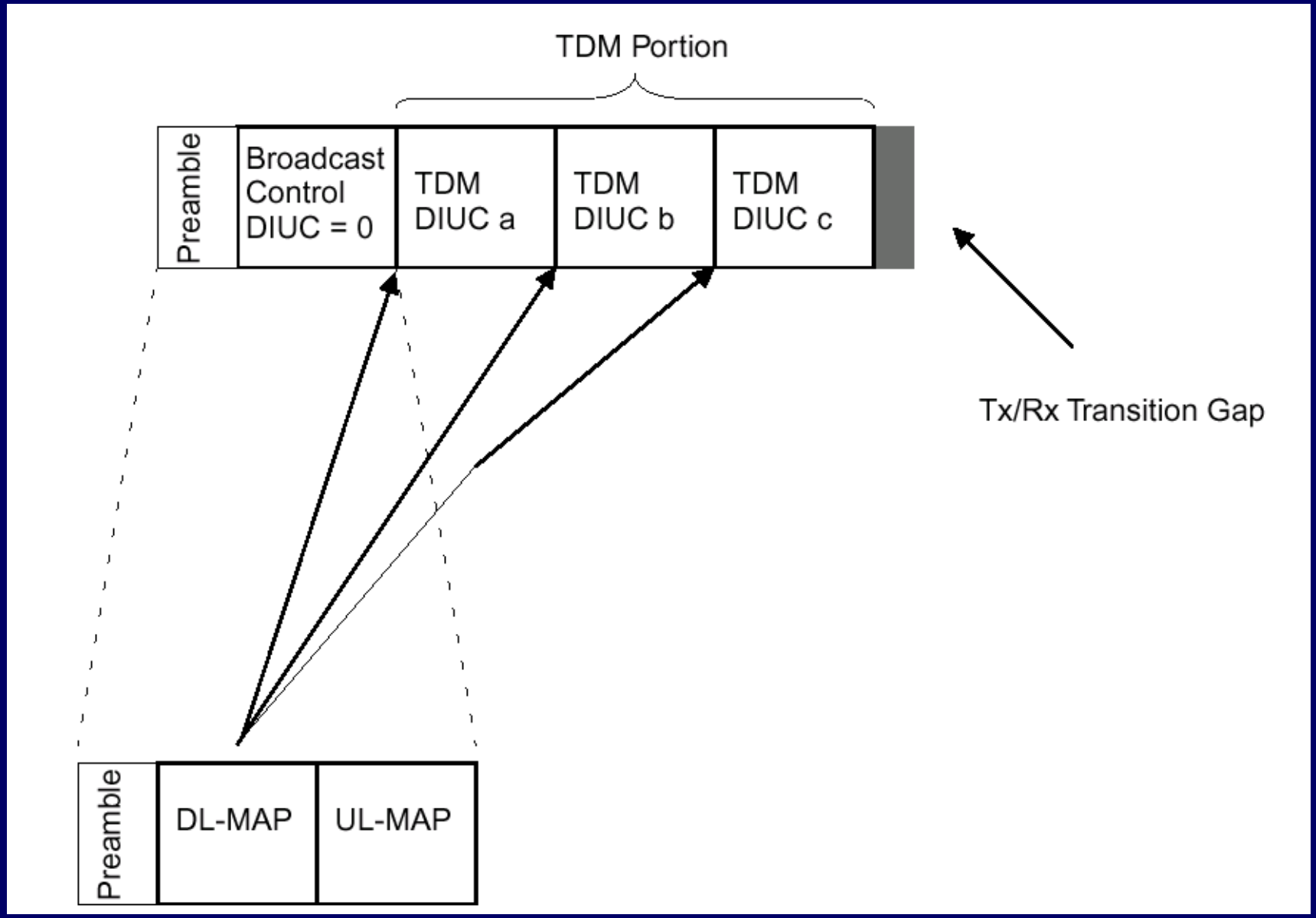


(burst-by-burst adaptivity not shown)

