

The Wireless Internet as defined by IEEE 802 Standards

*IEEE Computer Society
Distinguished Visitors Program*

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Chair, IEEE 802.16 Working Group

<http://WirelessMAN.org>

Outline

- IEEE Standards Association
- IEEE 802 LAN/MAN Standards Committee
 - Local and Metropolitan Area Networks
- IEEE 802 Wireless Standards Program
 - IEEE 802.11 Wireless Local Area Networks
 - IEEE 802.15 Wireless Personal Area Networks
 - IEEE 802.16 Wireless Metropolitan Area Networks

IEEE-SA

The IEEE Standards Association

Develops and publishes IEEE Standards

Membership

- **Individual (IEEE Membership +\$10/year)**
- **corporate**

IEEE-SA Standards Board

- **oversees standards development**
- **approves projects and standards**

IEEE 802

The LAN/MAN Standards Committee

Wired:

- 802.3 (Ethernet)
- 802.17 (Resilient Packet Ring) [no drafts yet]

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: Mobile Broadband Wireless Access
 - Held one session in March 2003

More IEEE 802 Wireless Activities

- **802.18: Regulatory Technical Advisory Group**
- **802.19: Coexistence Technical Advisory Group**
- **802 Executive Committee Study Group on Handoff**

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

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

Distribution of IEEE 802 Standards

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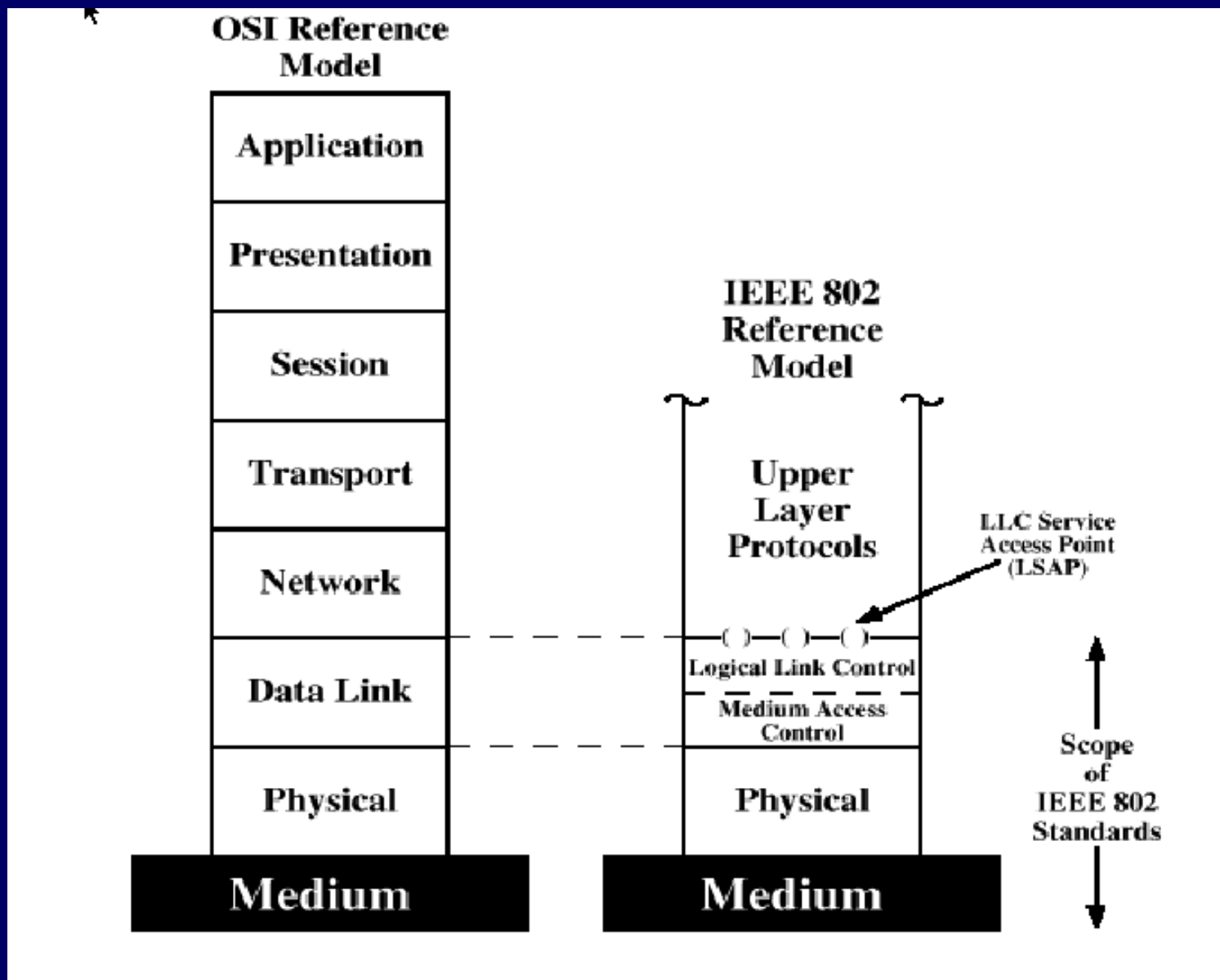
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...Partnering with industry to close the digital
divide

[Main page](#)

IEEE 802® standards are now available at no charge in PDF format. The Get IEEE 802™ pilot program grants public access to view and download individual IEEE Local and Metropolitan Area Network (IEEE 802®) standards at no charge. IEEE 802® standards will be added to the Get IEEE 802™ program six months after publication.

Scope of 802 Standards



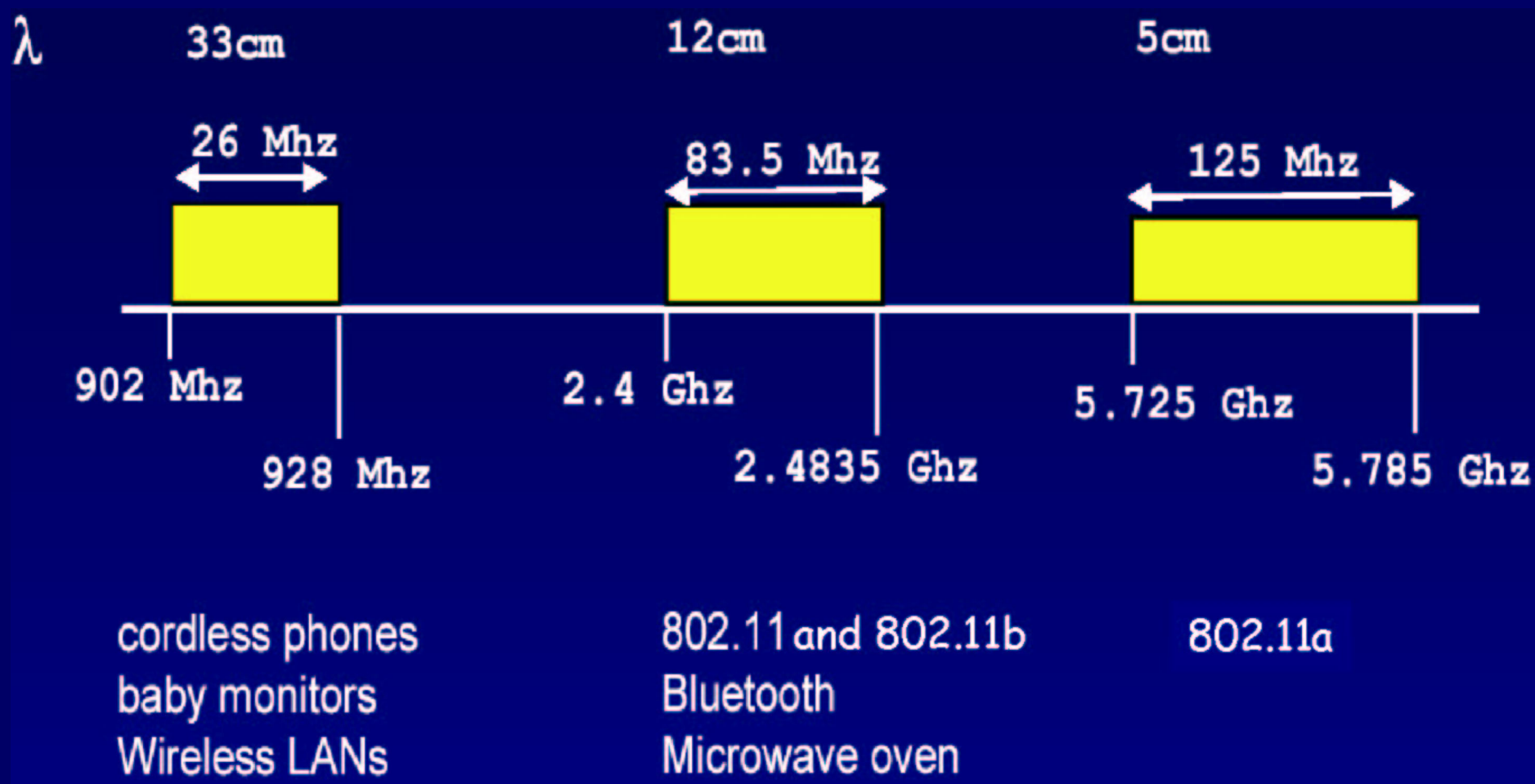
IEEE 802.11 (Wireless LAN)

