Physical Layer (part 3) Transmission Media

Computer Networks

Spring 2013

Transmission Media Choices

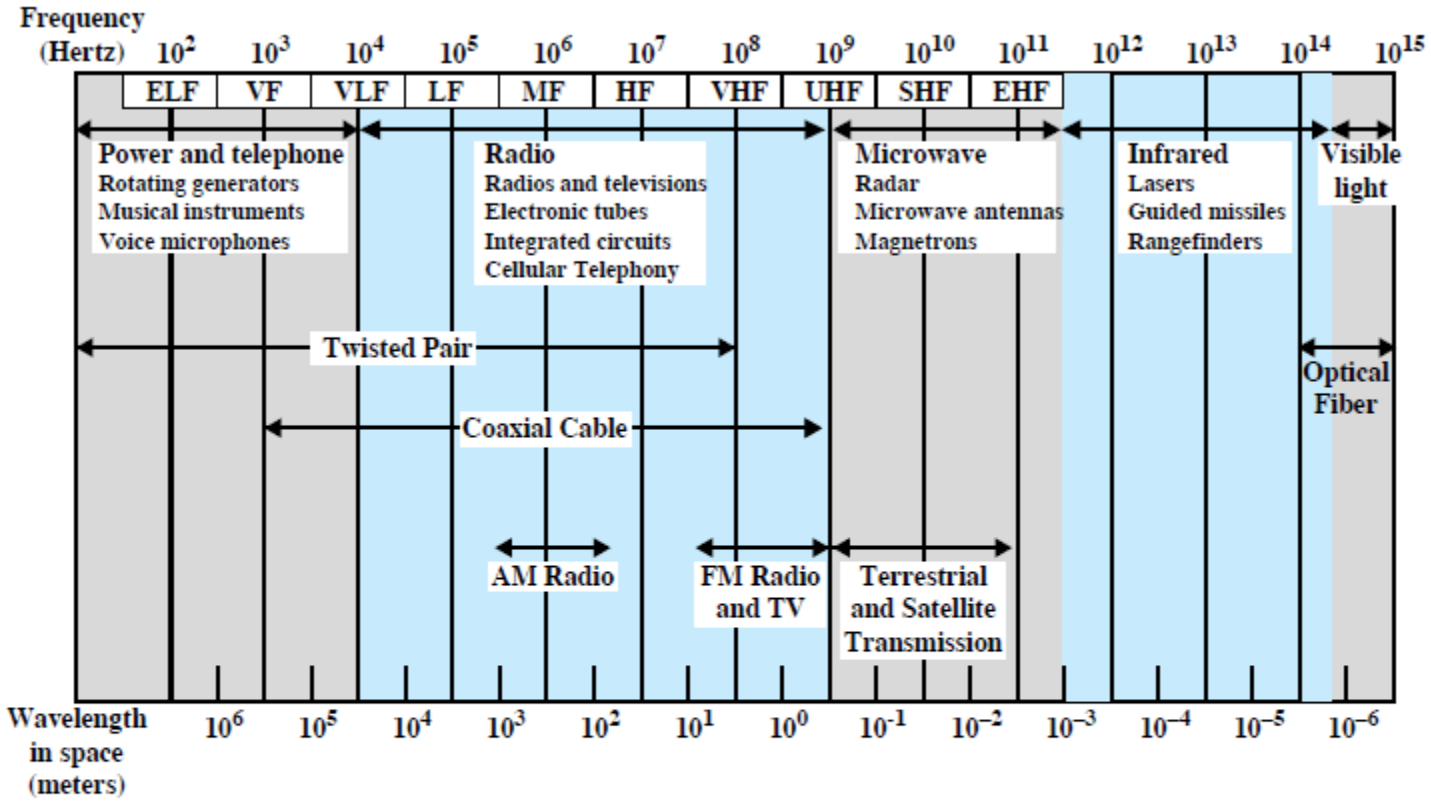
- Twisted Pair
  - Dial-Up
  - ADSL
- Coaxial Cable
  - Baseband
  - Broadband
- Optical Fiber
  - Multimode step-index
  - Multimode graded-index
  - Single-mode step-index
- Wireless Communications

Transmission Media

Transmission medium:: the physical path between transmitter and receiver.

- Repeaters or amplifiers may be used to extend the length of the medium.
- Communication of electromagnetic waves is *guided* or *unguided*.
  - *Guided media*:: waves are guided along a physical path (e.g., twisted pair, coaxial cable and optical fiber).
  - *Unguided media*:: means for transmitting but not guiding electromagnetic waves (e.g., the atmosphere and outer space).

Telecommunications Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Figure 4.1 Electromagnetic Spectrum for Telecommunications

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Guided Media Characteristics

Table 4.1 Point-to-Point Transmission Characteristics of Guided Media [GLOV98]

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μs/km	40 km

THz = TeraHertz = 10^{12} Hz

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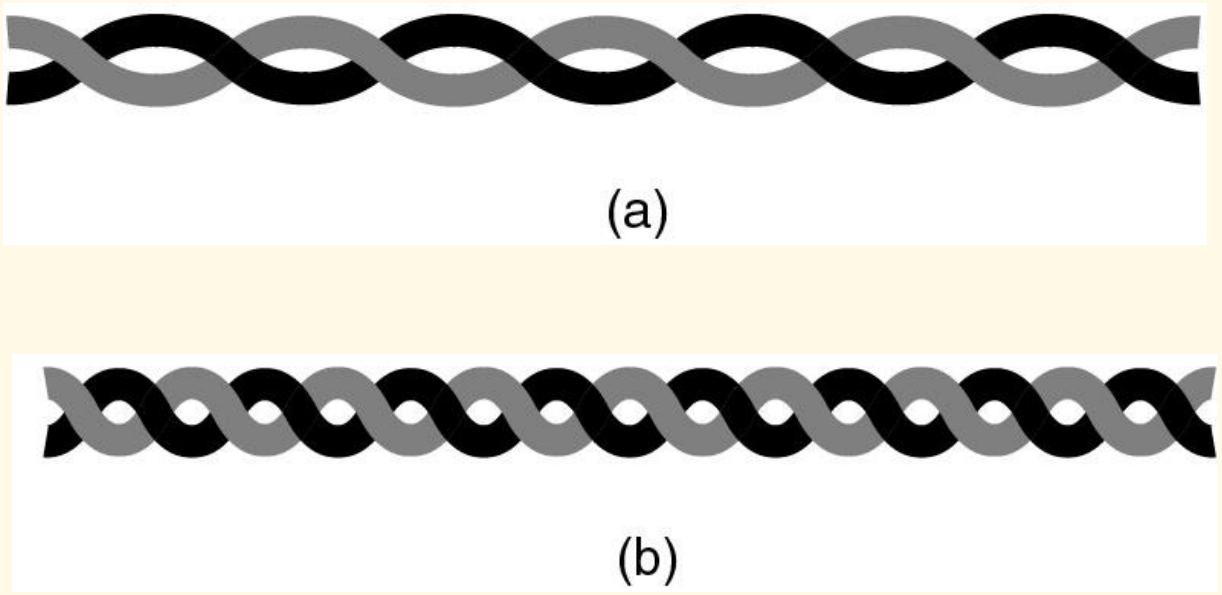
Twisted Pair

- Two insulated wires arranged in a spiral pattern.
- Copper or steel coated with copper.
- The signal is transmitted through one wire and a ground reference is transmitted in the other wire.
- Typically twisted pair is installed in building telephone wiring.
- Local loop connection to central telephone exchange was twisted pair.

Twisted Pair

- Limited in distance, bandwidth and data rate due to problems with attenuation, interference and noise.
  - Issue: *cross-talk* due to interference from other signals.
  - "shielding" wire (shielded twisted pair (STP)) with metallic braid or sheathing reduces interference.
  - "twisting" reduces low-frequency interference and crosstalk.

Twisted Pair



Obsolete

Fig 2-3. (a) Category 3 UTP
(b) Category 5 UTP

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Twisted Pair

Transmission Characteristics

analog

- needs amplifiers every 5km to 6km

digital

- can use either analog or digital signals
- needs a repeater every 2km to 3km

limited:

- distance
- Bandwidth ???
- data rate ???

susceptible to interference and noise

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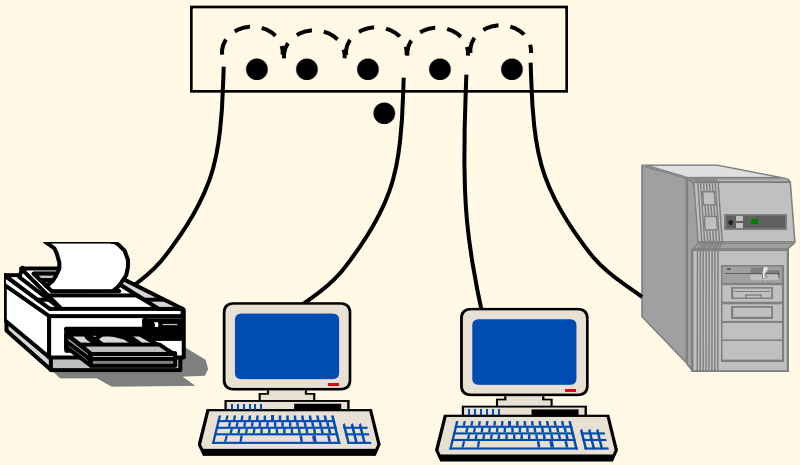
10-BASE -T

10 Mbps baseband transmission over **twisted pair**.
Two Cat 3 cables, Manchester encoding,
Maximum distance - 100 meters

Ethernet Hub



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"Modern" Twisted Pair

Table 4.2 Twisted Pair Categories and Classes

	Category 5e Class D	Category 6 Class E	Category 6A Class E_A	Category 7 Class F	Category 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1,000 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR (dB)	6.1	18.6	19	42.1	44.1

UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair

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EIA/TIA 568 and ISO/IEC 11801 Wiring Grades

Grade 1 - Unshielded Untwisted wiring.
Commonly called inside wire by the Telco community.

Grade 2 - Unshielded twisted pair (UTP) derived from IBM Type 3 spec.

Category 3 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 16 MHz. May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 4 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 20 MHz. May be used with 10Base-T, 100Base-T4, and 100Base-T2 Ethernet. (Obsolete)

Category 5 - Unshielded twisted pair with 100 ohm impedance and electrical characteristics supporting transmission at frequencies up to 100 MHz. May be used with 10Base-T, 100Base-T4, 100Base-T2, and 100Base-TX Ethernet. May support 1000Base-T, but cable should be tested. (Superceded by Cat5e)

EIA/TIA 568 and ISO/IEC 11801 Wiring Grades

Category 5e - "Enhanced Cat 5" exceeds Cat 5 performance. Very similar to Cat 5, it has improved specifications for NEXT (Near End Cross Talk), PSELFEXT (Power Sum Equal Level Far End Cross Talk), and attenuation. May be used for 10Base-T, 100Base-T4, 100Base-T2, 100BaseTX and 1000Base-T Ethernet. (Minimum acceptable wiring grade)

Category 6 - TIA approved Cat 6 specification in 2002 with bandwidth to 250 MHz. Backward compatible with lower Categories, Cat 6 supports the same Ethernet standards as Cat 5e and uses two pair in each direction as opposed to all four for 1000Base-T over Cat 5e. This cable standard is suitable for 10BASE-T, 100BASE-TX (Fast Ethernet), 1000BASE-T/1000BASE-TX (Gigabit Ethernet) and 10GBASE-T (10-Gigabit Ethernet).

Category 6a - Category 6a (or Augmented Category 6) The latest TIA standard from the TIA is defined at frequencies up to 500 MHz. May be used for 10/100/1000BASE-T and 10GBASE-T.

Category 7 - Proposed standard to support transmission at frequencies up to 600 MHz over 100 ohm twisted pair.

EIA/TIA 568 and ISO/IEC 11801 Wiring Grades

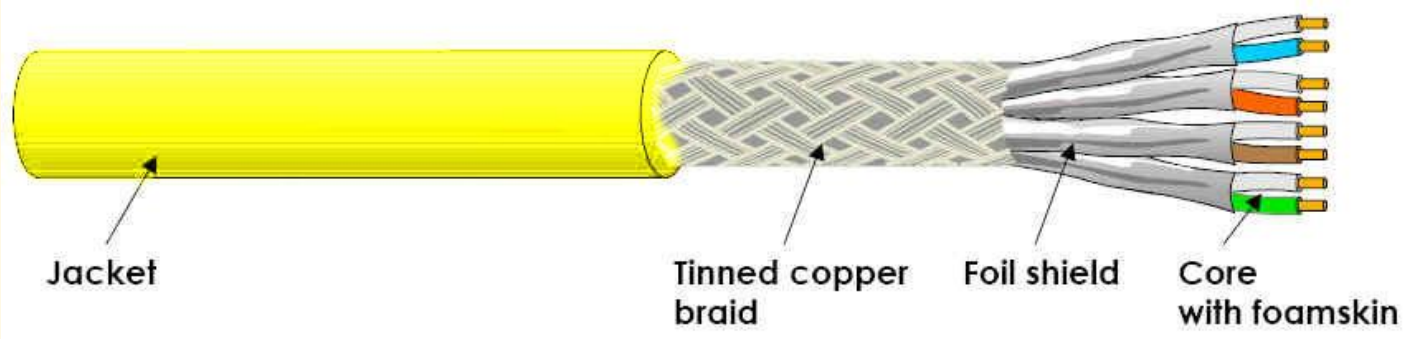
NOTES:

1) EIA 568 limits UTP copper cabling to maximum distance of 100 meters (328 feet). 90 meters of cable plus 10 meters of patch cord split between both ends.