Adaptive Burst Profiles

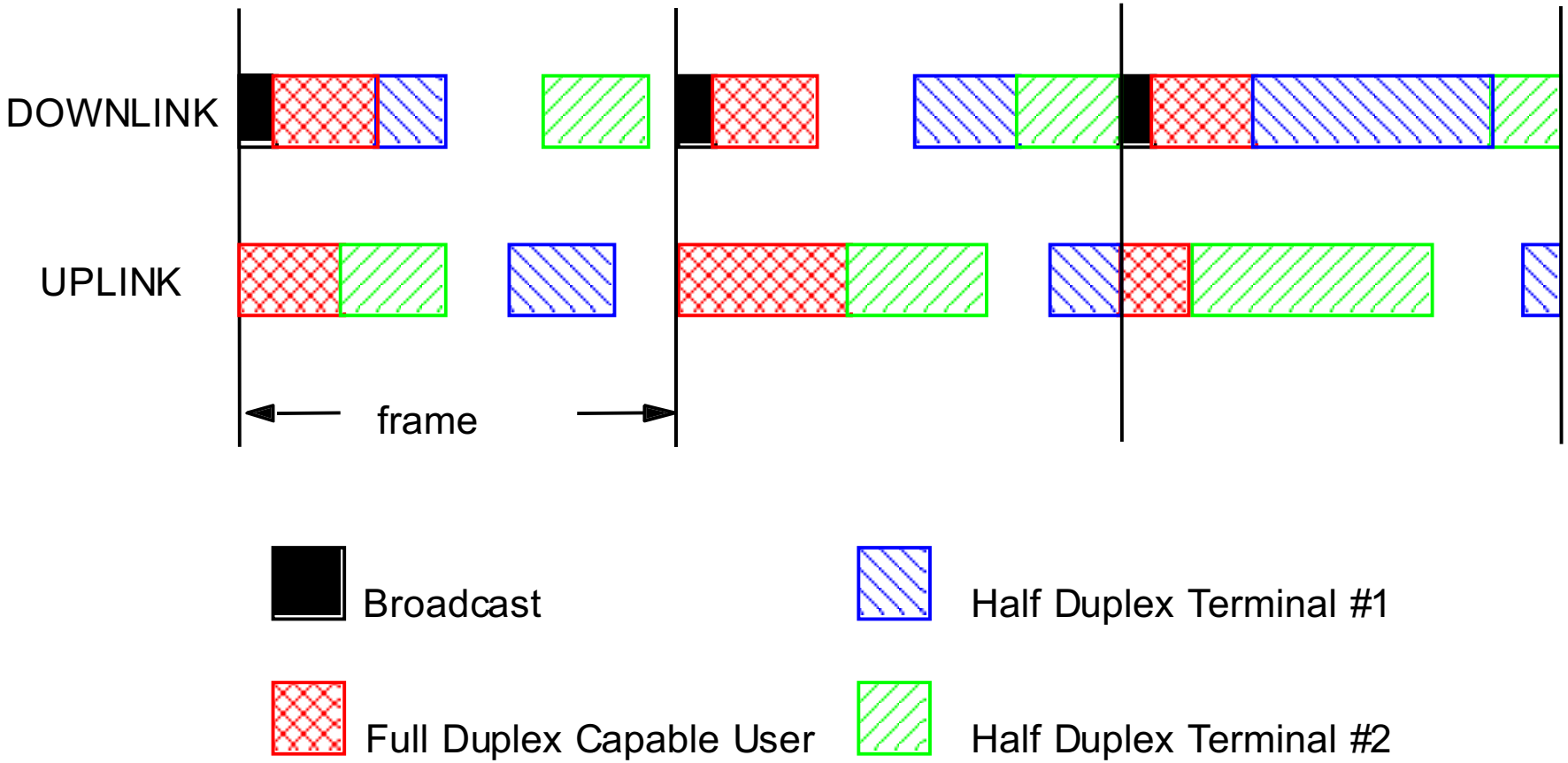
- Burst profile
  - Modulation and FEC
- Dynamically assigned according to link conditions
  - Burst by burst, per subscriber station
  - Trade-off capacity vs. robustness in *real time*
- Roughly doubled capacity for the same cell area
- Burst profile for downlink broadcast channel is well-known and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