- Originally developed mainly for corporate-type environments
 - To eliminate cost of stringing Ethernet cable
- New factors
 - Powerful laptop computers with PCMCIA slots
 - Widespread full-time high-speed Internet access
- 802.11 Access Points introduced into homes and public spaces
- Due to standard:
 - Prices have plummeted
 - Links have become interchangeable
- 802.11 is experiencing wild growth

IEEE 802.11 History

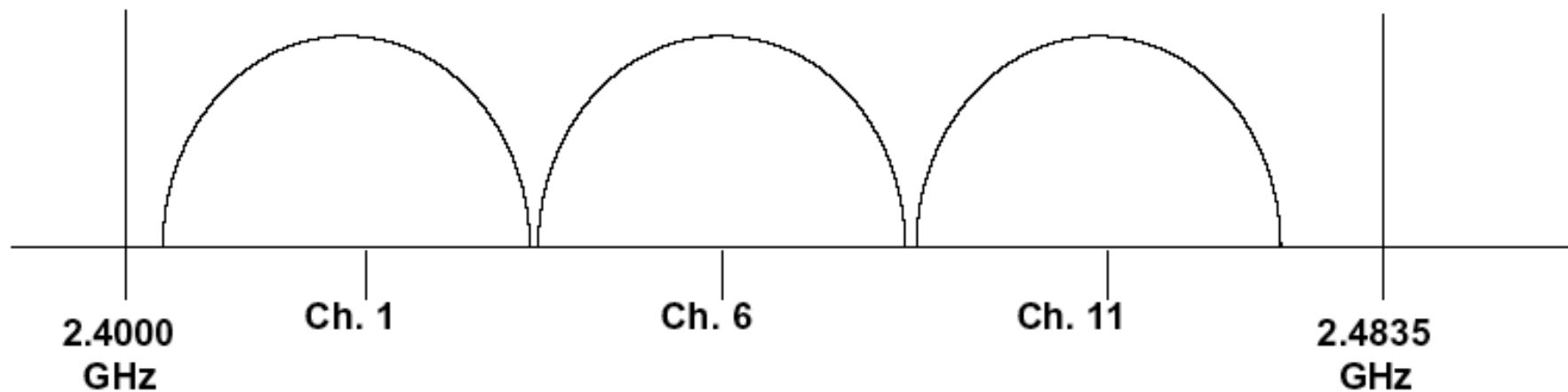
- 802.11 Working Group initiated IEEE 802's wireless effort in 1990
- published base standard (IEEE 802.16) in 1997
 - Medium access control layer (MAC):
 - CSMA/CA + RTS/CTS
 - Physical layer (PHY): 3 options
 - Infrared (little used)
 - Microwave: 2 Mbit/s; obeys spread-spectrum rules laid down for license-exempt use in 2.4–2.4835 GHz U.S. ISM band
 - Many other countries have followed
- 802.11b-1999: 11 Mbit/s DSSS PHY
- 802.11a-1999: 54 Mbit/s OFDM PHY (5-6 GHz)

License-Exempt Spectrum (popular U.S. bands)



Source: Yang Richard Yang, Dept. of Computer Science, Yale University

20 MHz 802.11 Channels in 2.4 GHz Band

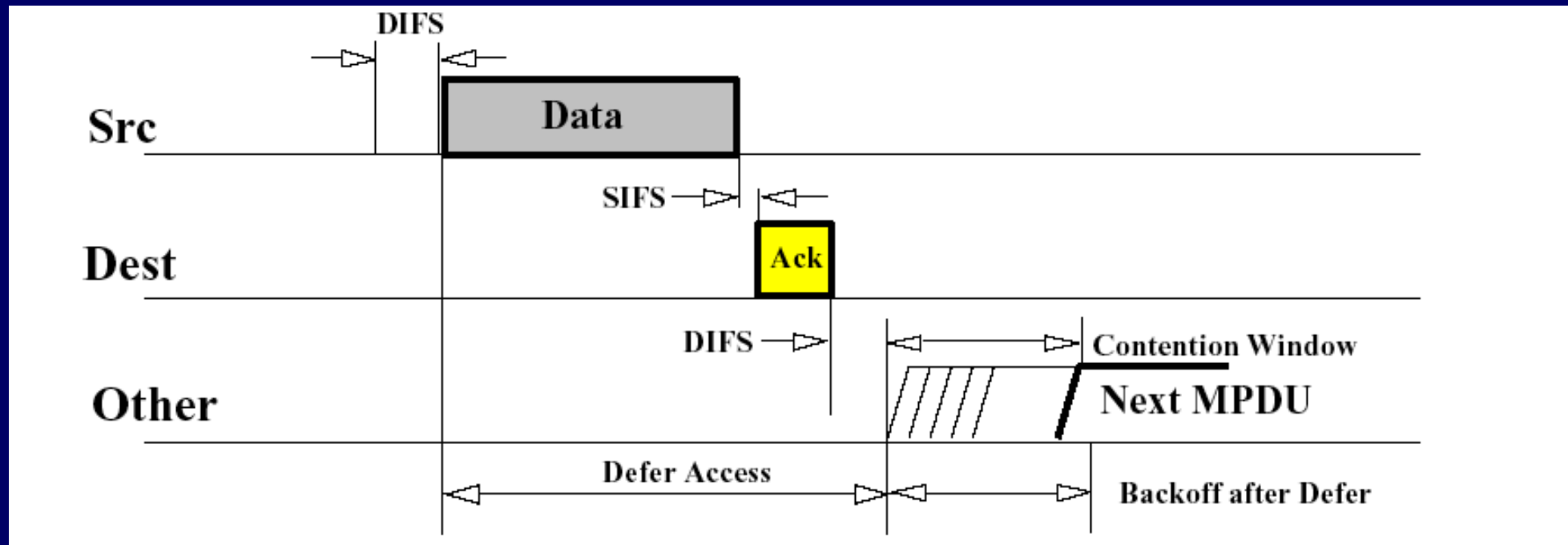


Source: IEEE 802.11 Tutorial (Jim Zyren and Al Petrick)

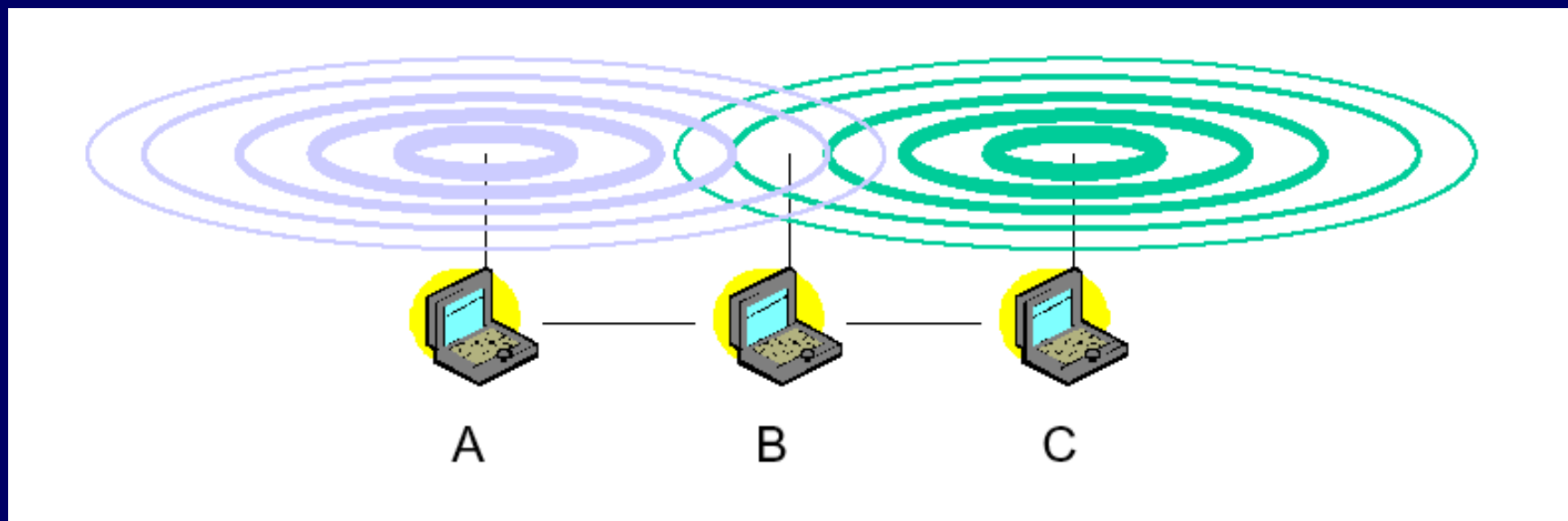
IEEE 802.11 Medium Access Control¹⁵

- "Distributed Coordination Function" (DCF)
 - carrier-sense multiple access with collision avoidance (CSMA/CA)
- Derived from Ethernet
 - carrier-sense multiple access with collision detection (CSMA/CD)
 - Backoff window
 - collision detection impossible
 - Disparate signal levels
 - Half-duplex radios
 - Carrier-sensing is often impossible
 - RTS/CTS required

CSMA



Hidden Terminal Problem



Source: Yang Richard Yang, Dept. of Computer Science, Yale University

RTS/CTS

- To address hidden terminal problem
 - Which makes carrier-sensing problematic
- Start with Request-to-Send (RTS)
- Intended Recipient issues Clear-to-Send (CTS)
- Devices within range of recipient detect CTS
 - Update their Network Allocation Vector
 - "virtual carrier sense"
- Ability to generate RTS is optional
 - Many 802.11 devices cannot do it
- Response to RTS/CTS is mandatory
- RTS/CTS adds overhead

Point Coordination Function (PCF)¹⁹

- Alternative to DCF (CSMA/CA)
- Central controller allocates channel access
- Intended to support Quality of Service (QoS) requirements (voice, video, multimedia, etc.)
- Defined in standard, but not implemented or deployed widely (or at all?)

