Broadband Metro and Access Networks

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Overview

1. Trends in Networking
2. Metro Networks:
   1G and 10G Ethernet, Resilient Packet Ring, SONET/SDH vs Ethernet, Next Gen SDH
3. Access Networks: xDSL, Cable Modems, Broadband Wireless Access, WiMAX, Optical Wireless, Satellite, Passive Optical Networks
4. Broadband: Key References
5. List of Acronyms

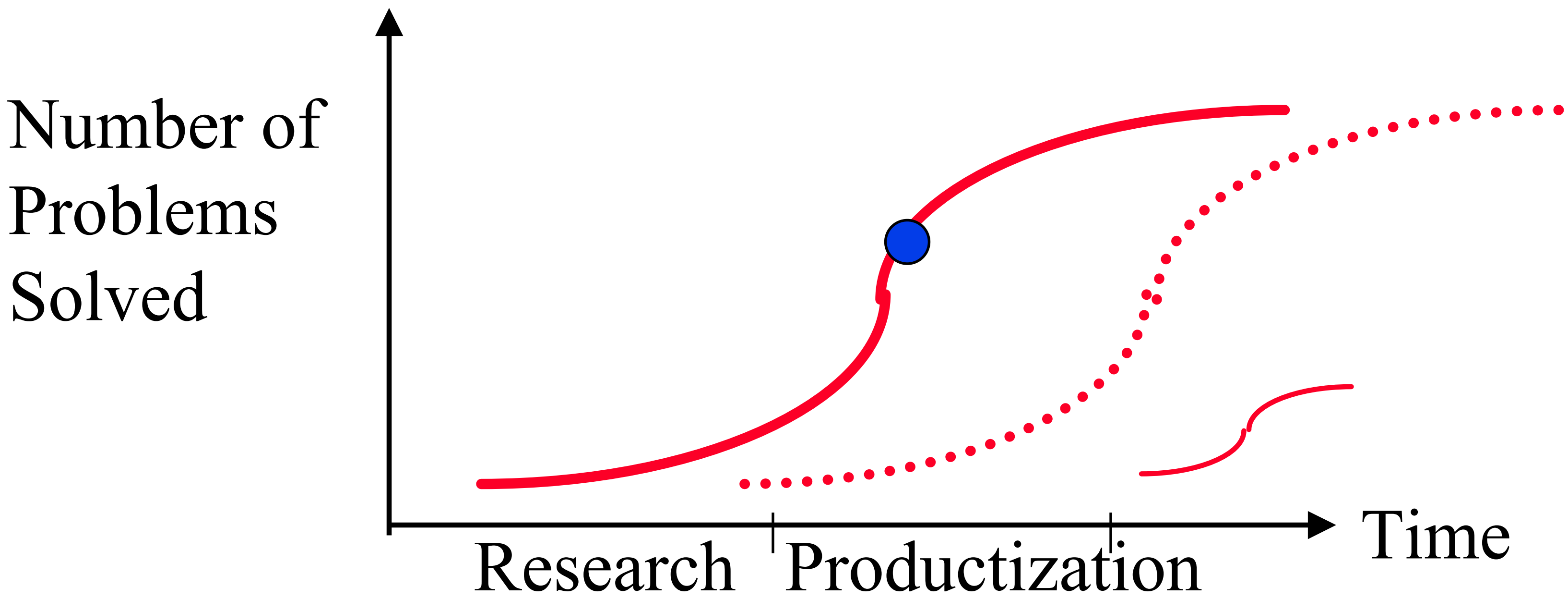
Tentative Schedule

9:00-10:00	Trends
10:00-10:15	Metro Networks
10:15-10:30	*Coffee*
10:30-11:15	Metro Networks
11:15-12:00	Access Networks
12:00-1:00	Lunch
1:00-1:15	Access Networks
1:15-2:15	Fixed Broadband Wireless Access
2:15-3:00	Cellular Wireless Access
3:00-3:15	Coffee
3:15-4:30	Fiber to the home
4:30-5:00	Conclusion

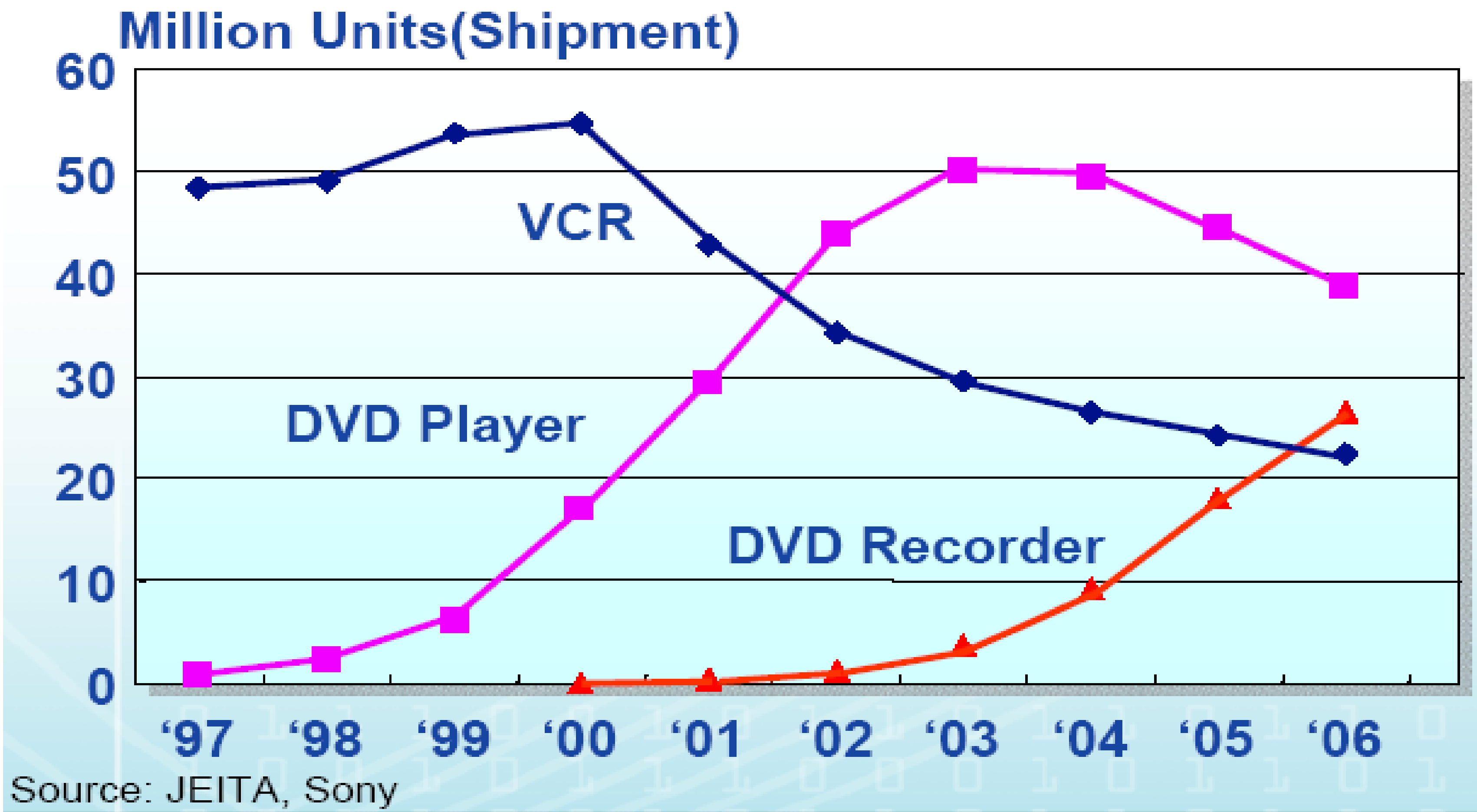
Pre-Test

- 10GBASE-LX4
- LCAS
- GFP
- QAM
- ADSL2+
- OFDM
- MIMO
- GPRS
- 1xEV-DV
- EFM

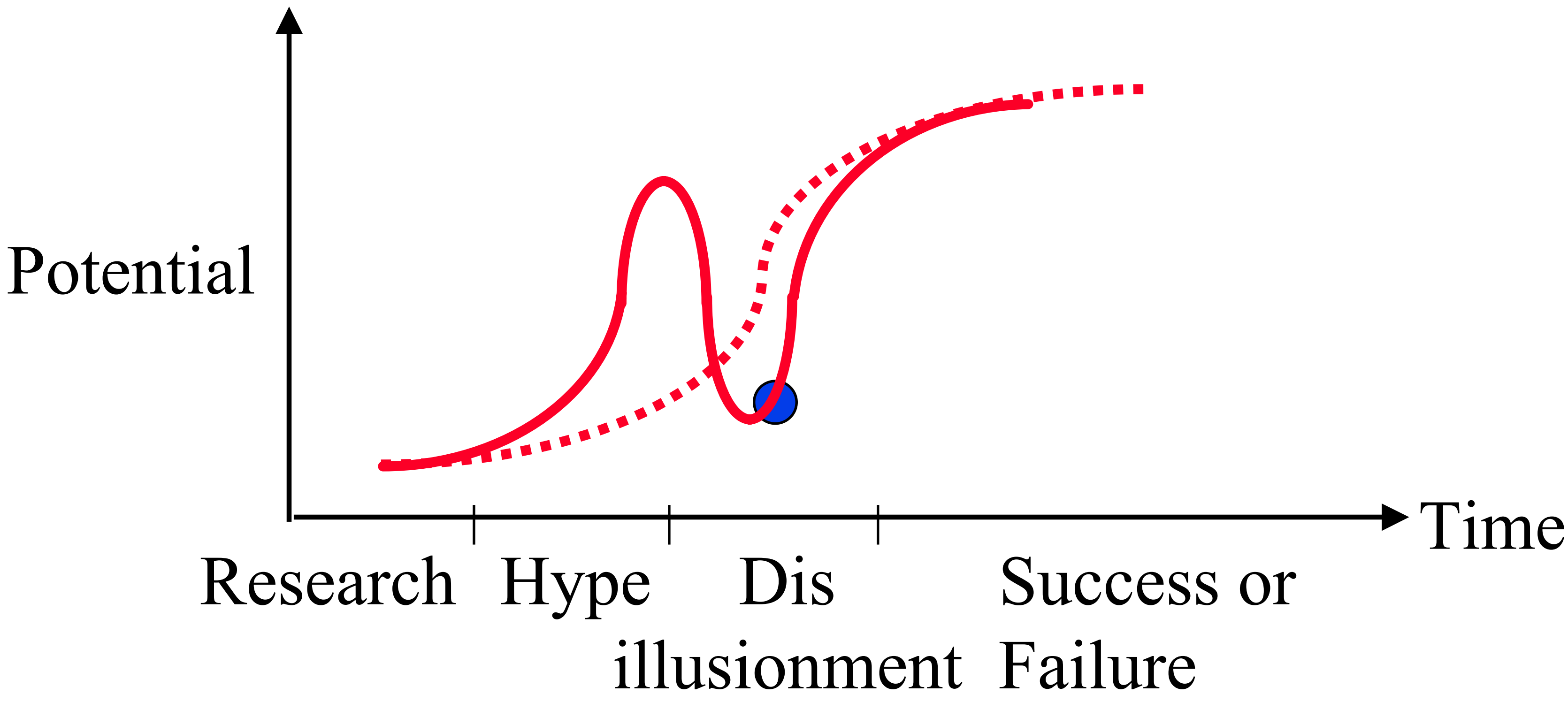
Life Cycles of Technologies



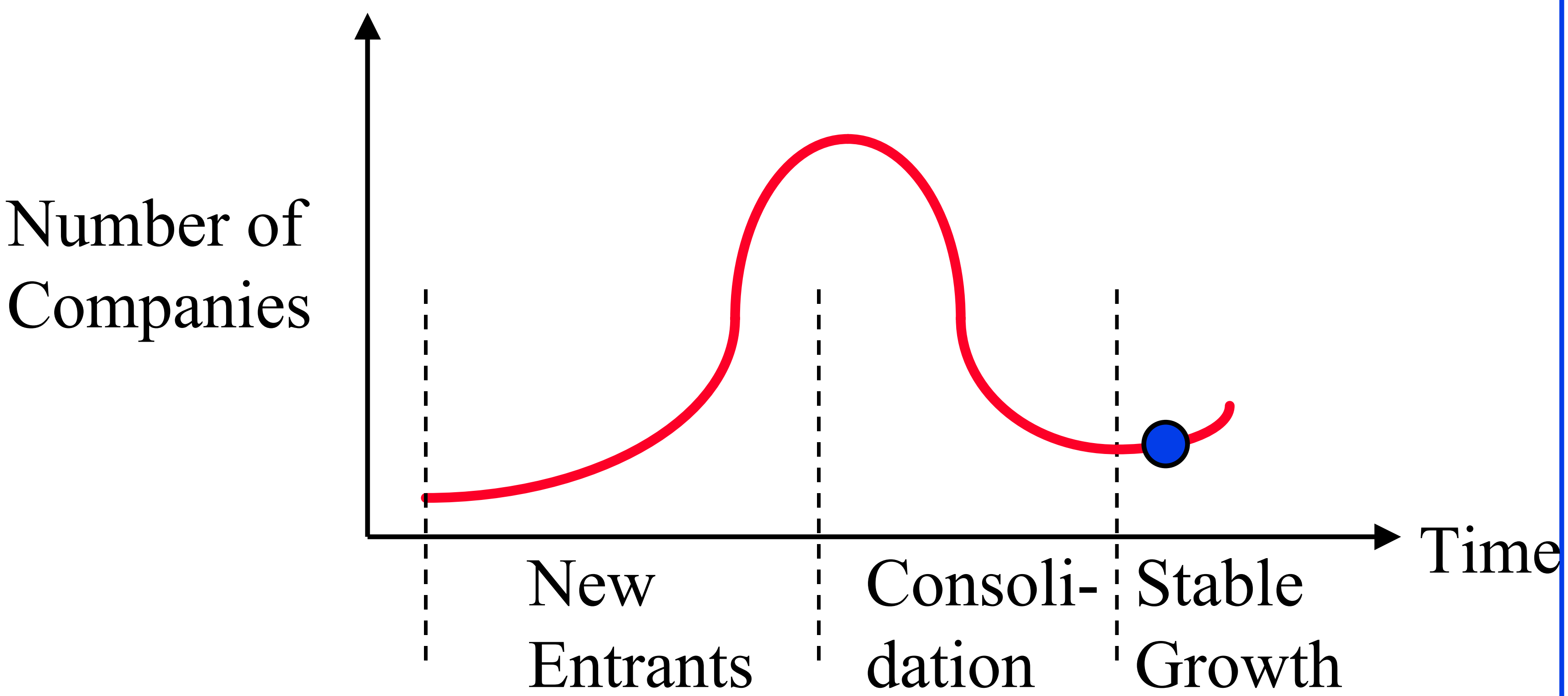
VCR vs DVD


Million Units(Shipment)
60
50
40
30
20
10
0
VCR
DVD Player
DVD Recorder
'97
'98
'99
'00
'01
'02
'03
'04
'05
'06
Source: JEITA, Sony

Hype Cycles of Technologies



Industry Growth



Trend: Back to ILECs

1. CLECs to ILECs
   ILEC: Slow, steady, predictable.
   CLEC: Aggressive, Need to build up fast
   New networks with newest technology
   No legacy issues
2. Back to Voice
   CLECs wanted to *start* with data
   ILECs want to *migrate* to data
   ⇒ Equipment that support voice circuits but allow packet based (hybrids) are more important than those that allow only packet based

Top 10 Developments of 2004

1. Large investments in Security
2. Wireless (WiFi) is spreading (Intel Centrino)
3. More Cell phones than POTS.
   Smart Cell phones w PDA, email, video, images ⇒ Mobility
4. Broadband Access is growing faster than cell phones
5. Fiber is creeping towards home
6. Ethernet extending from Enterprise to Access to Metro …
7. Wiring more expensive than equipment ⇒ Wireless Access
8. Multi-Protocol Label Switching for traffic engineering
9. Voice over Internet Protocol (VOIP) is in the Mainstream
10. Multi-service IP: Voice, Video, and Data ⇒ Virtual Networks

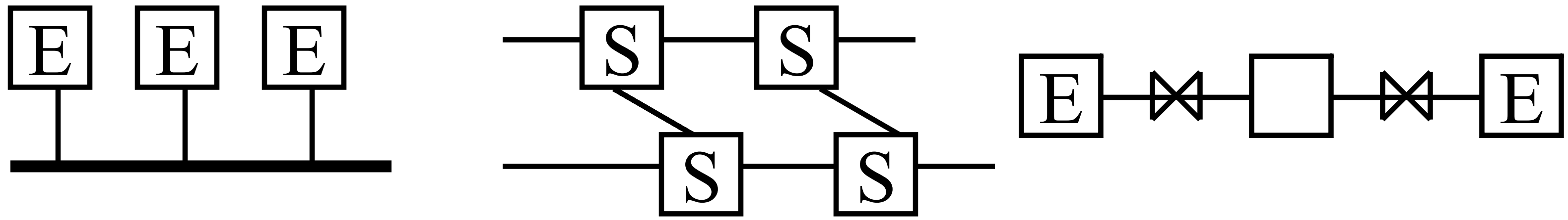
Other Trends

- Entertainment: Passive to Interactive
  Interactive $\Rightarrow$ Time shifting, Time compression (Ad removal), Games
- Mobility: SUVs are becoming like homes
  TV, DVD, Games, Cell phones with all PC programs, Internet

Convergence

- Distance: LAN vs MAN
- Plays: Data, Voice, Video
- L3 Protocols: IP
- L2 Protocols: Ethernet and SONET
- Phy: Circuit switched vs Packet switched
- HTTP

LAN to WAN Convergence



- Past: Shared media in LANs. Point to point in WANs.
- Today: No media sharing in LANs
  - Datalink protocols limited to frame formats
  - No distance limitations due to MAC. Only Phy.
- 10 GbE over 40 km without repeaters
- Ethernet End-to-end.
- Ethernet carrier access service:$50/mo 100Mbps

Core Networks

- Higher Speed/λ: 10 Gbps to 40 Gbps to 160 Gbps
- Longer Distances/Regens: 600 km to 6000 km
- More Wavelengths: 16 λ's to 160 λ's

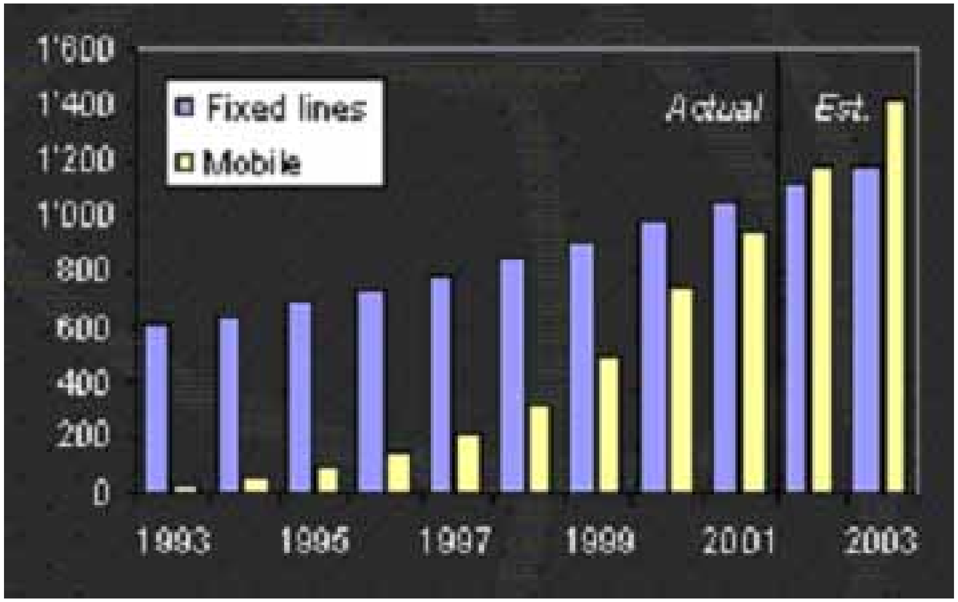
Access Networks

- 63.84 M DSL subscribers worldwide. 2003 growth rate of 77.8% is more than the peak growth rate of cellular phones.
- All countries are racing to a leadership position in broadband
- Digital-Divide ⇒ 30M subs@10Mbps, 10M@100Mbps in Japan by 2005
- Telecom epicenter has moved from NA+Europe to Asia Pacific

Rank	Country	DSL per 100 Phones	Rank	Country	DSL per 100 Phones
1	South Korea	28.3	6	Israel	14.5
2	Taiwan	19.8	7	Denmark	14.2
3	Belgium	16.7	8	Finland	13.6
4	Hong Kong	16.1	9	Singapore	13.4
5	Japan	15.7	10	France	12.1
			32	USA	5.6

Mobility

- 1.35 Billion Mobile subscribers vs 1.2 Billion Fixed line subscribers at the end of 2003 [ITU]
- Number of wired phones in USA is declining for the first time since the Great Depression.
- 70% of internet users in Japan have mobile access
- Vehicular mobility up to 250 Km/h (IEEE 802.20)

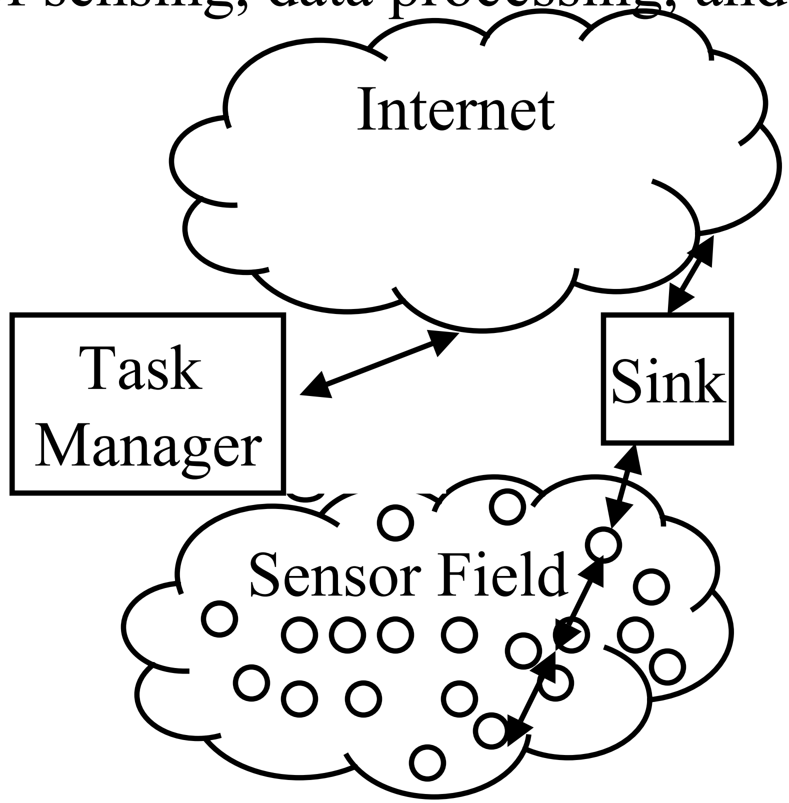


Wireless Issues

- Security (IEEE 802.11i)
- Higher Data rate (IEEE 802.11n, 100 Mbps, using Multiple-input multiple-output antennae)
- Longer distance (WiMAX, >1Mbps to 50 km)
- Seamless Networking ⇒ Handoff (IEEE 802.21)
- Mobility (IEEE 802.20)
- Automated RF management (Cell sites)
- Large scale networks (RFID, Sensors)

Sensor Networks

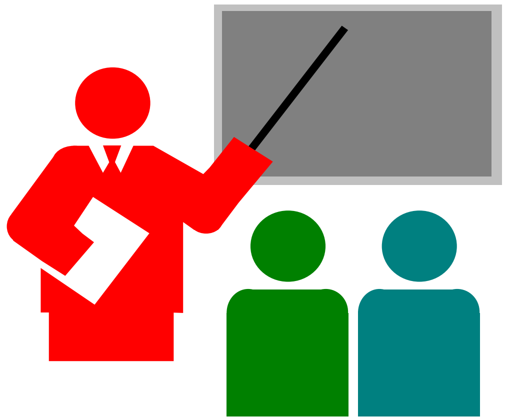
- Person-to-person comm. ⇒ Machine-to-Machine Comm.
- A large number of **low-cost**, **low-power**, **multifunctional**, and small sensor nodes consisting of sensing, data processing, and communicating components
- Key Issues:
  1. Scalability
  2. Power consumption
  3. Fault tolerance
  4. Network topology
  5. Transmission media
  6. Cost
  7. Operating environment
  8. Hardware constraints



Top Networking Research Topics

1. Security
2. Large scale wireless networks (RFID, Sensors)
3. Mobility
4. High-Speed wireless
5. Network-based computing (Grid computing)
6. Optical packet switching
7. Virtual Networking

Summary



1. Hype Cycles of Technologies
   ⇒ Recovering from the bottom
2. Trend: Back to ILECs
   ⇒ Compatibility more important than latest technology
3. Top 10 Developments of 2004: Security, Wireless, …
4. Convergence
5. Core market stagnant. Metro and Access more important.