TDD Downlink Subframe



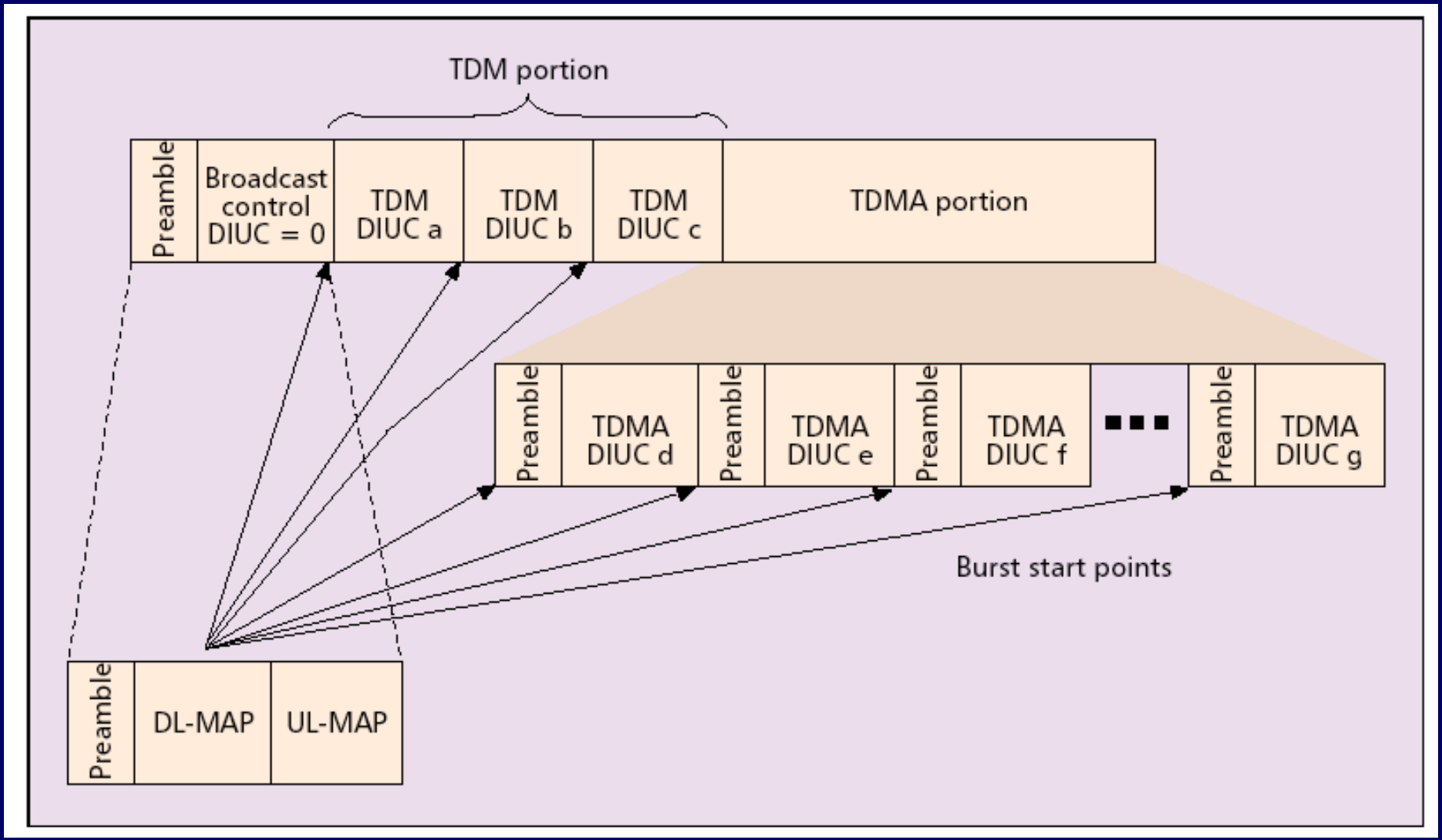
DIUC: Downlink Interval Usage Code

Burst FDD Framing



Allows scheduling flexibility