802.11e QoS

- Draft standard adding QoS support to MAC
- Long development time
- Draft still not stable or fully supported
- Does not focus on PCF
- Basis is "extended DCF"

Other 802.11 Work in Progress

- Project 802.11g: high-rate PHY in 2.4 GHz band
 - Adaptation of 802.11a OFDM PHY
 - Hope to complete in Summer 2003
- Project 802.11i: Security
 - 802.11 uses Wired Equivalent Privacy (WEP)
 - WEP designed to “protect authorized users of a wireless LAN from casual eavesdropping”
 - Weaknesses in WEP have been discovered, and successful attack algorithms are available
 - external security, beyond the wireless link, may be required for sensitive applications

IEEE 802.15 (Wireless PAN)

- Wireless Personal Area Networks
- link portable devices
- unlicensed bands
 - 2.4 GHz band and below, to this point
- with ranges up to 10 m
- Critical features:
 - low cost
 - small size
 - low power consumption

IEEE 802.15 Projects

- IEEE Std 802.15.1-2002:
 - Standard based on Bluetooth Specification v. 1.1
- Projects in progress
 - 802.15.3
 - 802.15.3a
 - 802.15.4

IEEE 802.15.1: Bluetooth

- IEEE Std 802.15.1-2002:
 - Standard based on Bluetooth Specification v. 1.1
- “cable-replacement” technology
- Same 2.4 GHz band as 802.11 (FHSS)
- Intended as low-cost wireless communication between laptop computers, PDAs, mobile telephones, headsets, printers, etc.
- networking is ad hoc and based on small temporary master-slave “piconets”
- Data rates up to 721 kbit/s, plus 3 voice channels
- Typically 1 mW

IEEE 802.15.3: High-Rate WPAN

- IEEE Project 802.15.3
- Up to 55 Mbit/s
- QoS for multimedia
- MAC is based on temporary piconets but differs from that of 802.15.1
- 802.15.3a is developing of enhanced PHY () to support at least 110 Mbit/s
 - likely to be based on ultra-wideband communications
 - Many (~35) proposals in March 2003

IEEE 802.15.4: Low-Rate WPAN

- IEEE Project 802.15.4
- another unique MAC
- data rates up to 250 kbit/s
- very low power consumption (for battery life on the order of months or years)
- low complexity (targeting costs of US\$2 per radio)
- Applications expected in sensors, toys, and location tracking

IEEE 802.16 (Wireless MAN)

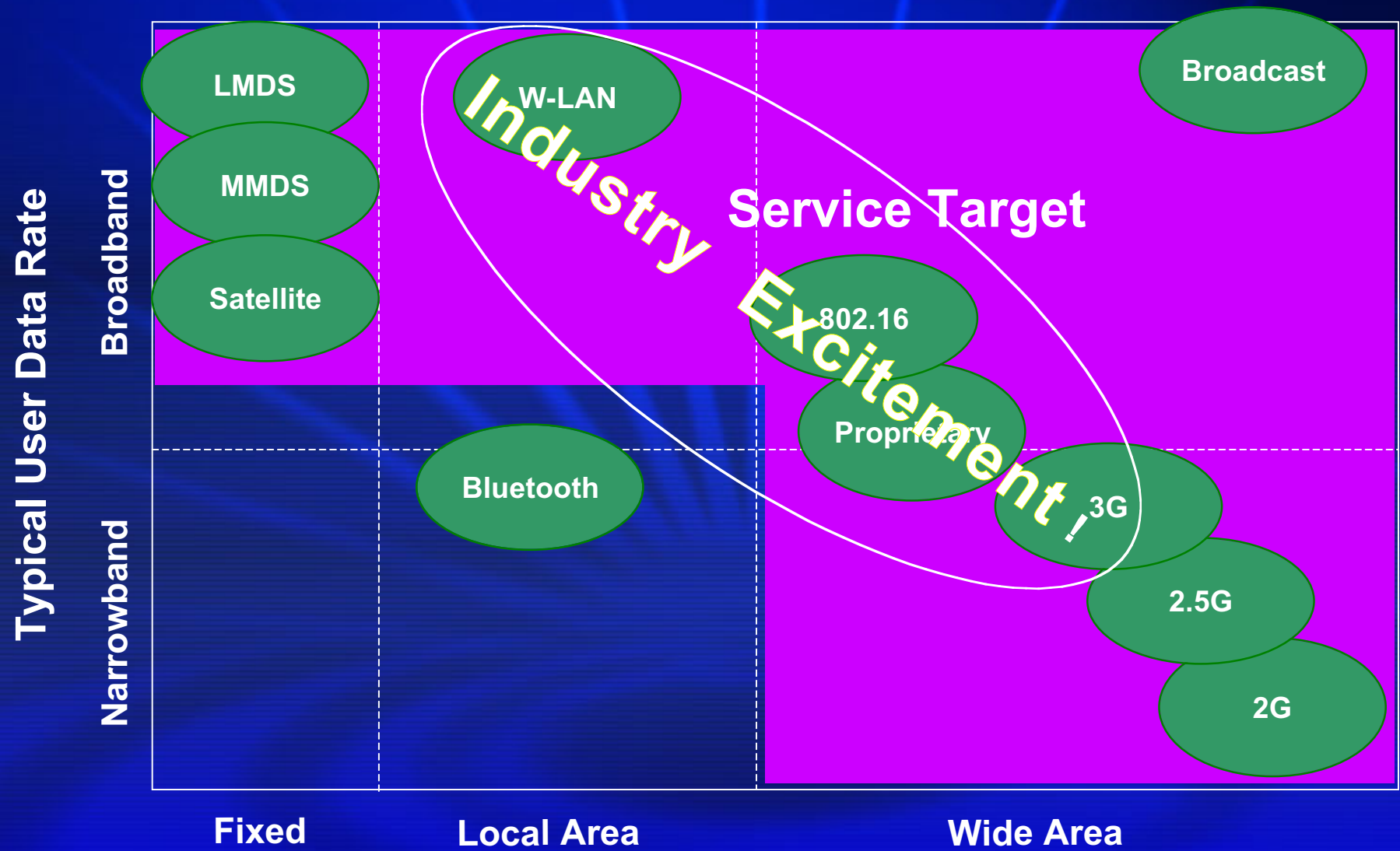
- **Wireless Metropolitan Area Networks**
- **Broadband Wireless Access**
 - Primarily "fixed" (non-moving)
 - May evolve to support mobile users