Metro Networks

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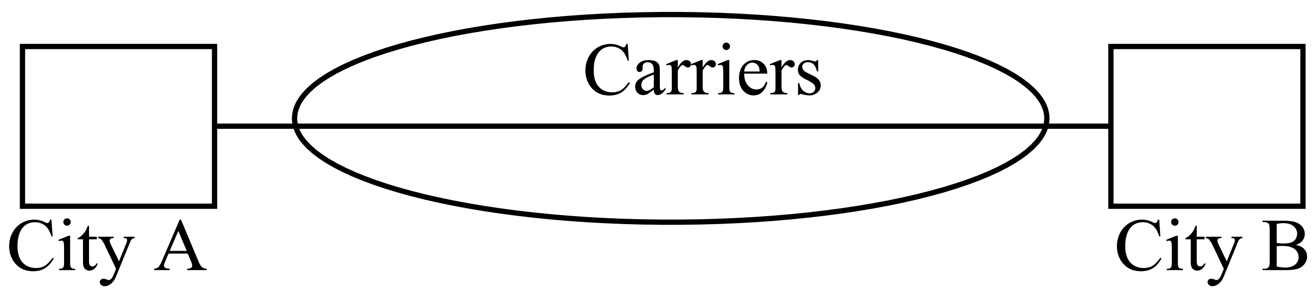
- SONET/SDH
- 1 GbE and 10GbE: Key Design Decisions
- Metro Ethernet Services
- SONET/SDH vs Ethernet: Issues and Remedies
- Resilient Packet Ring
- Networking Technologies: Failures vs Successes
- Next Generation SDH: VCAT, GFP, LCAS

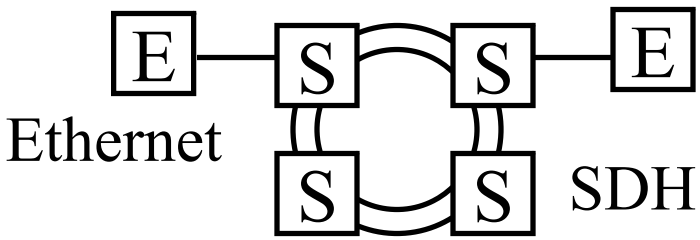
SONET/SDH

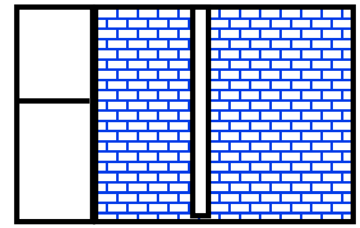
- SONET=Synchronous optical network
- Standard for digital optical transmission
- Developed originally by Bellcore to allow mid-span meet between carriers: MCI and AT&T. Standardized by ANSI and then by ITU

  ⇒ Synchronous Digital Hierarchy (SDH)
- You can lease a SDH connection from carriers



SDH Functions





- Protection: Allows redundant Line or paths
- Fast Restoration: 50ms using rings
- Sophisticated OAM&P
- Ideal for Voice: No queues. Guaranteed delay
- Fixed Payload Rates: 51M, 155M, 622M, 2.4G, 9.5G
  Rates do not match data rates of 10M, 100M, 1G, 10G
- Static rates not suitable for bursty traffic
- One Payload per Stream
- High Cost

1 GbE: Key Design Decisions

- P802.3z ⇒ Update to 802.3
  Compatible with 802.3 frame format, services, management
- 1000 Mb vs. 800 Mb Vs 622 Mbps
  Single data rate
- **LAN** distances only
- No Full-duplex only ⇒ **Shared** Mode
  Allows both hub and switch based networks
  No one makes or uses GbE Hubs
- Same min and max frame size as 10/100 Mbps
  ⇒ Changes to **CSMA/CD** protocol
  Transmit longer if short packets

10 GbE: Key Design Decisions

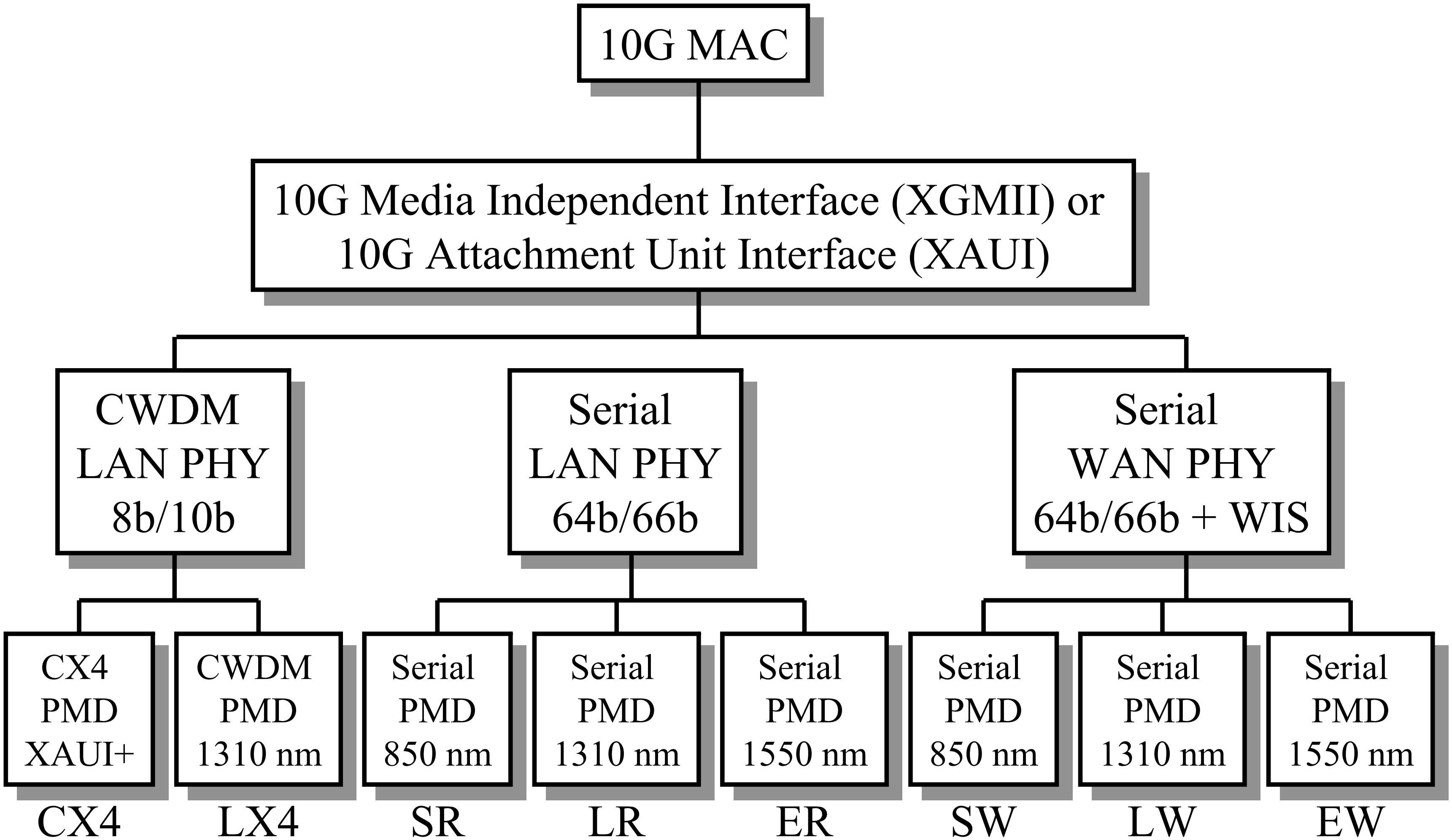
- P802.3ae ⇒ Update to 802.3
  Compatible with 802.3 frame format, services, management
- 10 Gbps vs. 9.5 Gbps. **Both** rates.
- LAN and **MAN** distances
- Full-duplex only ⇒ **No Shared** Mode
  Only switch based networks. No Hubs.
- Same min and max frame size as 10/100/1000 Mbps
  Point-to-point ⇒ **No CSMA/CD** protocol
- 10.000 Gbps at MAC interface
  ⇒ Flow Control between MAC and PHY
- Clock jitter: 20 or 100 ppm for 10GbE
  Incompatible with 4.6 ppm for SONET

10 GbE PMD Types

PMD	Description	MMF	SMF
10GBASE-R:			
10GBASE-SR	850nm Serial LAN	300 m	N/A
10GBASE-LR	1310nm Serial LAN	N/A	10 km
10GBASE-ER	1550nm Serial LAN	N/A	40 km
10GBASE-X:			
10GBASE-LX4	1310nm WWDM LAN	300 m	10 km
10GBASE-W:			
10GBASE-SW	850nm Serial WAN	300 m	N/A
10GBASE-LW	1310nm Serial WAN	N/A	10 km
10GBASE-EW	1550nm Serial WAN	N/A	40 km
10GBASE-LW4	1310nm WWDM WAN	300 m	10 km

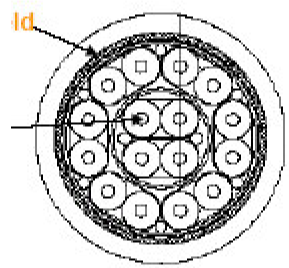
- S = Short Wave, L=Long Wave, E=Extra Long Wave
- R = Regular reach (64b/66b), W=WAN (64b/66b + SONET Encapsulation), X = 8b/10b ❑ 4 = 4 λ's

10GbE PHYs


10G MAC
10G Media Independent Interface (XGMII) or
10G Attachment Unit Interface (XAUI)
CWDM
LAN PHY
8b/10b
Serial
LAN PHY
64b/66b
Serial
WAN PHY
64b/66b + WIS
CX4
PMD
XAUI+
CWDM
PMD
1310 nm
Serial
PMD
850 nm
Serial
PMD
1310 nm
Serial
PMD
1550 nm
Serial
PMD
850 nm
Serial
PMD
1310 nm
Serial
PMD
1550 nm
CX4
LX4
SR
LR
ER
SW
LW
EW

10GBASE-CX4

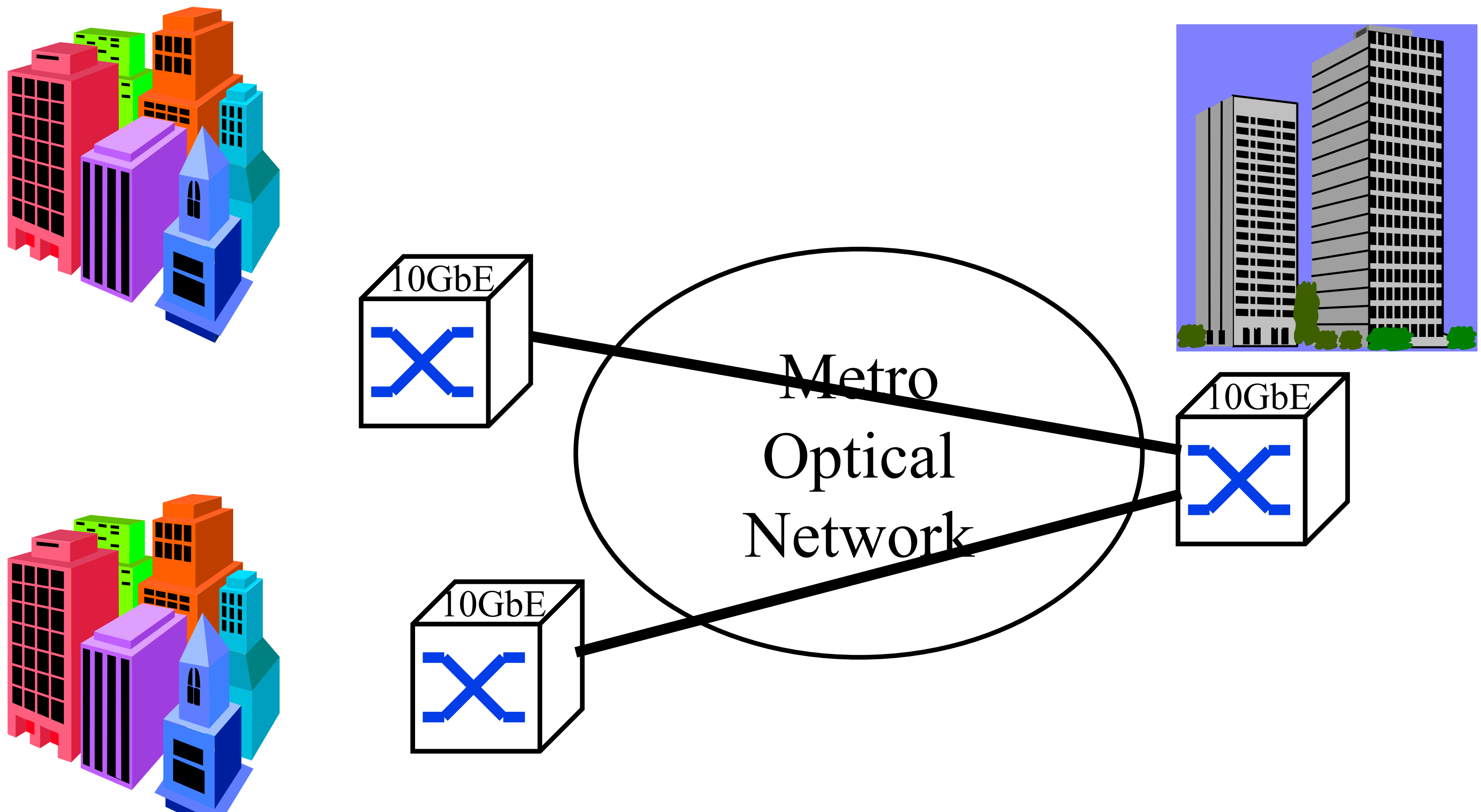
- For data center applications (Not for horizontal wiring):
  - Switch-to-switch links, Switch-to-server links
  - External backplanes for stackables
- Twinax cable with 8 pairs
- Based on Infiniband 4X copper PHY. IB4X connectors.
- 10G to 15m (std). Some vendors can do 25-30m.
- Standard: Dec 2003. Passed Sponsor Ballot.
- IEEE 802.3ak, http://www.ieee802.org/3/ak



10GBASE-T

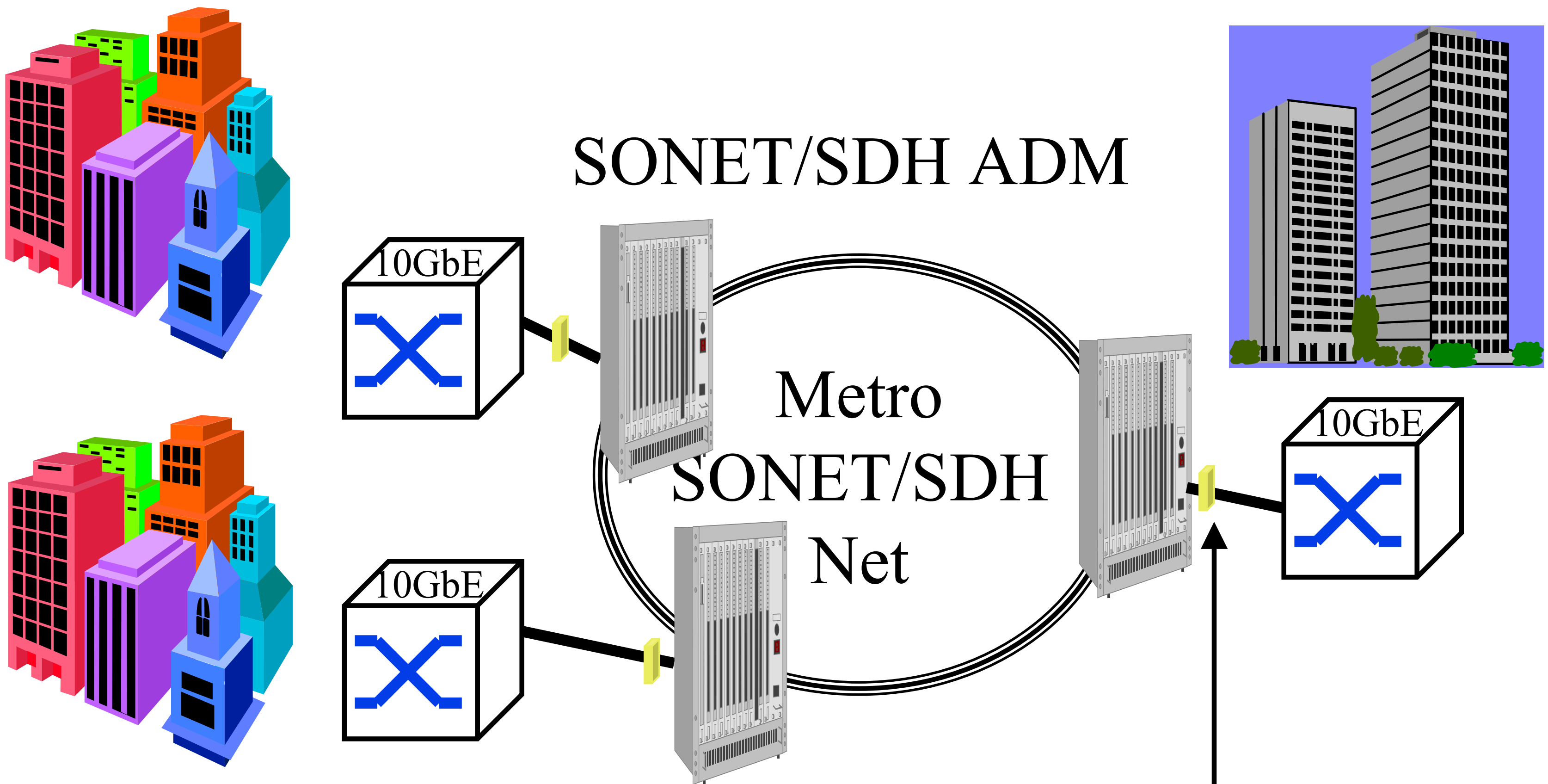
- New PHY for data center and horizontal wiring
- Compatible with existing 802.3ae MAC, XGMII, XAUI
- Standard: Start: Nov 2003 Finish: Jul 2005
- 100 m on Cat-7 and 55+ m on Cat-6
- Some startups working on Cat-5e
- Cost 0.6 of optical PHY. Greater reach than CX4
- 10-level coded PAM signaling with 3 bits/symbol
  833 MBaud/pair ⇒ 450 MHz bandwidth w FEXT cancellation (1GBASE-T uses 5-level PAM with 2 bits/symbol, 125 MBaud/pair, 80 MHz w/o FEXT)
- Full-duplex only. 1000BASE-T line code and FEC designed for half-duplex.
- IEEE 802.3an, http://www.ieee802.org/3/an/index.html

10 GbE over Dark Fiber



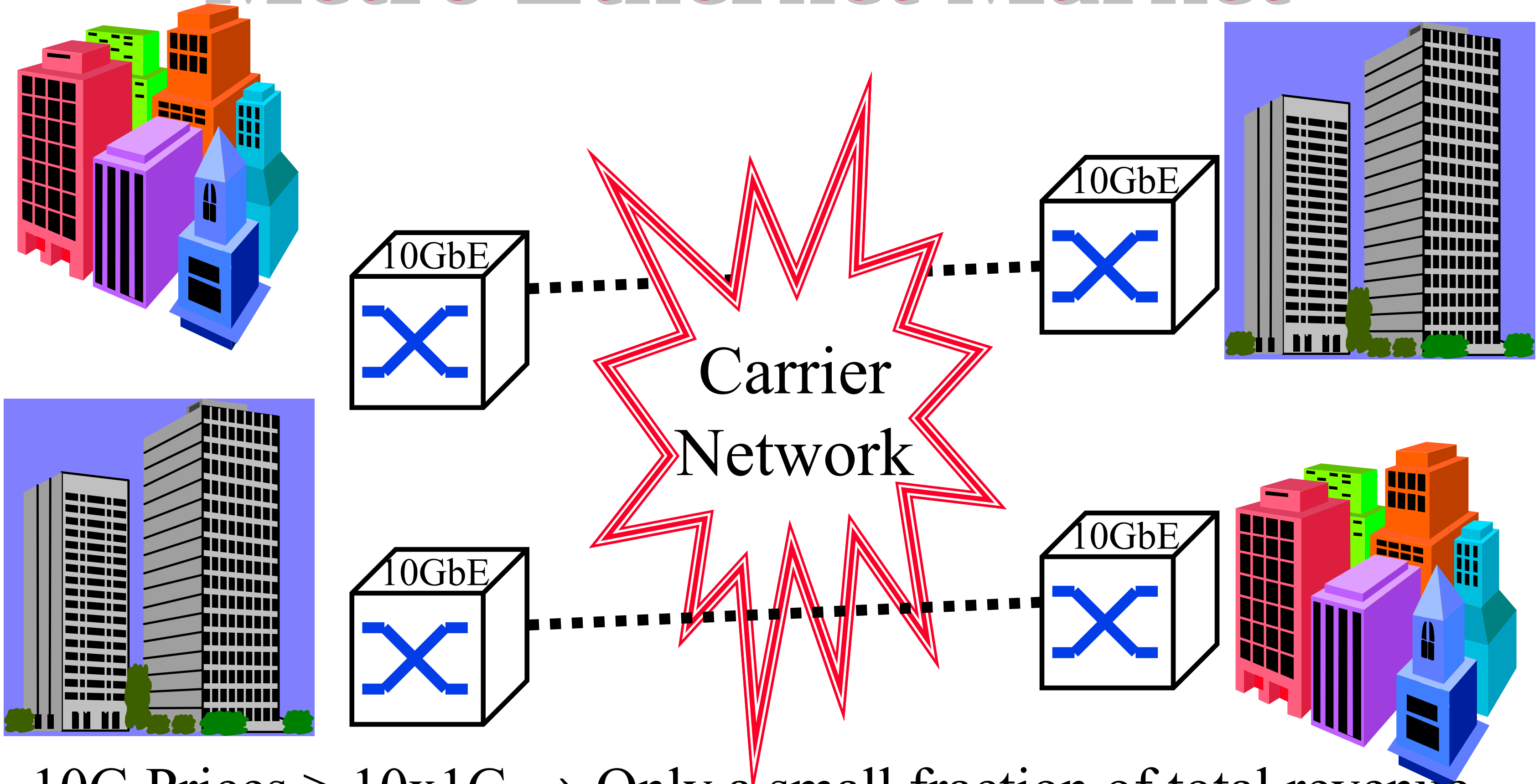
- Need only LAN PMD up to 40 km.
  No SONET/SDH overhead. No protection.

10 GbE over SONET/SDH



- Using WAN PMD.
  Legacy SONET/SDH. Protection via rings.
  ELTE = Ethernet Line Terminating Equipment

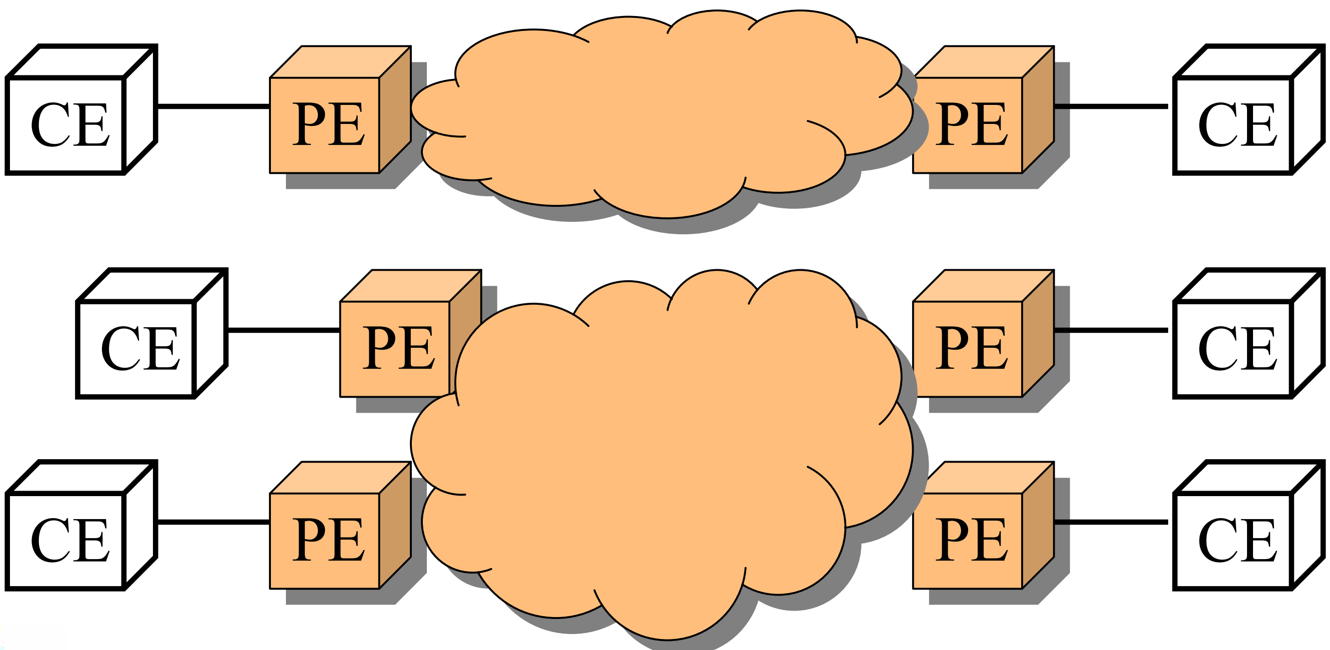
Metro Ethernet Market



- 10G Prices > 10x1G ⇒ Only a small fraction of total revenue. Prices decreasing fast ⇒300% Growth in 10G Q4'03.
- 10km XFP for $500
- Growth in 1G ports > Growth rate of 100M ports (instat.com)

Metro Ethernet Services

- User-to-network Interface (UNI) = RJ45
- Ethernet Virtual Connection (EVC) = Flows
- Ethernet Line Service (ELS) = Point-to-point
- Ethernet LAN Service (E-LAN) = multipoint-to-multipoint



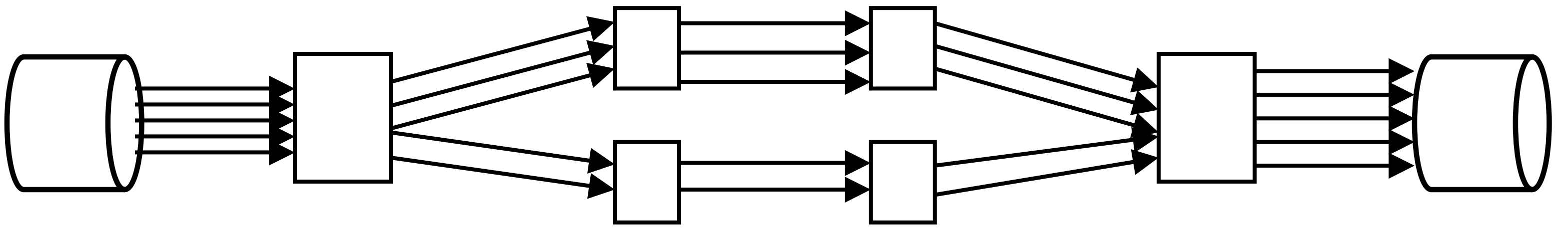
SONET/SDH vs Ethernet

Feature	SONET	Ethernet
Payload Rates	51M, 155M, 622M, 2.4G, 9.5G	10M, 100M, 1G, 10G
Payload Rate Granularity	Fixed	√Any
Bursty Payload	No	√Yes
Payload Count	One	√Multiple
Protection	√Ring	Mesh
OAM&P	√Yes	No
Synchronous Traffic	√Yes	No
Restoration	√50 ms	Minutes
Cost	High	√Low
Used in	Telecom	Enterprise

SONET/SDH vs Ethernet: Remedies

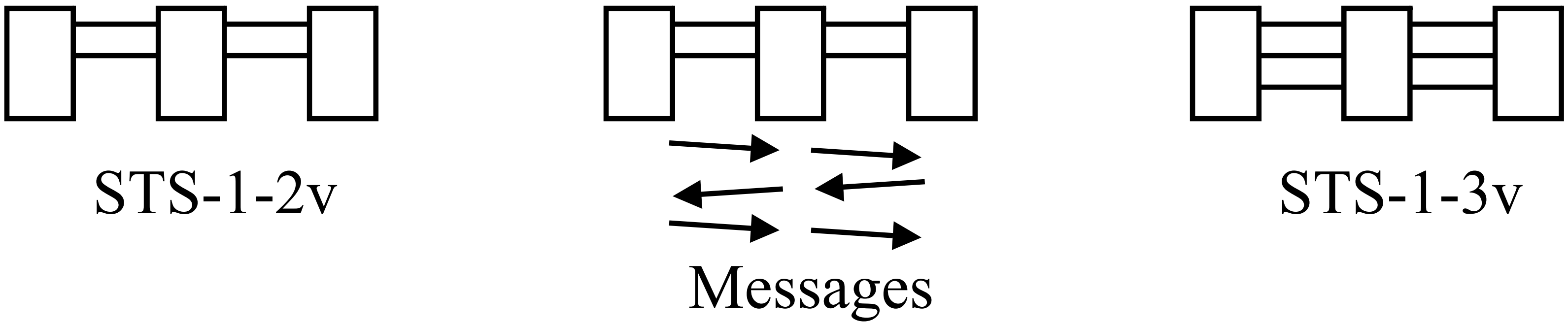
Feature	SONET	Ethernet	Remedy
Payload Rates	51M, 155M, 622M, 2.4G, 9.5G	10M, 100M, 1G, 10G	10GE at 9.5G
Payload Rate Granularity	Fixed	√Any	Virtual Concatenation
Bursty Payload	No	√Yes	Link Capacity Adjustment Scheme
Payload Count	One	√Multiple	Packet GFP
Protection	√Ring	Mesh	Resilient Packet Ring (RPR)
OAM&P	√Yes	No	In RPR
Synchronous Traffic	√Yes	No	MPLS + RPR
Restoration	√50 ms	Minutes	Rapid Spanning Tree
Cost	High	√Low	Converging
Used in	Telecom	Enterprise	

SONET Virtual Concatenation



- VCAT: Bandwidth in increments of VT1.5 or STS-1
- For example: 10 Mbps Ethernet in 7 T1's = VT1.5-7v
  100 Mbps Ethernet in 2 OC-1 = STS-1-2v,
  1GE in 7 STS-3c = STS-3c-7v
- The concatenated channels can travel different paths
  ⇒ Need buffering at the ends to equalize delay
- All channels are administered together.
  Common processing only at end-points.