2) The FCC recently changed the requirement for telephone inside wiring to minimum of Cat 3 due to crosstalk problems with nontwisted quad-four. Cat 3 is no longer recognized by TIA. The minimum wiring grade for structured wiring is Cat 5e.

3) For installation to meet specific Category requirements all components must meet or exceed the designated Category. Using a Cat 3 receptacle (or patch cord) on Cat 6 reduces performance to Cat 3.

Category 7/Class F



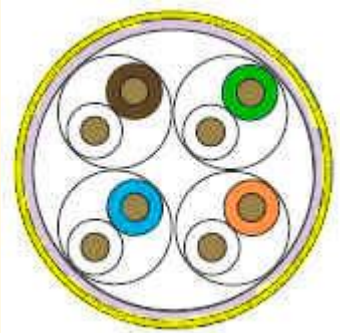
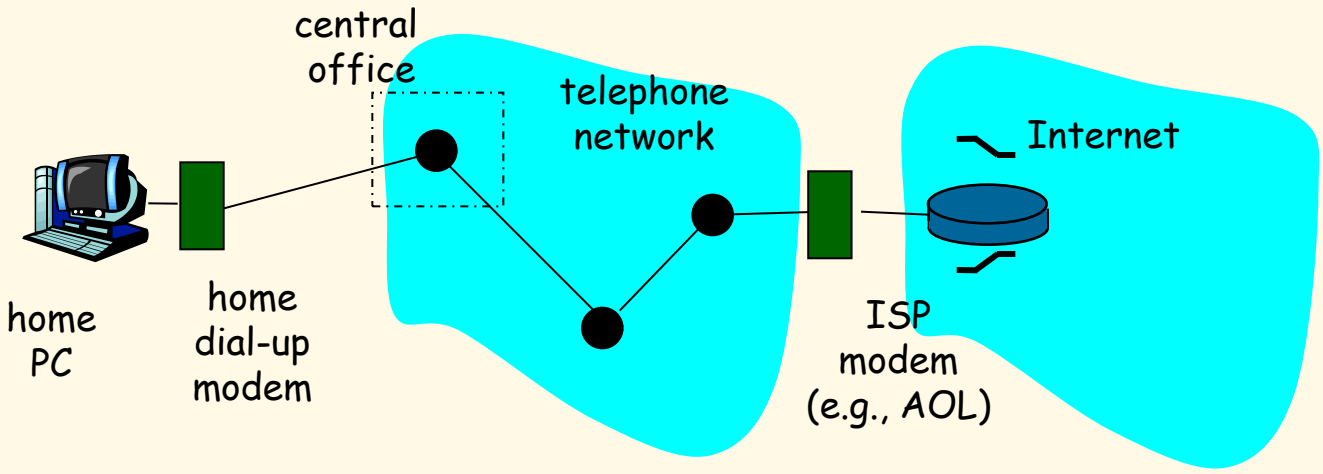


Figure-1 S/FTP Cable

Supports 10GBASE-T

Dial-up Modem



- Uses existing telephony infrastructure
  - Home is connected to central office.
- up to 56Kbps direct access to router (often less).
- Can't surf and phone at same time: not "always on".

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Digital Subscriber Line

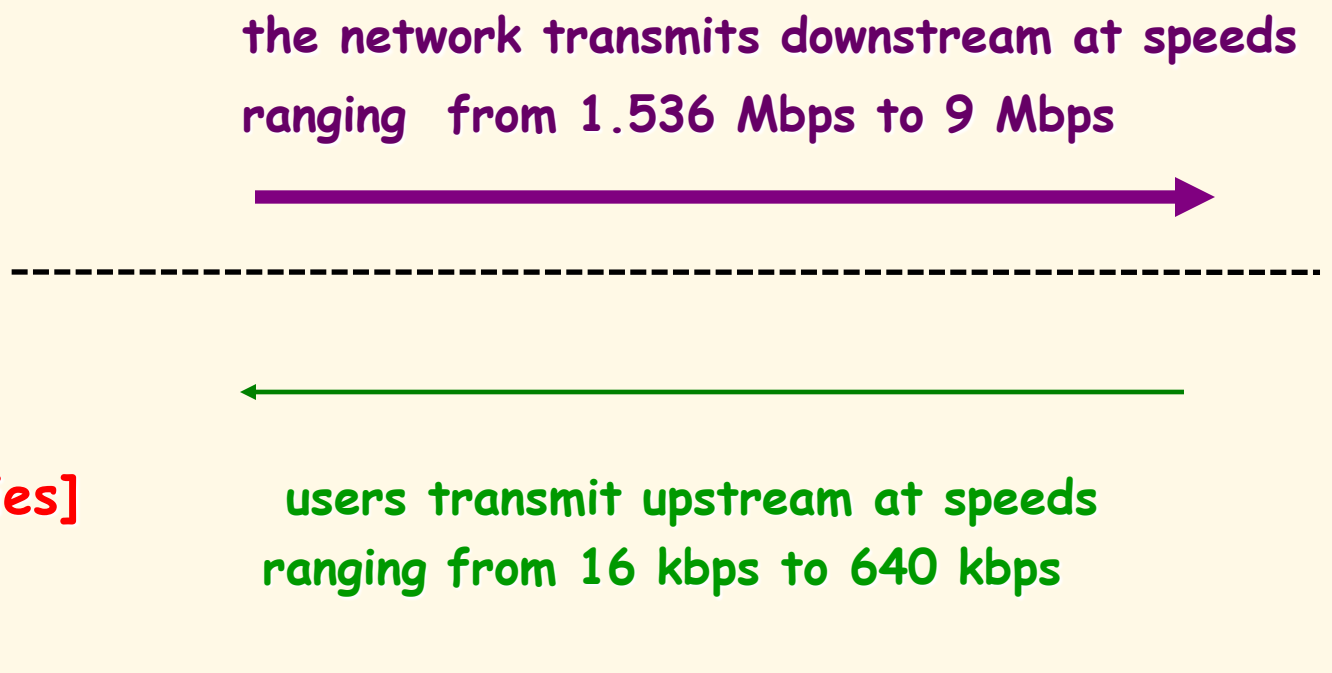
Telephone companies originally transmitted within the 0 to 4K HZ range to reduce crosstalk. Loading coils (small amplifiers) were added within the subscriber loop to provide a flatter transfer function to further improve voice transmission within the 3K HZ band while increasing attenuation at the higher frequencies.

ADSL (Asymmetric Digital Subscriber Line)

- Uses existing twisted pair lines to provide higher bit rates that are possible with *unloaded twisted pairs* (i.e., there are no loading coils on the subscriber loop.)

ADSL

asymmetric bidirectional digital transmissions [higher frequencies]



0 to 4K HZ — used for conventional analog telephone signals

Digital Subscriber Lines

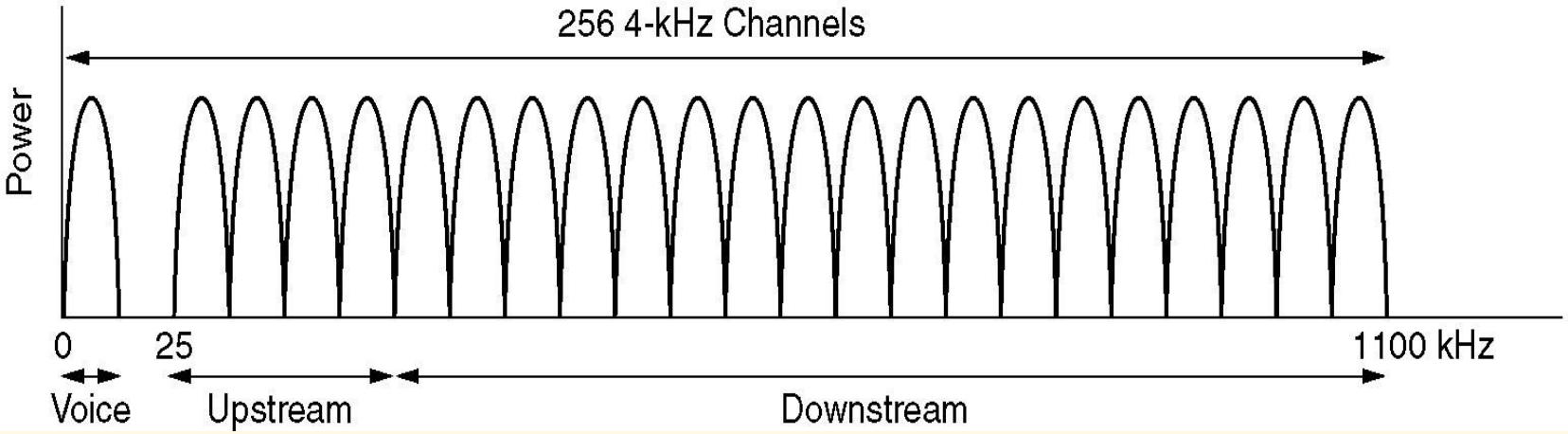


Figure 2-28. Operation of ADSL using discrete multitone modulation.

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ADSL

- ITU-T G992.1 ADSL standard uses Discrete Multitone (DMT) that divides the bandwidth into a large number of small subchannels.
- A splitter is required to separate voice signals from the data signal.
- The binary information is distributed among the subchannels. Each subchannel uses QAM.
- DMT adapts to line conditions by avoiding subchannels with poor SNR.

Digital Subscriber Lines

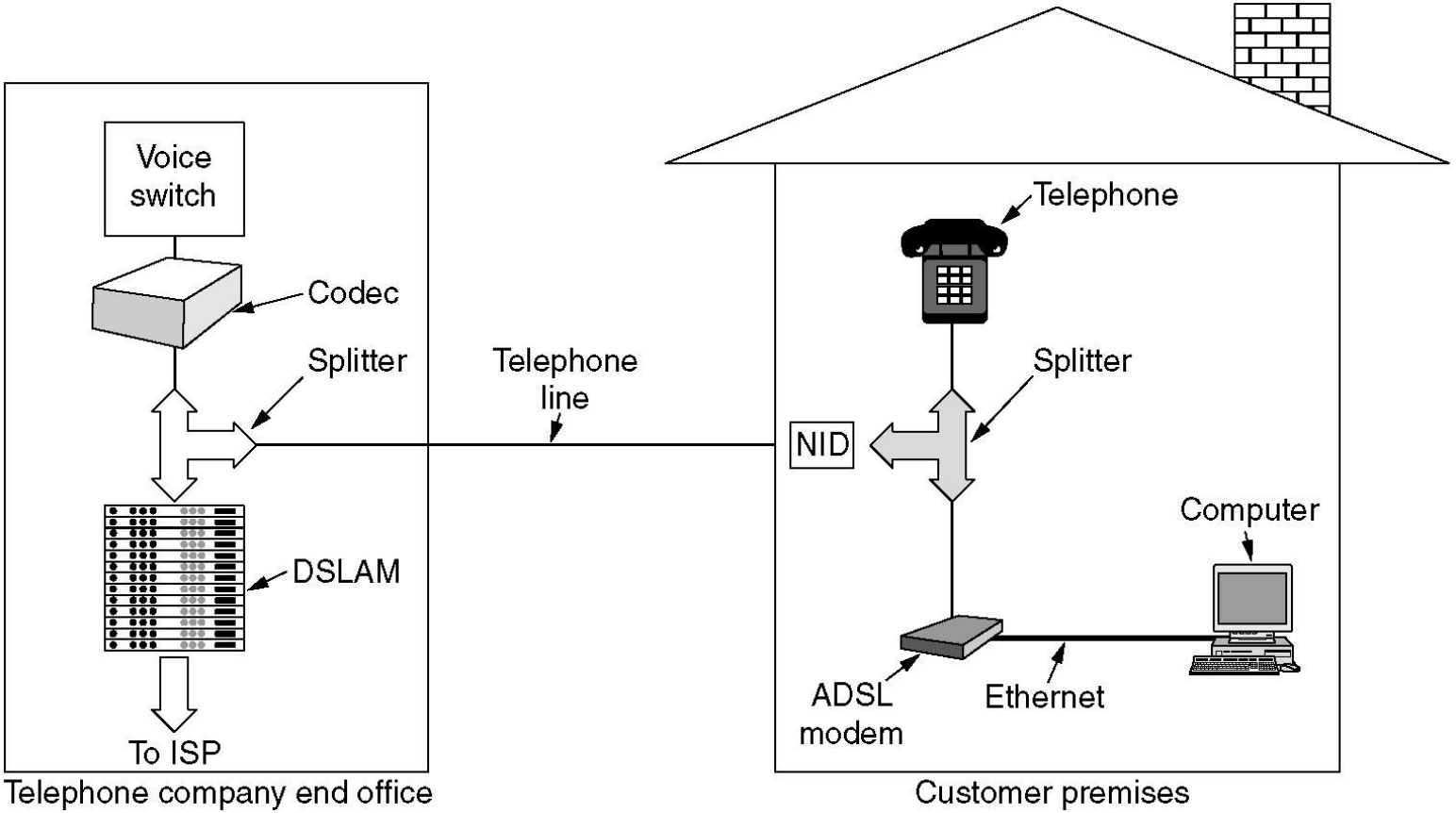

Figure 2-29. A typical ADSL equipment configuration.