Broadband Access to Buildings

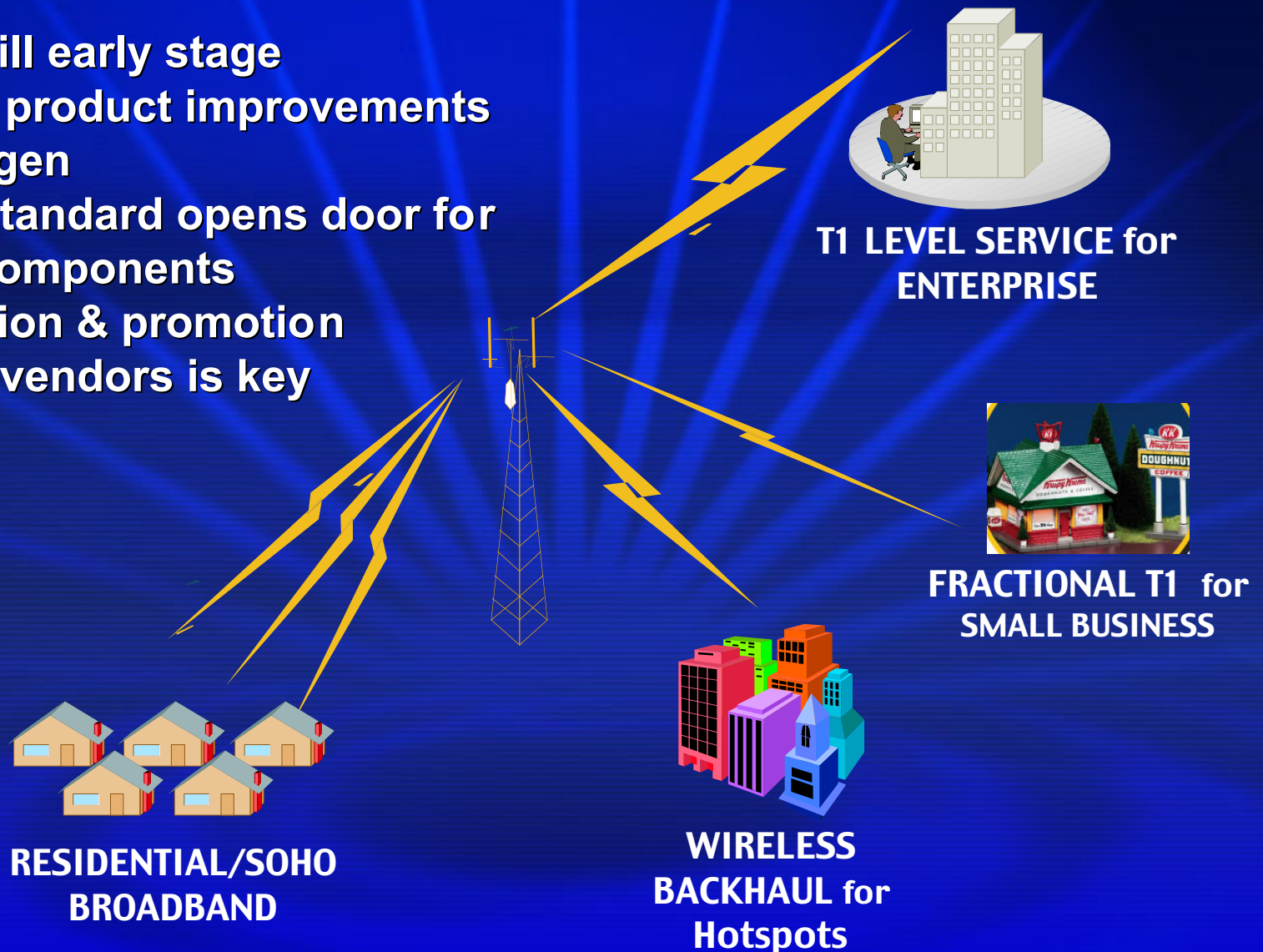
- **The “Last Mile”**
 - Fast local connection to network
- **Business and residential customers demand it**
 - Data
 - Voice
 - Video distribution
 - Real-time videoconferencing
 - etc.
- **Network operators demand it**
- **High-capacity cable/fiber to every user is expensive**
 - Construction costs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

Wireless Access Methodologies



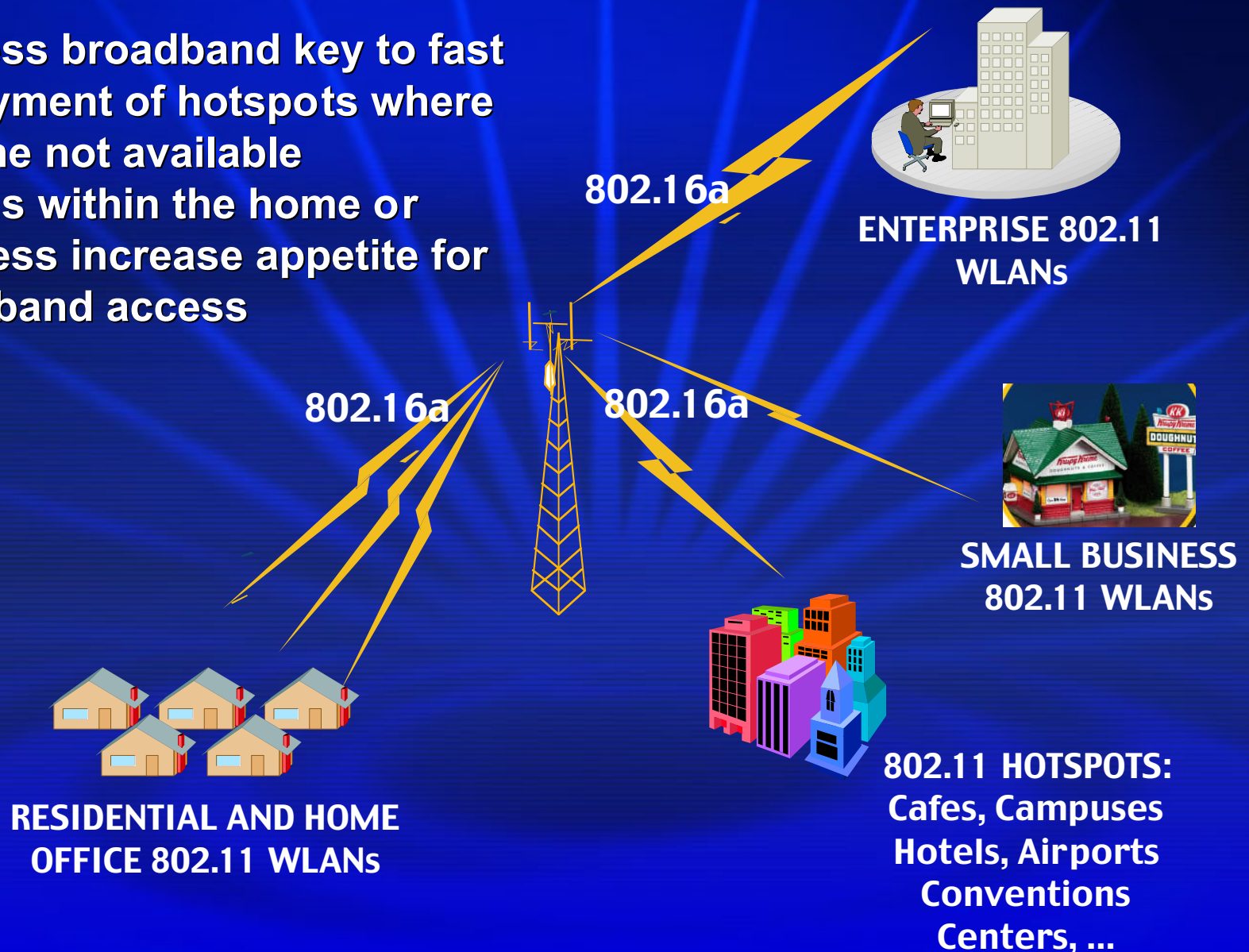
802.16a Last Mile Market Segments

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



802.11 Drives Demand for 802.16a

- Wireless broadband key to fast deployment of hotspots where wireline not available
- WLANs within the home or business increase appetite for broadband access



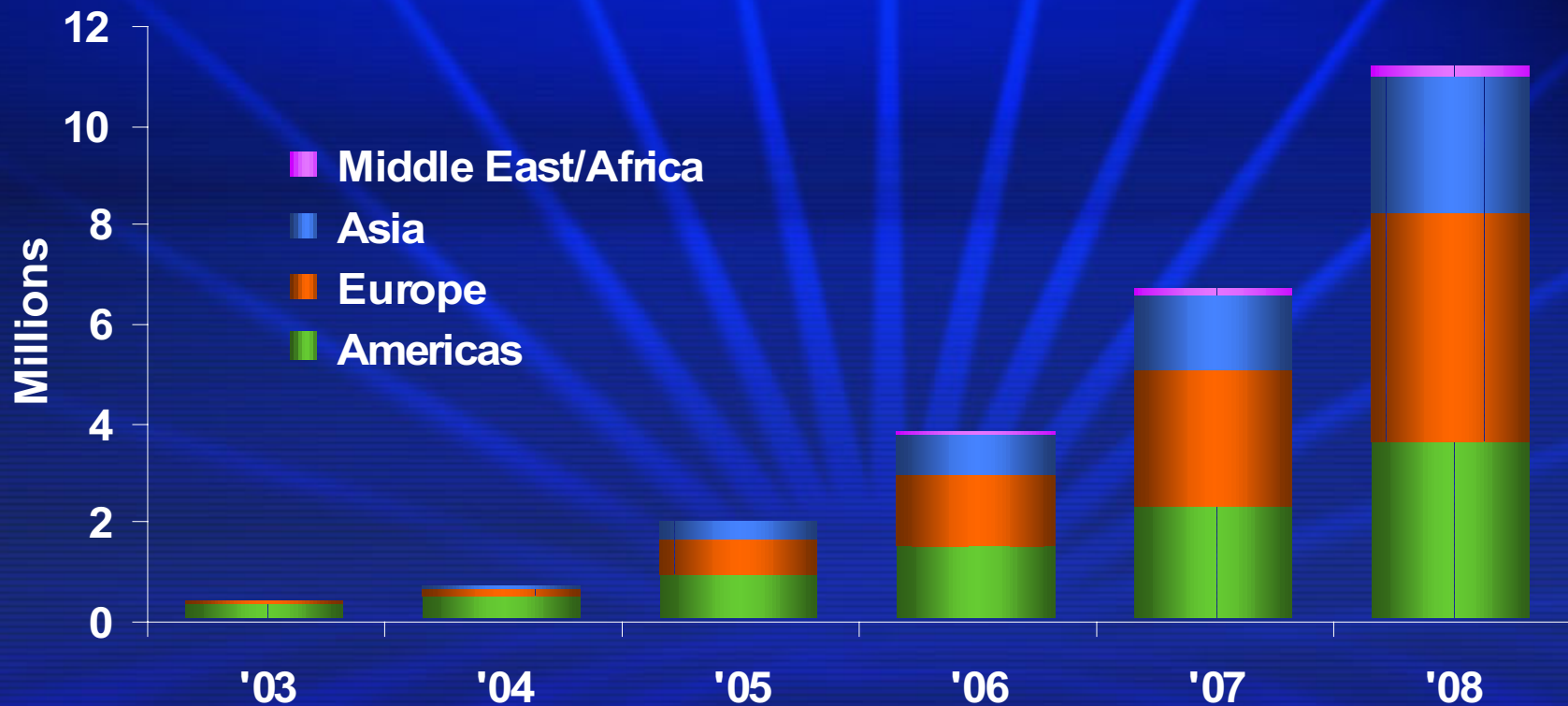
Today's Wireless Performance

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

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

802.16 Wireless Access

Worldwide < 11 GHz Subscriber Base by Region
(802.16a and Proprietary)



Assumptions

- 802.16a standard is adopted -> reducing customer premise equipment price
- Does not consider Hotspot subscribers

Source: Intex Management Services primary research for Intel, December '02. Based upon April '02 report, "The WW Market for Broadband Wireless Access, 2002".