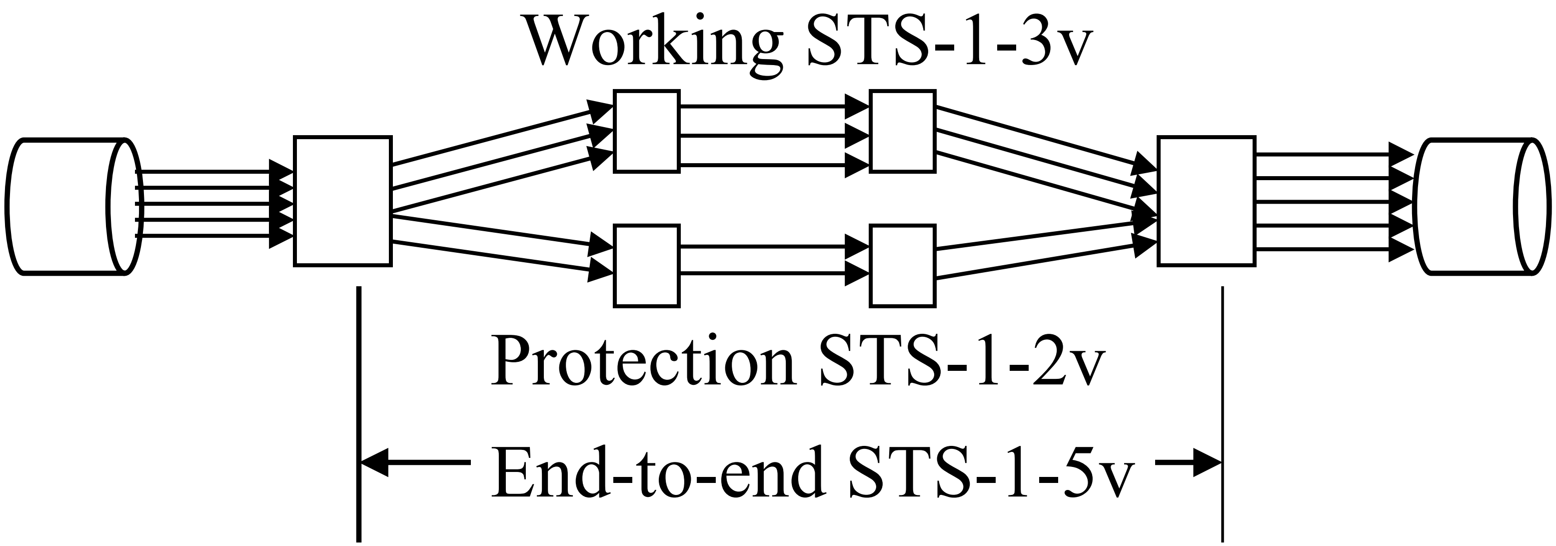
SONET LCAS



- Link Capacity Adjustment Scheme for Virtual Concatenation
- Allows hitless addition or deletion of channels from virtually concatenated SONET/SDH connections
- Control messages are exchanged between end-points to accomplish the change

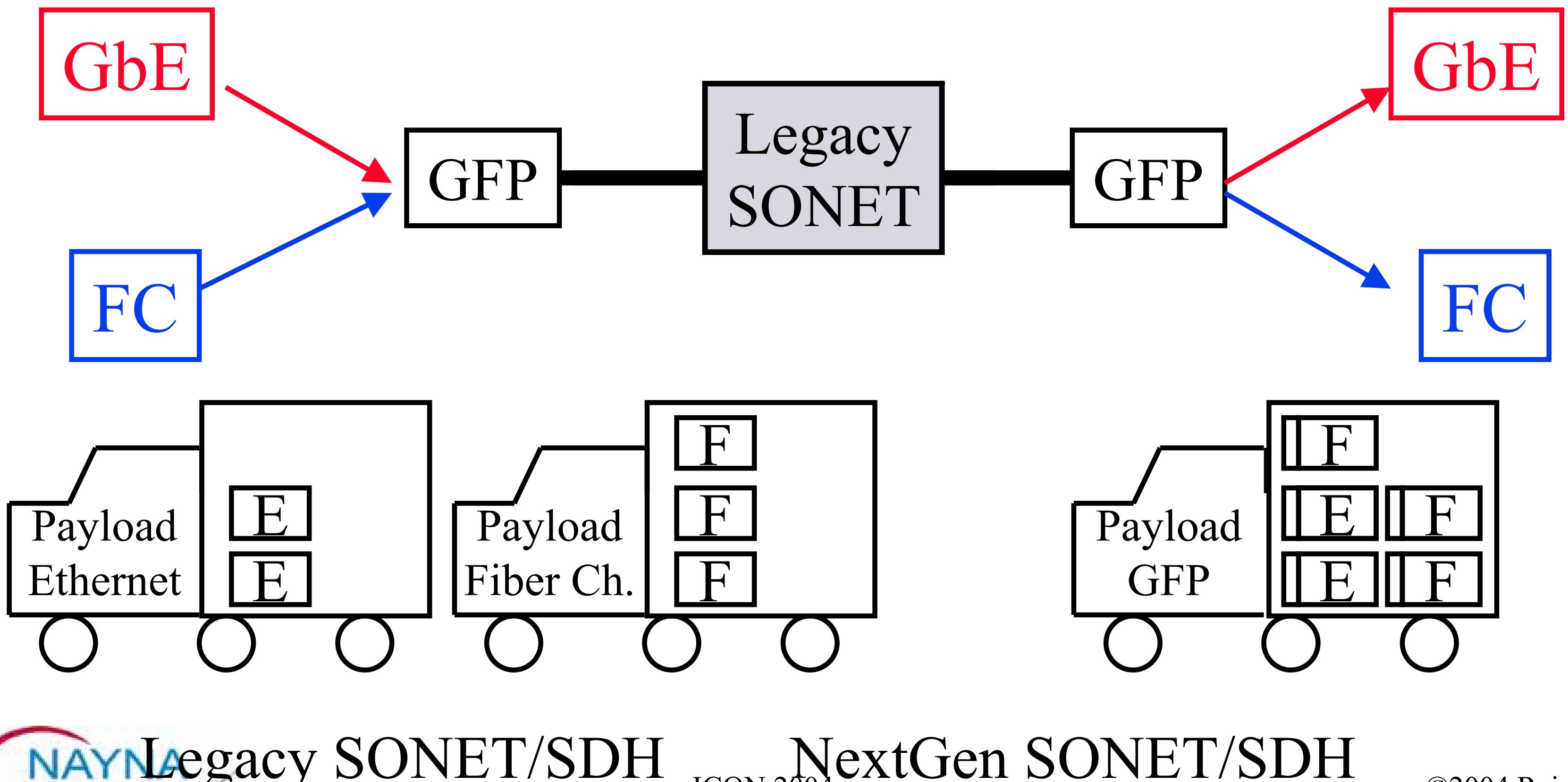
LCAS (Cont)

- Provides enhanced reliability. If some channels fail, the remaining channels can be recombined to produce a lower speed stream



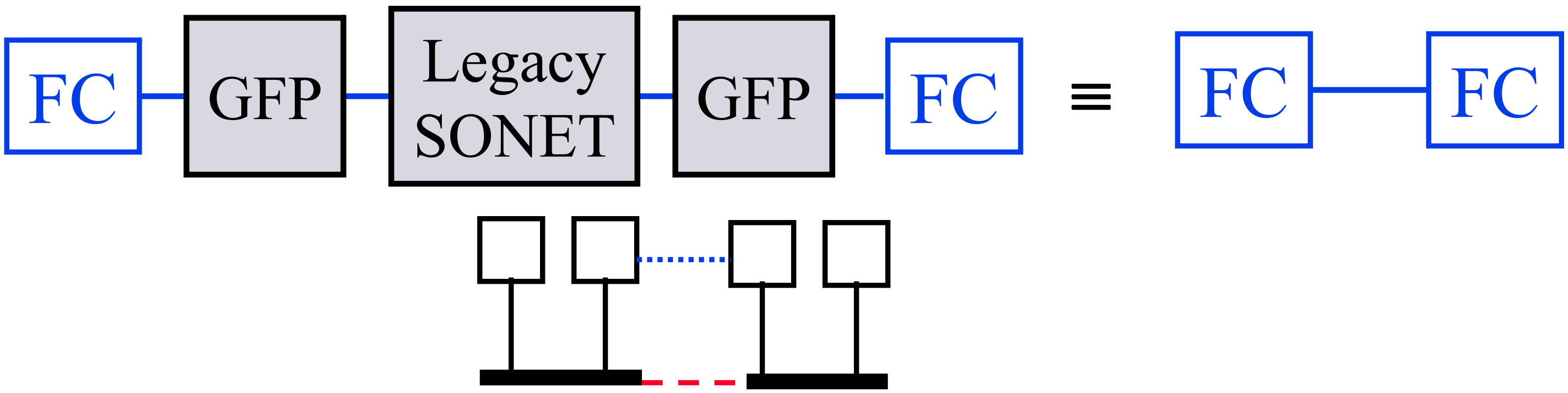
Generic Framing Procedure (GFP)

- Allows multiple payload types to be aggregated in one SONET path and delivered separately at destination



Transparent GFP

- Allows LAN/SAN PHY extension over SONET links
  Control codes carried as if it were a dark fiber.



- Problem: 8b/10b results in 1.25 Gb stream for 1 GbE
- Solution: Compress 80 PHY bits to 65 bits
  $\Rightarrow$ 1.02 Gbps SONET payload per GbE

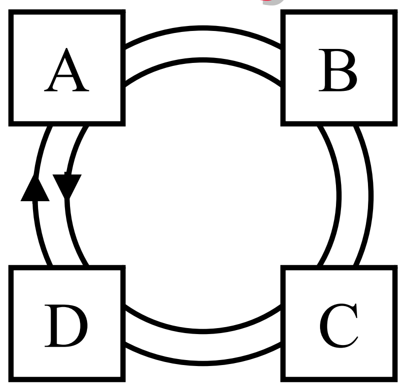
Enterprise vs Carrier Ethernet

Enterprise	**Carrier**
Distance: up to 2km	Up to 100 km
Scale:	
- Few K MAC addresses	Millions of MAC Addresses
- 4096 VLANs	Millions of VLANs Q-in-Q
Protection: Spanning tree	Rapid spanning tree (Gives 1s, need 50ms)
Path determined by spanning tree	Traffic engineered path
Simple service	SLA
Priority ⇒ Aggregate QoS	Need per-flow QoS
No performance/Error monitoring (OAM)	Need performance/BER

Networking and Religion

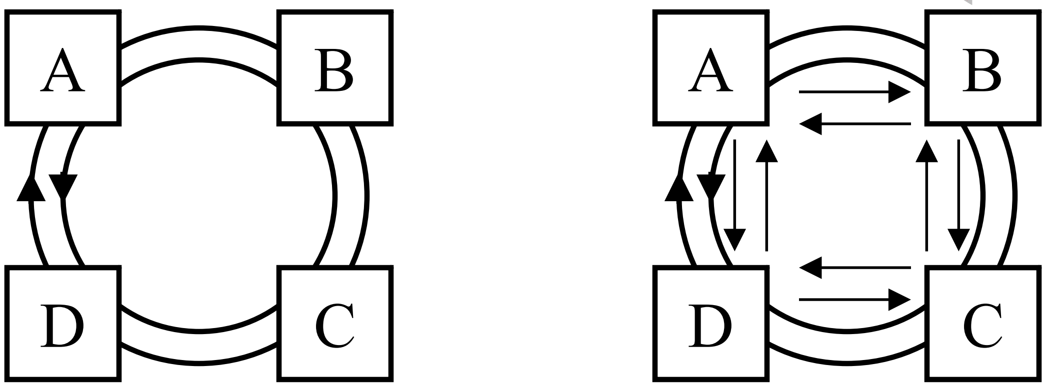
Both are based on a set of beliefs

RPR: Key Features



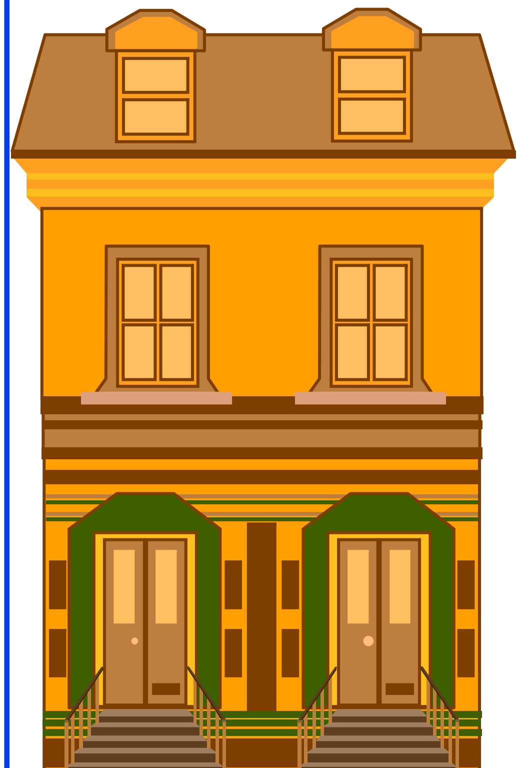
- Dual Ring topology
- Supports broadcast and multicast
- Packet based ⇒ Continuous bandwidth granularity
- Max 256 nodes per ring
- MAN distances: Several hundred kilometers.
- Gbps speeds: Up to 10 Gbps

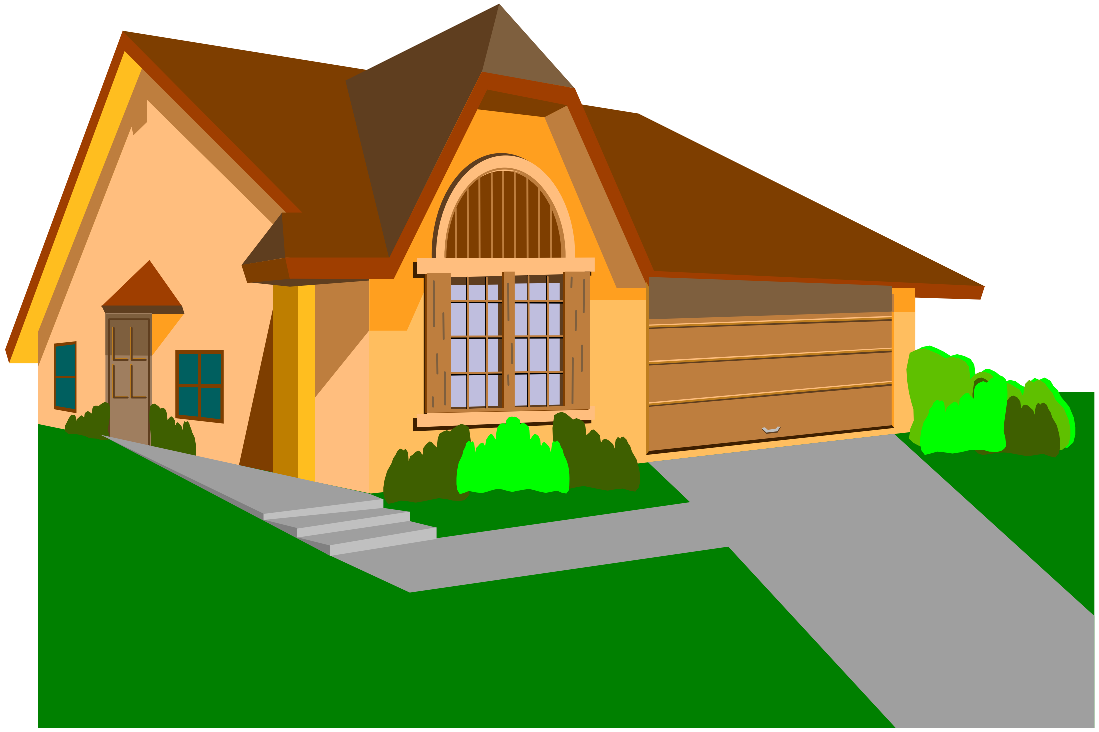
RPR Features (Cont)



- Both rings are used (unlike SONET/SDH)
- Normal transmission on the shortest path
- Destination stripping ⇒ Spatial reuse
  Multicast packets are source stripped
- Several Classes of traffic: A0, A1, B-CIR, B-EIR, C
- Too many features and alternatives too soon (702 pages)

Old House vs New House





- New needs:
  Solution 1: Fix the old house (cheaper initially)
  Solution 2: Buy a new house (pays off over a long run)

Networking: Failures vs Successes

- 1980: Broadband (vs baseband)
- 1984: ISDN (vs Modems)
- 1986: MAP/TOP (vs Ethernet)
- 1988: OSI (vs TCP/IP)
- 1991: DQDB
- 1994: CMIP (vs SNMP)
- 1995: FDDI (vs Ethernet)
- 1996: 100BASE-VG or AnyLan (vs Ethernet)
- 1997: ATM to Desktop (vs Ethernet)
- 1998: Integrated Services (vs MPLS)
- 1999: Token Rings (vs Ethernet)

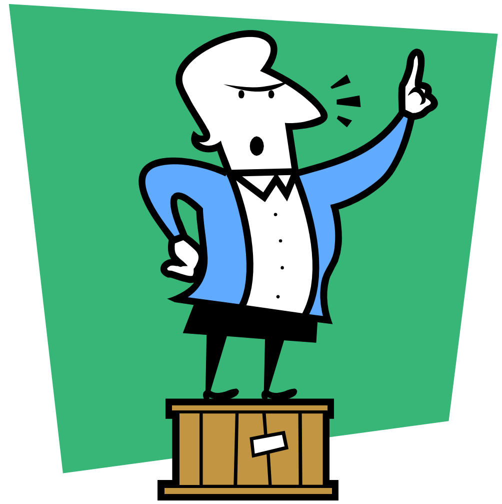
Requirements for Success

- Low Cost: Low startup cost ⇒ Evolution
- High Performance
- Killer Applications
- Timely completion
- Manageability
- Interoperability
- Coexistence with legacy LANs
  Existing infrastructure is more important than new technology

Laws of Networking Evolution

1. Existing infrastructure is more important then deploying new technology
    - Ethernet vs ATM, IP vs ATM
    - Exception: Killer technology, immediate savings
2. Modifying existing protocol is more acceptable than new protocols
    - TCP vs XTP
    - Exception: New applications (VOIP – SIP, MEGACO, …)
3. Traffic increases by a factor of X/year
   Total revenue remains constant (or decreases)
   $\Rightarrow$ Price/bps goes down by $\cong$ X/year (X = 2 to 4)

Summary



- 1 GbE supports but does not use CSMA/CD.
- 10 GbE does not support CSMA/CD.
  Two speeds: 10,000 Mbps and 9,584.640 Mbps
- RPR to provide carrier grade reliability

Summary (Cont)

- Virtual concatenation allows a carrier to use any arbitrary number of STS-1's or T1's for a given connection. These STS-1's can take different paths.
- LCAS allows the number of STS-1's to be dynamically changed
- Frame-based GFP allows multiple packet types to share a connection
- Transparent GFP allows 8b/10 coded LANs/SANs to use PHY layer connectivity at lower bandwidth.

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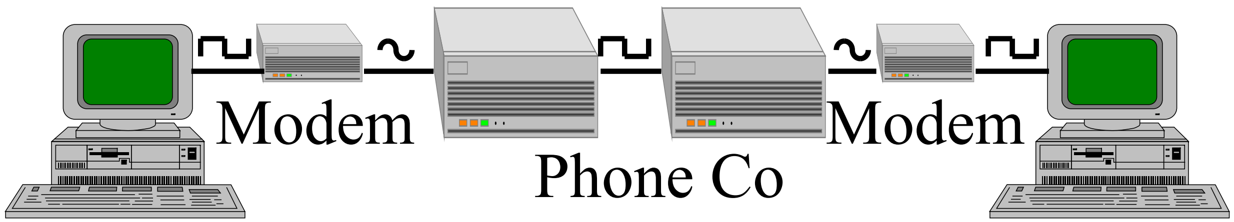
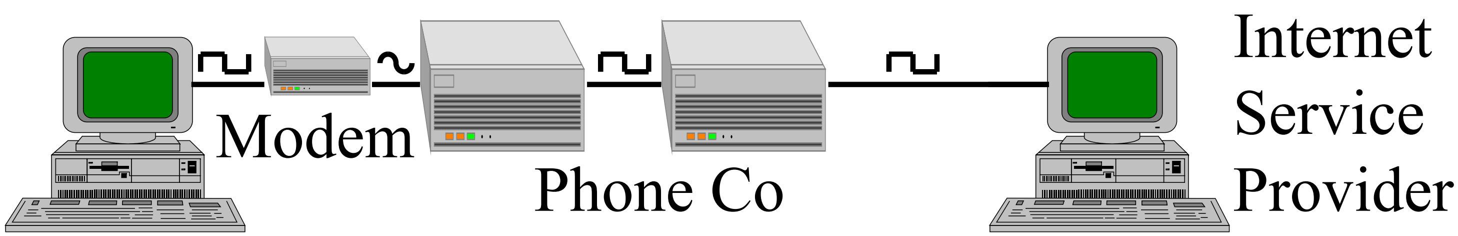
- xDSL
- Cable Modems and Hybrid Fiber Coax (HFC)
- Bi-Directional Satellite
- Optical Wireless Access
- **Broadband Wireless Access** (BWA) and WiMAX
- **Mobile Broadband Wireless Access** (MBWA)
- **Fiber To The X** (FTTx): Passive Optical Network (PON)

56 kbps Modems

- Past:

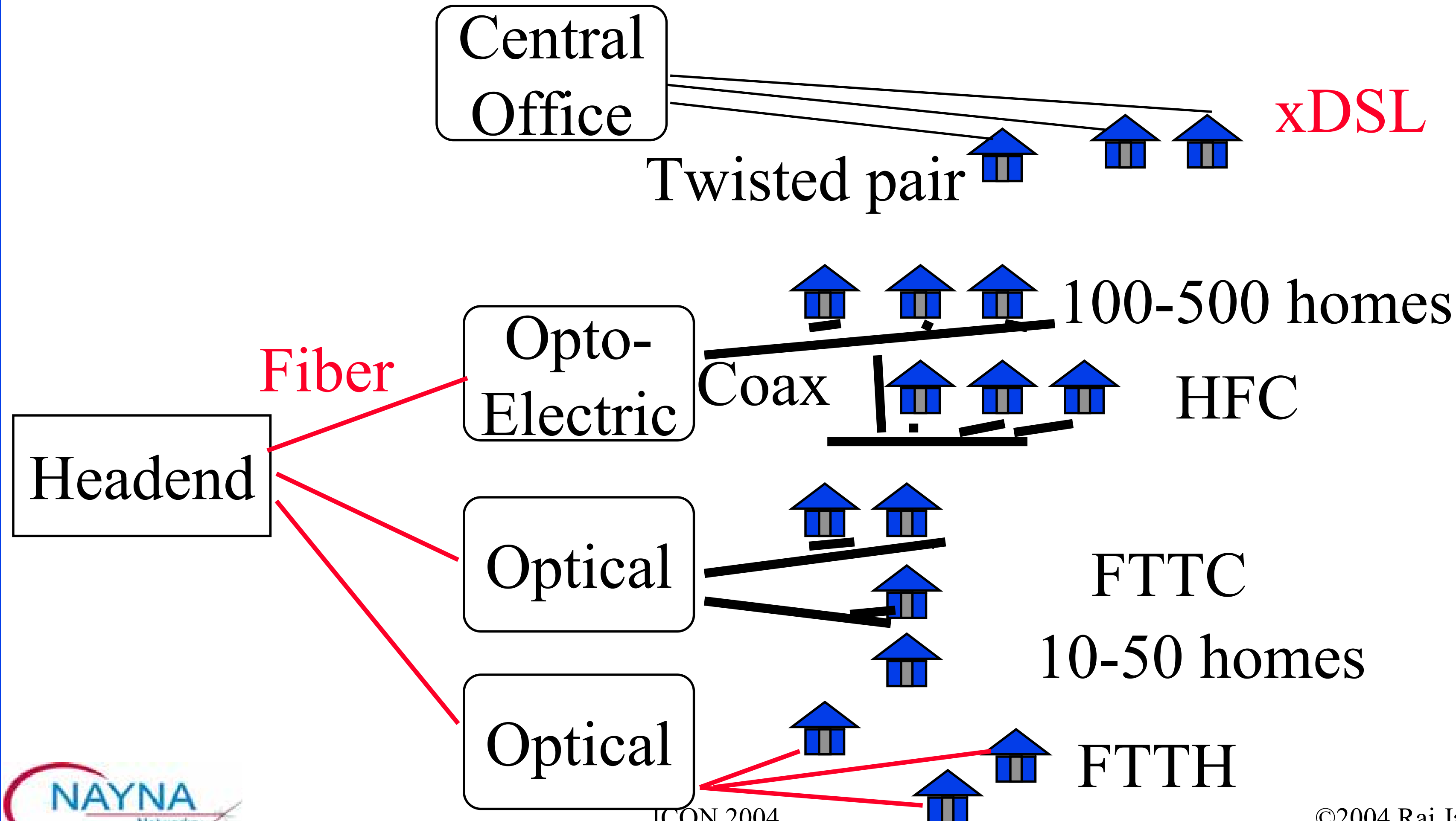


- Current:



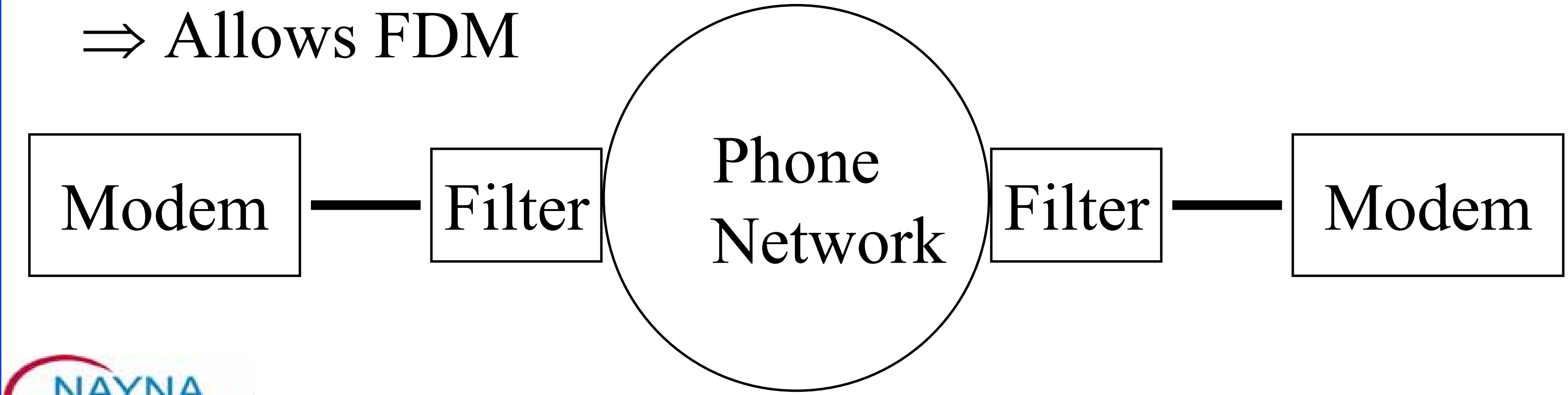
- ISP's have direct digital link (T1 or T3)
- Only one D/A/D conversion ⇒ Higher speed possible

Residential Access Networks (RANs)



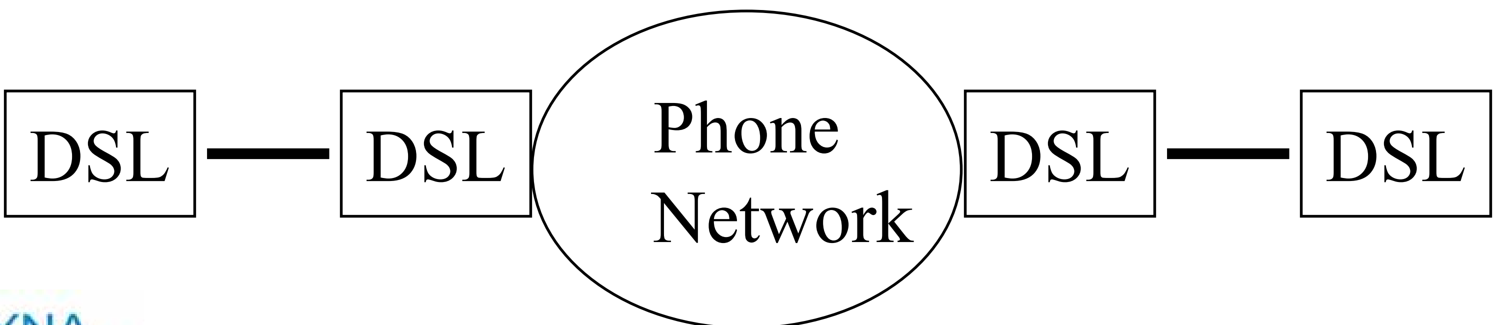
Why Modems are Low Speed?