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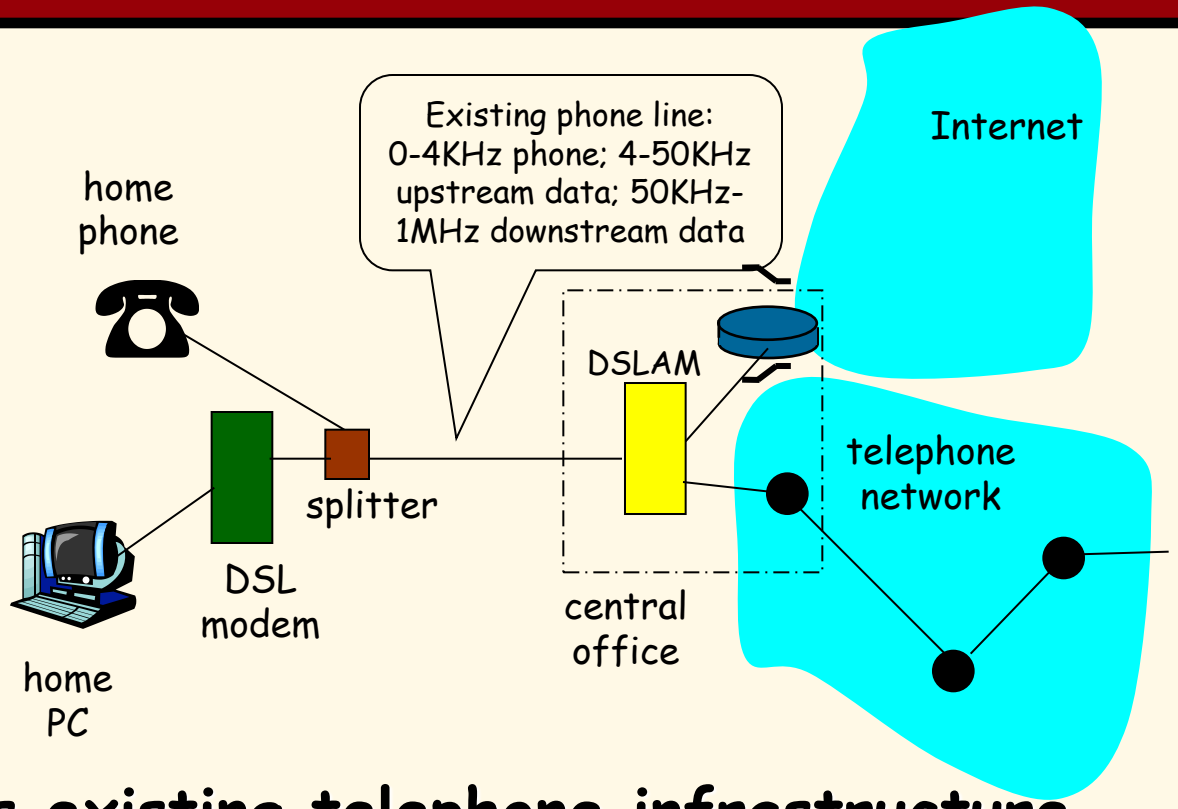
Digital Subscriber Line (DSL)



- Also uses existing telephone infrastructure.
- up to 1 Mbps upstream (today typically < 256 kbps)
- up to 9 Mbps downstream (today typically < 1 Mbps)
- dedicated physical line to telephone central office. K & R

Comparison of xDSL Alternatives

	ADSL	HDSL	SDSL	VDSL
Data rate	1.5 to 9 Mbps downstream 16 to 640 kbps upstream	1.544 or 2.048 Mbps	1.544 or 2.048 Mbps	13 to 52 Mbps downstream 1.5 to 2.3 Mbps upstream
Mode	Asymmetric	Symmetric	Symmetric	Asymmetric
Copper pairs	1	2	1	1
Range (24-gauge UTP)	3.7 to 5.5 km	3.7 km	3.0 km	1.4 km
Signaling	Analog	Digital	Digital	Analog
Line code	CAP/DMT	2B1Q	2B1Q	DMT
Frequency	1 to 5 MHz	196 kHz	196 kHz	≥ 10 MHz
Bits/cycle	Varies	4	4	Varies

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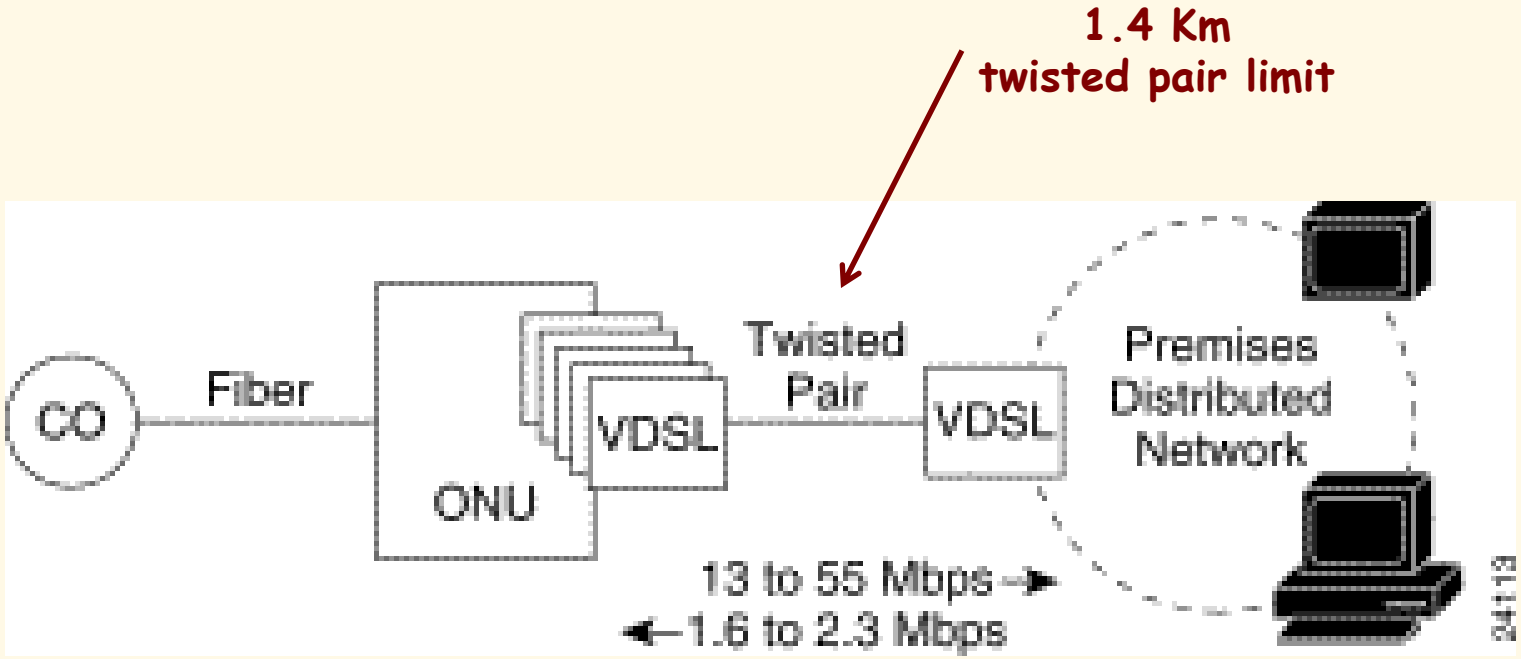
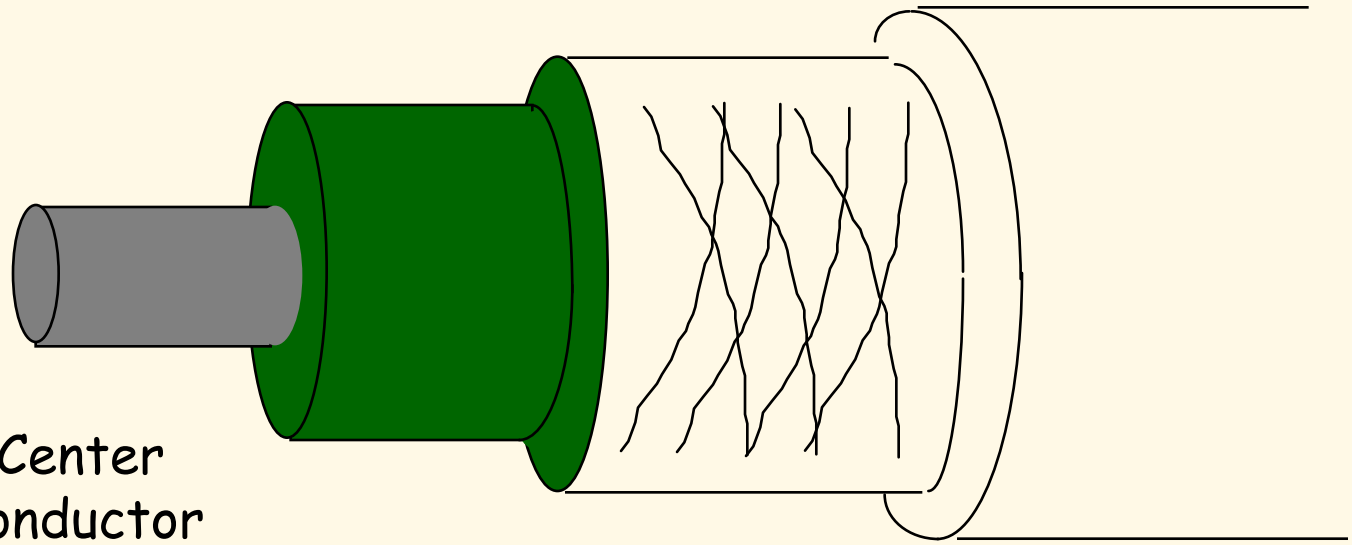
VDSL


1.4 Km
twisted pair limit
CO
Fiber
ONU
VDSL
Twisted
Pair
VDSL
Premises
Distributed
Network
13 to 55 Mbps
1.6 to 2.3 Mbps
24113

Coaxial Cable



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Coaxial Cable

- Discussion divided into two basic categories for coax used in LANs:
  - 50-ohm cable [baseband]
  - 75-ohm cable [broadband or single channel baseband]
- In general, coaxial cable has better noise immunity for higher frequencies than twisted pair.
- Coaxial cable provides much higher bandwidth than twisted pair.
- However, the cable is 'bulky'.

Baseband Coax

- 50-ohm cable is used exclusively for digital transmissions.
- Uses Manchester encoding, geographical limit is a few kilometers.