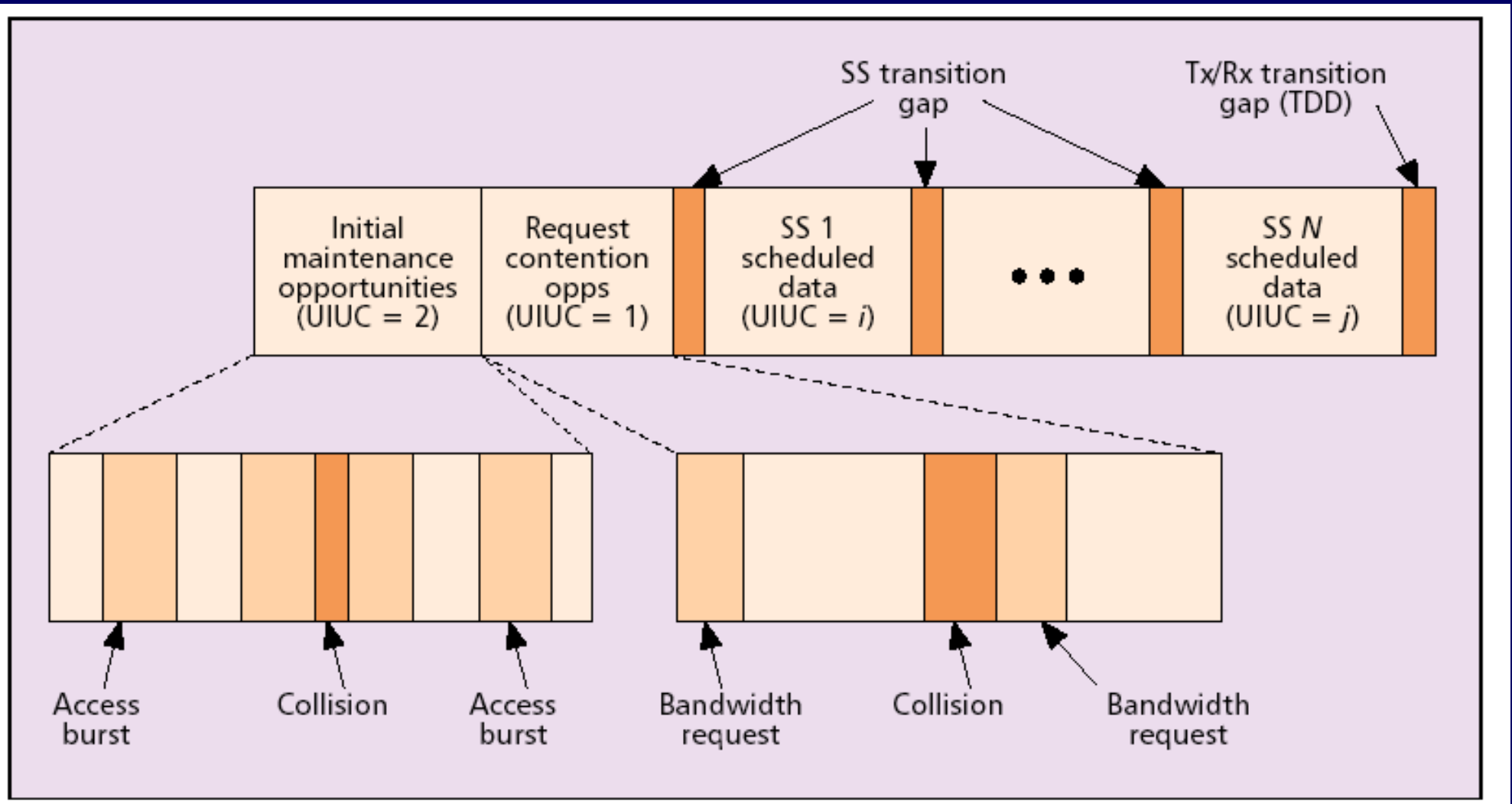
FDD Downlink Subframe



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)

Typical Uplink Subframe (TDD or FDD)