- Telephone line bandwidth = 3.3 kHz
- V.34 Modem = 28.8 kbps ⇒ 10 bits/Hz
- Better coding techniques. DSP techniques.
- Cat 3 UTP can carry higher bandwidth
- Phone companies put 3.3 kHz filters at central office ⇒ Allows FDM



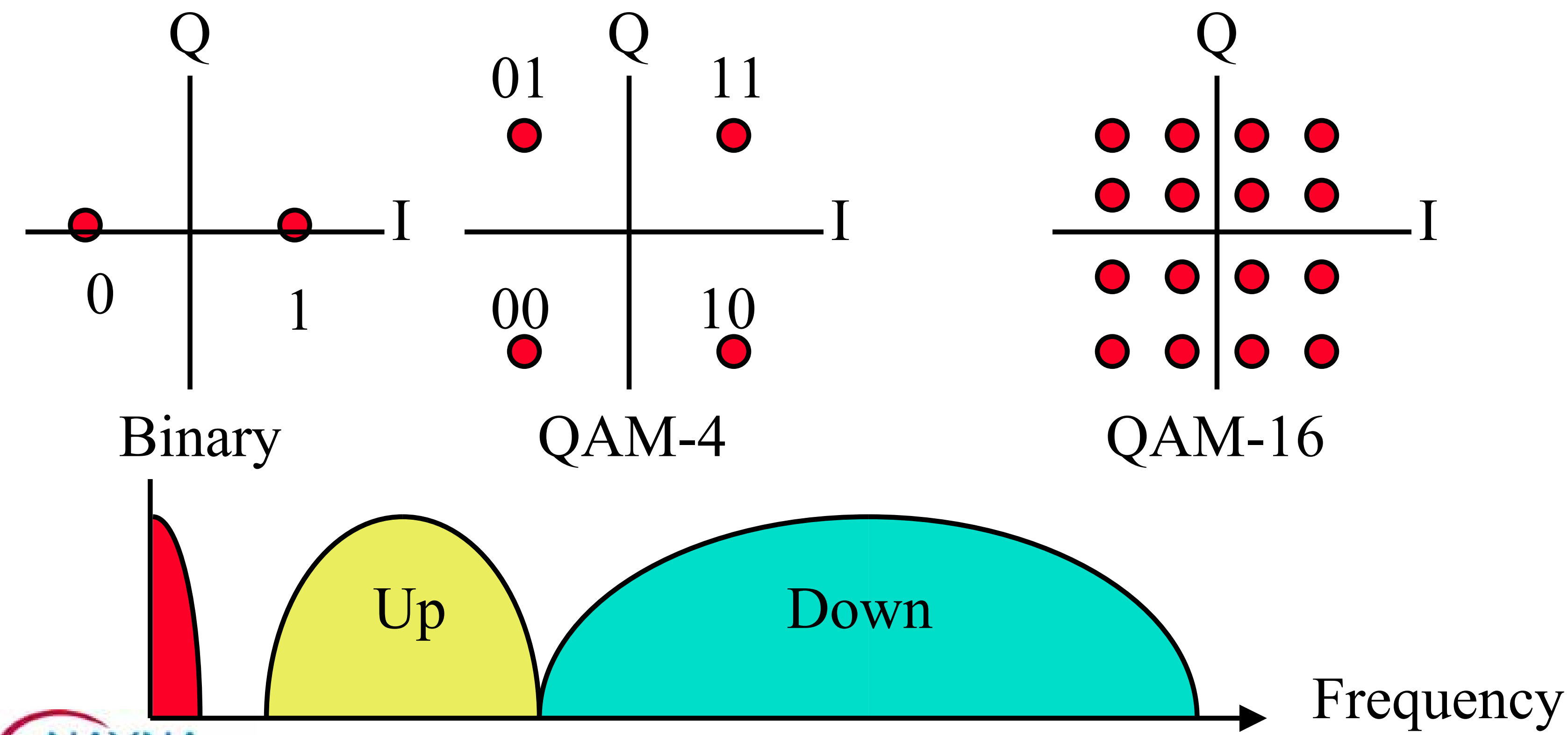
DSL

- Digital Subscriber Line = ISDN
- 64×2 + 16 + overhead
  = 160 kbps up to 18,000 ft
- DSL requires two modems (both ends of line)
- Symmetric rates ⇒ transmission and reception on same wire
  ⇒ Echo cancellation
- ISDN uses 0 to 80 kHz ⇒ Can't use POTS simultaneously



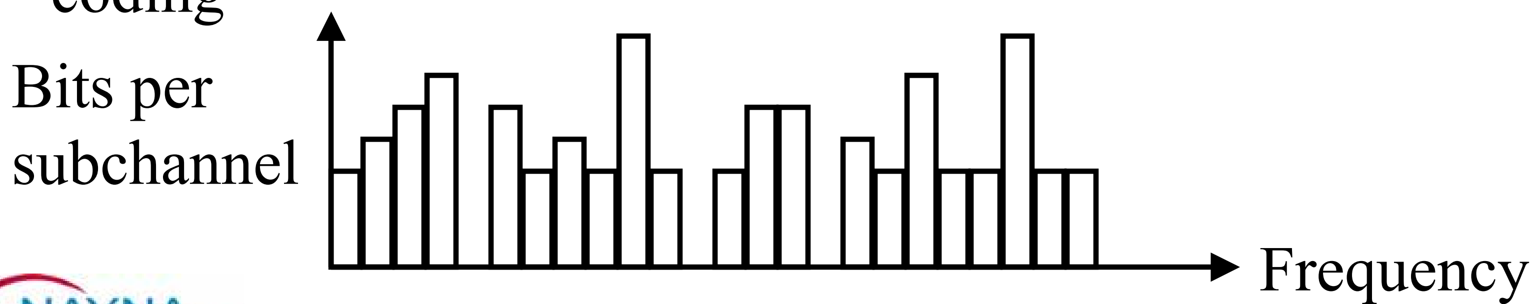
QAM

- Quadrature Amplitude and Phase Modulation
- I = In phase, Q=Quadrature signal
- Symbols occupy entire available bandwidth



Discrete Multi-Tone (DMT)

- Multicarrier modulation
- Inverse Discrete Fourier Transform (IDFT) to partition bandwidth into subchannels or tones
  E.g., 256/32 tones 4.3125 kHz apart = 1104/138 kHz Down/up
- Each tone is QAM modulated. 4kBaud symbols=250us frame
  Each tone carries 2 to 15 bits (Rate adaptive)
- Measure SNR of each subchannel
  Avoid severely degraded channels
  Lower data rate on degraded channels
- Built-in Reed-Solomon FEC with interleaving and Trellis coding



DMT vs QAM

- First line-code war: ANSI T1E1.4 ADSL Olympics in 1993

DMT	QAM
Multi-carrier Modulation	Single-Carrier Modulation
Used in wireless, ADSL, ADSL2, ADSL2+. Allows migration. Implementation in the same chipset.	Used in Modems, Satellite, HPNA, DOCSYS, HDSL, SDSL, SHDSL, IDSL, RADSL, 5-level PAM used in 100BT2 and 1000BT
Requires digital signal processing due to FFT and iFFT	No DSP
DSP firmware download	Hardwired
Needs training sequence and initialization	No training sequence or handshake
Dynamic Spectrum Management:on-the-fly PSD change. Line bonding.	SNR averaging improves effective bandwidth
Erasure of a part of a symbol kills the whole symbol	Short symbols not affected by impulse noise
VDSL Alliance: Ikanos, Stmicro, Alcatel	VDSL Coalition: Infineon
Requires licensing	Public domain

- Final Decision: ANSI T1E1.4 June 2003: DMT Std, QAM in TRQ

Copper Broadband Systems I

Acronym	Description	Standards	Year	Modu-lation	# of Pairs	Up Mbps	Down Mbps	Spectrum in kHz
ADSL	Asymmetric DSL	T1.413 G.992.1	1995	DMT	1	1	8	25-138 U 25-1104 D
G.Lite	Splitterless ADSL	G.992.2 T1.419	1999	DMT	1	1	1.5	25-138 U 25-552 D
RADSL	Rate Adaptive DSL	T1.TR.59		CAP	1	1	8	25-138 U 25-1104 D
ADSL2	ADSL 2nd Gen	G.992.3	2003	DMT	1	1	12	0-276 U 0-1104 D
G.Lite.bis	ADSL2 Lite	G.992.4	2003	DMT	1	1		
ADSL2+	Double Rate ADSL2	G.992.5	2003	DMT	1	1	24	0-276 U 0-2208 D
VDSL	Very high bit rate DSL	T1.424 G.vdsl	2002	DMT or QAM	1	13	22	25-12000
EFM	Ethernet in the First Mile	10PASS-TS 2BASE-TL	2004	DMT DMT	1 1	10 2	10 2	25-12000 25-138

Copper Broadband Systems II

Acronym	Description	Standards	Year	Modu-lation	# of Pairs	Up Mbps	Down Mbps	Spectrum in kHz
ISDN BRI	Basic Rate ISDN	T1.601 G.961	1986	2B1Q	1	0.160	0.160	0-80
IDSL	ISDN over DSL				1	0.144	0.144	
T1	T1	T1.403		AMI	2	1.544	1.544	0-1544
E1	E1	G.703		HDB3	2	2.048	2.048	0-2048
HDSL	High Bit-Rate DSL	G.991.1 T1.TR.28	1992	2B1Q	2	1.544	1.544	0-370
HDSL2	HDSL 2nd Gen	T1.418 G.991.2		TC-PAM	1	1.544	1.544	0-300 U 0-440 D
HDSL4	4-wire HDSL 2nd Gen	T1.418 G.991.2		TC-PAM	2	1.544	1.544	0-130 U 0-400 D
SDSL	Symmetric DSL	TS 101 524	1998	2B1Q	1	2.312	2.312	0-700
G.shdsl	Single pair HDSL	G.991.2 T1.422	2000	TC-PAM	1	2.312	2.312	0-400

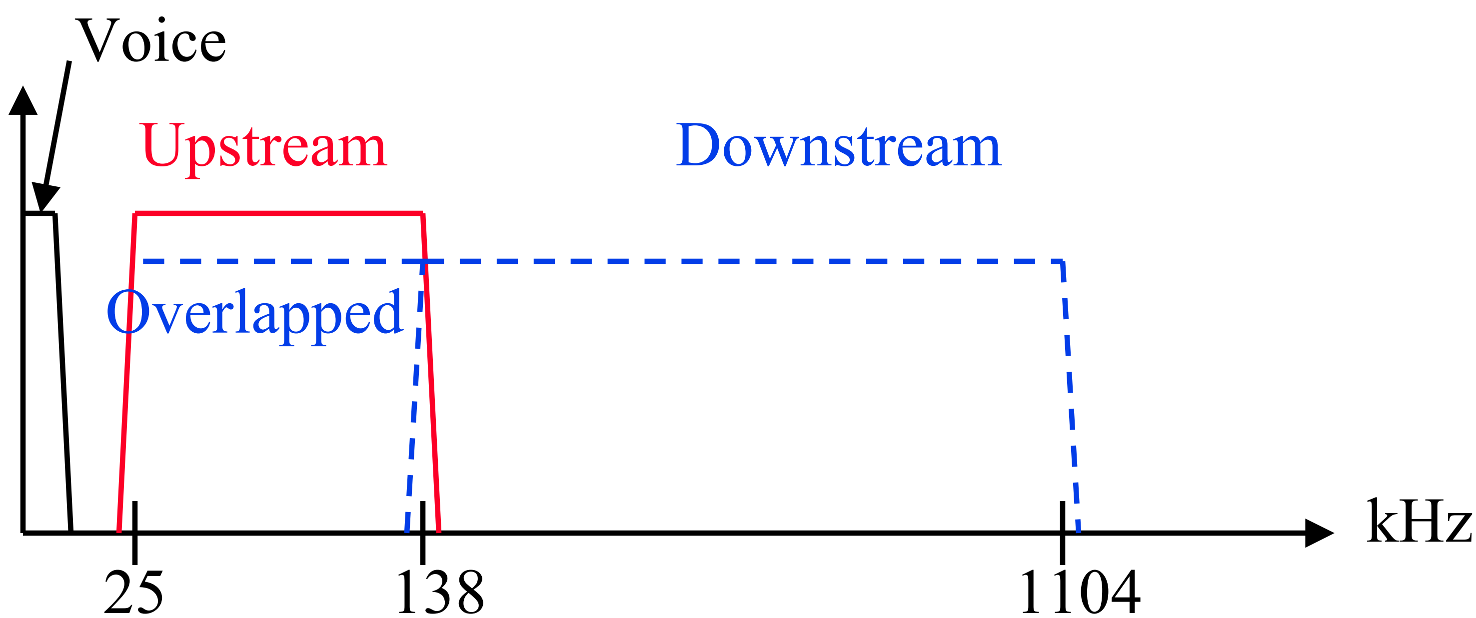
ADSL

- Asymmetric Digital Subscriber Line
- Asymmetric $\Rightarrow$ upstream << Downstream
- Symmetric $\Rightarrow$ Significant decrease in rate
- Originally, 6 Mbps downstream, 640 kbps upstream
  Now up to 25 Mbps downstream
- Up to 7500 m
- Using existing twisted pair lines
- No interference with phone service (0-3 kHz)
  $\Rightarrow$ Your phone isn't busy while netsurfing
- ANSI T1.413 Standard
- Quickest alternative for Telcos. Low cost winner.

Why Asymmetric?

- Unshielded twisted pair $\Rightarrow$ Crosstalk
- Downstream signals are all same amplitude $\Rightarrow$ Not affected
- Upstream signals start at different distances $\Rightarrow$ Different amplitudes $\Rightarrow$ Weak signals are highly affected
- Solutions:
  1. Use asymmetric rates
  2. Use lower frequencies for upstream (Cross talk increases with frequencies)

ADSL Spectrum



- G.992.1 Annex A: ADSL over POTS (25-138 kHz up)
- G.992.1 Annex B: ADSL over ISDN (120-276 kHz up)
- G. 992.1 Annex C: ADSL over Time-Compression Multiplex ISDN

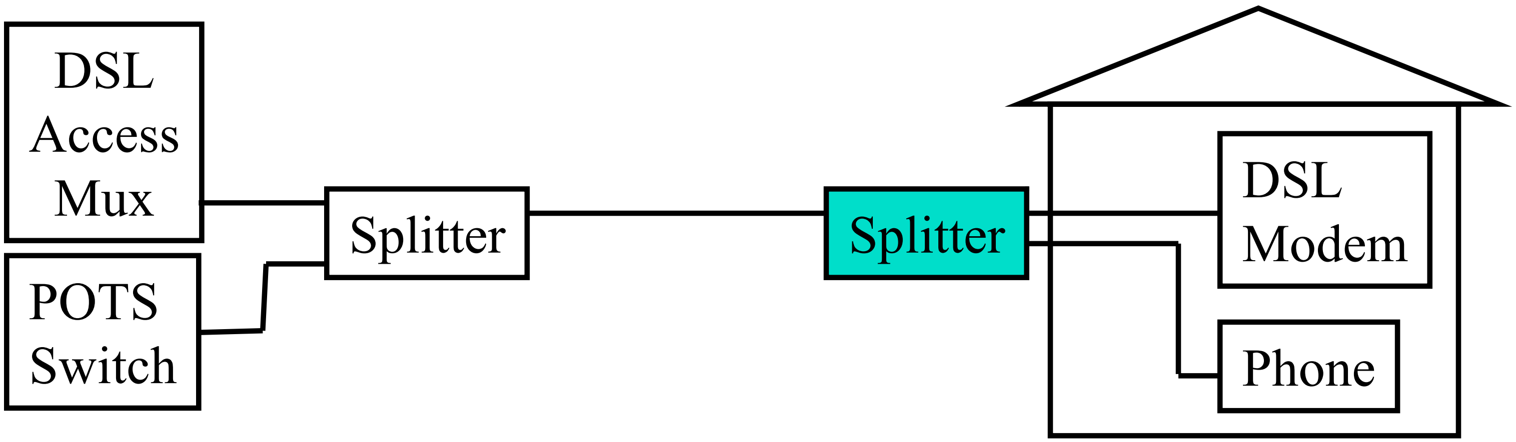
ADSL Lite (G.Lite)

- Designed for easy installation and lower cost
- Lower data rate and longer reach

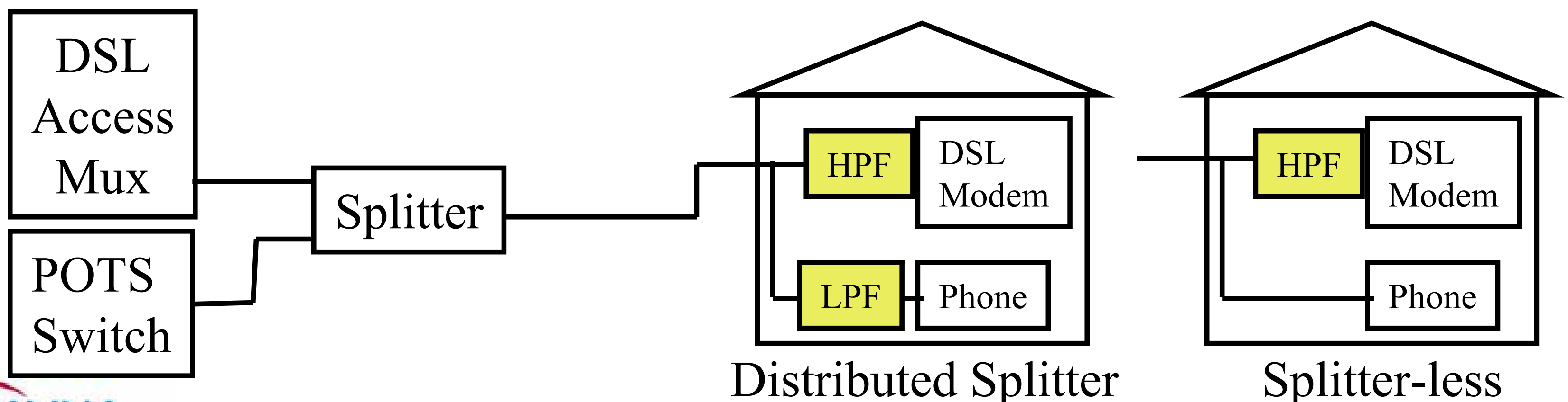
Full Rate ADSL (G.992.1)	Universal ADSL (G.992.2)
Optimized for data rate	Optimized for cost
8Mbps up, 800 kbps down	1.5 Mbps up, 512 kbps down
256 tones	128 tones
15 bits/tone	8 bits/tone
Echo canceled	FDM with EC option
Full initialization	Fast retrain
No power management	Power management

G.Lite Installation

- ADSL: Splitter outside the house ⇒ Truck Roll.



- ADSL Lite: No splitter outside the house

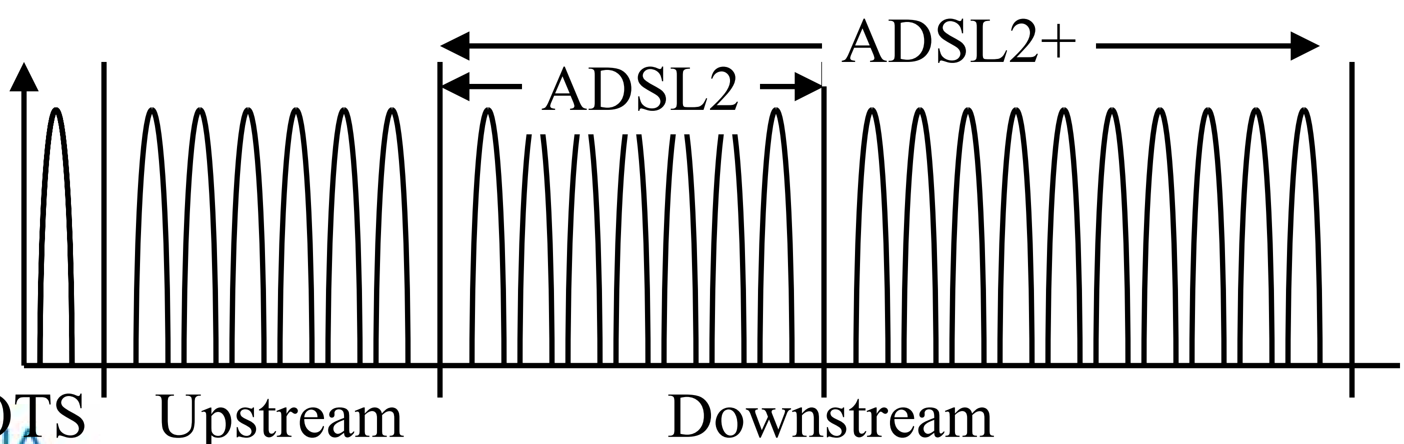


ADSL2

- G.992.3 also known as G.dmt.bis
  G.992.4 is G.lite.bis
  Completed in July 2002
- 0-276 kHz up, 0-1104 kHz down.
  Subset within these masks can be used.
  E.g., 25-276 kHz up, 25-1104 kHz down with POTS.
- 12 Mbps down, 1 Mbps up
  50 kbps more than ADSL on long lines
  600 feet more reach for the same data rate
- Programmable Framing Overhead, Improved Performance, Power Management, Diagnostics, Seamless Rate Adaptation (SRA), Multi-pair bonding, Dynamic Rate Partitioning, Fast Startup, All-digital mode, Multi-vendor Interoperability, Customer installable

ADSL2+

- G.992.5 (January 2003)
- Downstream frequency up to 2.2 MHz
- ADSL2 with double bandwidth downstream
  ⇒ **double data rate** (24 Mbps) on lines shorter than 5000 ft.
- Can use only 1.1MHz to 2.2MHz (mask frequency below 1.1MHz) Reduced cross-talk in a binder

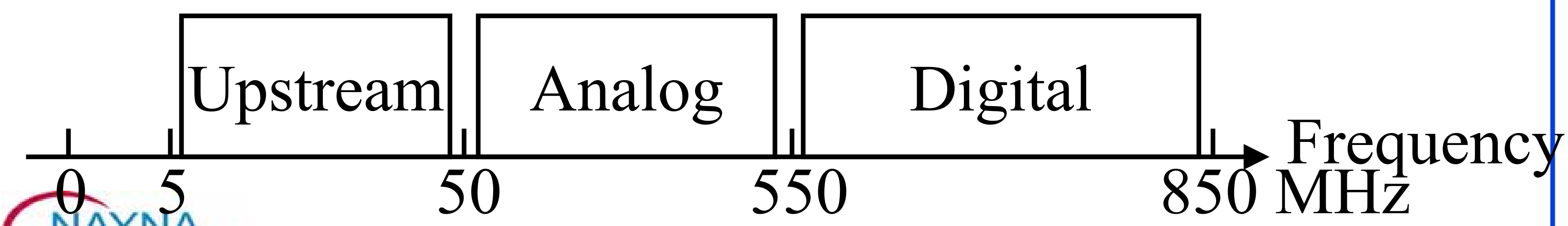


VDSL

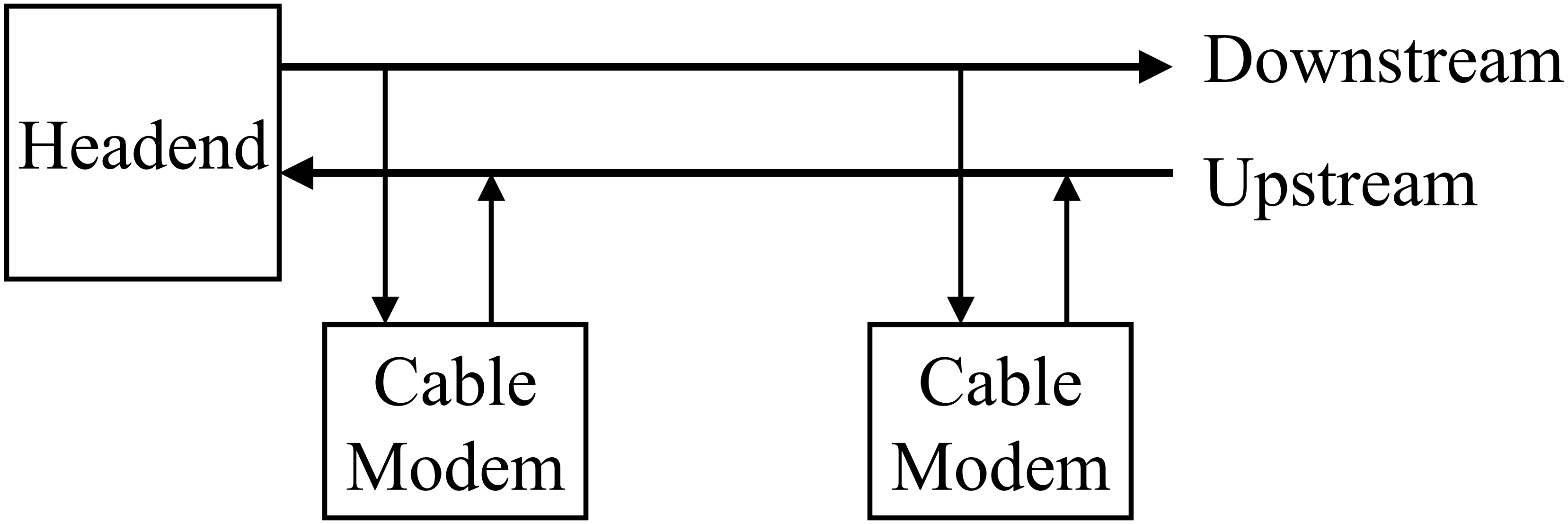
- Supports both symmetric and asymmetric bit rates:
  - Symmetric: 26 Mbps, 13 Mbps, 8 Mbps
  - Asymmetric: 52/6.4, 26/3.2, 12/2, 6/2 Mbps
    Ratios: 8:1, 6:1, 4:1, 3:1, 2:1
- Higher speed using higher bandwidth
  50 Mbps down and 30 Mbps up in Japan
  120 Mbps full-duplex touted by some vendors
- Need to overcome: bridged taps, crosstalk, impulse noise, RF ingress, RF egress (less than –80 dBm/Hz in amateur radio band)
- Band below 1.104 MHz may not be used to avoid interference with ADSL lines in the same bundle
- Dynamic Spectrum Management (DSM): Limit power. Increase cooperation between pairs.

Cable TV Spectrum

- 50-550 MHz reserved for NTSC analog cable in USA
- Divided into 6 MHz channels
- 5-50 MHz can be used for upstream channel and 550-850 MHz for downstream digital channel
  Low-Split system. Most Common.