Summary

- **Wireless - A spectrum of opportunities**
- **802.11 is first key disruption - 802.16 is Next**
- **Economics don't work for Broadband data over Cellular**
- **Interoperability/standards critical**

Intel is active in the entire ecosystem !

- **Broad bandwidth**
 - Up to 134 Mbit/s in 28 MHz channel (in 10-66 GHz air interface)
- **Supports multiple services simultaneously with full QoS**
 - Efficiently transport IPv4, IPv6, ATM, Ethernet, etc.
- **Bandwidth on demand (frame by frame)**
- **MAC designed for efficient use of spectrum**
- **Comprehensive and extensible security**
- **Supports multiple frequency allocations from 2-66 GHz**
 - OFDM 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 underway.**

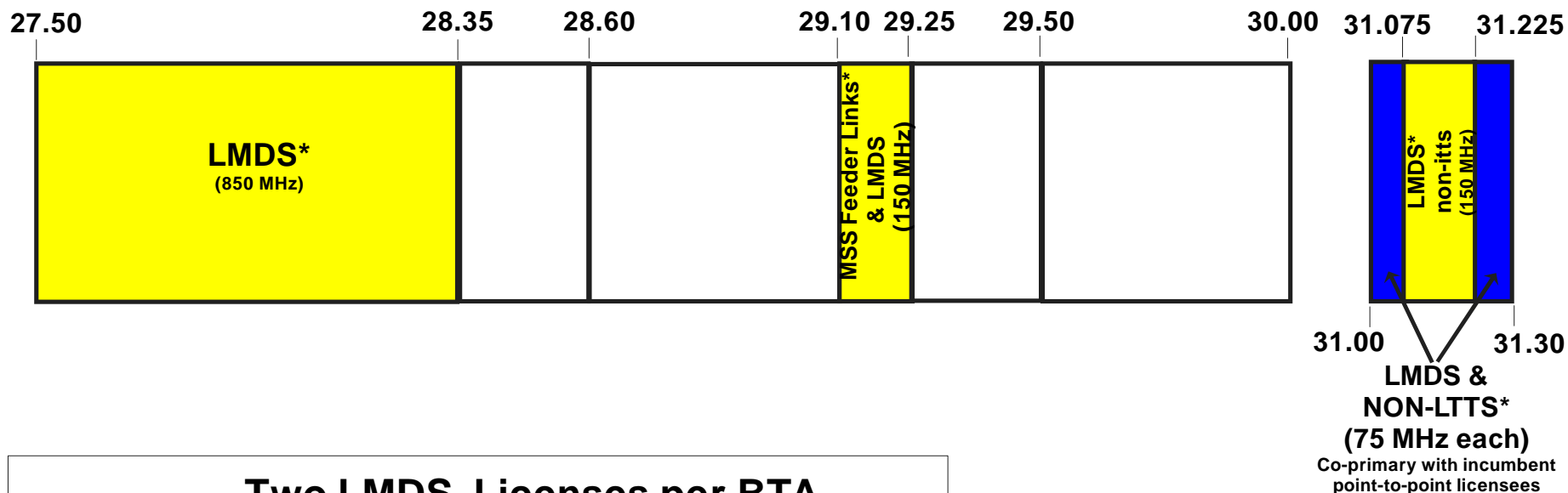
Millimeter-Wave Bands for Wireless MAN³¹

- 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

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

IEEE 802.16 History

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- **Project Development: 1998-1999**
- **Meet every two months:**
 - Session #1: July 1999
 - Session #21/Sept 2002 Cheju, Korea
 - Session #22/Nov 2002: Hawaii, USA (with 802)
 - Session #23/Jan 2003: San Jose, CA, USA
 - Session #24/Mar 2003: Dallas, TX, USA (with 802)
- **Future Sessions**
 - Session #25/Mar 2003: Dallas, TX, USA
 - with 802 wireless groups
 - Session #26/Jul 2003: San Francisco, USA
 - with 802

Participation in IEEE 802.16

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- *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

- 70 Members (peaked at 178)
- >800 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 Members (current and former)

- **CANADA (49)**
- **CHINA (1)**
- **FINLAND (4)**
- **FRANCE (2)**
- **GERMANY (3)**
- **GREECE (2)**
- **ISRAEL (22)**
- **ITALY (1)**
- **JAPAN (2)**
- **KOREA (6)**
- **SPAIN (1)**
- **TAIWAN (1)**
- **UK (12)**
- **USA (169)**

Cos. of 802.16 Members (current&former) [old] ³⁹

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

IEEE 802.16 Projects

- Air Interface (PHYs with common MAC)
 - **802.16**: 10-66 GHz
 - Completed in October 2001; Published in April 2002
 - Followup compliance docs
 - **P802.16c**, **P1802.16.1**, **P1802.16.3**, **P1802.16.3**
 - Profiles; PICS; Test Purposes; Abstract Test Suites,...
 - **802.16a**: 2-11 GHz
 - Licensed and license-exempt bands only
 - Approved January 2003
 - **P802.16d**: profiles (in ballot)
 - **P802.16e**: Mobile Wireless MAN
- Coexistence
 - **IEEE 802.16.2** (10-66 GHz)
 - Published in September 2001
 - **P802.16.2a**: amendment
 - with 2-11 GHz licensed
 - Approval expected in May 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.

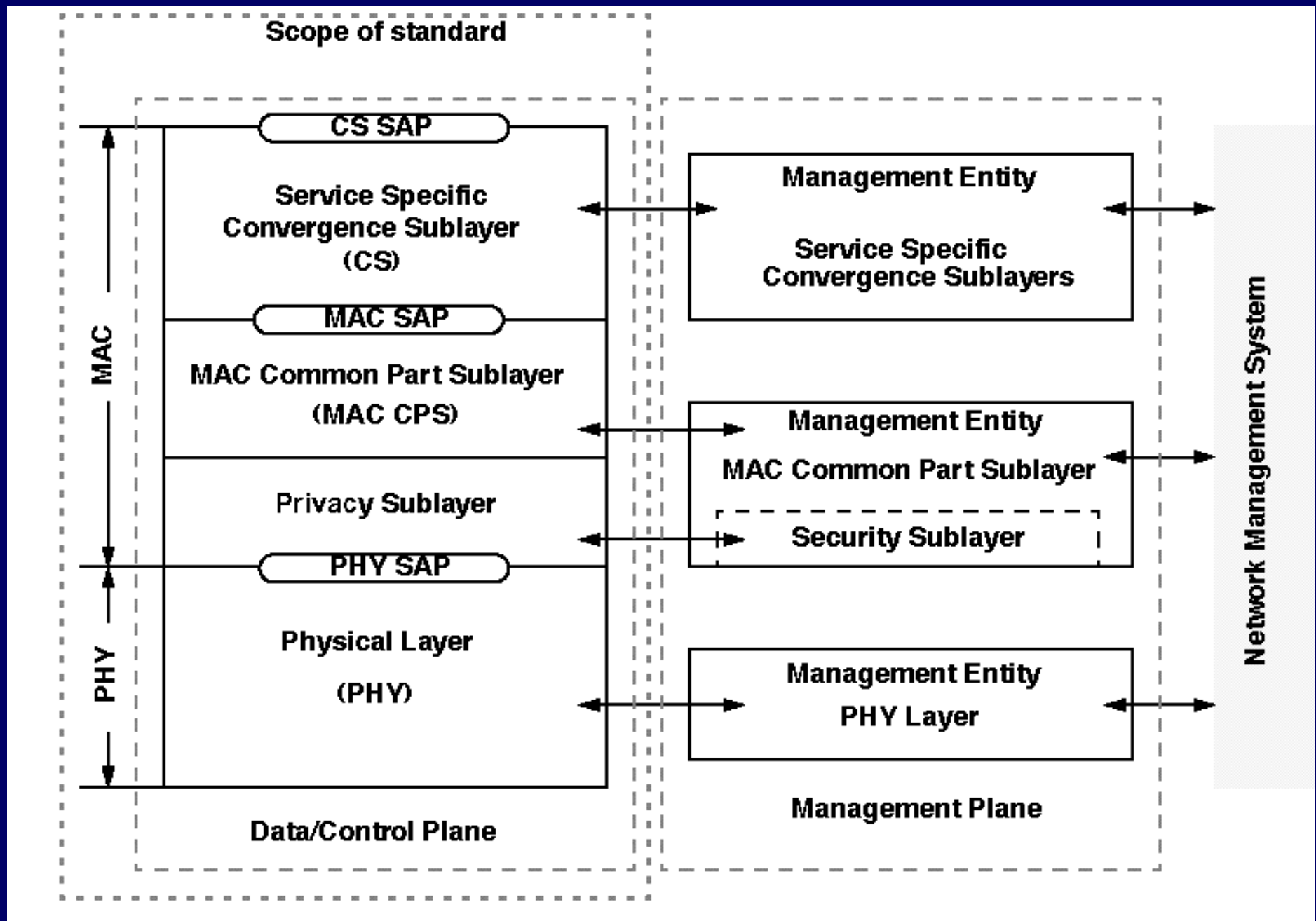
Keywords: fixed broadband wireless access network, metropolitan area network, microwave, millimeter wave, WirelessMAN™ standards