10Base5 Thick Ethernet :: thick (10 mm) coax

10 Mbps, 500 m. max segment length, 100 devices/segment, awkward to handle and install.

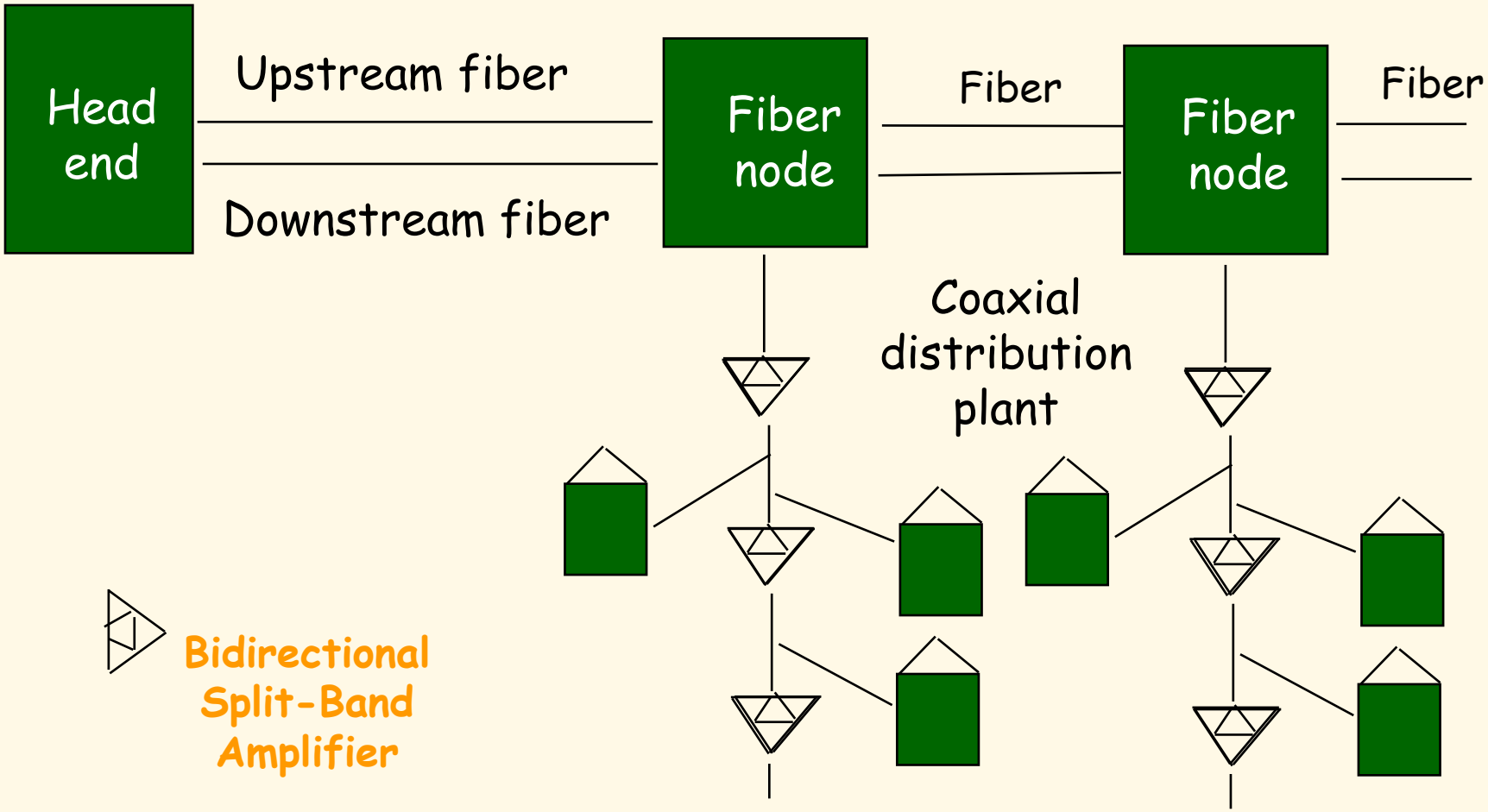
10Base2 Thin Ethernet :: thin (5 mm) coax

10 Mbps, 185 m. max segment length, 30 devices/segment, easier to handle, uses T-shaped connectors.

Broadband Coax

- 75-ohm cable (CATV system standard).
- Used for both analog and digital signaling.
- Analog signaling – frequencies up to 500 MHZ are possible.
- When FDM used, referred to as broadband.
- For long-distance transmission of analog signals, amplifiers are needed every few kilometers.

Hybrid Fiber-Coaxial System



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Residential Access: Cable Modems

- Does not use telephone infrastructure.
  - Instead uses cable TV infrastructure.
- HFC: Hybrid Fiber Coax
  - asymmetric: up to 40Mbps downstream,
  - 30 Mbps upstream
- A network of cable and fiber attaches homes to ISP router.
  - homes share access to router.
  - unlike DSL, which provides dedicated access.

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Residential Access: Cable Modems

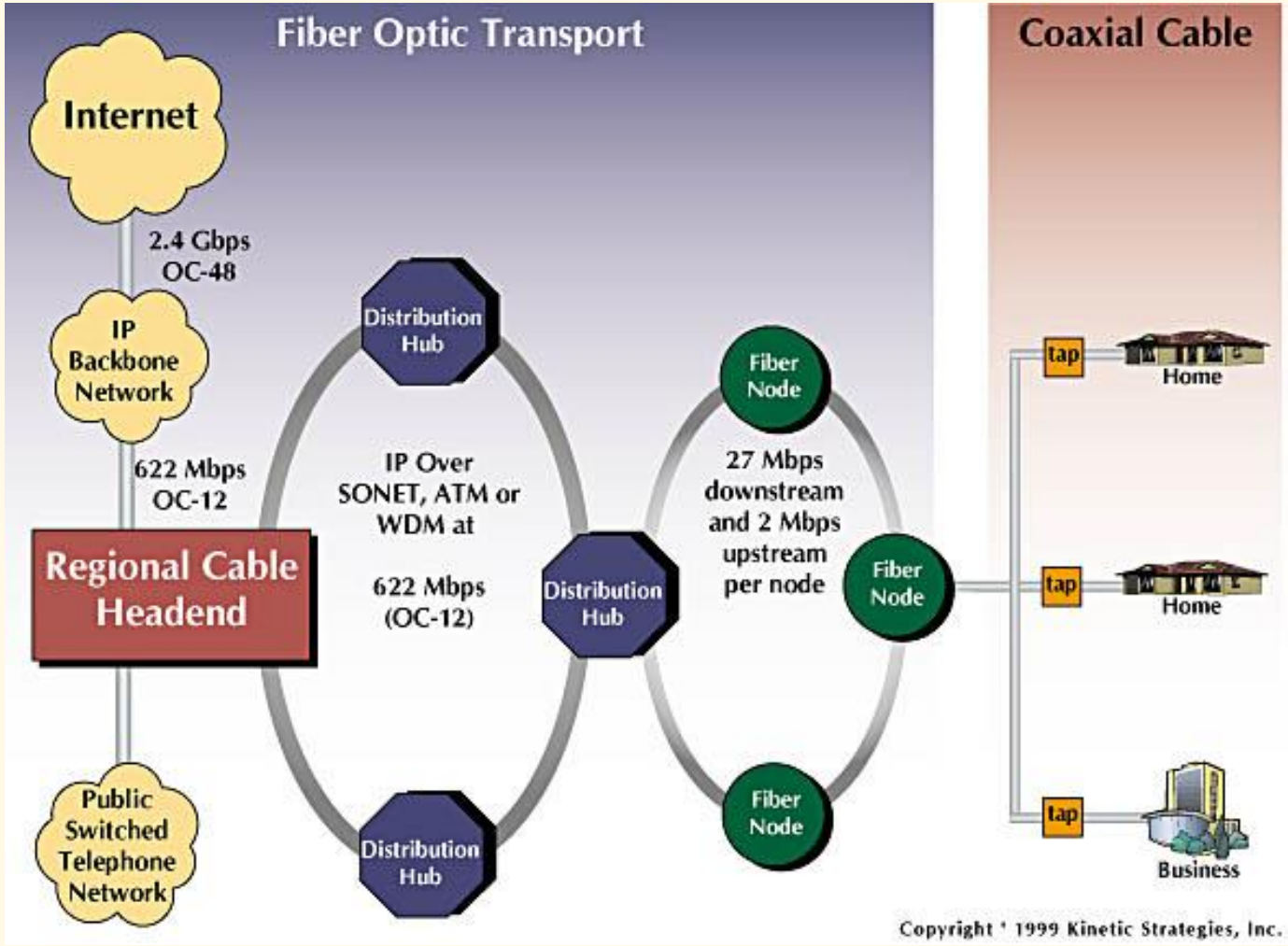

Diagram: http://www.cabledatacomnews.com/cmic/diagram.html

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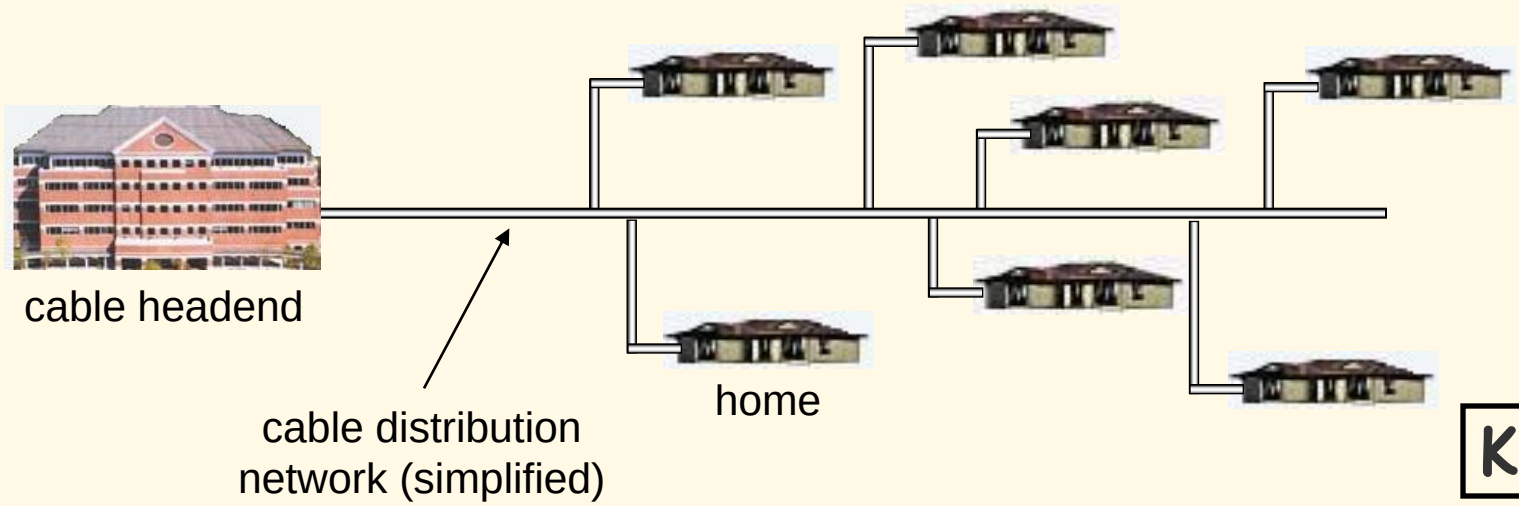
Cable Network Architecture: Overview