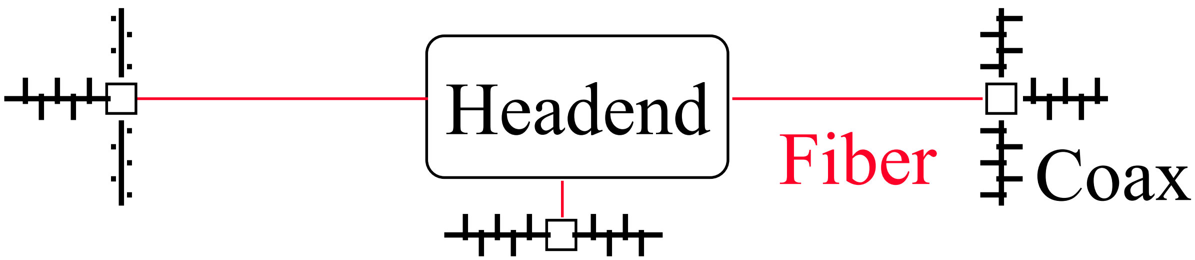


Media Sharing



- Headend controls all transmissions
- Downstream broadcast. Each modem picks up its information
- Upstream slots allocated by headend

Hybrid Fiber Coax (HFC)



- Reuse existing cable TV coax
- Replace trunks to neighborhoods by fibers
- 45 Mbps downstream, 1.5 Mbps upstream
- MAC protocol required to share upstream bandwidth
- 500 to 1200 homes per HFC link
- Sharing $\Rightarrow$ Security issues
- IEEE 802.14 standard for MAC and PHY

Cable Modems

- Modulate RF frequencies into cable.
  Signal received at the headend and
  converted to optical
- If cable is still one-way, upstream path through POTS
- $30 to $40 per month flat service charge

Comparison of RANs

Tech-nology	Typical Downstream Rate	Typical Upstream Rate	Max Distance	Homes Per Opt. Unit
HFC	45 Mbps Shared	1.5 Mbps Shared	N/A	500
FTTC	25-50 Mbps	25-50 Mbps	100 m	10-50
FTTH	1000 Mbps	1000 Mbps	N/A	10-200
ADSL	6 Mbps	640 kbps	4,000 m	1,000
VDSL	13-50 Mbps	1.6-5 Mbps	2,000 m	100

xDSL Vs Cable Modems

xDSL	Cable Modems
Phone company	Cable company
Switching experience but low bandwidth ckts	No switching but high bandwidth infrastructure
Point-to-point ⇒ Data privacy	Broadcast. Sharing ⇒ More cost effective
Currently 1.5 to 50 Mbps	10 to 30 Mbps
Perf = fn(location)	Independent of location
Phone everywhere	Cable only in suburbs (not in office parks)
Existing customers ⇒ ISDN and T1 obsolete	New Revenue

Summary

1. Filters limit phone wire to 4 kHz. Removing the filters leads to xDSL
2. ADSL is asymmetric because strong upstream signals interfere with weak signals at the central office
3. ADSL, ADSL2, VDSL, VDSL2 differ in the amount of frequency band used
4. Discrete Multi-Tone (DMT) allows QAM to be used on multiple carriers
5. Cable companies: High data rate but no switching experience. Carriers: Switching but low data rate.

Fixed Broadband Wireless Access

Raj Jain
CTO and Co-founder
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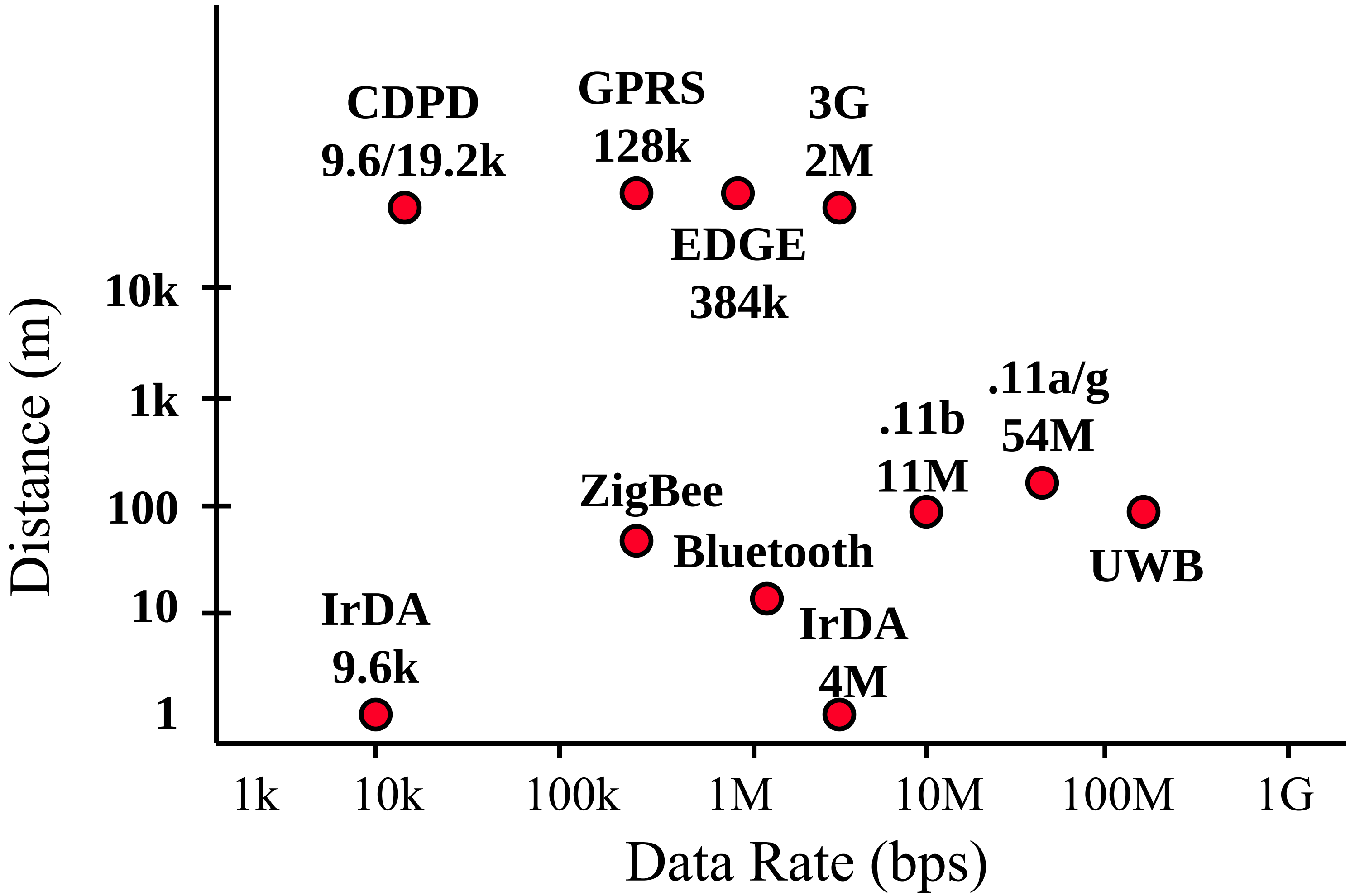
Email: jain@acm.org
www.nayna.com and http://www.cis.ohio-state.edu/~jain/

1. IEEE 802.11a/b/g
2. 802.11 Activities
3. IEEE 802.16 or WiMAX
4. Optical Wireless Access
5. Satellites for Data

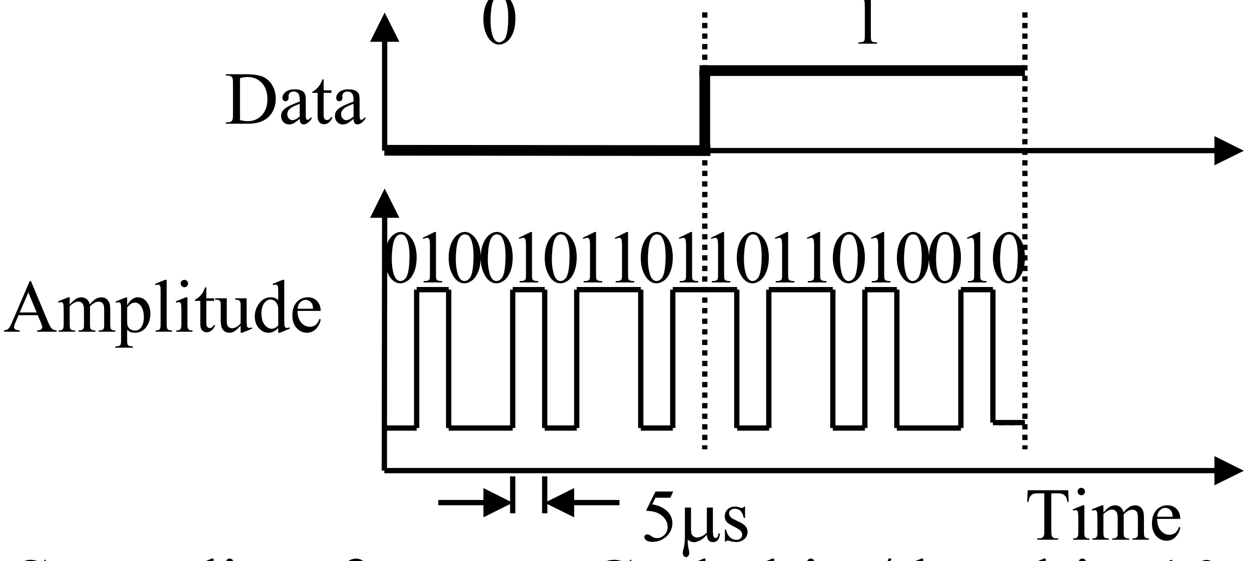
Wireless Networks



Frequency Selection

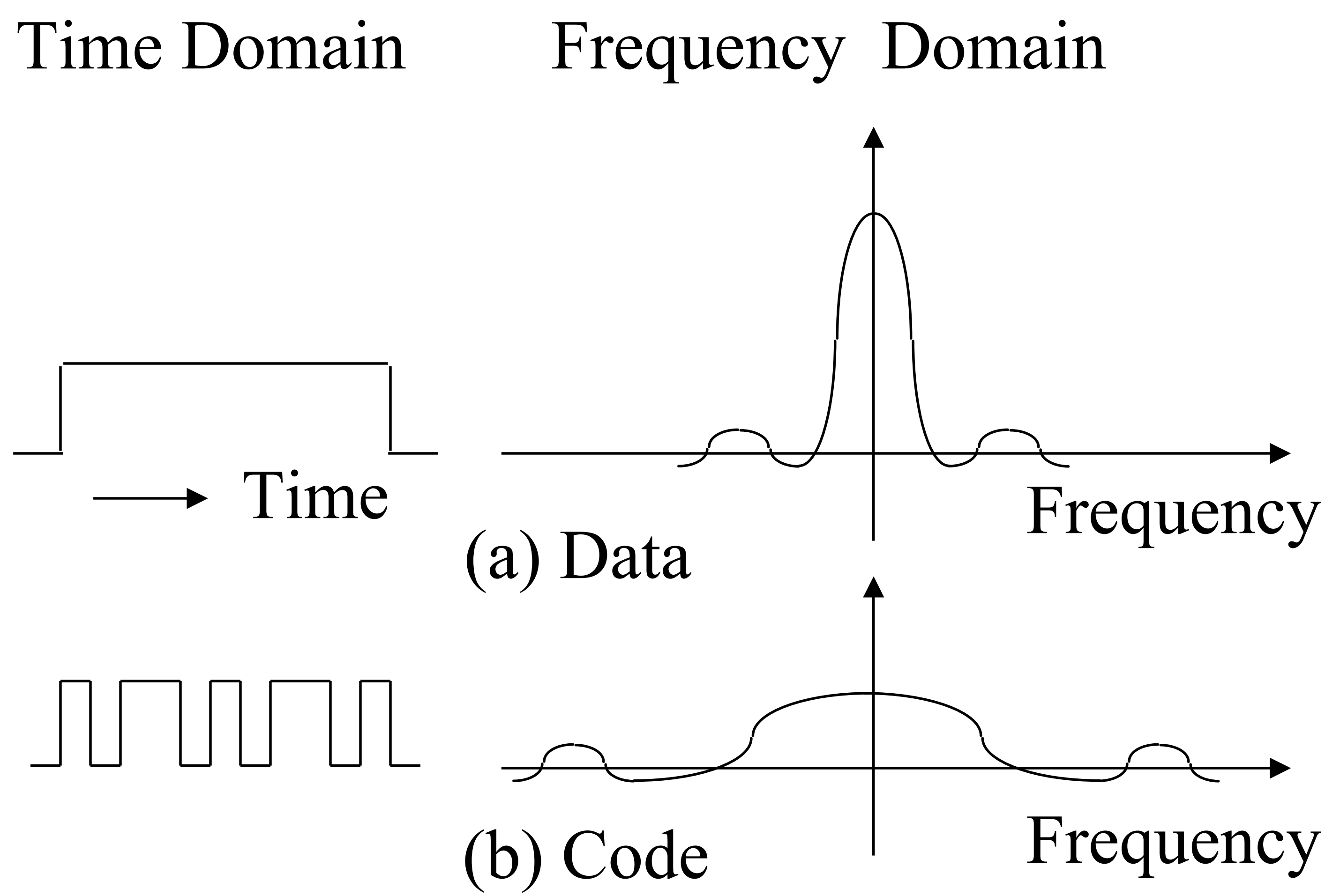
- Higher Frequencies have higher attenuation, e.g., 18 GHz has 20 dB/m more than 1.8 GHz
- Higher frequencies need smaller antenna
  Antenna $\geq$ Wavelength/2, 800 MHz $\Rightarrow$ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules
- Higher frequencies have more bandwidth and higher data rate
- Higher frequencies allow more frequency reuse
- Mobility $\Rightarrow$ Below 10 GHz

Direct-Sequence Spread Spectrum



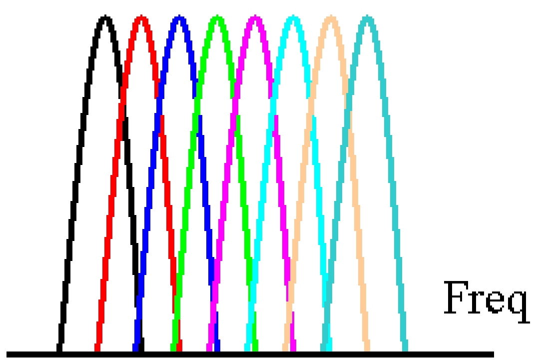
- Spreading factor = Code bits/data bit, 10-100 commercial (Min 10 by FCC), 10,000 for military
- Signal bandwidth >10 × data bandwidth
- Code sequence synchronization
- Correlation between codes ⇒Interference⇒ Orthogonal

DS Spectrum


Time Domain
Frequency Domain
Time
Frequency
(a) Data
(b) Code
Frequency

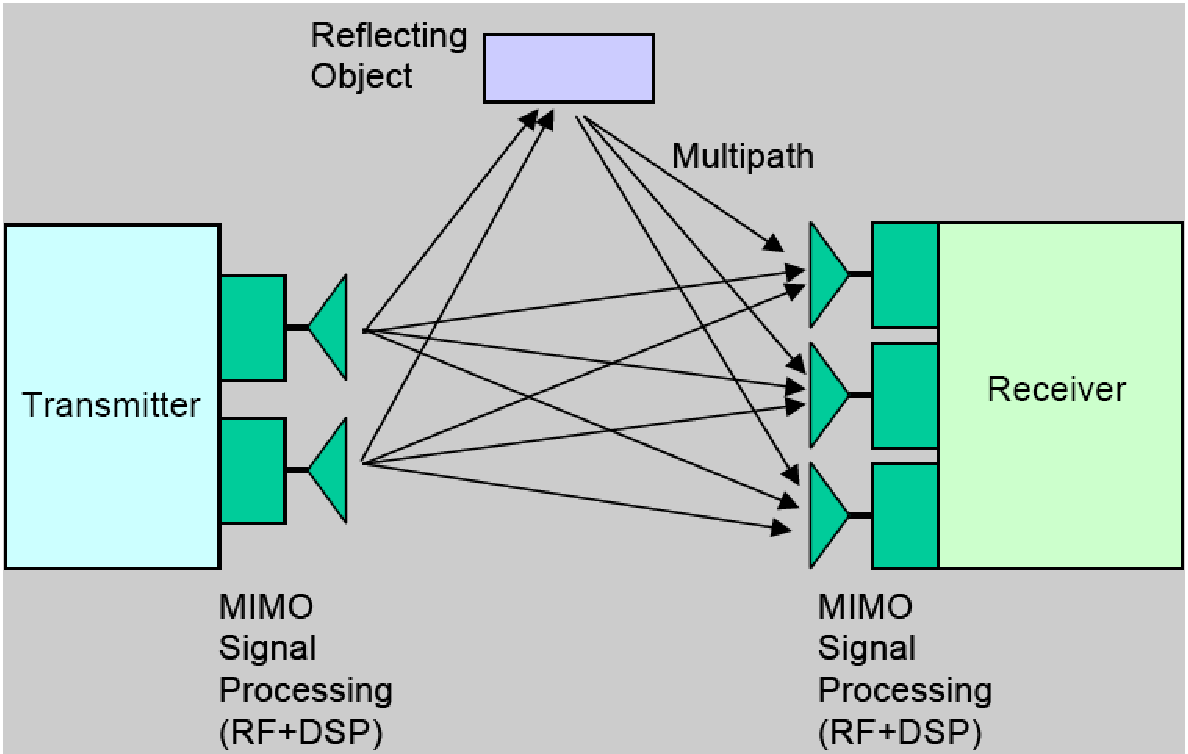
OFDM

- Orthogonal Frequency Division Multiplexing
- Multicarrier modulation similar to DMT
- Available frequency band is divided into 256 or more sub-bands. Orthogonal ⇒ Peak of one at null of others
- Each carrier is modulated with a BPSK, QPSK, 16-QAM, 64-QAM etc depending on the noise (Frequency selective fading)
- Used in 802.11a/g, 802.16, HDTV



MIMO

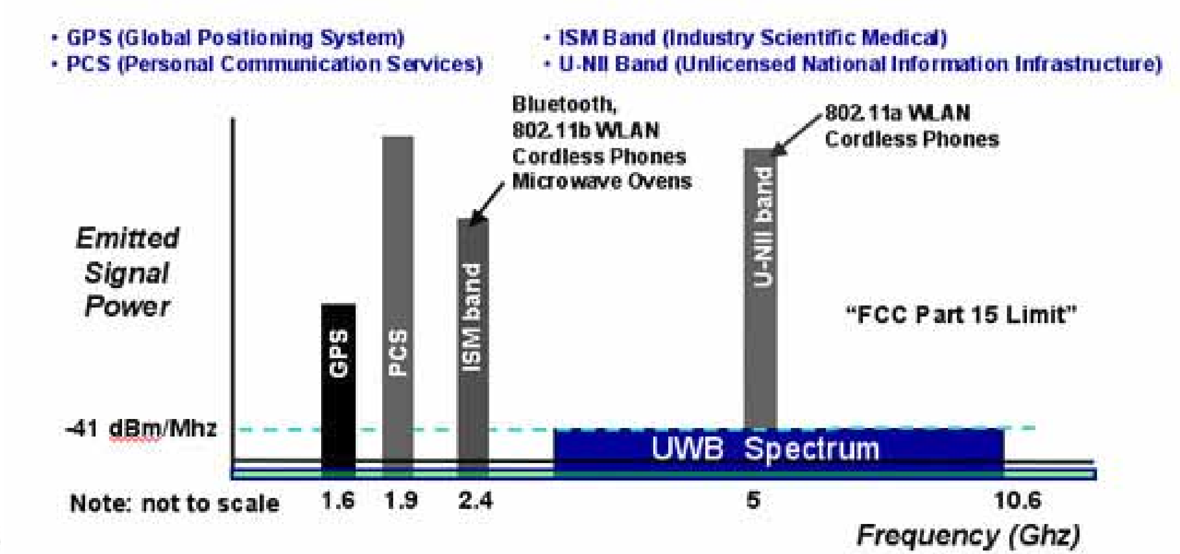
- Multiple Input Multiple Output
- 54 Mbps/20 MHz = 2.7 bps/Hz,
  MIMO $\Rightarrow$ 108 Mbps or 5.4 bps/Hz



Ultra-Wideband

- Very low power transmission over a large band: 5±2.5 GHz
- Transmit pico-second or ns pulses at very low power
  Total power is below allowed noise level
- Initially developed for Low Probability of Intercept and Detection (LPI/D) military radios
- Capable of 1 to 10Gbps transmission over short distances

30 ft wireless connection between computers, stereos, TVs



IEEE 802.11a

- 5 GHz ISM band
- 6, 9, 12, 18, 24, 36, 48, 54 Mbps in 802.11a using Orthogonal Frequency Division Multiplexing (OFDM)
- 6, 12, 24 Mbps is mandatory
- 52 sub-carriers modulated using BPSK/QPSK/64-QAM

IEEE 802.11b

- 2.4 GHz ISM Band
- 1, 2, 5.5, and 11 Mbps
- 8-chip Complementary Code Keying (CCK) modulation $\Rightarrow$ 8 bits/symbol and
- 1.375 Msymbols/s $\Rightarrow$ 11 MHz chipping rate (same as 802.11)
- High Rate Direct Sequence Spread Spectrum (HR/DSSS)
- Optional Packet Binary Convolutional Coding (PBCC) instead of CCK

IEEE 802.11b (Cont)

- Optional Short Preamble (56 bit sync instead of 128) $\Rightarrow$ Higher throughput for the same channel
- Optional Channel Agility provides interoperability with both FH and DS 802.11 modulations

IEEE 802.11b Coding

- Differential binary phase shift keying (DBPSK) for 1 Mbps: 0 = 0, 1 = $\pi/2$
- Differential Quadrature Phase Shift Keying (DQPSK) for 2 Mbps: 00 = 0, 01 = $\pi/4$, 10 = $\pi/2$, 11 = $3\pi/4$
- Complementary Code Keying (CCK)
  (Direct Sequence Spread Spectrum coding technique)
- CCK+DPBSK for 5.5 Mbps
- CCK+DQBSK for 11 Mbps

IEEE 802.11g

- 54 Mbps in 2.4 GHz band
- Complementary Code Keying (CCK) + Orthogonal Frequency Division Multiplexing (OFDM) + Packet Binary Convolutional coding (PBCC)

802.11 Activities

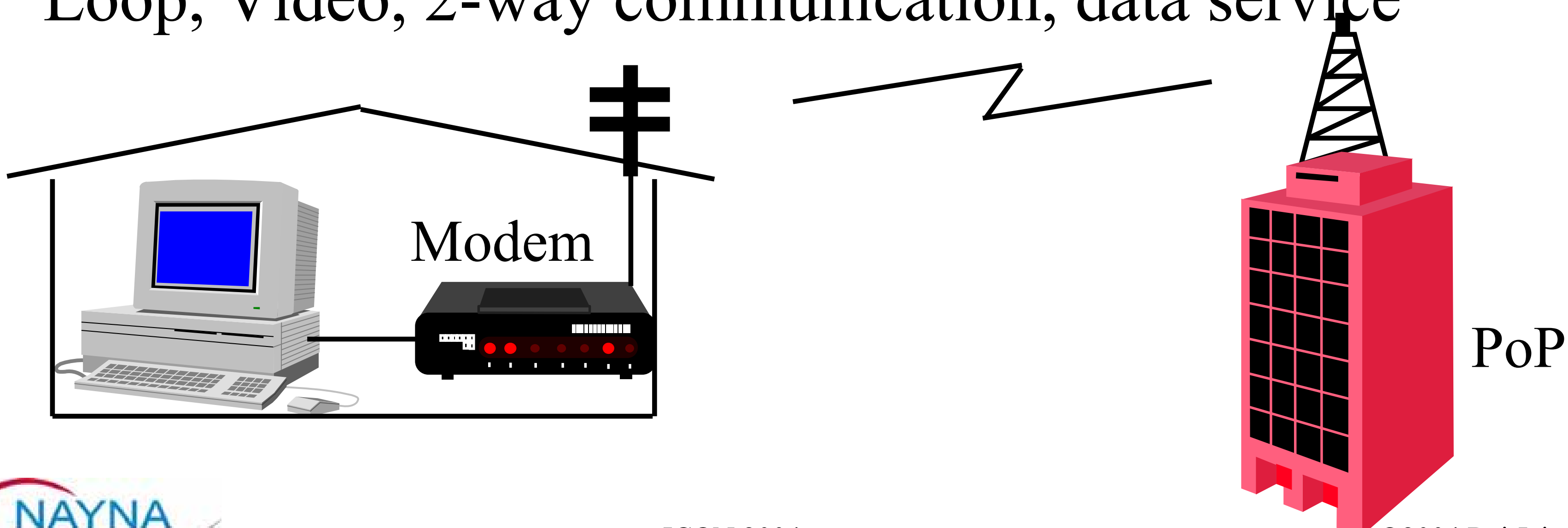
- 802.11c: Bridge Operation (Completed)
- 802.11d: Global Harmonization (regulatory issues)
- **802.11e**: MAC Enhancements for Quality of Service (in sponsor ballot, May 2004)
- 802.11f: Inter-Access Point Protocol
- 802.11h: Spectrum Managed 802.11a. Helps avoid interference with satellites in Europe.
- **802.11i**: MAC Enhancements for Enhanced Security (Draft 10, May 2004)
- 802.11j: 4.9-5 GHz operation in Japan
- 802.11k: Radio Resource Measurement Enhancements (V0.14, May 2004)
- 802.11m: Maintenance. Correct editorial and technical issues in 802.11a/b/d/g/h
- **802.11n**: Enhancements for higher throughput (100 Mbps) – Call for proposals May 2004
- 802.11r: Fast Roaming. Started July 2003.
- 802.11s: ESS Mesh Networks

802.11n

- Goal is to achieve > 100 Mbps at the interface between the MAC and the higher layers
- Uses multiple input multiple output antenna (MIMO)
- Data rate and range are enhanced by using spatial multiplexing (N antenna pairs) plus antenna diversity
- Occupies one WLAN channel, and in compliance with 802.11
- Backwards compatible with 802.11 a,b,g
- One access point supports both standard WLAN and MIMO devices

LMDS

- Local Multipoint Distribution Service (LMDS)
- Local ⇒ Within one cell. 2 to 5 miles range.
- Multipoint ⇒ Broadcast from base. Point-to-point from subscriber.
- Distribution ⇒ Multiple services = Wireless Local Loop, Video, 2-way communication, data service

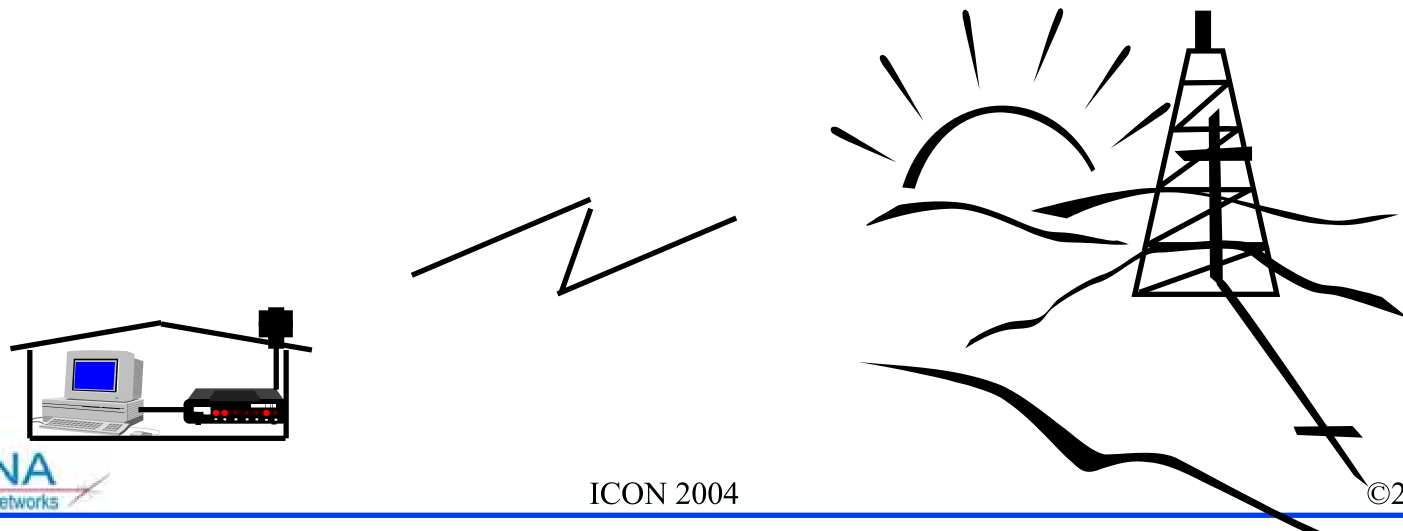


LMDS (Cont)

- 1.3 GHz around 28 GHz band (Ka Band)
  28 GHz ⇒ Rain effects
- 1 Gbps downstream and 200 Mbps upstream
  Most commercial offerings T1/E1
- FCC auctioned LMDS spectrum in 1998.
  A Block: 27.5-28.35GHz, 29.10-29.25GHz
  B Block: 31.00-31.075 GHz, 32.225-32.300 GHz
- Using TDMA, FDMA, or CDMA
- CellularVision offers 49-channel cable TV service using LMDS in NYC.
- NextLink, Teligent, and Winstar offer ATM-based service
- Equipment too expensive and short distance (100m or less)