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

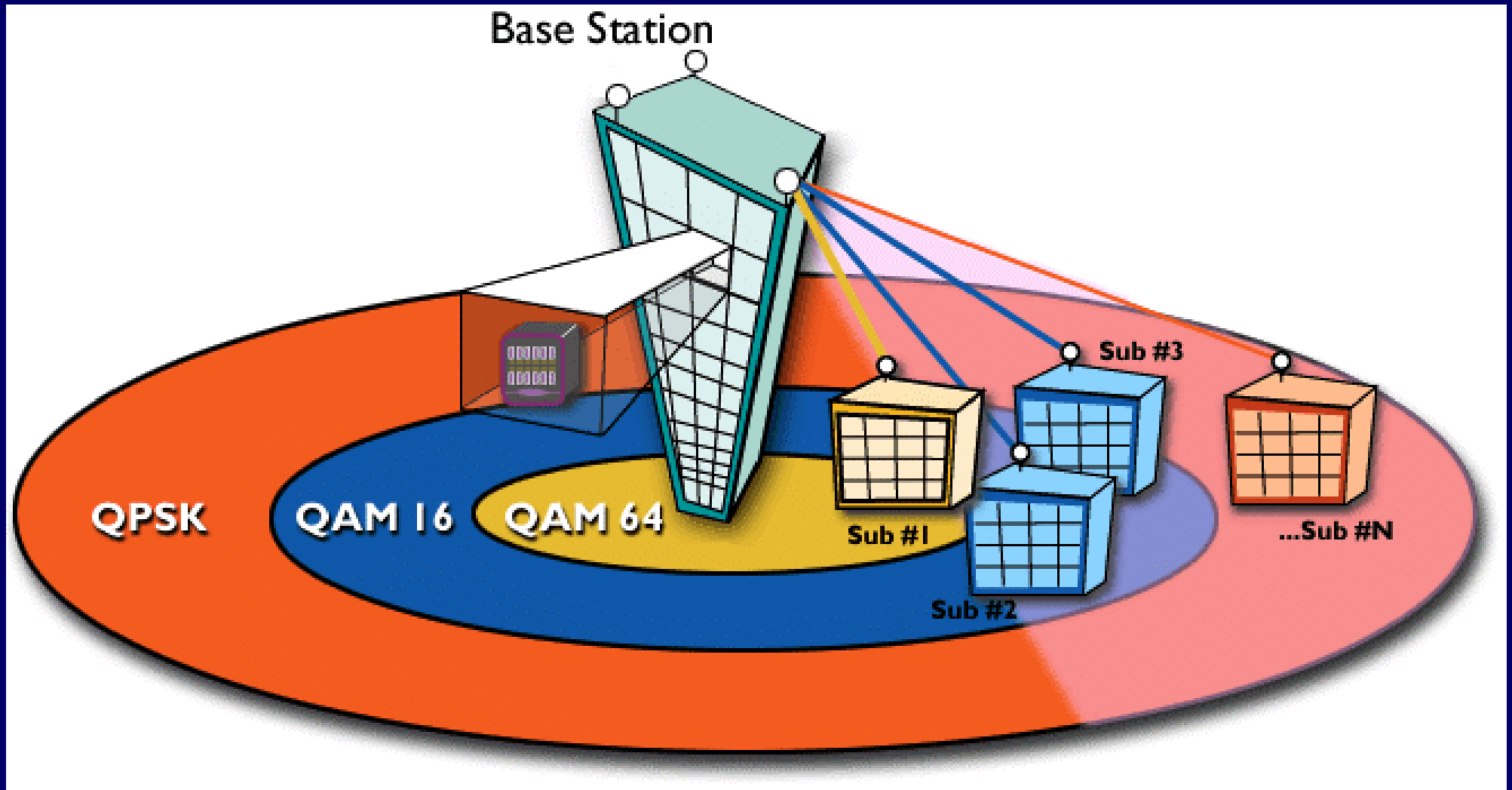
Reference Model

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Adaptive PHY

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(burst-by-burst adaptivity not shown)

Baud Rates & Channel Size (10-66 GHz)

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

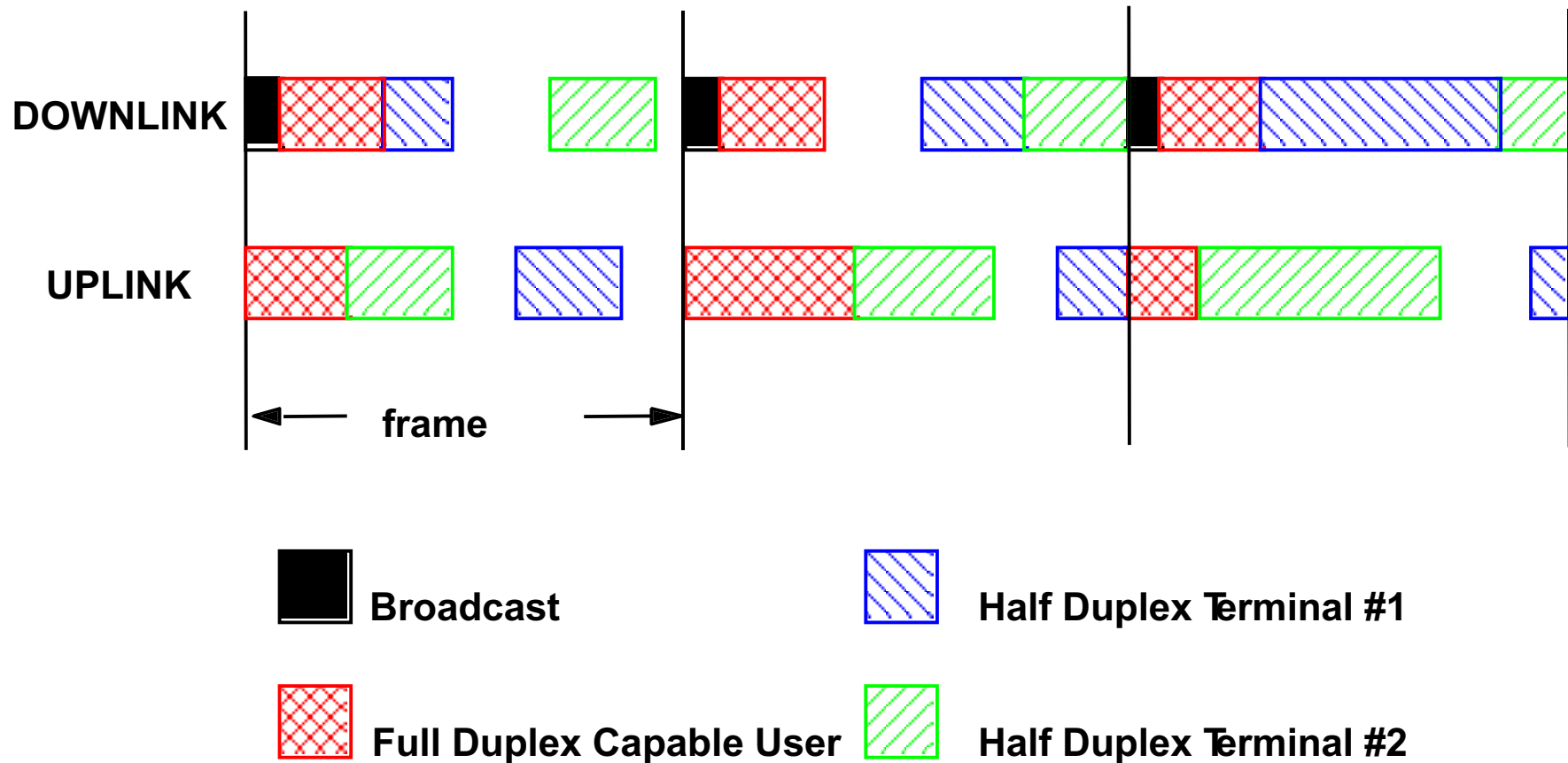
Channel Width (MHz)	Symbol Rate (Msym/s)	QPSK	16-QAM	64-QAM
		Bit Rate (Mbit/s)	Bit Rate (Mbit/s)	Bit Rate (Mbit/s)
20	16	32	64	96
25	20	40	80	120
28	22.4	44.8	89.6	134.4