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

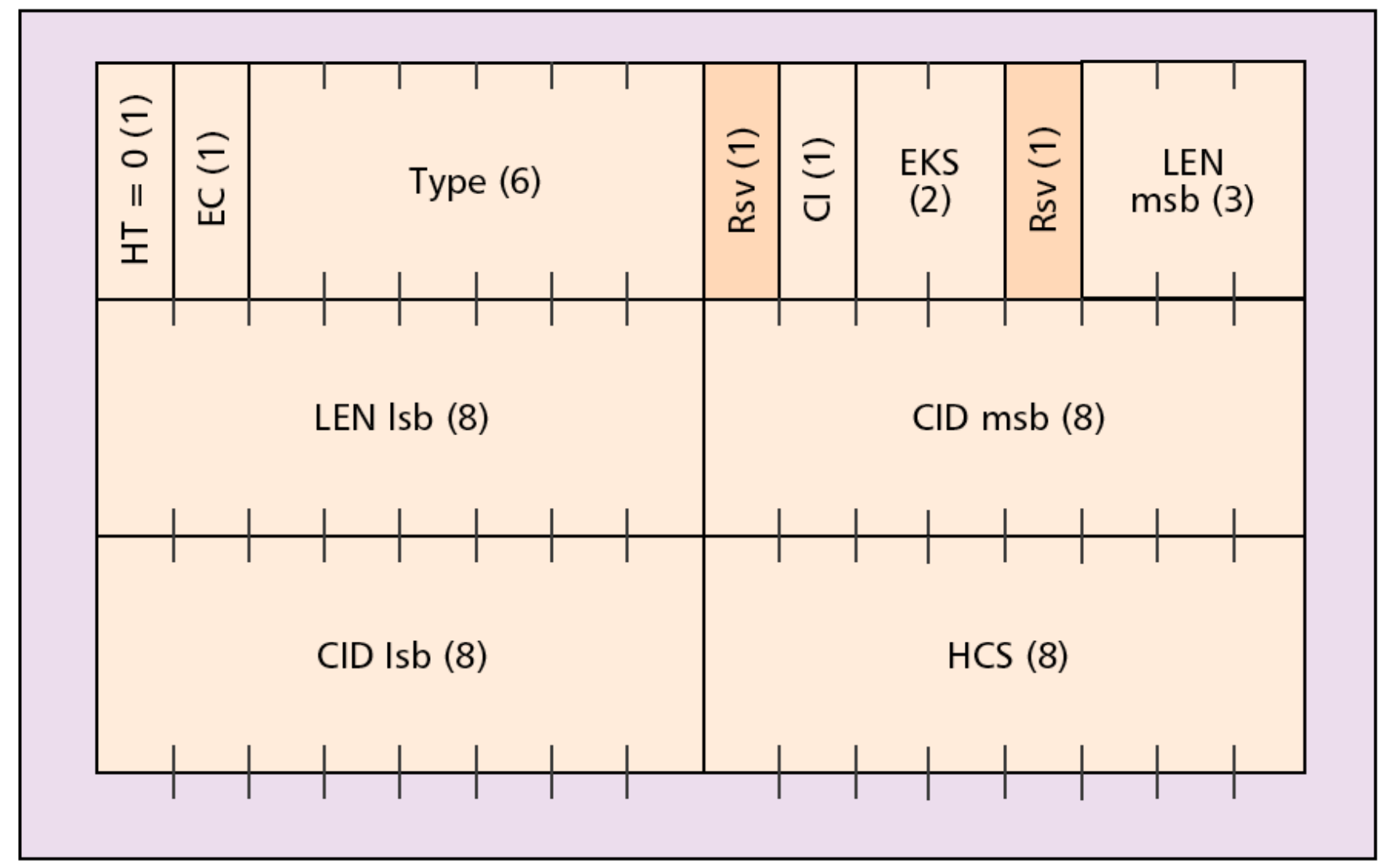
- Reed Solomon
  - RS GF(256), t = 0…16
- For most critical communications, RS is concatenated with a BCC
  - No interleaving, suitable for burst
  - BCC is a rate 2/3 block code based on a tail-bite termination of the $(7,5)_8$ Convolutional Code for every 16 data bits
- Shortening allowed
- Turbo Product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

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

QoS: Classes of Uplink Service

- 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 Subscriber Station (GPSS)
  - Grants (given as durations) are carried in the UL-MAP messages

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

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.

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)
  - Published today (15 January 2003)
  - 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 (P1802.16.1 in ballot)
  - Test Suite Structure & Test Purposes (started)