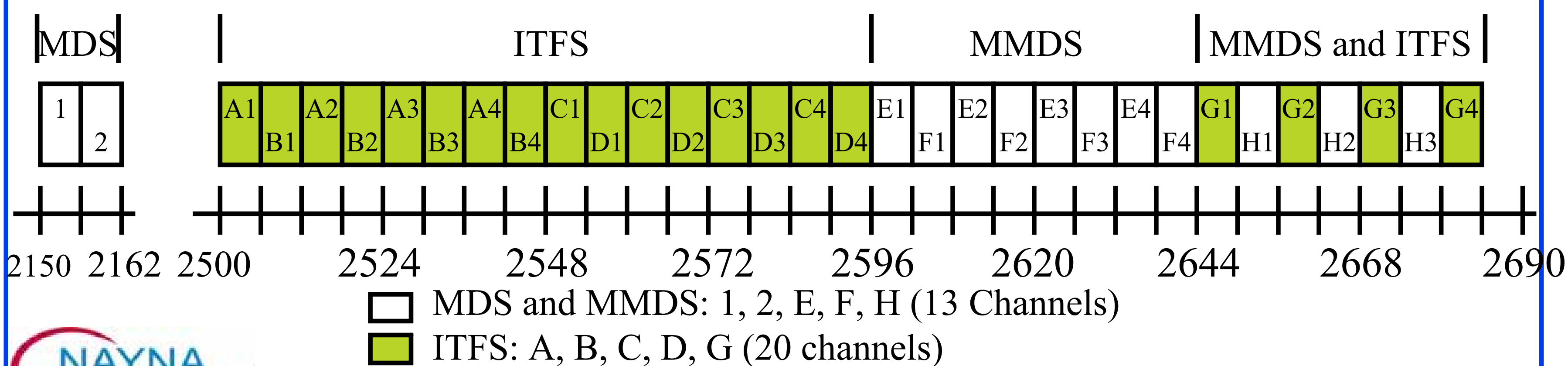
MMDS

- Multi-channel Multipoint Distribution Service (MMDS)
- 35-mile radius protected service areas or 3850 sq. miles per base
- Omni-directional or sectorized antennas on TV towers
- 99 data streams at 10 Mbps each
- Wireless cable for internet access in rural areas

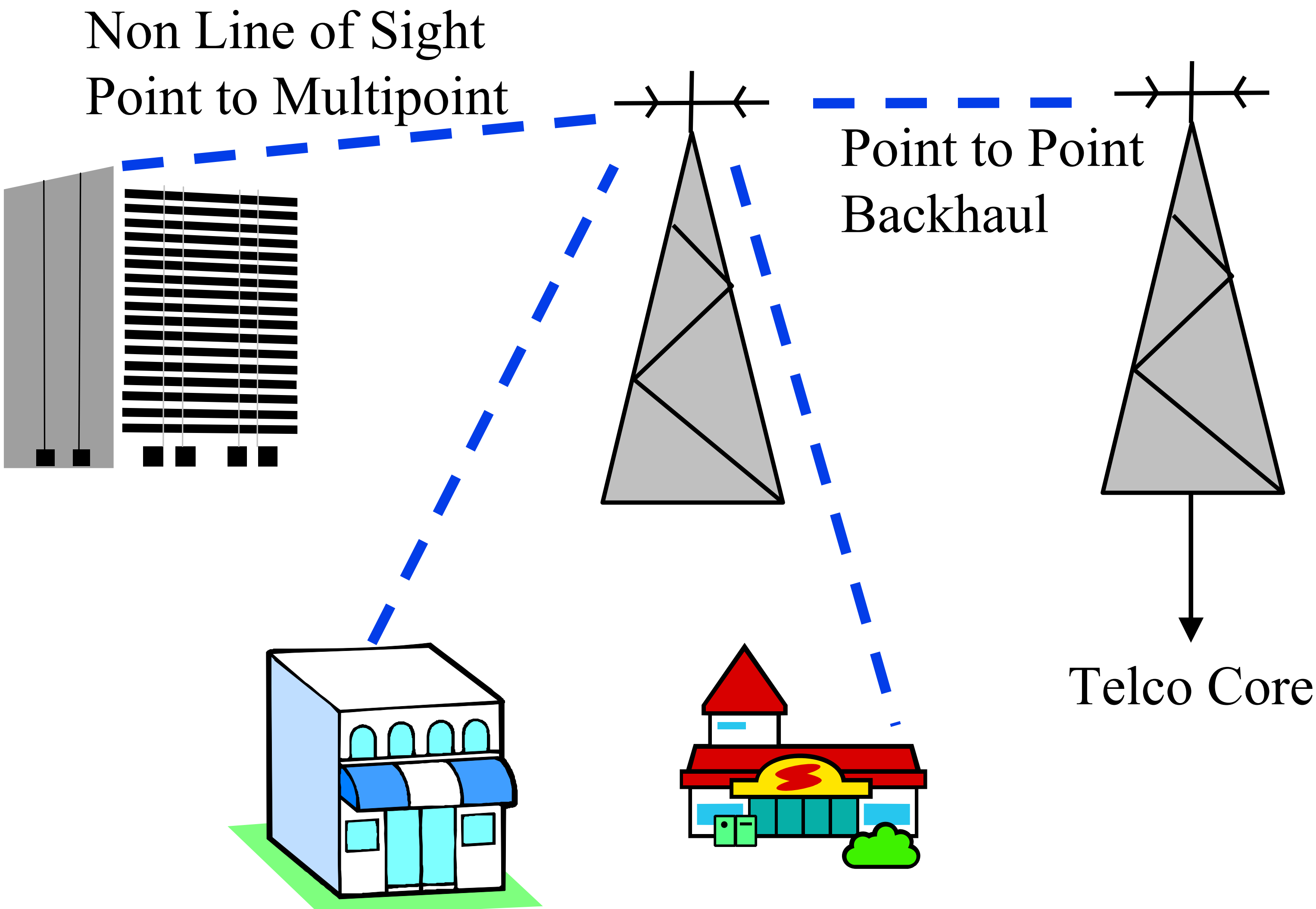


MMDS (Cont)

- Multipoint Distribution Service (MDS), Multichannel Multipoint Distribution Service (MMDS), and Instructional Fixed Television Fixed Service (ITFS) have 33 TV channels of 6 MHz each
  $\Rightarrow$ Over 1 Gbps using advanced coding
- 2.1, 2.5-2.7 GHz Band $\Rightarrow$ Not affected by rain
- Line of sight. Alternative to DSL



Broadband Wireless Access



Broadband Wireless Access (BWA)

- IEEE 802.16 Broadband wireless Access WG
- Delivers >1 Mbps per user
- Up to 50 km
- Data rate vs Distance trade off using adaptive modulation. 64QAM to QPSK
- Offers non-line of site operation
- 1.5 to 20 MHz channels
- Hundreds of simultaneous sessions per channel
- Both Licensed and unlicensed spectrum
- QoS for voice, video, and T1/E1

WiMAX

- A vendor organization for ensuring interoperability
- A WiMAX certified product will work with other WiMAX certified products
- Plugfests planed from Dec 2004 onwards
- WiMAX certified products will be available Q1'05
  - Outdoor subscriber stations similar to satellite dish by 2005 ≈$350
  - Indoor subscriber stations by 2005-2006 ≈ $250
  - Portable modems for laptops by 2006-2007 ≈ $100

IEEE 802.11 vs 802.16

	802.11	**802.16**
Range	Optimized for 100m	Optimized for 7-10 km Up to 50 km Multi-path delays tolerated
Coverage	Optimized for indoor	Optimized for outdoor Adaptive modulation Advanced Antenna
Scalability	Fixed 20 MHz channel (3 Non-overlapping channels in 802.11b, 5 in 802.11a)	1.5 MHz to 20 MHz Channels License and license exempt bands Allows Cell Planning
Spectral Efficiency	2.7 bps/Hz $\Rightarrow$54 Mbps in 20 MHz	3.8 bps/Hz $\Rightarrow$ 75 Mbps in 20 MHz 5 bps/Hz $\Rightarrow$ 100 Mbps in 20 MHz
MAC	Contention based	Grant based
QoS	Simple	Sophisticated

802.16 Flavors

- 802.16 (December 2001):
  - Fixed broadband wireless interface
  - 10-66 GHz $\Rightarrow$ Line of sight only $\Rightarrow$ Point-to-point
- 802.16c (December 2002):
  - WiMAX system Profiles added
- 802.16a (January 2003):
  - Extensions for 2-11 GHz non line of sight
  - Point-to-multipoint applications
- 802.16REVd (Q3 2004):
  - Add WiMAX system profiles
- 802.16e (2005):
  - Padestrain speed mobility in 2-6 GHz licensed bands
  - Enables roaming

IEEE 802.16 Flavors

	802.16	802.16a	802.16e
Date	Dec 2001	802.16a: Jan 2003 802.16a Rev d: Q3'04	Q3'04
Spectrum	10-66 GHz	<11 GHz	<6 GHz
Conditions	Line of Sight only	Non line of Sight	Non Line of sight
Bit Rate	32-134 Mbps at 28 MHz Channels	Up to 75 Mbps at 20 MHz	Up to 15 Mbps at 5 MHz
Modulation	QPSK, 16QAM, 64 QAM	OFDM 256 Sub carriers, QPSK, 16 QAM, 64 QAM	OFDM 256 Sub carriers, QPSK, 16 QAM, 64 QAM
Mobility	Fixed	Fixed	Pedestrian

Mobile Broadband Wireless Access (MBWA)

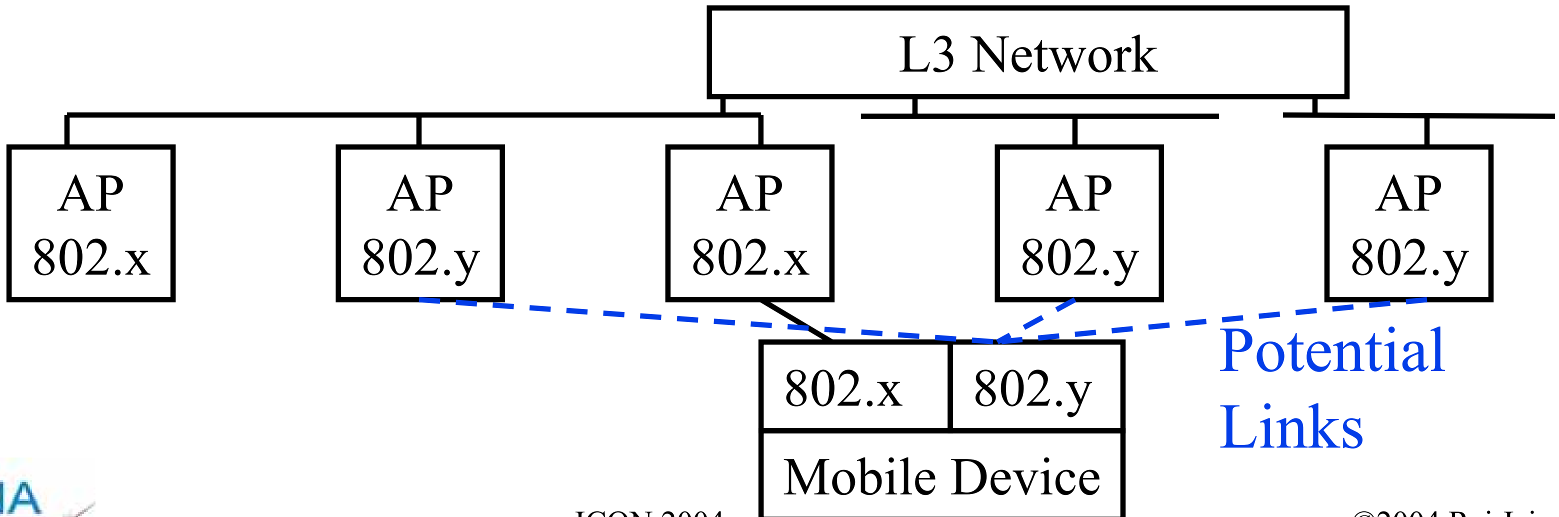
- IEEE 802.20 working group
- Optimized for IP data transport
- Licensed band below 3.5 GHz
- >1 Mbps data rate
- Vehicular mobility up to 250 Km/h
- Designed for green field wireless data providers
- Incumbent cellular providers with voice services may prefer 3G

Comparison of MBWA Stds

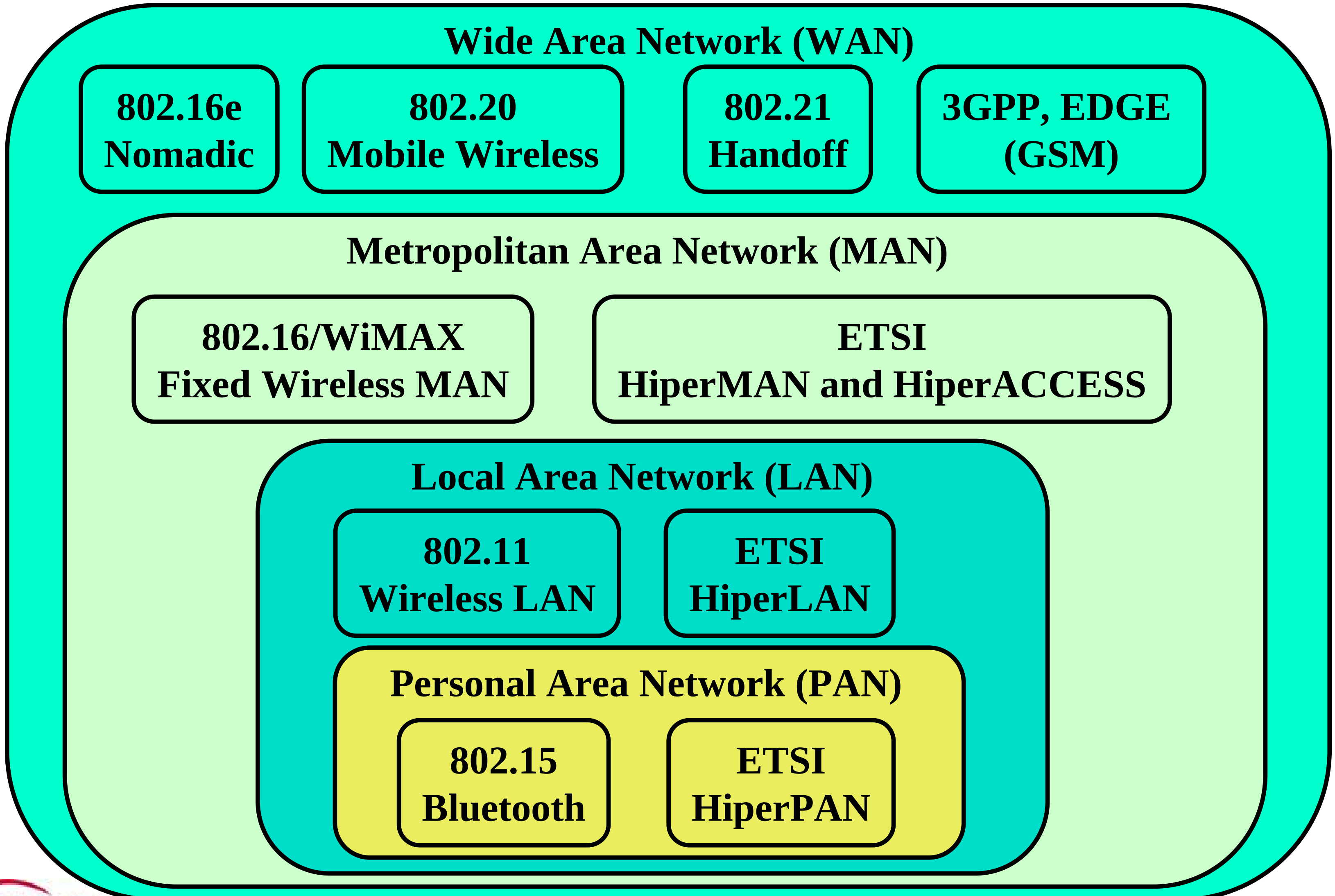
	802.16e	802.20	3G
Provider	Fixed Wireless adding mobility as enhencement	Wireless data service provider	Cellular voice service provider evolving to data support
Technology	Extension to 802.16a MAC and PHY	New MAC and PHY	W-CDMA, CDMA-2000
Design Restrictions	Optimized for backward compatibility	Optimized for full mobility	Evolution of GSM or IS-41
Bands	Licensed 2-6 GHz	Licensed below 3.5 GHz	Licensed below 2.7 GHz
Orientation	Packet oriented	Packet Oriented	Circuit oriented
Latency	Low Latency data	Low Latency data	High Latency data

Handoff

- IEEE 802.21 Working group (formed Nov 03)
- Handoff between 802.3, 802.11, 802.15, 802.16, …
- Example Scenario:
  - Docked Laptop with 802.3, 802.11, and 802.16e
  - Laptop undocks and switches to 802.11
  - User moves outside the building, laptop switches to 802.16e

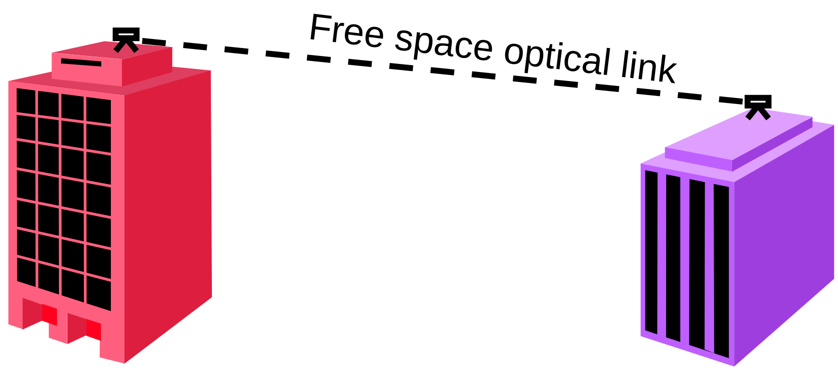


Wireless Standards



Optical Wireless Access

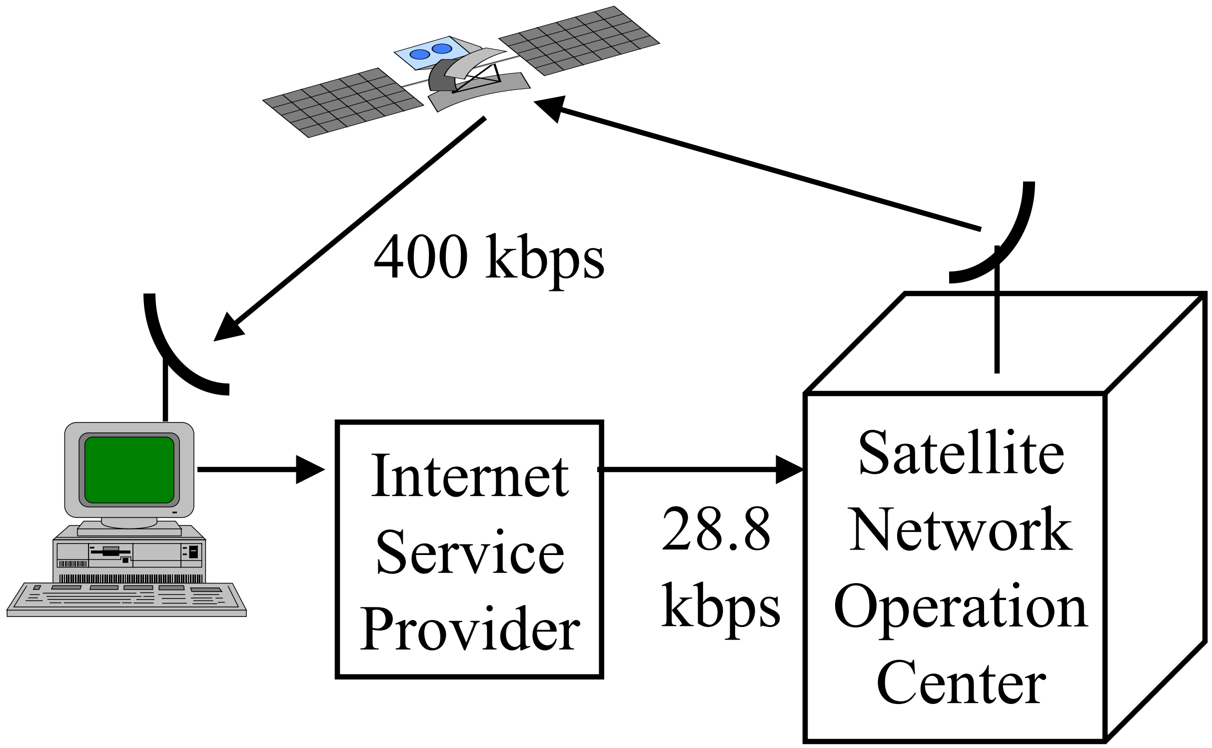
- Also known as "Free Space Optics (FSO)"
- Optical transceiver
  - Laser diode transmitter (780 nm, 1550 nm)
  - Photo detector (PIN diode, APD)
- Wireless ⇒ Fast rooftop deployment, No spectrum licenses
- Optical link requires line of site ⇒ Alignment critical
- Very high bandwidth (OC-3, OC-12, OC-48, 1GbE)



Optical Wireless (Cont)

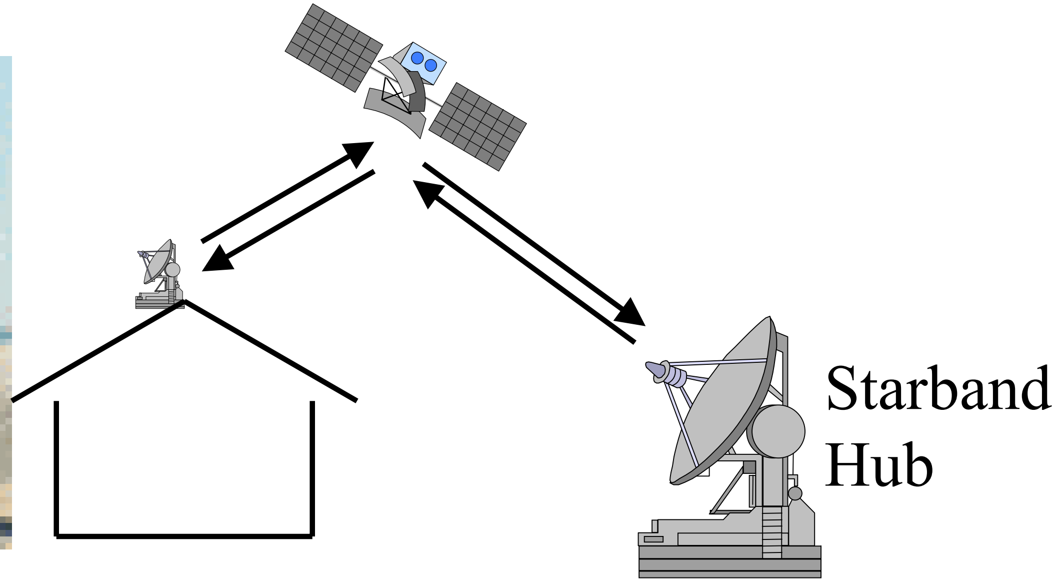
- Immunity from interference
- Easy installation
  $\Rightarrow$ Unlimited bandwidth, Easy Upgrade
- Transportable upon service termination or move
- Affected by weather (fog, rain, sun)
  $\Rightarrow$ Need lower speed Microwave backup
- Depends on location
  - San Diego, CA (coastal fog)
  - Sacramento, CA (radiant fog)
  - Tucson, AZ (almost no fog)

Satellites for Data



- DirecPC from Hughes
- One-way high-speed connection: phone line for return path
- 400 kbps download
- $40/month of unlimited access

Bi-Directional Satellite



- Asymmetric: 500 kbps down, 50 or 128 kbps up
- Long propagation delays: Accelerator software
- Bi-directional satellite systems for mobile applications
- Service affected in heavy downpour
- www.starband.com and www.motosat.com

Summary

1. WPA and IEEE 802.11i provide security for wireless networks
2. 802.11e provides QoS and 802.11n will provide 100Mbps.
3. IEEE 802.16 or WiMAX is designed for metro-wide access at high speed.
4. 802.16 is LOS, 16a is NLOS, 16d includes profiles, 16e provides limited mobility
5. 802.20 will provide mobility and .21 will provide handoff.

Cellular Wireless Access

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- Wireless Generations: 1G, 2G, 2.5G, 3G
- CDMA
- GSM
- CDPD
- GPRS, EDGE
- EV-DV, EV-DO
- WCDMA, CDMA2000, TD-SCDMA
- HSDPA

Wireless Generations

- 1G: Analog Cellular Phones. Needs a modem. 9.6 kbps max.
- 2G: Digital Cellular Phones. No modem required. 19.3 kbps max. GSM, CDMA
- 2.5G: GPRS. 144kbps. Data only.
- 3G: Future high-speed data access with Voice. 64 kbps to 2 Mbps.

1G and 2G Wireless

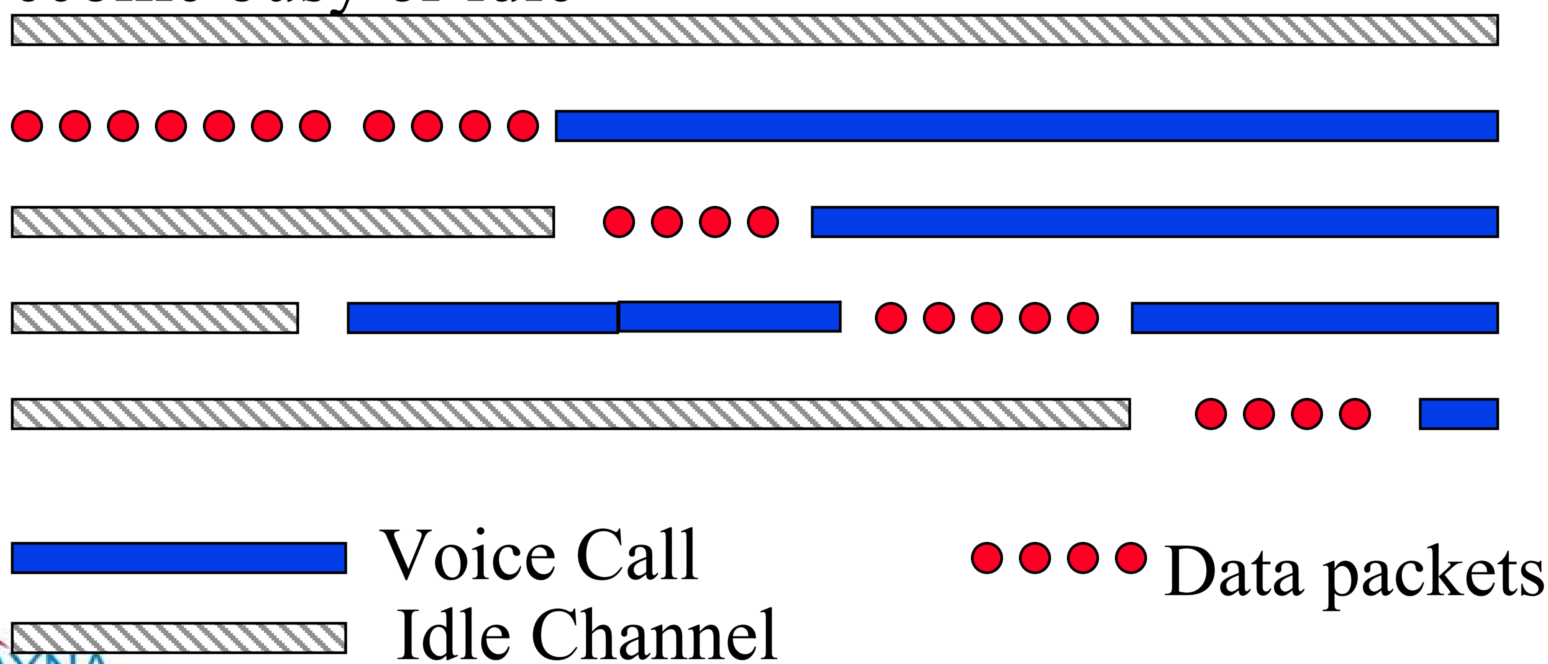
Analog
Voice
FDMA
AMPS (U.S.)
TACS (Europe)

Digital
Voice + Low Speed Data
TDMA
IS-54 D-AMPS
IS-136 US TDMA
GSM
DCS1800
DCS1900
NA GSM
CDMA
IS-95

- Digital provides more users, smaller footprint circuits, easier handoffs.
- IS-54 has analog control channel for compatibility with AMPS. Did not succeed.