Multiple Access and Duplexing

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- 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)

Burst FDD Framing

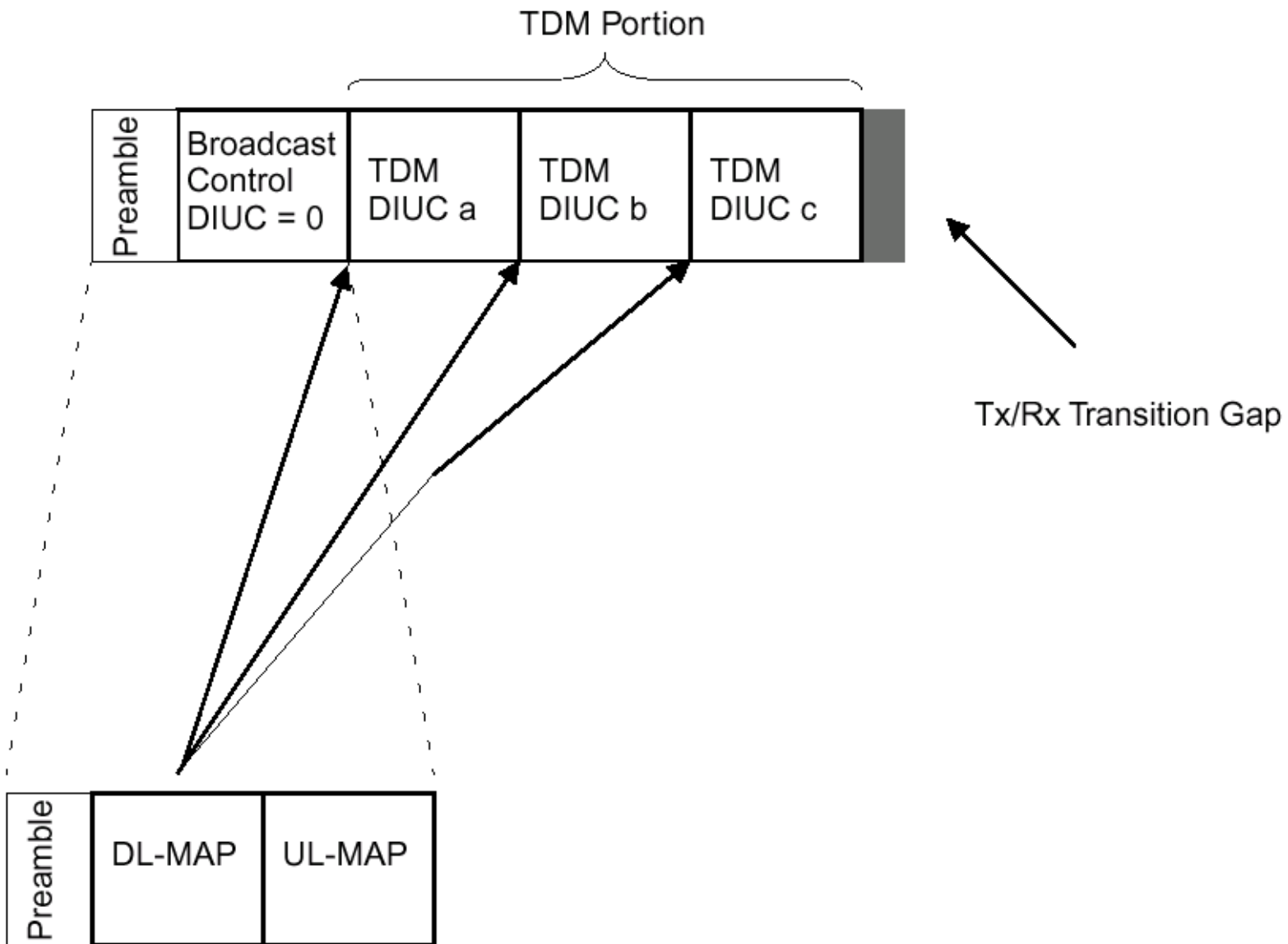


Allows scheduling flexibility

Adaptive Burst Profiles

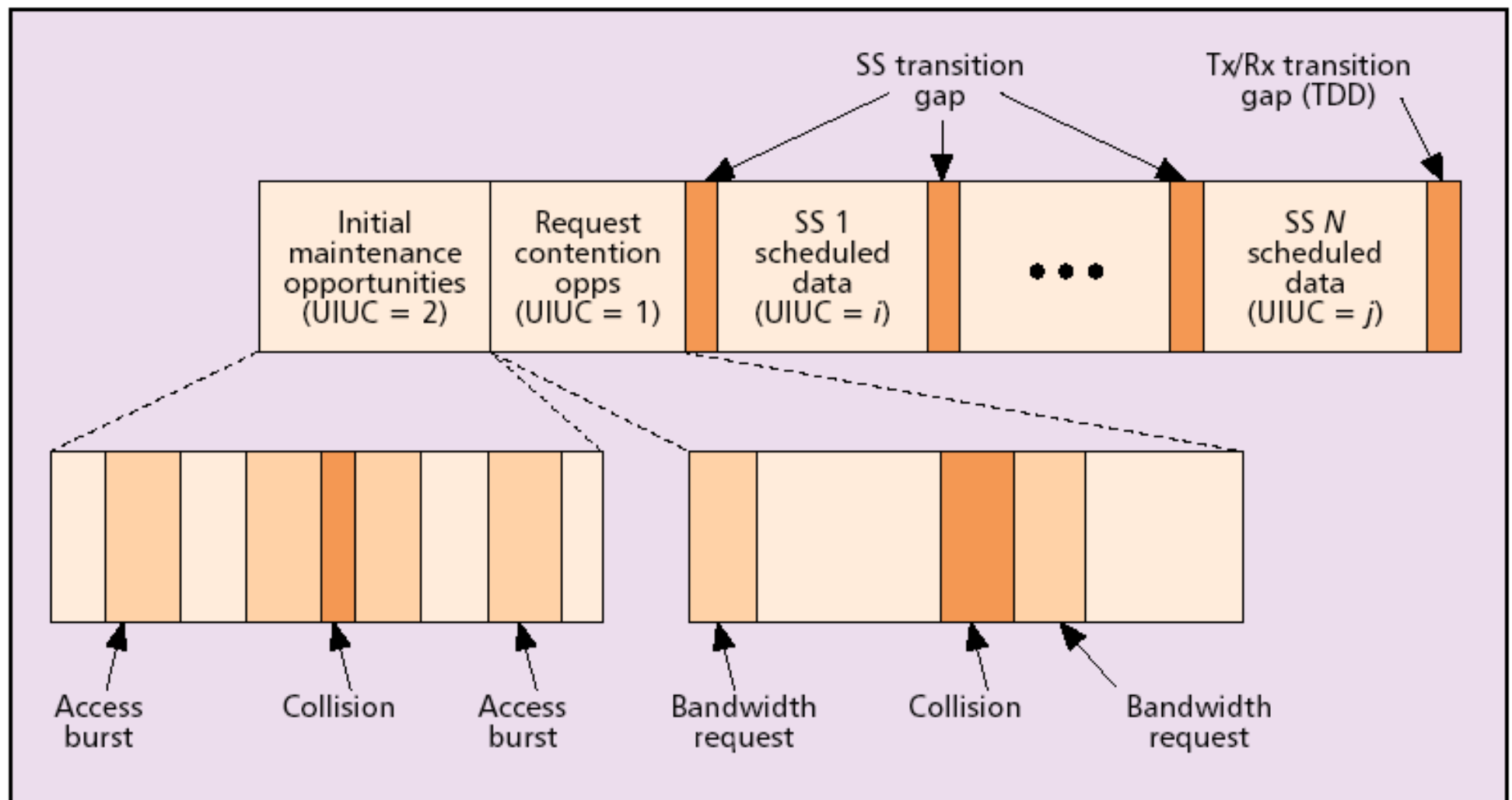
- **Burst profile**
 - Modulation and FEC
- **Dynamically assigned according to link conditions**
 - Burst by burst, per subscriber station
 - Trade-off capacity vs. robustness in *real time*
- **Roughly doubled capacity for the same cell area**
- **Burst profile for downlink broadcast channel is well-known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

TDD Downlink Subframe



DIUC: Downlink Interval Usage Code

Typical Uplink Subframe (TDD or FDD) ⁵¹



802.16 MAC: Overview

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- **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**

ATM Convergence Sublayer

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- **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**