Amendment Project
IEEE P802.16a

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

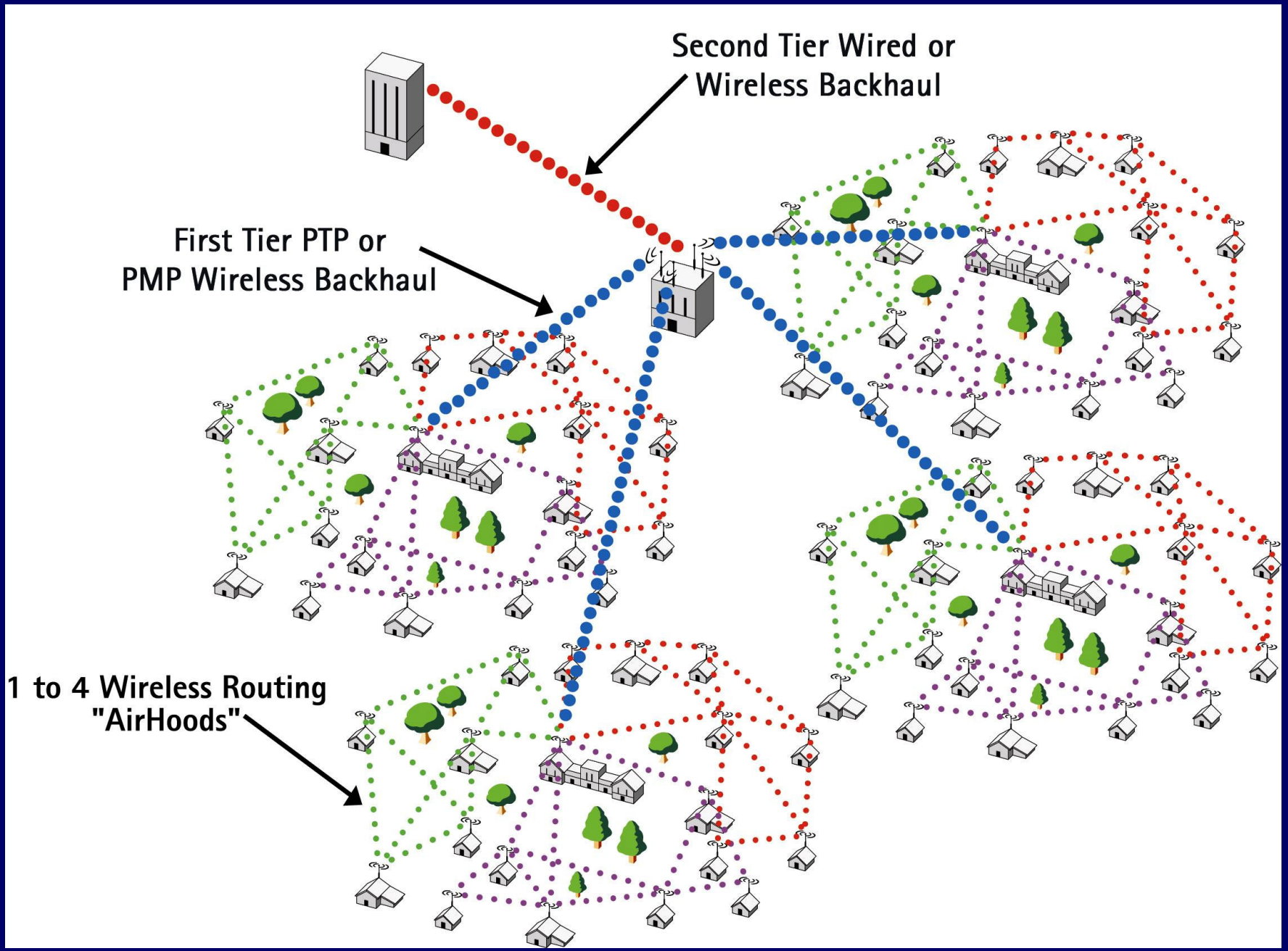
802.16a PHY Alternatives: Different Applications, Bandplans, and Regulatory Environments

- 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

Key 802.16a MAC Features

- OFDM/OFDMA Support
- ARQ
- Dynamic Frequency Selection (DFS)
  - license-exempt
- Adaptive 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
    - alternative approach to non-line-of-sight

Mesh-based WirelessMAN



Source: Nokia Networks

What's Next ?

- Complete 2-11 GHz work
- Enhance 10-66 GHz spec
  - System Profiles are done
  - Interoperability test protocol underway
- New enhancements
  - Mobility

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.