Typically 500 to 5,000 homes



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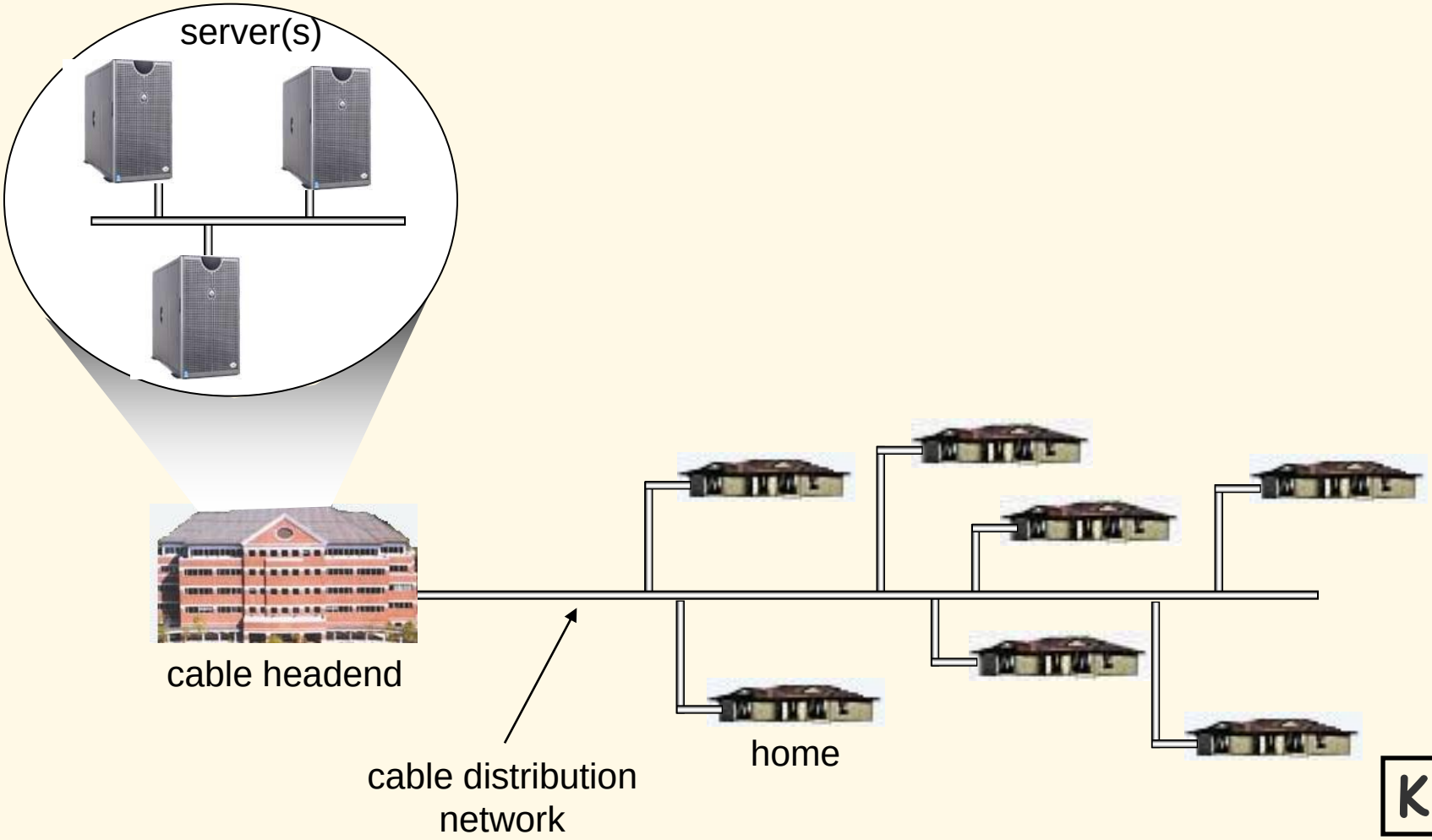
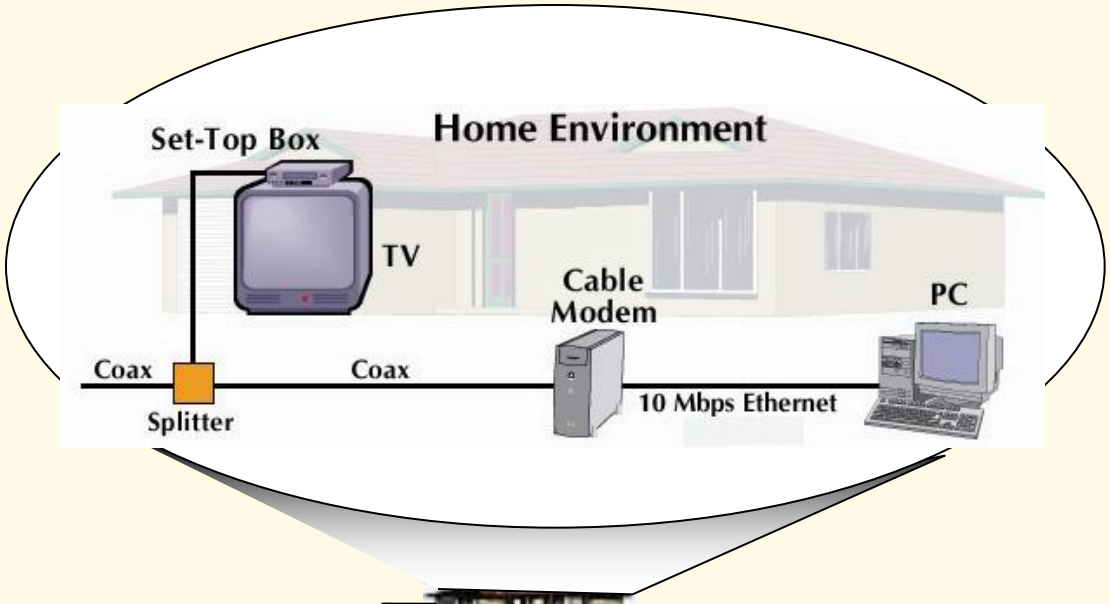
Cable Network Architecture: Overview



Cable Network Architecture: Overview



cable headend

cable distribution network (simplified)

home

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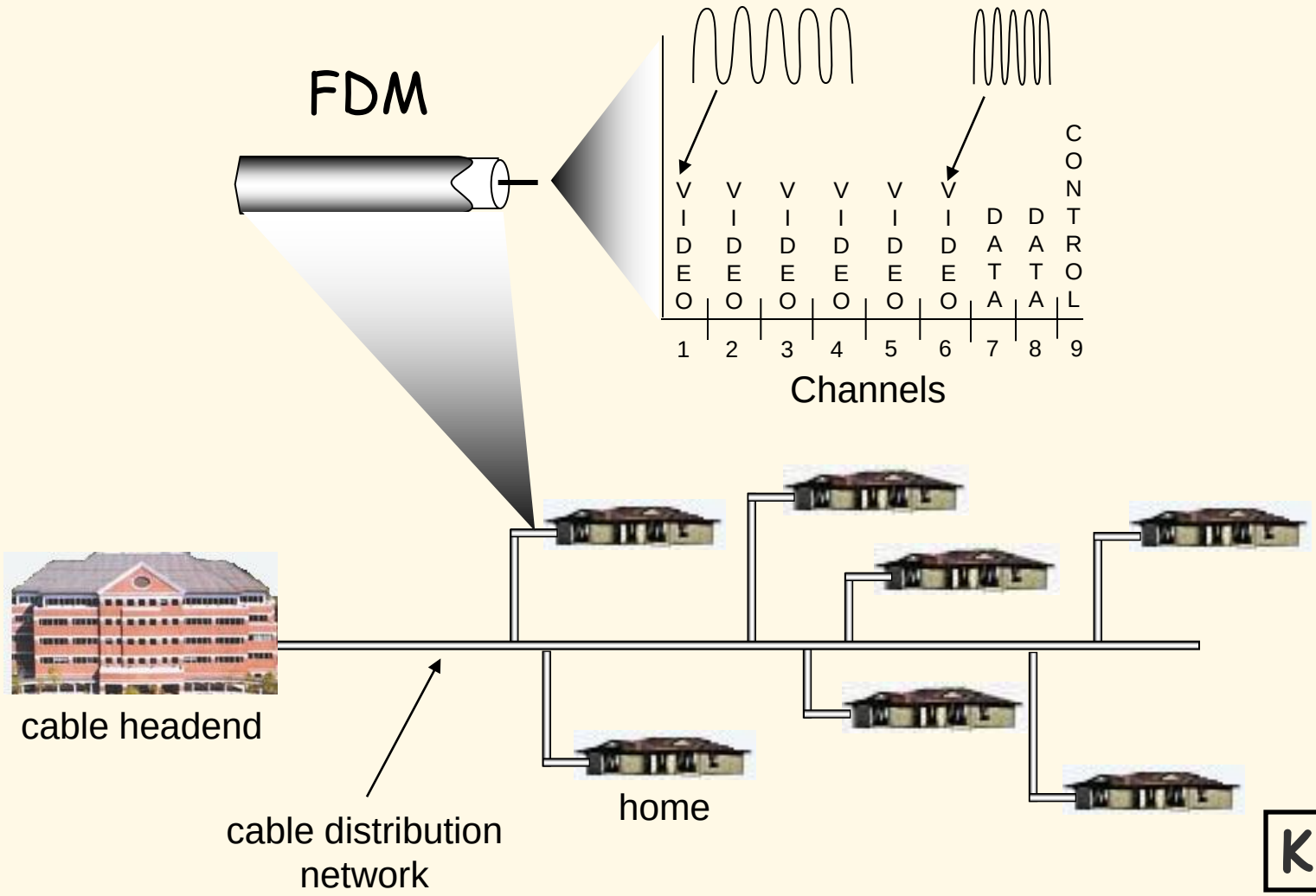
Cable Network Architecture: Overview



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DOCSIS (Data-Over-Cable Service Interface Specification)

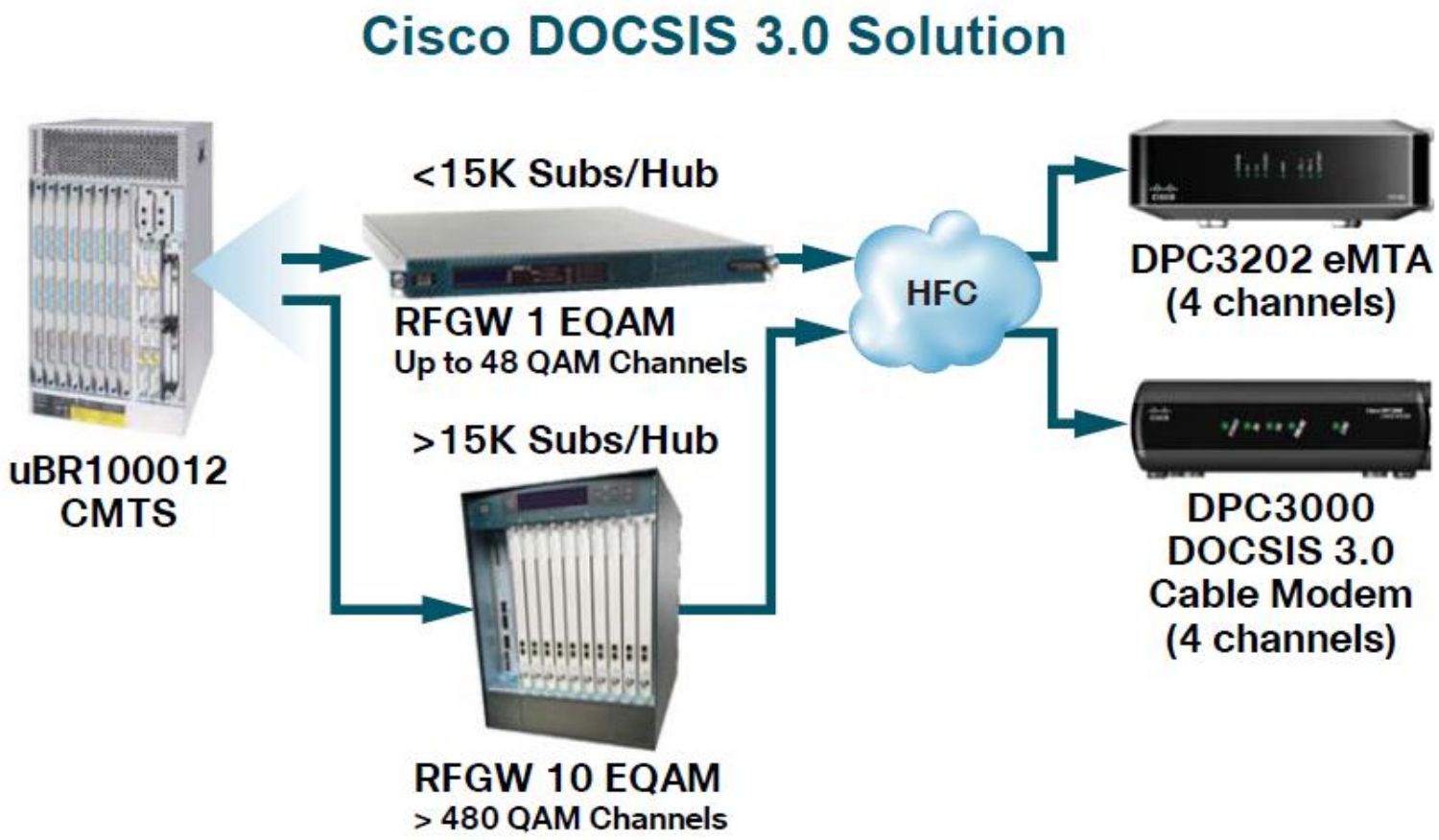
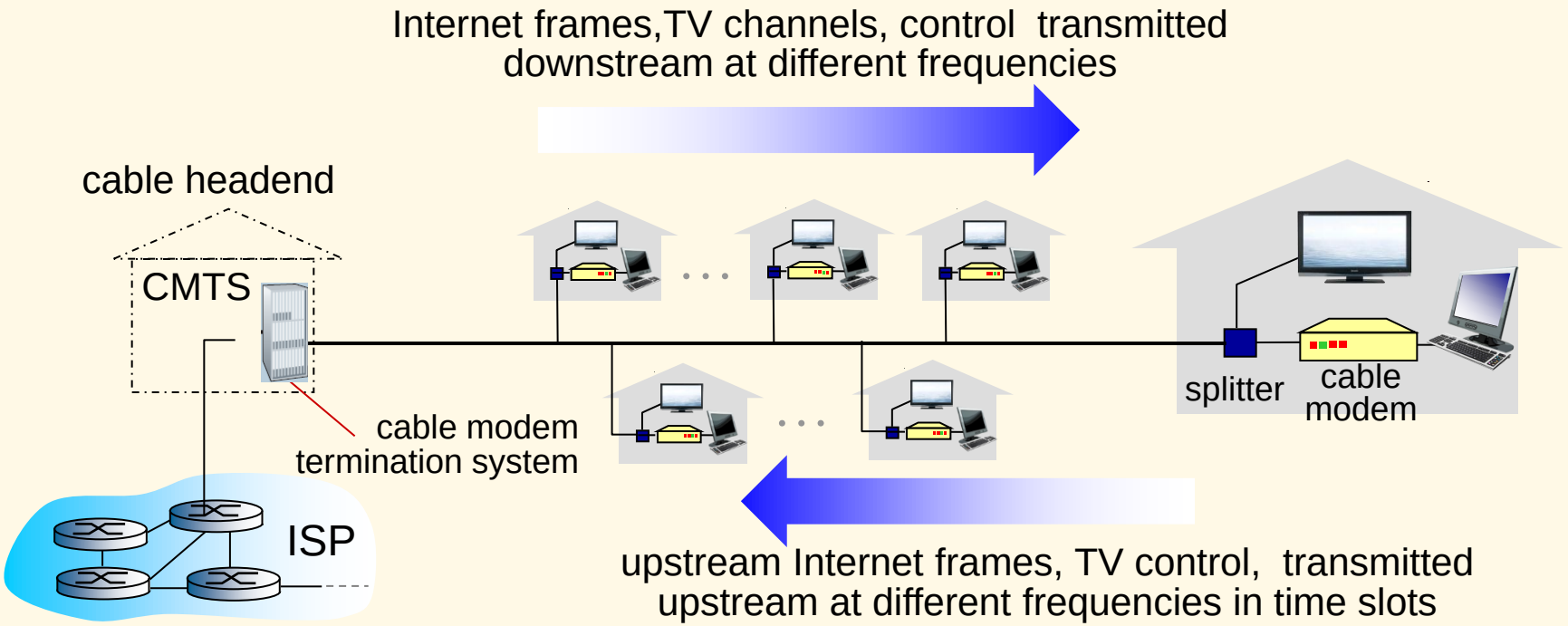


Figure 4. M-CMTS and DOCSIS 3.0 Downstream Channel Bonding

Cable Access Networks



- FDM over upstream, downstream frequency channels
- multiple 40Mbps downstream (broadcast) channels (6MHz)
  - single CMTS transmits into channels and received by all modem receivers.