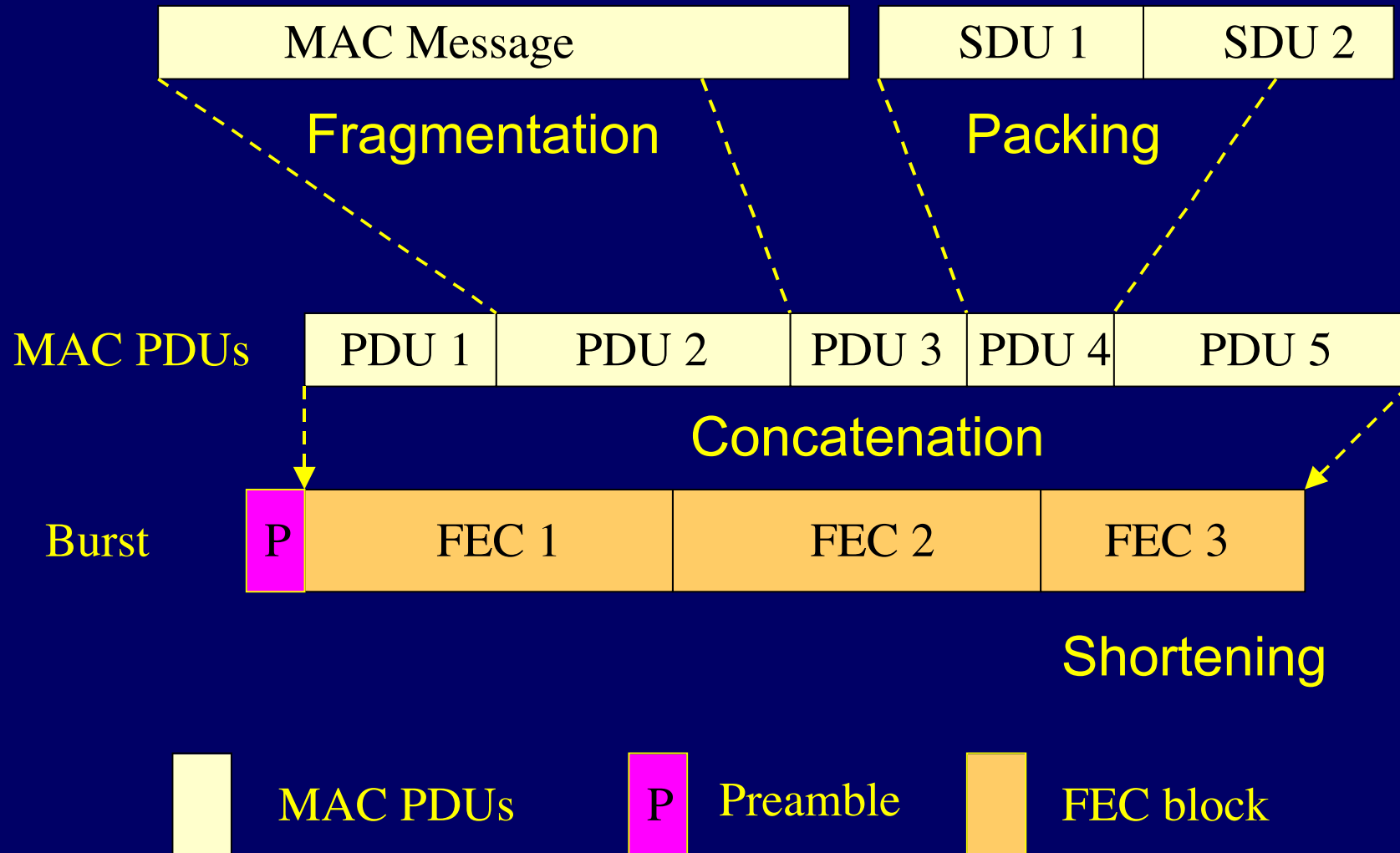
Packet Convergence Sublayer

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- 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 PDU Transmission

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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 compliance specs**

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

Non-Line-of-Sight

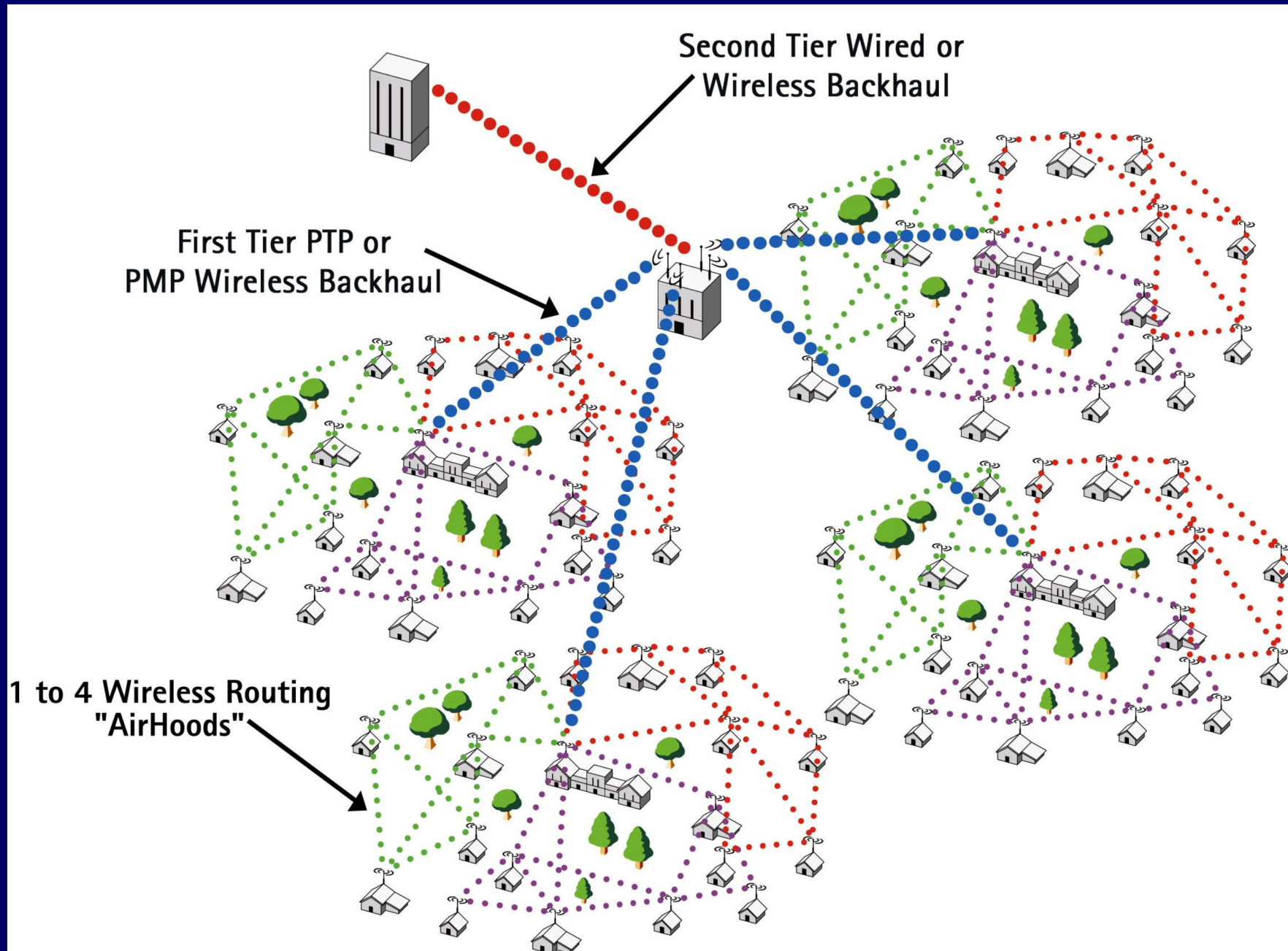
- **OFDM (WirelessMAN-OFDM Air Interface)**
 - 256-point FFT with TDMA (TDD/FDD)
- **OFDMA (WirelessMAN-OFDMA Air Interface)**
 - 2048-point FFT with OFDMA (TDD/FDD)
- **Single-Carrier (WirelessMAN-SCa Air Interface)**
 - TDMA (TDD/FDD)
 - BPSK, QPSK, 4-QAM, 16-QAM, 64-QAM, 256-QAM
 - Most vendors will use Frequency-Domain Equalization

Key 802.16a MAC Features

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- **OFDM/OFDMA Support**
- **ARQ**
- **Dynamic Frequency Selection (DFS)**
 - license-exempt
- **Advanced Antenna System (AAS) support**
- **Mesh Mode**
 - Optional topology
 - Subscriber-to-Subscriber communications
 - Complex topology and messaging, but:
 - addresses license-exempt interference
 - Address Non-Line-of-Sight in a unique way
 - scales well

Mesh-based WirelessMAN



Mobility Enhancements

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March 2002:

- 802.16 Study Group on Mobile Broadband Wireless Access

January 2003:

- First meeting of 802.16e Task Group

IEEE Standard 802.16: Tutorial

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

TOPICS IN BROADBAND ACCESS

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

Carl Eklund, Nokia Research Center

Roger B. Marks, National Institute of Standards and Technology

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

IEEE 802.16 Resources

**IEEE 802.16 Working Group on Broadband
Wireless Access**

info, documents, tutorials, email lists, etc:

<http://WirelessMAN.org>



Conclusion

IEEE 802 wireless standards are:

- **open in development and application**
- **addressed at worldwide markets**
- **engineered as optimized technical solutions**
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