Free IEEE 802 Standards

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

http://WirelessMAN.org

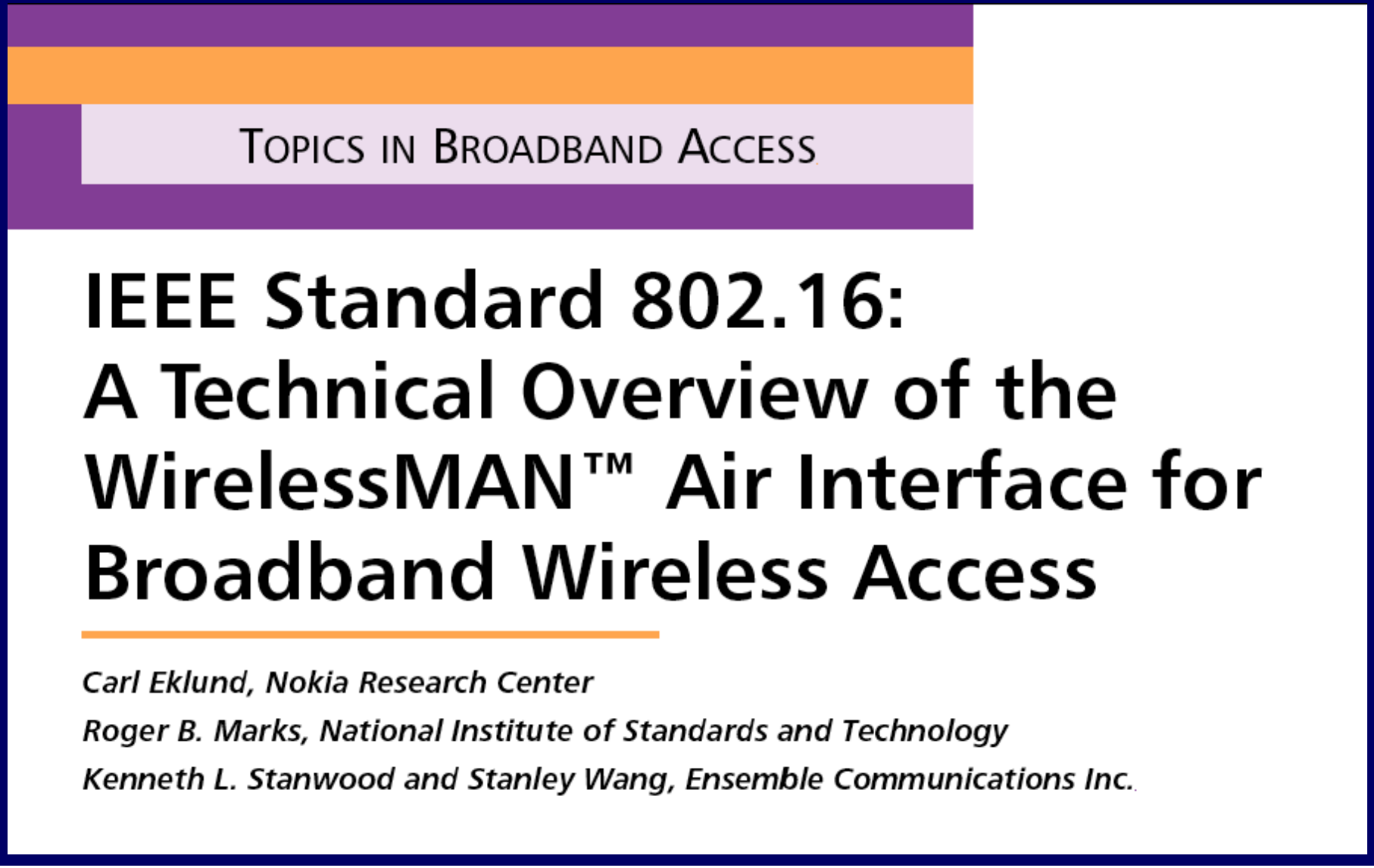
beginning six months after publication

- 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)



Conclusion

IEEE 802.16 WirelessMAN standards are:

- open in development and application
- addressed at worldwide markets
- engineered as optimized technical solutions
- significantly complete
  - With test spec documents in development
- being enhanced for expanded opportunities

IEEE 802.16 Resources

IEEE 802.16 Working Group on Broadband Wireless Access

info, documents, tutorials, email lists, etc:

http://WirelessMAN.org

Left to Right: Bob Stewart (IEEE 802 Originator); Roger Marks (IEEE 802.16 Chair); Don Loughry (former IEEE 802 Chair)

IEEE Computer Society Santa Clara Valley Chapter, Stanford University: 15 January 2003
Talk: "The IEEE 802.16 WirelessMAN[TM] Standard for Broadband Wireless Metropolitan Area Networks," by Roger Marks.

Left to Right: Ken Stanwood (IEEE 802 Task Group C Chair); Bob Stewart (IEEE 802 Originator); Roger Marks (IEEE 802.16 Chair); John Liebetreu (IEEE 802.16 Task Group 4 PHY Chair)

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