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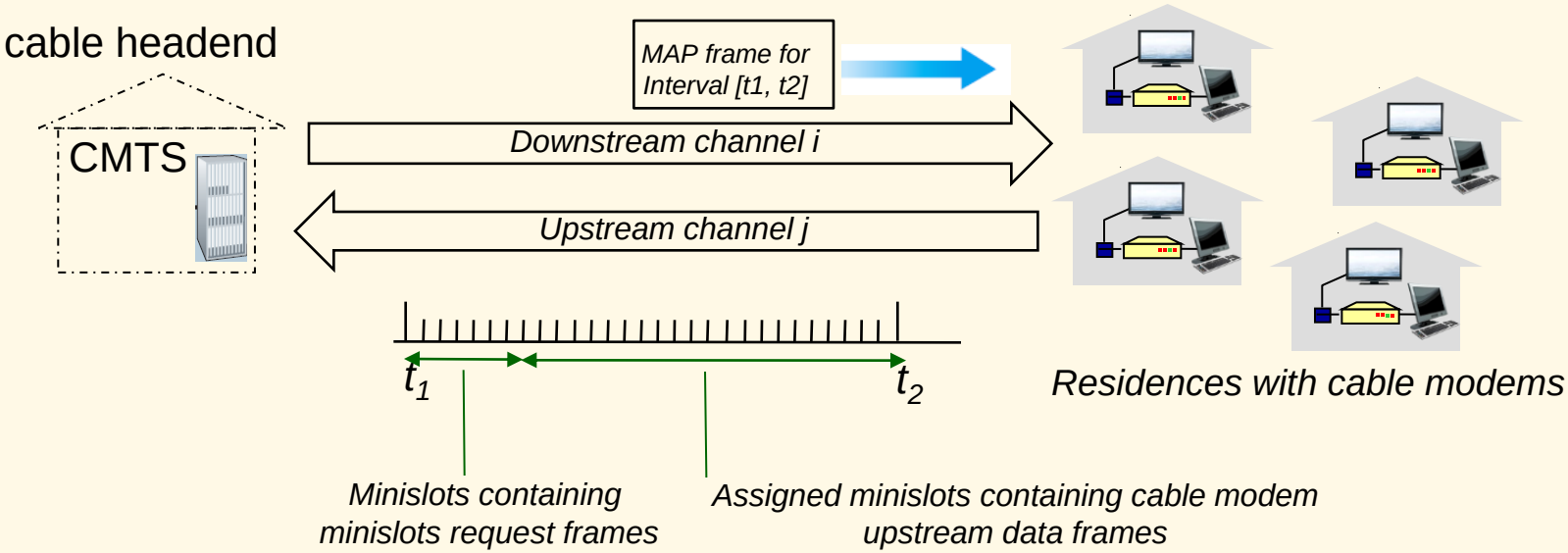
DOCSIS Cable Access Networks



- multiple 30 Mbps upstream channels (6.4MHz)
- TDM-like upstream mini-slots

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DOCSIS (Data-Over-Cable Service Interface Specification)

- CMTS explicitly grants permission to individual modems to transmit during specific mini-slot in a downstream MAP frame.
- Cable modems send requests for upstream slots in mini-slot request frame.
- Since theses requests are sent random access collisions are possible.
- Cable modem cannot detect collision, but infers it from lack of response from CMTS.
- When collision inferred, modem uses binary exponential backoff.

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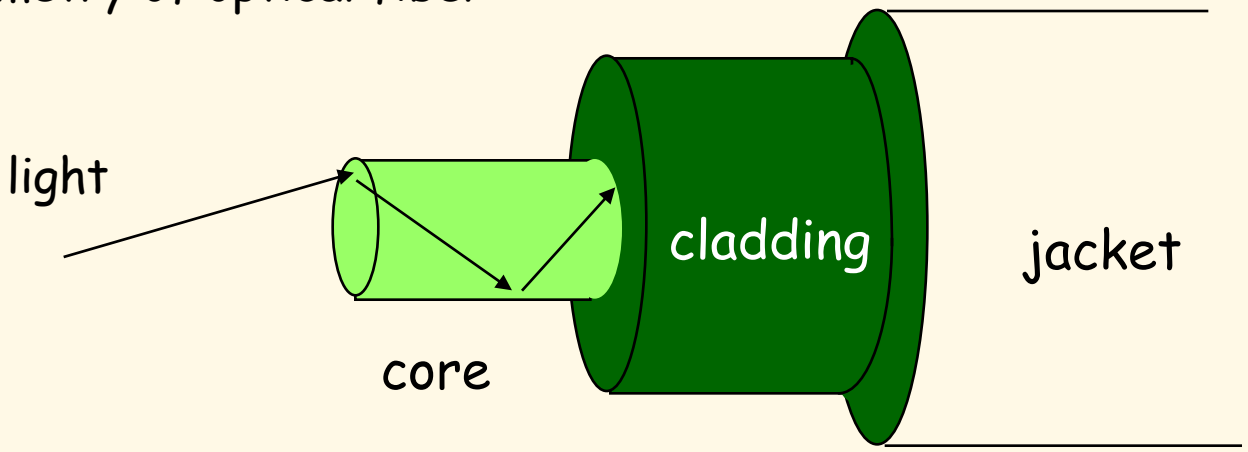
Optical Fiber

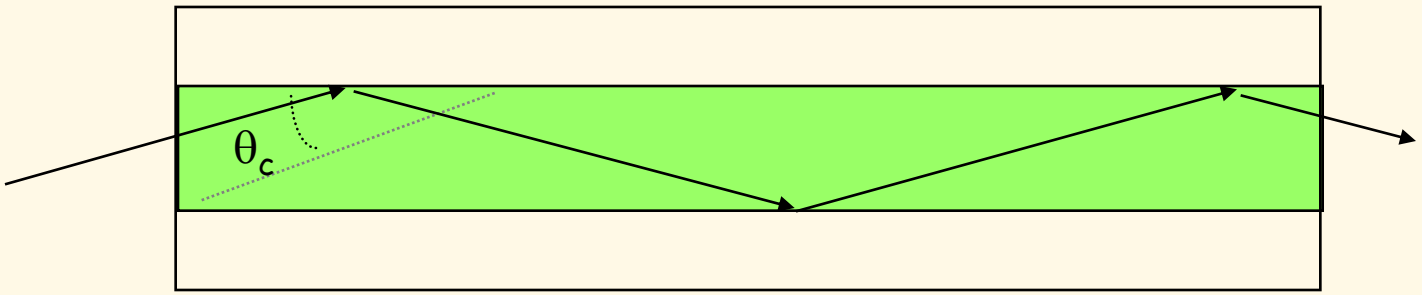
- Optical fiber:: a thin flexible medium capable of conducting optical rays. Optical fiber consists of a very fine cylinder of glass (core) surrounded by concentric layers of glass (cladding).
- a signal-encoded beam of light (a fluctuating beam) is transmitted by total internal reflection.
- Total internal reflection occurs in the core because it has a higher optical density (index of refraction) than the cladding.
- Attenuation in the fiber can be kept low by controlling the impurities in the glass.

Optical Fiber

(a) Geometry of optical fiber



(b) Reflection in optical fiber



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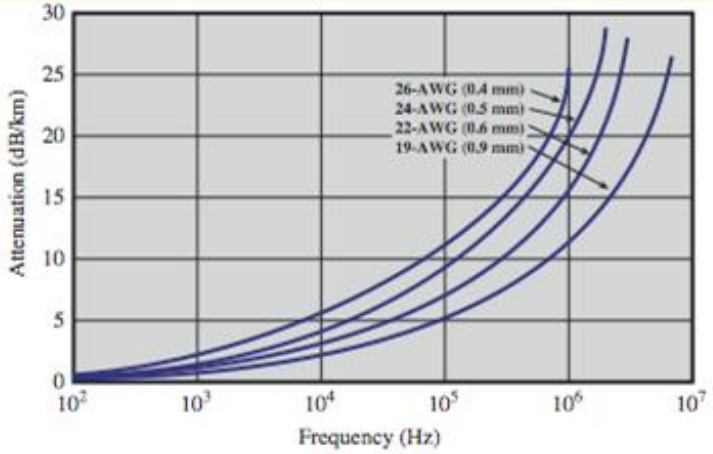
Optical Fiber

- Lowest signal losses are for ultrapure fused silica – but this is hard to manufacture.
- Optical fiber acts as a wavelength guide for frequencies in the range 10^{14} to 10^{15} HZ which covers the visible and part of the infrared spectrum.
- Three standard wavelengths : 850 nanometers (nm.), 1300 nm, 1500 nm.
- *First-generation optical fiber* :: 850 nm, 10's Mbps using LED (light-emitting diode) sources.
- *Second and third generation optical fiber* :: 1300 and 1500 nm using ILD (injection laser diode) sources, gigabits/sec.

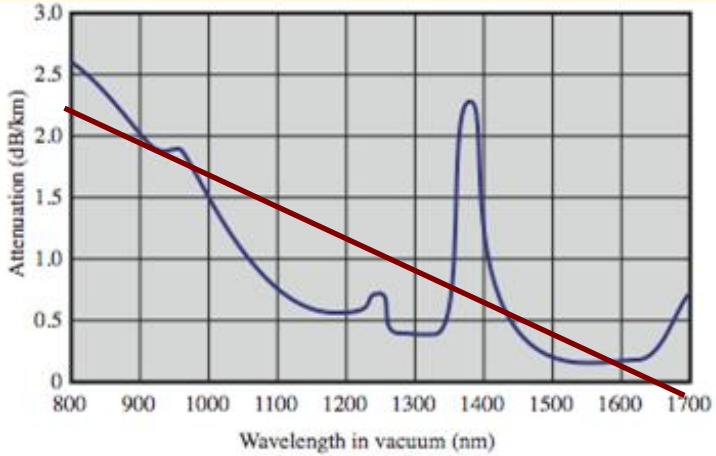
Optical Fiber

- Attenuation loss is lower at higher wavelengths and affected by absorption and scattering of light rays.
- There are two types of detectors used at the receiving end to convert light into electrical energy (photo diodes):
  - PIN detectors – less expensive, less sensitive
  - APD detectors – Avalanche PhotoDiodes (long haul fiber systems)
- ASK is commonly used to transmit digital data over optical fiber {referred to as intensity modulation}.