Cellular Digital Packet Data (CDPD)

- Originally named "Celluplan" by IBM
- Allows data to use idle cellular channels
- Data hops from one channel to next as the channels become busy or idle



CDPD

- Nationwide cellular packet data service
- Connectionless and connection-oriented service
  Connectionless $\Rightarrow$ No ack, no guarantees
  Connection-oriented $\Rightarrow$ reliable delivery, sequencing, flow control
- Point-to-point and multipoint connections
- Quickly hops-off a channel grabbed by cellular system. Currently, dedicated channels.

CdmaOne

- Code Division Multiple Access (CDMA)
- CdmaOne = 2G, CDMA2000 = 3G
- Each user uses the entire spectrum. 22-40 calls per carrier.
- Different spreading code for each user.
- Neighboring cells can use the same frequency spectrum (but different codes).
- Precise power control is critical.
- Can serve more users than TDMA or GSM
- Data users limited to 9.6 kbps
- IS-95: CdmaOne

GSM

- Global System for Mobile Communication (GSM)
- 1982: Started as "Groupe Special Mobile" by Conference of European Posts and Telecom (CEPT)
- Good speech quality, ISDN compatibility, and fraud secure.
- Specs completed in 1990, Service began in 1992.
- 900 MHz operation in Europe.
- UK allocated 1800 MHz and adapted GSM standard as "DCS 1800"
- DCS 1800 also used in Russia and Germany.

GSM (Cont)

- FCC allocated 1900 MHz for PCS. Many carriers adapted GSM standard as "DCS 1900" or "North American GSM"
- VoiceStream, Powertel, and Bellsouth Mobility use NA GSM.
- 280 GSM networks in 100 countries worldwide.

GPRS

- General Packet Radio Service (GPRS)
- Standard GSM has 8 slots per 200 kHz channel
  $\Rightarrow$ 9.6 kbps data
- GPRS allows any number of slots to a user
  - 4 different codings used depending upon channel condition
  - 9.05 kbps to 21.4 kbps per slot
  - 76-171 kbps using all 8 slots.
- GPRS user can hop channels (as in CDPD). 2.5G Technology

Gi = GSM User

Gpi = GPRS User

	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_0	t_1	t_2	
Uplink 1	G1		G2		GP2			GP1	G1		G2	
Uplink 2				GP1			GP2					
Downlink 1	G1	GP1	G2		GP2			GP1	G1		G2	
Downlink 2	GP1				GP1					GP2		

GPRS (Cont)

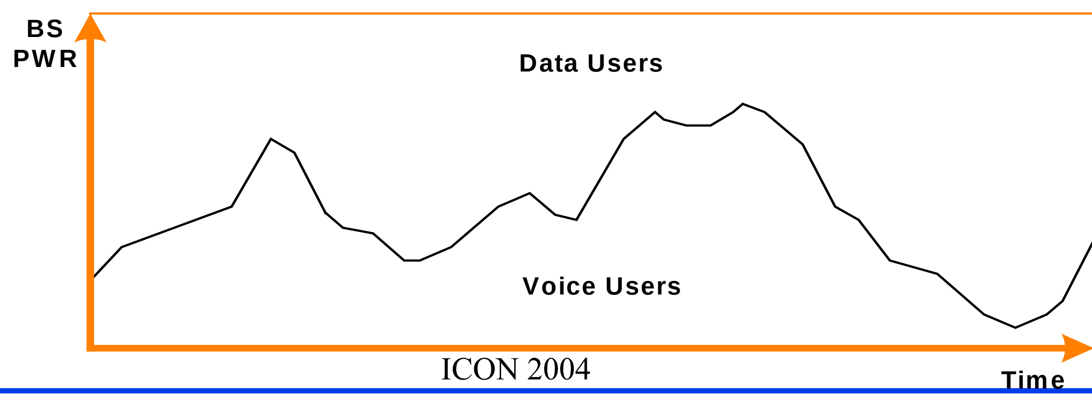
- Supports intermittent and bursty data transfers
  Point-to-multipoint also supported
- Need to add two new elements to GSM networks:
  - Service GPRS support node (SGSN)
    – Security, Mobility, Access control
  - Gateway GPRS support node (GGSN)
    – Connects to external packet switched networks
- Standardized by ETSI

EDGE

- Enhanced Data Rates for GSM Evolution (EDGE)
- Standard GSM uses Gaussian Minimum Shift Keying (GMSK) modulation
- EDGE changes to 8-PSK modulation ⇒ 3 bits/Hz
- GPRS+EDGE ⇒ 384 kbps
- Need better radio signal quality
- 76 mobile network operators in 50 countries have committed to deploy EDGE (March 2004) http://www.gsacom.com/news/gsa_158.php4

1xEV-DV

- 1x Evolution to Data and Voice (1xEV-DV)
- Single 1.25 MHz bandwidth shared between voice and data users
- 3.1 Mbps peak data rate on Forward Packet Data Channel
- Voice users are usually scheduled first
- Dynamic allocation of the unused BS power to data users every slot cycle (1.25 ms)



1xEV-DV vs. 1xEV-DO

- EV-DV uses 1 RF channel for data and voice while EV-DO requires separate carrier frequencies
- Fully compatible with CdmaOne and CDMA2000 allowing all types of handoff between those systems ⇒ economical, incremental deployment; uninterrupted voice and data coverage
- EV-DV provides smooth coexistence between voice and data services
- IS-2000 Rel 0 BS can be upgraded to support EV-DV Rel C by addition of channel card and SW upgrade
- To upgrade the same BS to support EV-DO in addition to 1x, a separate RF path (from antennas through PA's to channel card) is needed

3G

- Also known as ITU IMT-2000 Project.
  Started in 1980.
- Goal: To have one world-wide standard and a common frequency band for mobile networking
- Result:
  - Three frequency bands: Below 1 GHz, 1.7GHz, 2.5GHz
  - Three different technologies: W-CDMA (Europe) CDMA2000 (North America) , and TD-SCDMA in China.

W-CDMA

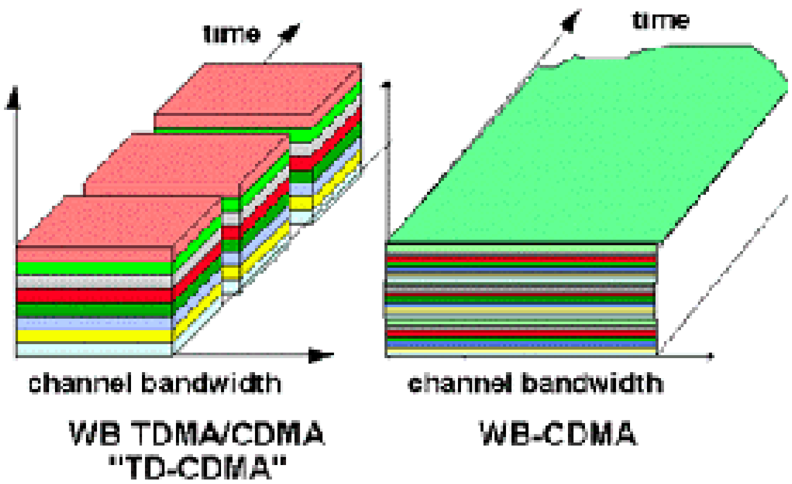
- Wideband CDMA
- Proposed by ETSI Alpha group
- W-CDMA has 5MHz single carrier system (FDD-DS)
- 3GPP.org

CDMA2000

- Proposed by Third Generation Partnership Project 2 (3GPP2.org).
- 3GPP2: Partnership of 5 Telecom standards bodies: ARIB and TTC in Japan, CWTS in China, TTA in Korea and TIA in North America
- Full backward compatibility with IS-95B (cdmaOne)
- CDMA2000 3x also known as CDMA-MC (multi-carrier) is a 3G technology. It uses n carriers of 1.2288 MHz each. 1x, 3x, 6x, 9x, 12x
- Operators can overlay CDMA2000 1x now over cdmaOne.
  - Also known as CDMA2000 1xEV.
  - Implemented in two steps: 1xEV-DO, 1xEV-DV. These are 2.5G technologies.

TD-SCDMA

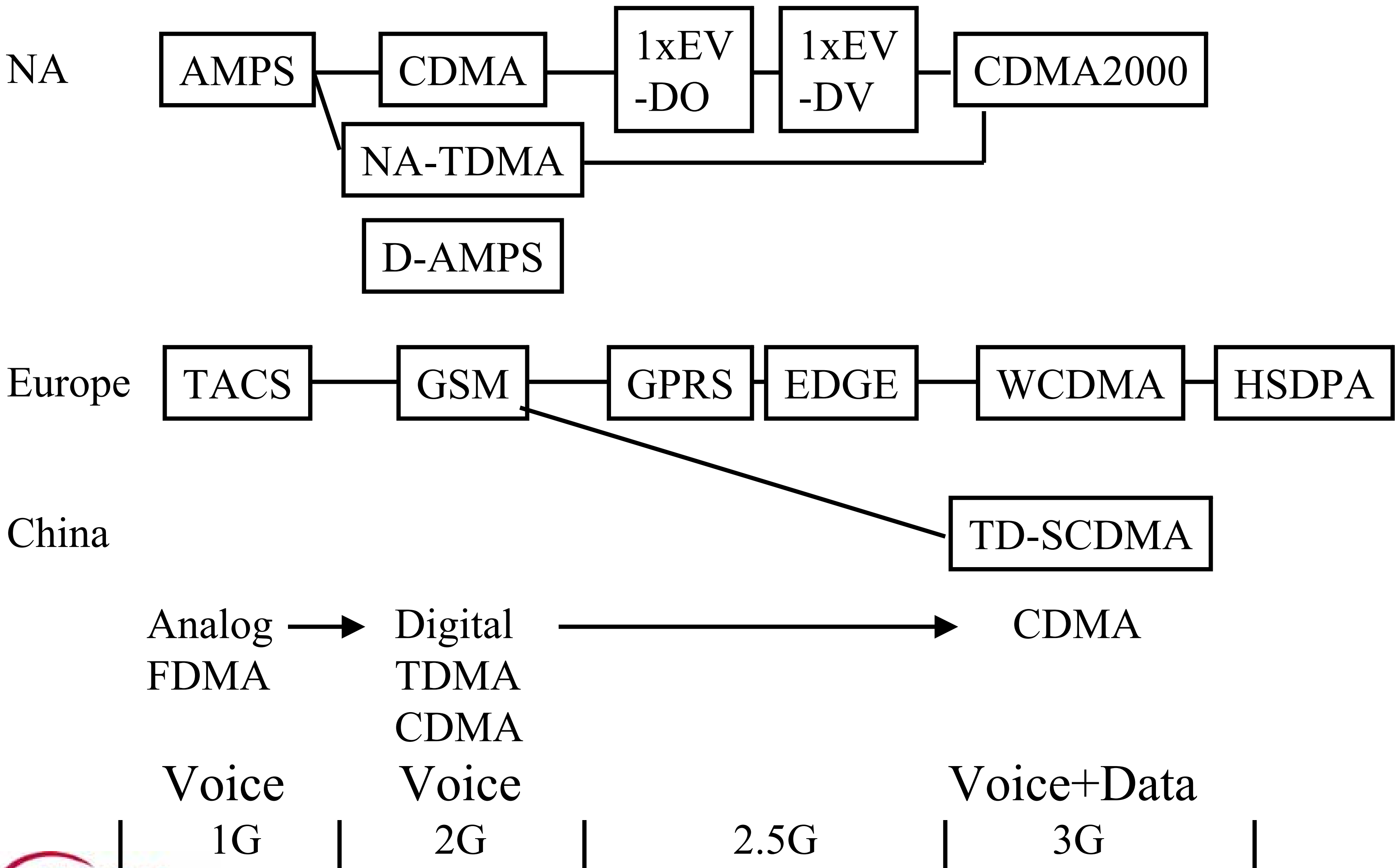
- Time Division Synchronous CDMA
- Proposed by China Wireless Telecommunication Standards group (CWTS)
- Uses Time Division Duplex (TDD)
- Synchronous ⇒ All base station clocks are synchronized
- http://www.tdscdma-forum.org/



HSDPA

- High-Speed Downlink Packet Access for WCDMA
- Improved spectral efficiency for downlink $\Rightarrow$ Asymmetric
- Up to 10 Mbps in theory, 2Mbps+ in practice
- Announced by Siemens, then by Ericsson, Alcatel, Fujitsu
- Adaptive modulation and coding (AMC)
- Multi-code (multiple CDMA channels) transmission
- Fast physical layer (L1) hybrid ARQ (H-ARQ)
- Packet scheduler moved from the radio network controller (RNC) to the Node-B (base station)
  $\Rightarrow$ advanced packet scheduling techniques
  $\Rightarrow$ user data rate can be adjusted to match the instantaneous radio channel conditions.

Summary


NA
AMPS
CDMA
1xEV -DO
1xEV -DV
CDMA2000
NA-TDMA
D-AMPS
Europe
TACS
GSM
GPRS
EDGE
WCDMA
HSDPA
China
TD-SCDMA
Analog FDMA
Digital TDMA CDMA
CDMA
Voice
Voice
Voice+Data
1G
2G
2.5G
3G

Broadband Access Using Ethernet in the First Mile (EFM)

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Overview

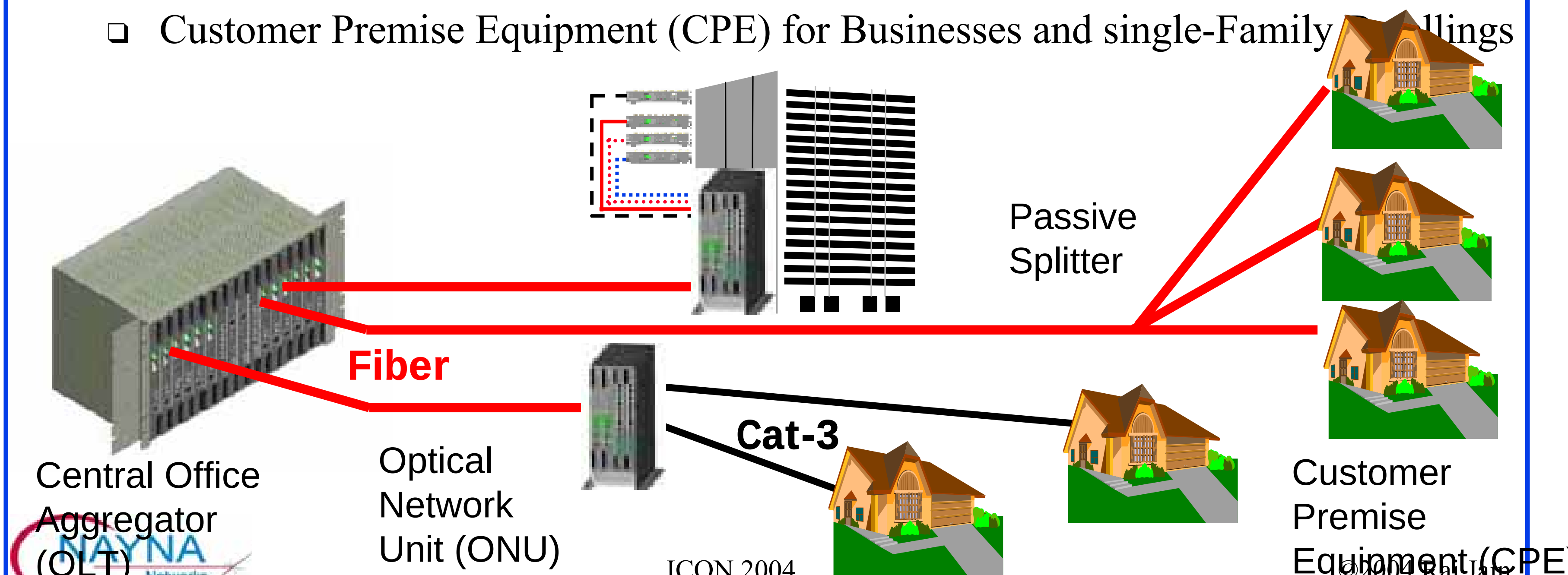
- The Market Drivers
- Ethernet in the First Mile
- Ethernet Passive Optical Network (EPON)
- EPON vs GPON
- Recent PON Developments
- EFM Product Differentiators

The Market Drivers

- Global Competition ⇒ National initiatives:
  - Japan (clear leader; NTT planning to invest $47B in FTTH, 11/4/2004 news)
  - Korea, Canada, Sweden, China, Holland, Germany, UK, France, Australia, US beginning to move in the direction
- Optical equipment prices have come down drastically ($200 to $500/Subscriber) to similar levels as DSL
- Copper plant typical life span 25-30 years; ILECs use PONs for rebuild and green field installations.
- 130 different independent telcos and municipalities have launched FTTP initiatives.
- US FCC ruling of removing restrictions from RBOCs; incentive for FTTH

Ethernet in the First Mile (EFM)

- **IEEE 802.3ah Standard** Specifies three approaches:
  - Point-to-point bidirectional communication over a single fiber
  - Point-to-Multipoint communication over a single fiber (**EPON**)
  - High-speed data over Cat-3 cables (phone wire)
- Components for EFM:
  - Optical Line Terminal (OLT) at Central Office
  - Optical Network Unit (ONU) at basement or curb
  - Customer Premise Equipment (CPE) for Businesses and single-Family Dwellings

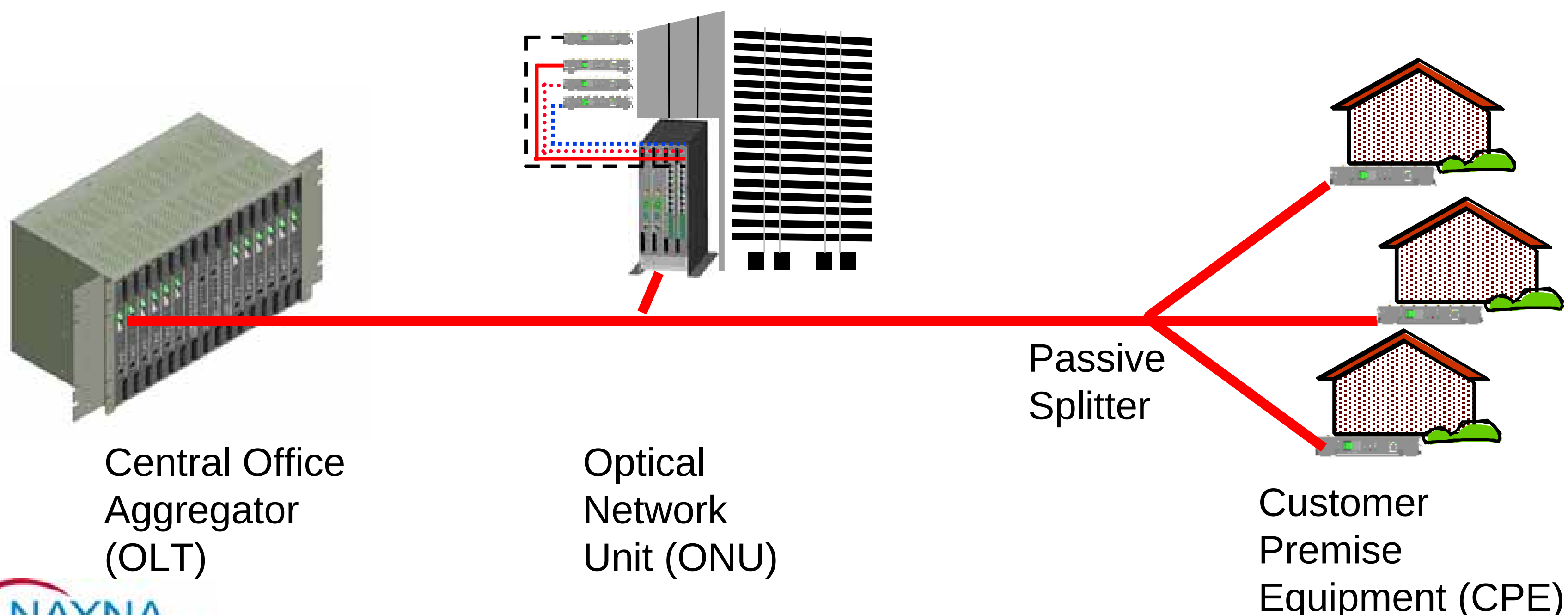


EFM PHYs

- 2BASE-TL — Baseband PHY based on SHDSL, L ⇒ 2.7km
- 10PASS-TS — Duplex on a single voice UTP pair using VDSL
  QAM constellations are used to modulate carriers of DMT, S⇒0.7km. Pass⇒Voice+Data
  -O = Central Office, -R = CPE
- 100BASE-LX10 — Duplex Fiber PHY w 10km 1310nm laser
- 100BASE-BX10-D — Bi-directional 1550nm downstream laser
- 100BASE-BX10-U — Bi-directional 1310nm upstream laser
- 1000BASE-LX10 — Extended (10km) 1310nm long-wavelength laser
- 1000BASE-BX10-D — Bi-directional 1490nm downstream laser
- 1000BASE-BX10-U — Bi-directional 1310nm upstream laser
- 1000BASE-PX10-D — PON 1490nm downstream laser 10 km
- 1000BASE-PX10-U — PON 1310nm upstream laser 10 km
- 1000BASE-PX20-D — PON 1490nm downstream laser 20 km
- 1000BASE-PX20-U — PON 1310nm upstream laser 20 km

Ethernet Passive Optical Network (EPON)

- A single fiber is used to support multiple customers
- No active equipment in the path ⇒ Highly reliable
- OLT assigned time slots upstream.
- Optical Line Terminal (OLT) in central office
- Optical Network Terminal (ONT) on customer premises
  Optical Network Unit (ONU) at intermediate points w xDSL



PONs vs Point-to-Point:

- **Reduced OpEx**: Passive network
  - High reliability ⇒ Reduced truck rolls
  - Reduced power expenses
  - Shorter installation times
- **Reduced CapEx**:
  - 16 -128 customers per fiber. Solves conduit congestion.
  - 1 Fiber +(N+1) transceivers vs 2N Fibers + 2N transceivers
- **Increased Revenue Opportunities**:
  Multi-service: RF Video, Data, E1/T1, Voice, IP Video
- **Scalable**:
  - CO Equipment Shared ⇒ New customers can be added easily
  - Bandwidth is Shared ⇒ Customer bandwidth can be changed

Types of PONs

- **APON**: Initial name for ATM based PON spec. Designed by Full Service Access Network (FSAN) group
- **BPON**: Broadband PON standard specified in ITU G.983.1 thru G.893.7 = APON renamed
  - 155 or 622 Mbps downstream, 155 upstream
- **GPON**: Gigabit PON standard specified in ITU G.984.1 and G.984.2
  - 1244 and 2488 Mbps Down, 155/622/1244/2488 up
- **EPON**: Ethernet based PON draft being designed by IEEE 802.3ah.
  - 1000 Mbps down and 1000 Mbps up.

GPON vs EPON

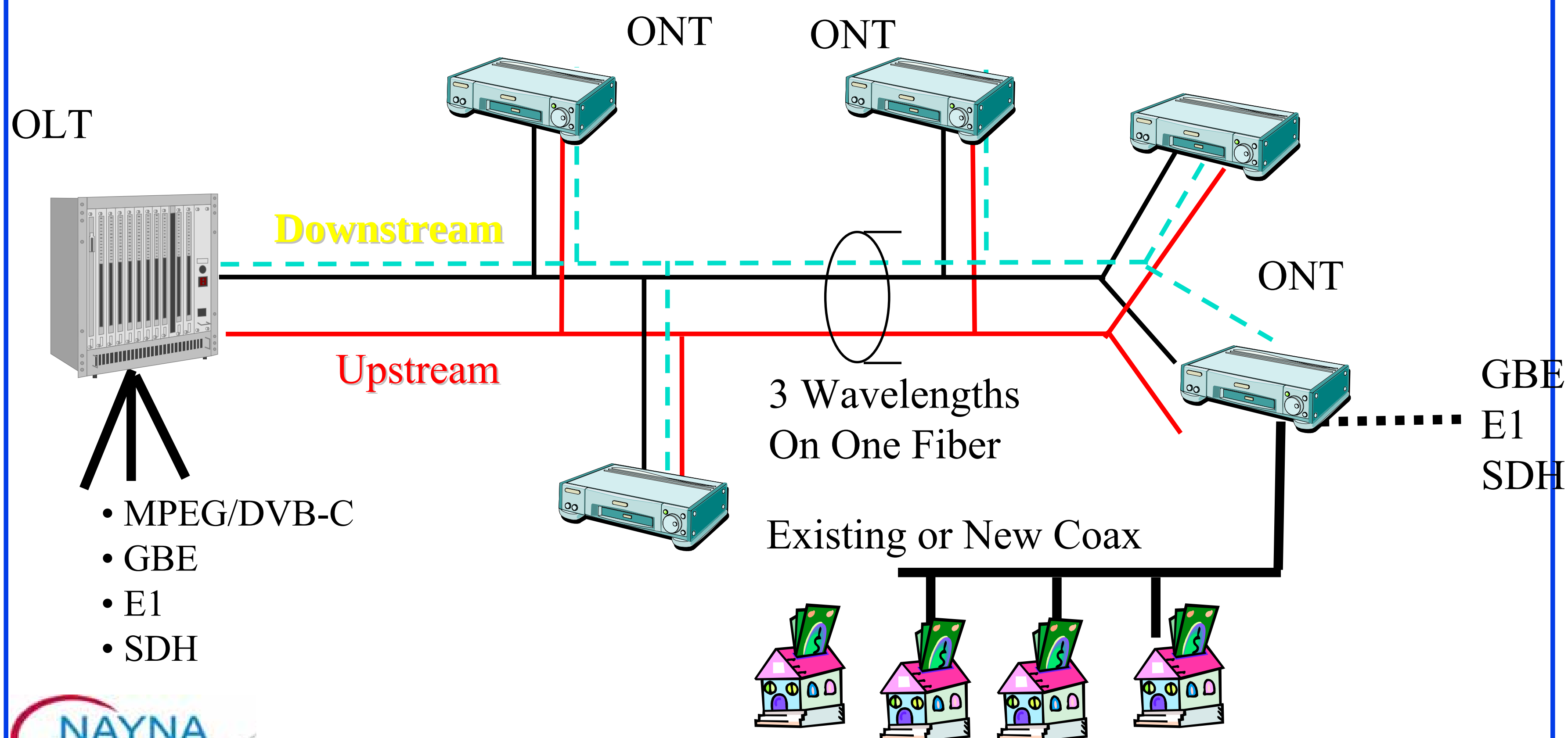
GPON	EPON
ATM-based	Ethernet Based
10% Cell Tax ⇒ 1 Gbps payload	No segmentation overhead
Legacy	New trend
US RBOCs	US Munis + Asia + Europe
US 10th in Broadband penetration	Asia and Europe are broadband leaders
RBOCs already selected suppliers	Large potential market
ATM Switches Expensive	Ethernet Switches Cheap
Components relatively expensive.	Other components also high volume.
ITU design ⇒ Expensive Optics	IEEE Design ⇒ Cheap Optics
Re-conversion when connecting to IP backbone	Native mode IP connection
Can connect to SONET backbone	Can connect to SONET backbone
ATM non-existant in Enterprise Networks	Compatible with Enterprise Networks
T1/T3 supported	T1/T3 supported
ATM DSLAM easier to connect	Most DSLAM also have Ethernet or T1/T3 uplinks
ATM personnel difficult to find	Easier to maintain