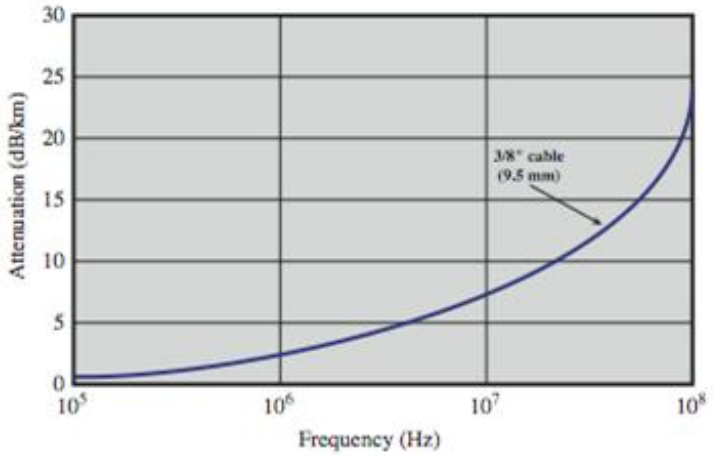
Attenuation in Guided Media



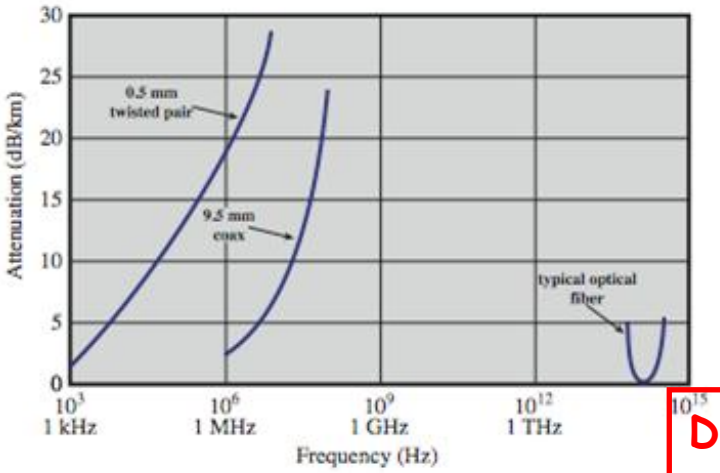
(a) Twisted pair (based on [REEV95])



(c) Optical fiber (based on [FREE02])



(b) Coaxial cable (based on [BELL90])



(d) Composite graph

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Wavelength Division Multiplexing

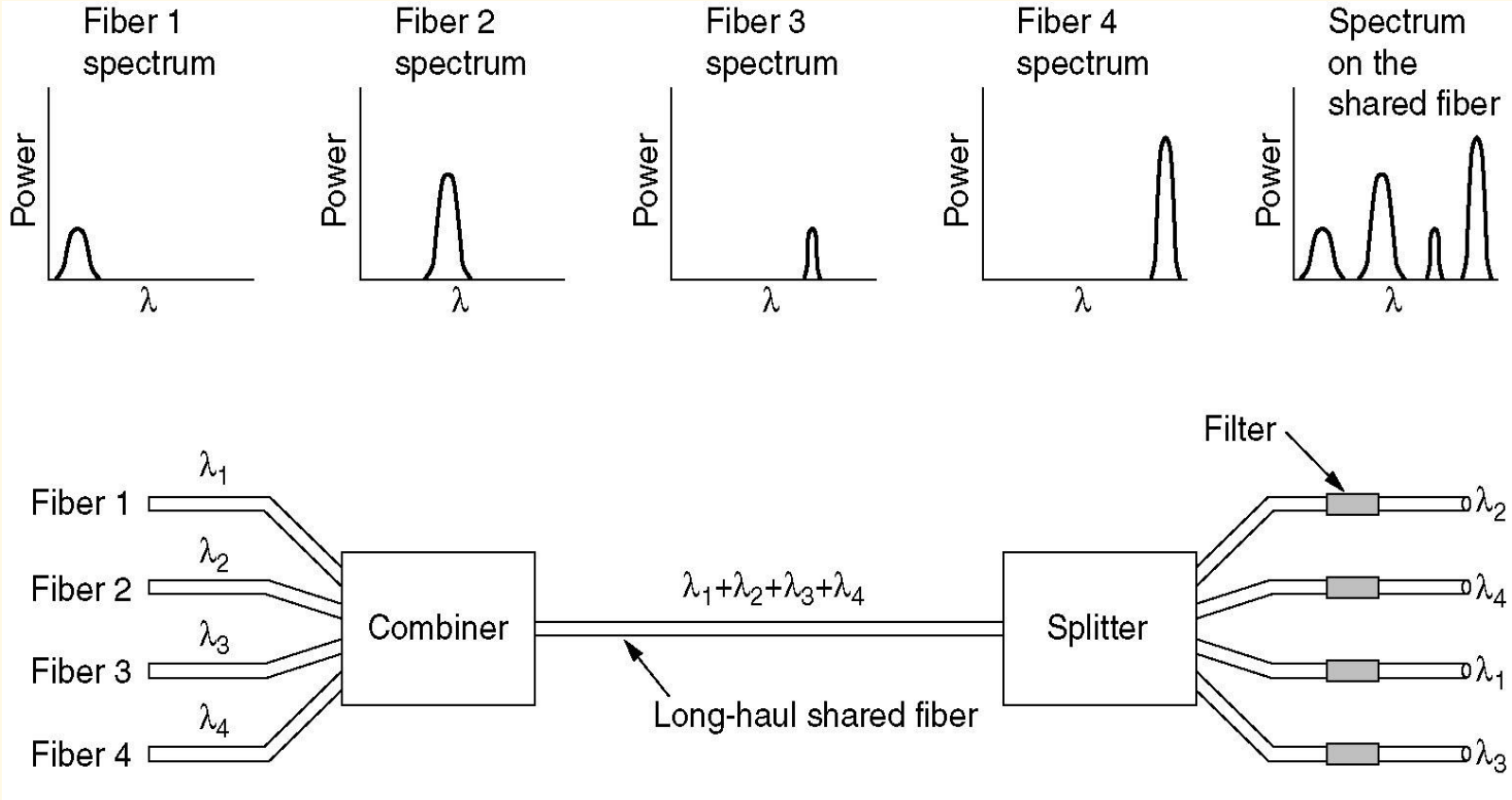

Figure 2-32.

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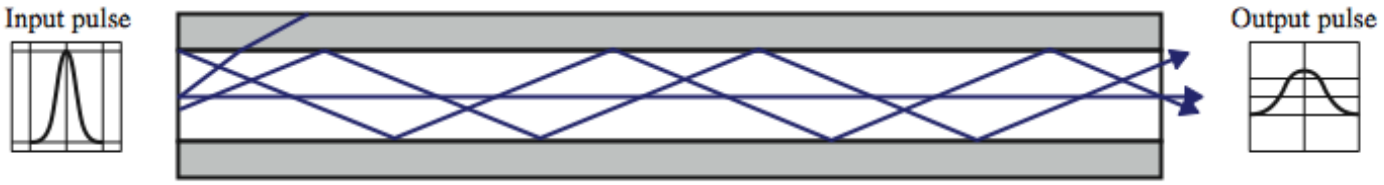
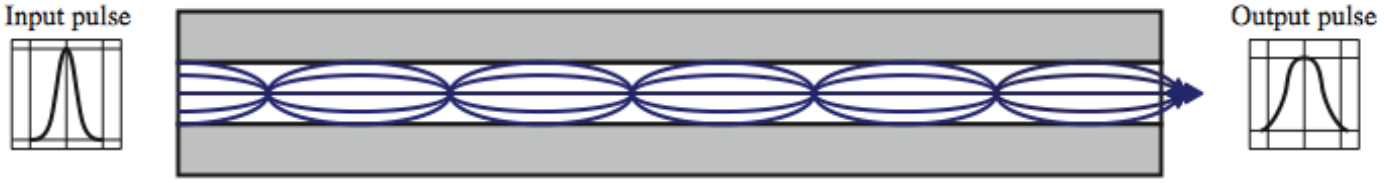
Optical Fiber

- Three techniques:
  - Multimode step-index
  - Multimode graded-index
  - Single-mode step-index
- Presence of multiple paths → differences in delay → optical rays *interfere* with each other → spacing needed between light pulses.
- A narrow core can create a single direct path which yields higher speeds.
- WDM (Wavelength Division Multiplexing) yields more available capacity.

Optical Fiber Transmission Modes



(a) Step-index multimode



(b) Graded-index multimode

(c) Single mode

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Frequency Utilization for Fiber Applications

Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

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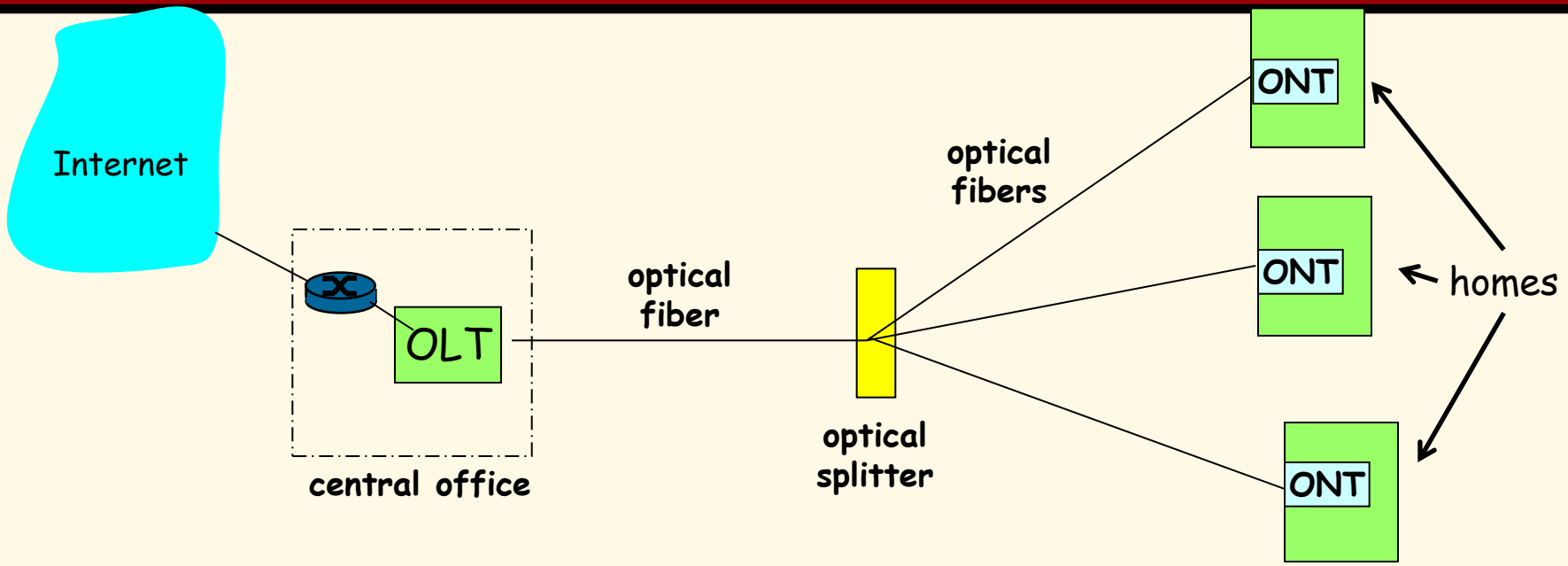
Fiber to the Home (e.g. FIOS)



- Optical links from central office to the home
- Two competing optical technologies:
  - Passive Optical network (PON) ← Verizon FIOS
  - Active Optical Network (AON)
- Much higher Internet rates. Fiber also carries television and phone services.

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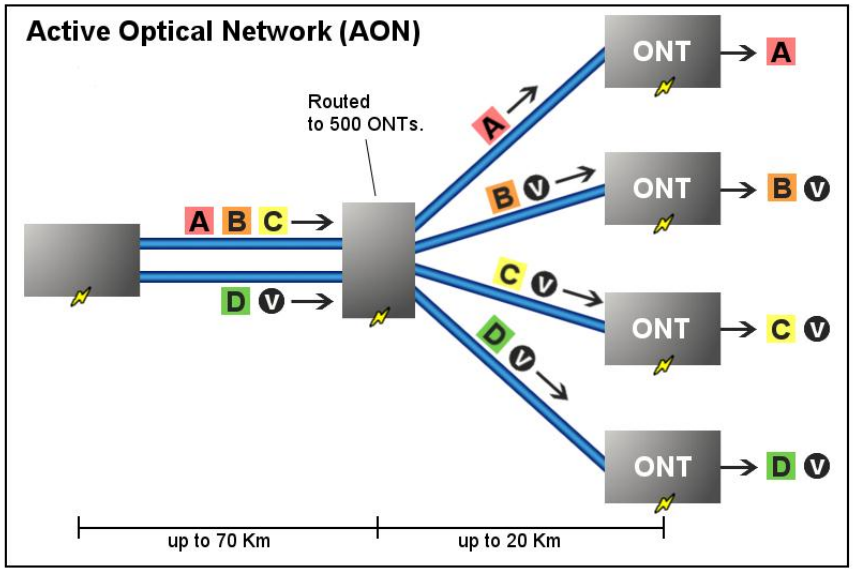
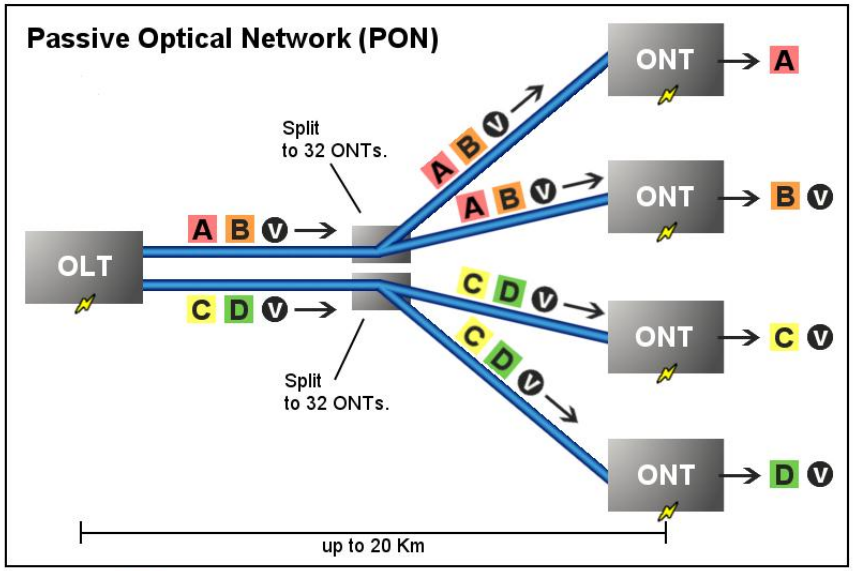
AON Active Optical Network

- Uses electrical powered switches
- More range
- Less reliable

PON Passive Optical Network

- Optical splitters do not need electrical power.
- Hard to isolate failure
- Transmission speed may be slower during peak hours.





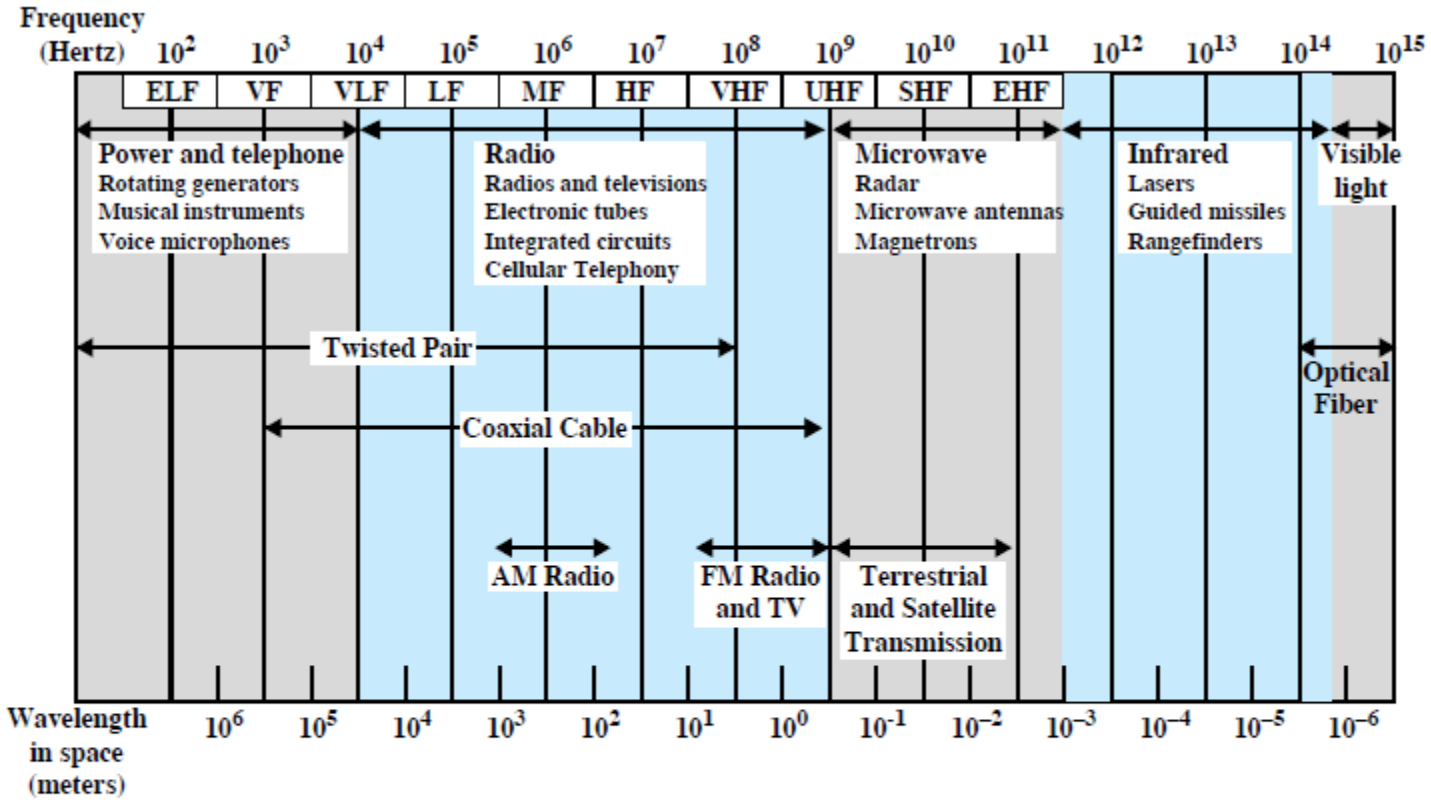
Key: A - Data or voice for a single customer. V - Video for multiple customers.

Wikipedia

Wireless Communications (briefly)

- An application of omni-directional wireless communications to provide high-speed communications among a number of computers located in close proximity.
- In 1996 FCC in US announced its intentions to make 350 MHz of spectrum in the 5.15 to 5.35 GHz and 5.725 to 5.825 GHz bands available for unlicensed use in LAN applications.

Telecommunications Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Figure 4.1 Electromagnetic Spectrum for Telecommunications

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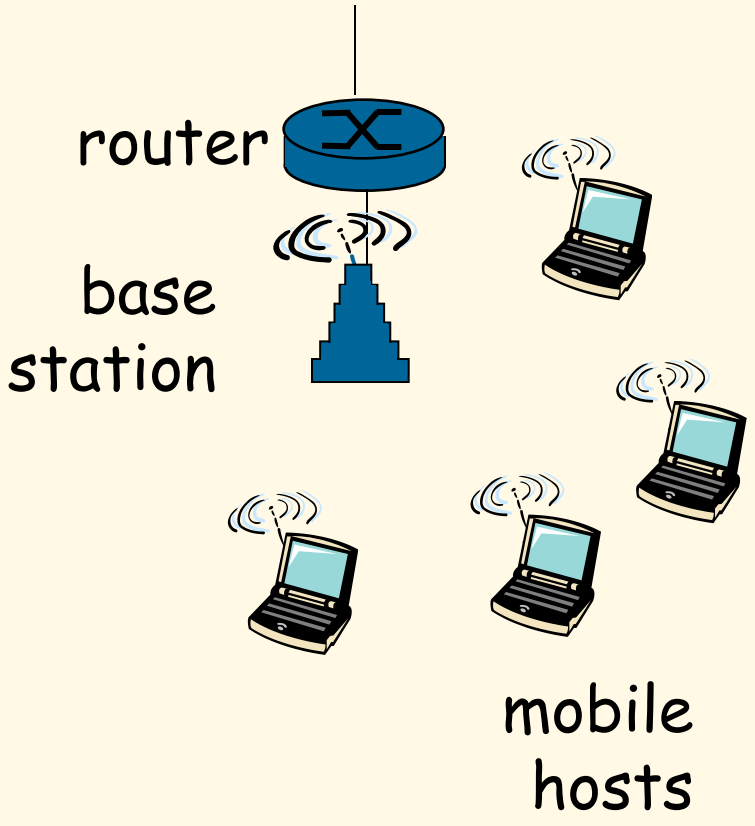
Wireless Access Networks

- shared *wireless* access network connects end system to router
  - via base station aka "access point"
- **Wireless LANs:**
  - 802.11b/g /n(WiFi): 11, 54, 100's Mbps, Bluetooth, Zigbee (802.15.4)
- **Wide Area Wireless Access:**
  - provided by telco operator
  - ~1Mbps over cellular system (EVDO, HSDPA, 4G LTE)
  - next up (?): WiMAX (10's Mbps) over wide area



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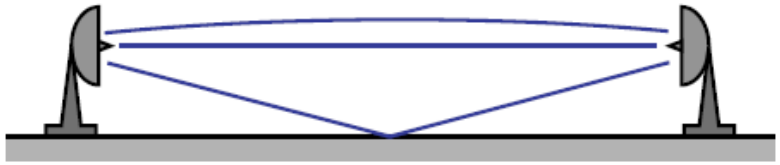
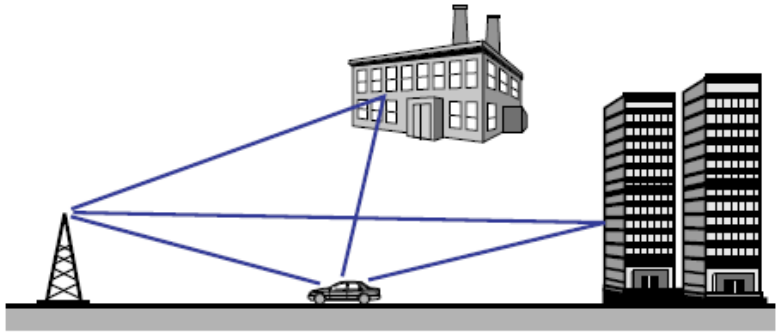
Wireless Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

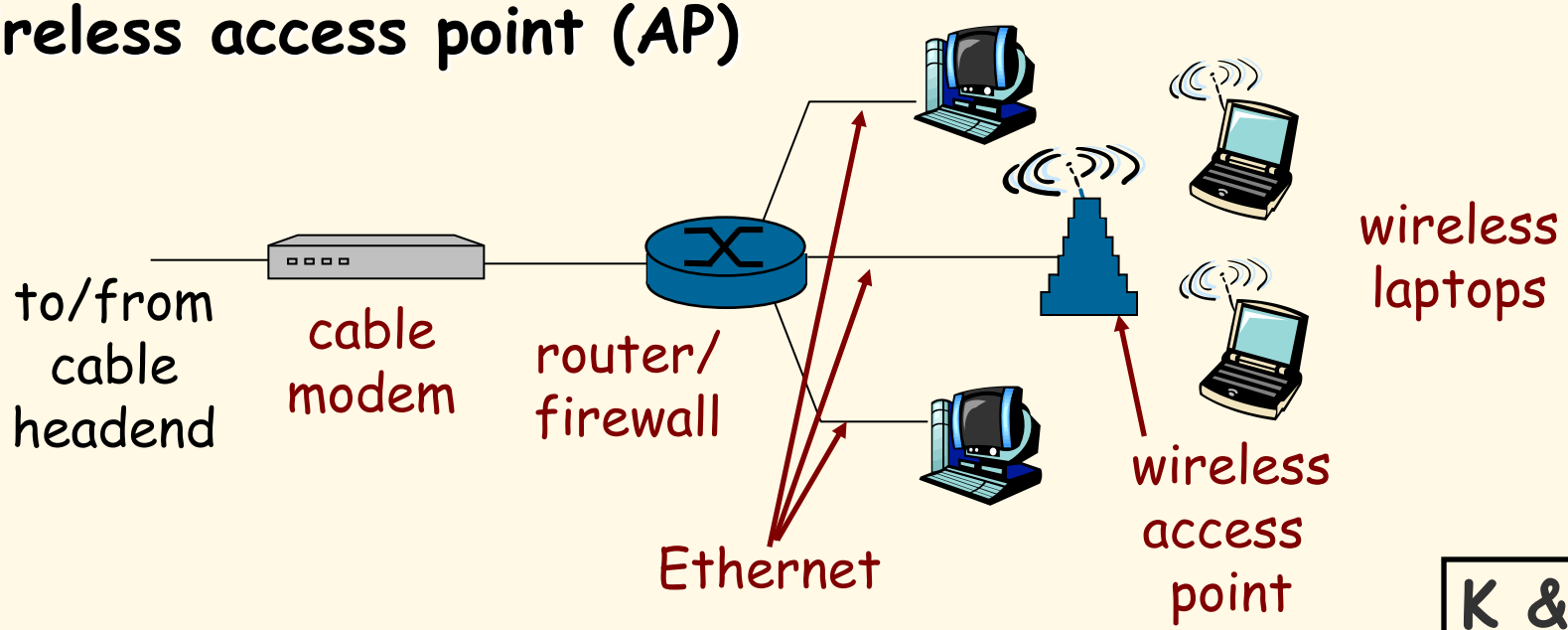
Figure 4.11 Examples of Multipath Interference

DCC 8th Ed. Stallings

Residential Networks

Typical residential network components:

- DSL or cable modem
- Router/firewall/NAT
- Ethernet
- Wireless access point (AP)



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Transmission Media Summary

- Twisted pair
  - Noise, interference and attenuation are issues.
  - Cat5e modern required minimum (Fast Ethernet)
  - Dial-Up and DSL (ADSL) Connections
- Coaxial cable
  - Baseband versus Broadband
  - Cable is HFC (Hybrid Fiber-Coax)
  - FDM and asymmetric channel capacities

Transmission Media Summary

- Optical Fiber
  - Wavelength Division Multiplexing of light
  - Very High Capacities
  - Three standard wavelengths
  - Three standard techniques
  - Fiber to the home
- Wireless Communications
  - 'crowded' frequency spectrum
  - WLAN and Wide Area wireless
  - Common Residential 'Last Hop' to the Internet involves wireless AP (router, firewall, NAT).