Recent PON Developments

- GPON recommendations G.984.x are out.
  EPON is final.
- FCC removed fibers from unbundling
- SBC, Verizon, Bellsouth issued an RFP in USA
  - Carriers in Japan and Europe are seriously investigating FTTH
  - Most big telecom vendors were caught off-guard with no PON equipment
- NTT issued 2 RFPs on EPON
- Most action in Access rather than in Core or Metro
- Fiber-to-the-Home Installations Expected to Reach Approximately One Million by 2004 [FTTH Council]. Actual 3 million in Japan alone.
- "2005 is shaping up to be a watershed year that could set the course for carrier fiber-to-the-premises (FTTP) expansion plans for years to come" - Lightreading
- **Conclusion: 2005 will be the year of PON and EFM**

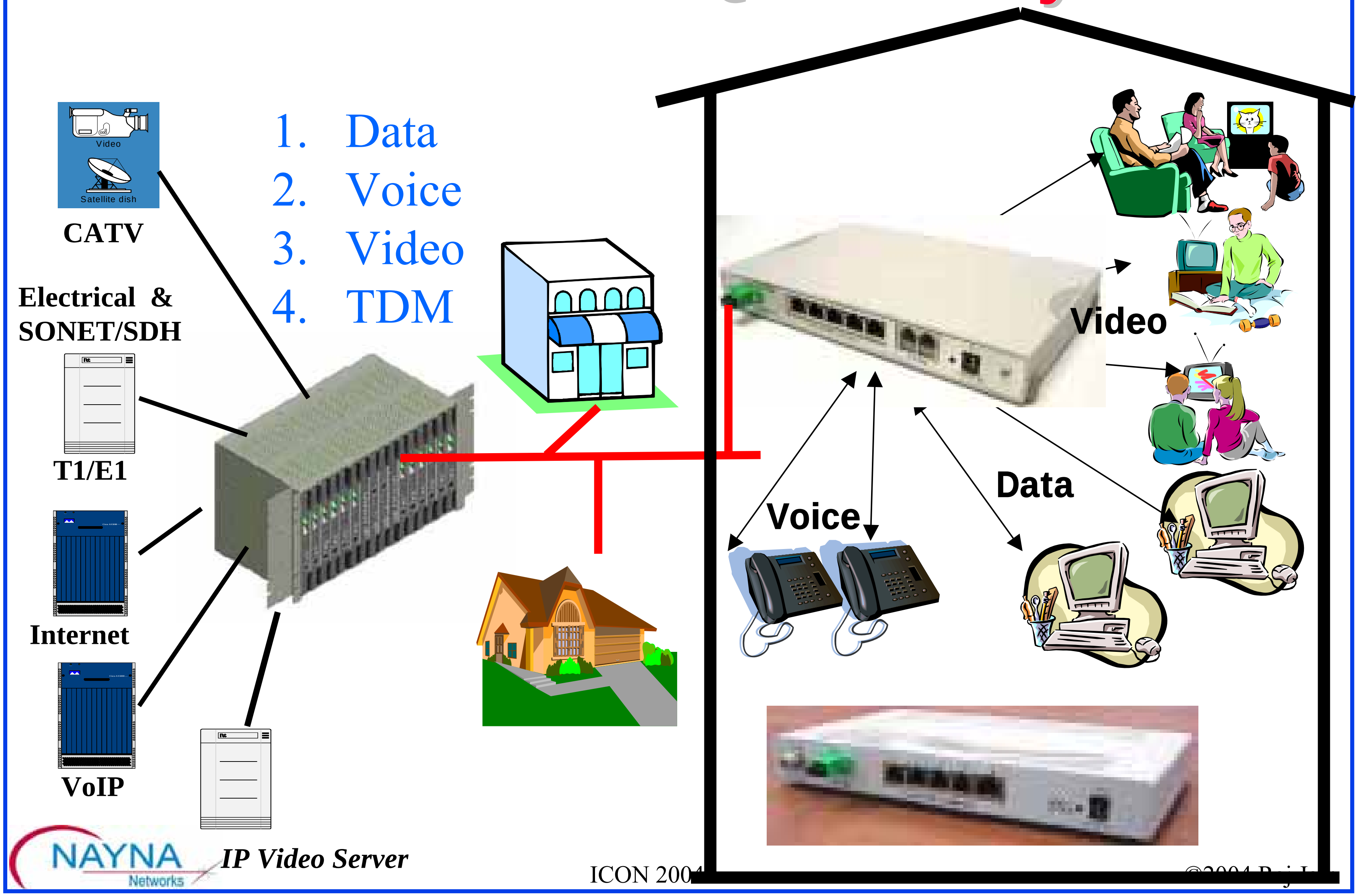
Broadcast Video Over PON

- Analog or Digital Video on 1550 nm.
- Revenue enhancing opportunity for CATV MSOs
- Revenue for Telecom carriers using Video over IP

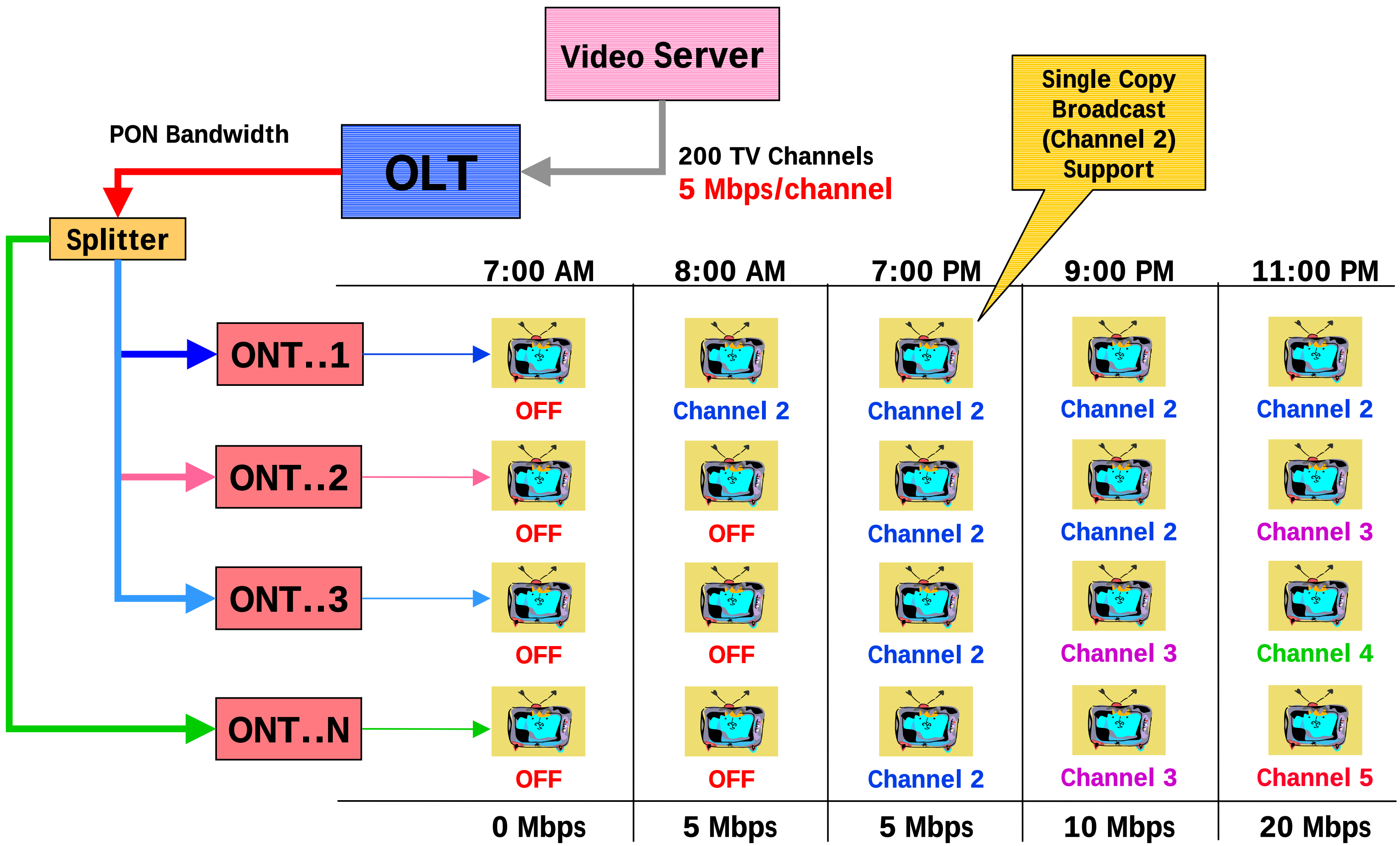


EFM with Quad Play

1. Data
2. Voice
3. Video
4. TDM

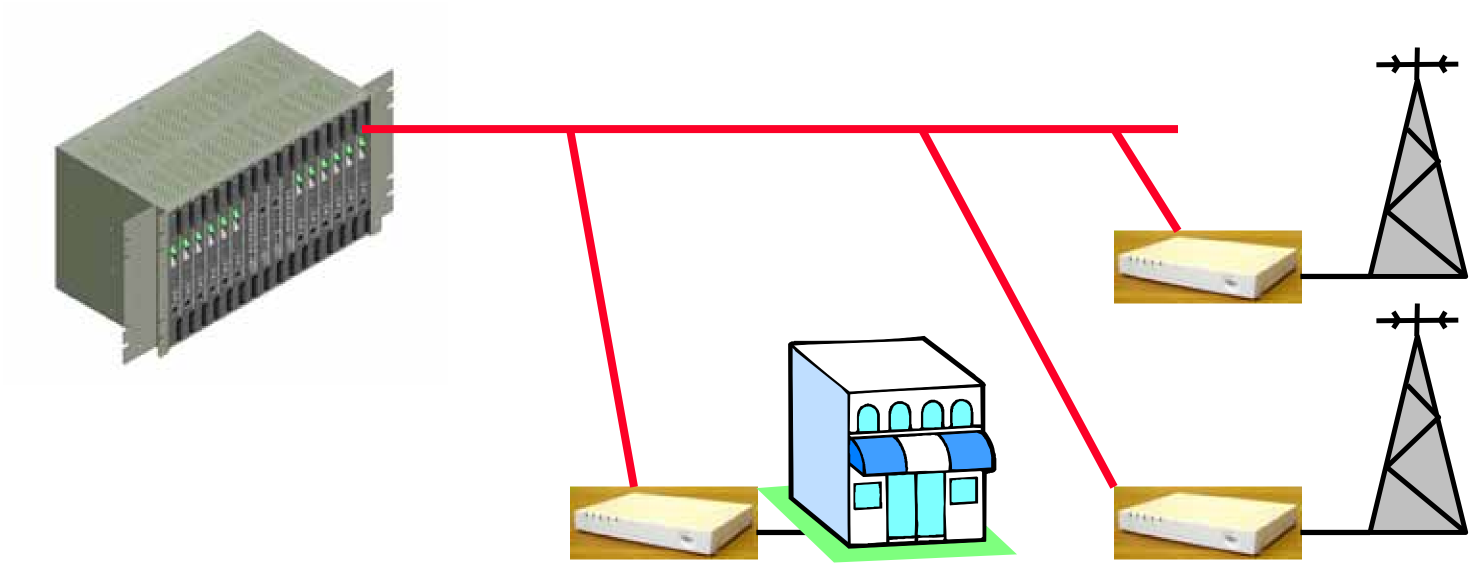


Broadcast TV Bandwidth Optimization over PON



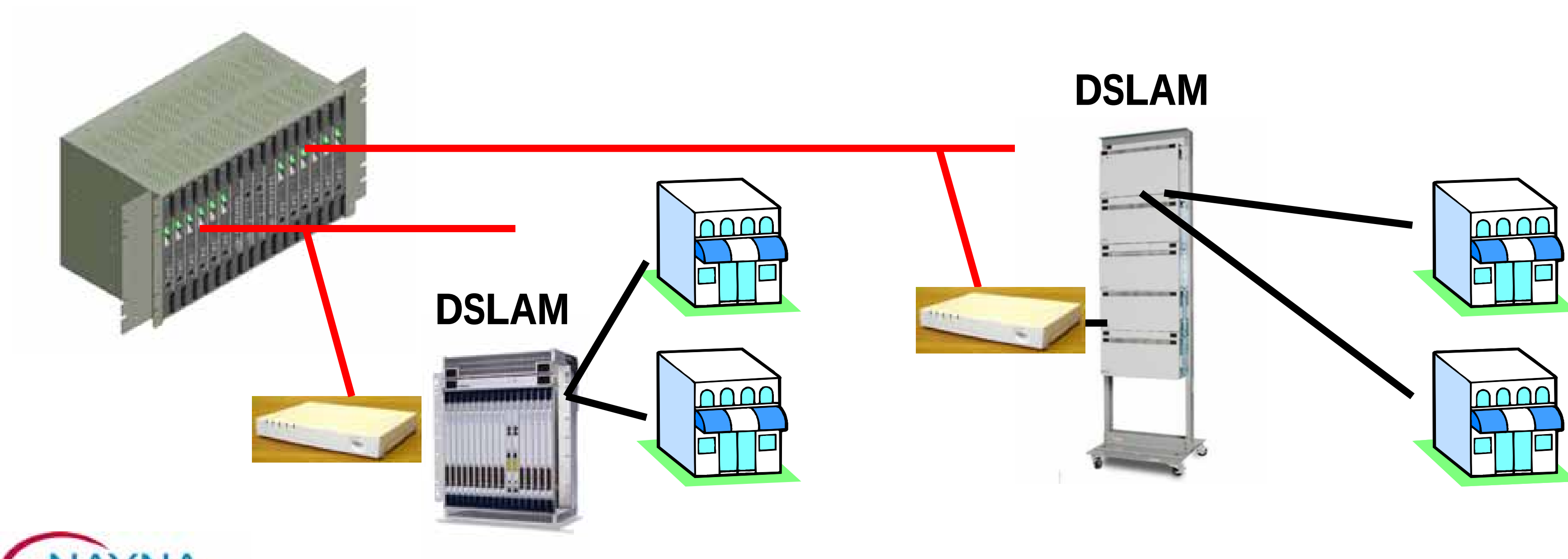
TDM over EFM

- Leased lines (T1/E1/J1) are still a big revenue generators for ILECs. Used for PBX traffic by businesses.
- Pseudo Wire Edge-to-Edge (PWE3) working group in IETF is defining a standard for TDM over IP
- Cellular operators are investigating using EFM for backhaul

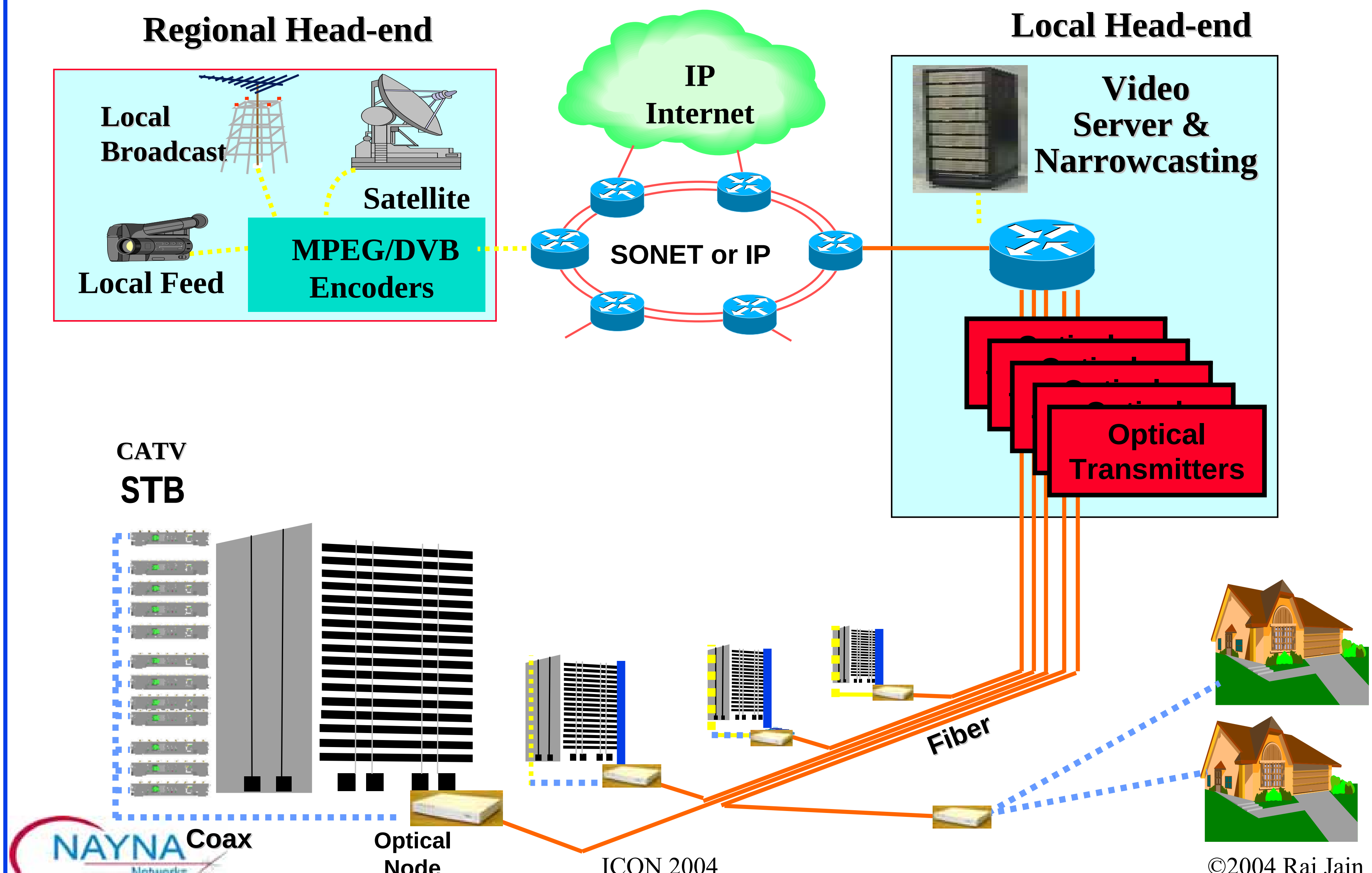


EFM + xDSL

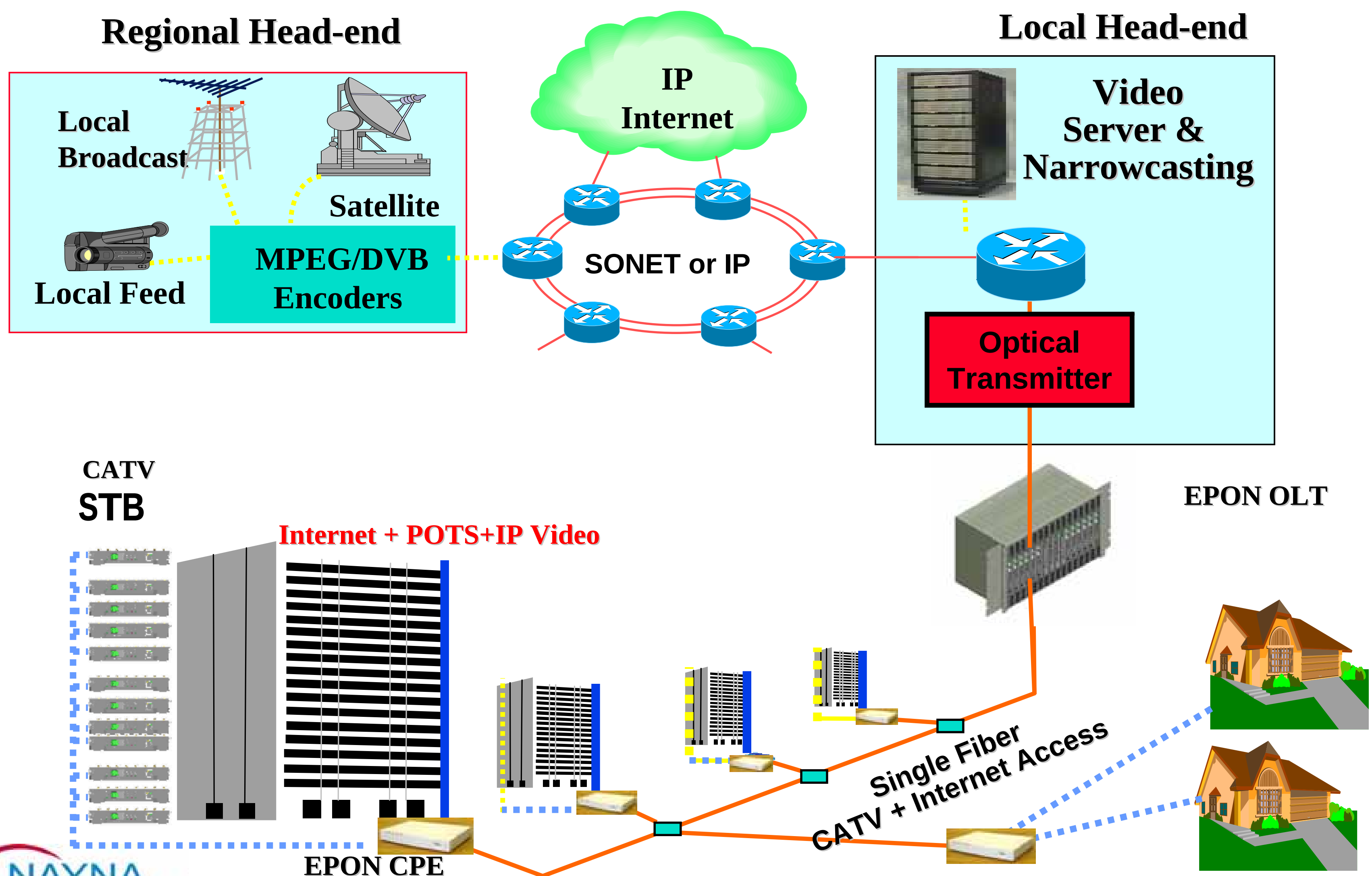
- FTTN: EFM to the curb
- 2-100 Mbps service over copper
- Legacy ATM based DSL service legacy residential CPEs



Hybrid-Fiber Coax (HFC)



CATV with EPON



EFM Product Differentiators

- **Revenue Enhancing Features**:
  - Multi-Service Support: Internet, Video, Voice, TDM
    $\Rightarrow$ IEEE 802.1p support, QoS, High-speed switching
  - Video: Analog, Digital and IP Video services
  - Multiple ISP and VoD service provider support
  - Multiple data services with throughput, delay, Jitter
  - SLA monitoring
  - End-user Authentication: Prevent unauthorized usage
- **CapEx Reduction Features**:
  - Support any mix of network topologies: P2P, Bus, Tree, …
  - Optimized multicast traffic throughput (Broadcast Video)

EFM Product Differentiators (Cont)

- **OpEx Reduction Features**:
  - Plug and Play CPE
  - Automatic CPE Configuration from Central office
  - Integration with Carrier OSS via SNMP
- **Customer Satisfaction Improvement Features**:
  - Customer privacy and security via VLANs
  - Supports customers' VLANs
  - Redundancy support for high-availability

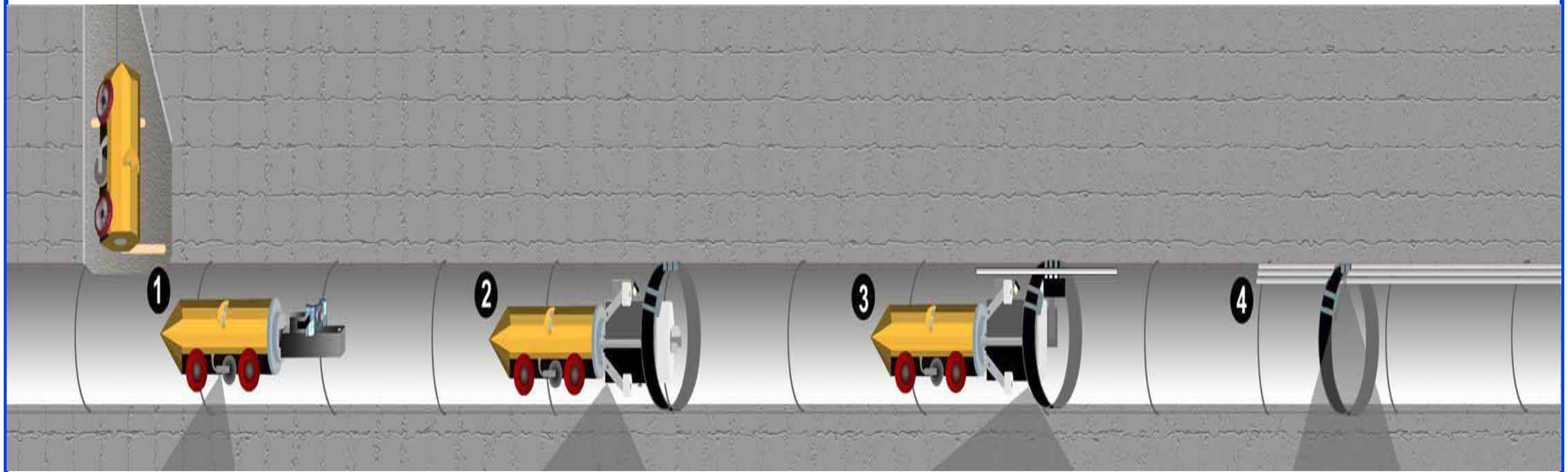
Summary

1. 2005 will be the year of EFM.
2. EFM reduces OpEx and CapEx for carriers and increase carrier revenue opportunities with value-added services
3. Multi-service support in next-generation EFM products is a key differentiator.
4. EFM products need to offer quad-play: Data, voice, video, and TDM to be effective

Fiber Access Thru Sewer Tubes (FAST)

- Right of ways is difficult in dense urban areas
- Sewer Network: Completely connected system of pipes connecting every home and office
- Municipal Governments find it easier and more profitable to let you use sewer than dig street
- Installed in Zurich, Omaha, Albuquerque, Indianapolis, Vienna, Ft Worth, Scottsdale, ...
- Corrosion resistant inner ducts containing up to 216 fibers are mounted within sewer pipe using a robot called Sewer Access Module (SAM)
- Ref: http://www.citynettelecom.com, NFOEC 2001, pp. 331

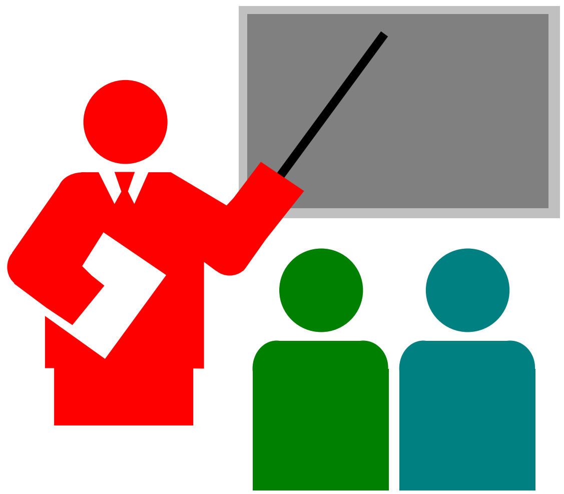
FAST Installation



1. Robots map the pipe
2. Install rings
3. Install ducts
4. Thread fibers

Fast Restoration: Broken sewer pipes replaced with minimal disruption

Summary



- ILEC dominance ⇒ Evolutionary technologies
- SONET vs Ethernet in metro broadband
- xDSL to Wireless access
- Cellular vs Wireless ISP debate
- Fiber to the node or FTTH

Broadband: Key References

- Networking History & Trends: References, http://www.cse.ohio-state.edu/~jain/refs/ref_trnd.htm
- Gigabit Ethernet, 10 Gigabit Ethernet and RPR: References, http://www.cse.ohio-state.edu/~jain/refs/gbe_refs.htm
- High Speed Access From Home References, http://www.cse.ohio-state.edu/~jain/refs/rbb_refs.htm
- Wireless Networking and Mobile IP References, http://www.cse.ohio-state.edu/~jain/refs/wir_refs.htm

Thank You!