Fiber Optic Networks (Single-wavelength)

Fiber Optic Networks Preview

- Trends in telecommunications and data networks
- Comparison of linear bus and star topologies
- FDDI Networks
- SONET/SDH Telecommunications Standard
- ATM/SONET

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Trends

- **Trends in telecommunications and computers**
  - **Volume and applications ever increasing bandwidth**
    - » **Telecommunications rates**

Modems	300/1200/2400/9600/26k/56k b/s
T1 data	1.544 Mb/s
T3 data	44.783 Mb/s
ISDN	23 64-kb/s channels & 1 16-kb/s channel

    - » **Computers**

RS232 interface	9600 b/s
Token Ring Network	4 or 16 Mb/s
Ethernet	10 Mb/s
Coax Hyperchannel	50 Mb/s
FDDI	100 Mb/s
GaAs FDDI (proposed)	600 Mb/s
HIPPI channel	800 Mb/s

Fast Ethernet 100 Mb/s
Gigabit Ethernet 1 Gb/s
Fibre channel 1 Gb/s

Network Trends (cont.)

- *Telecommunications systems*:
  - Mixture of analog signals (voice, TV) and digital data (computer interchanges)
  - Telcomm *trunk system* thoroughly digitized
    - »User connections usually analog
  - Needs data exchange via carrier networks
    - »Trend away from centralized computers to confederation of “peer" computers
- Trends toward video conferencing and image transmission raise bandwidth demands

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- World-wide standards needed so national systems can be interconnected

Fiber Optic Networks: Trends (cont.)

- ***Computer networks*:**
  - **Increased bandwidth required for**
    - » **Increasing complexity in packet headers**
    - » **Use of error-correcting codes**
    - » **Increasing complexity of network control overhead as network use increases**
      - **e.g., Token passing (or random access strategies)**
    - » **Increased security**
    - » **Requirements for graceful network degradation**

- **Networks can be divided into following (roughly-defined) categories:**
  - ***Local area networks* (LANs): interconnect users within department, building, or campus.**
  - ***Metropolitan Area Networks* (MANs): interconnect users within city or metropolitan area**
  - ***Wide Area Networks* (WANs): interconnect users within wide geographical area (e.g., within a country)**

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- Note: computer network people and telecommunications people seldom talk to each other

Networks: Fiber Role

- Fiber bandwidth helps to innovative data networks
- Multiplexing techniques:
  - Time-division multiplexing (TDM)
  - Frequency-division multiplexing (FDM)
  - Code-division multiplexing (CDMA)
  - Wavelength division multiplexing (WDM)
- Network control protocols
  - Central control (frequently with controlled switches)
  - Token passing
  - Contention arbitration schemes (e.g., CSMA/CD used in Ethernet)

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Networks: Topologies

- **Several topologies:**
  - **Star**
  - **Linear bus,**
  - **Ring**
  - **Others**

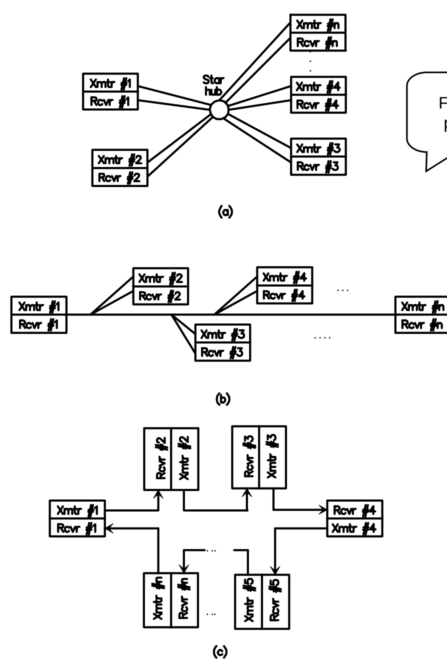

Fig. 8.1
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- Other: e.g., Leaf topology

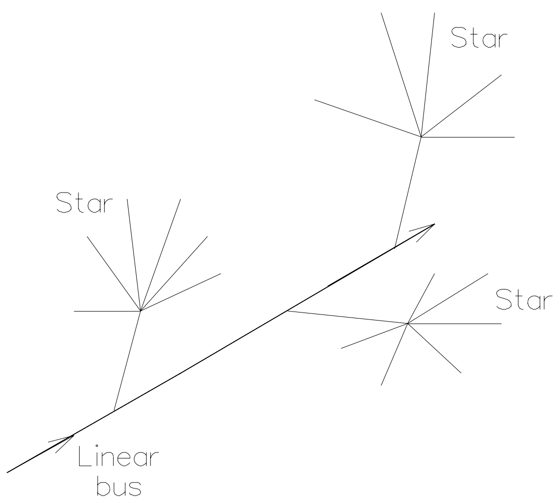

Fig. 8.2
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Network Topologies (cont.)

- *Star network*
  - Pros:
    - » Simple to add terminals, esp. if spare lines added at inception
    - » Losses increase as log(*N*)
  - Cons:
    - » Central point of failure at node
- *Linear bus network*
  - Pros:
    - » Similar to familiar electrical data bus
  - Cons:
    - » Difficult to add stations without interfering with network operation
    - » Losses increase with *N*
- *Ring network*
  - Pros:
    - » Continuous monitoring of ring
  - Cons:
    - » Vulnerable
      - • Needs bypass switches
      - • Needs path redundancy

Networks: Design Tradeoffs

- Power budget analysis
  - Compare...
    - » Linear bus network and...
    - » Star network
  - Ensure enough power to
    - » Reach furthest station
    - » Without saturating nearest station
  - Result:
    - » All else being equal, star has inherent loss advantage over linear bus as number of stations grows

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Star-Network Power Budget

- **Power in fiber at coupler input: P_F; min RCVR power: P_R**
- **Losses:**
  - **Insertion loss: l_{insert}**
  - **Power splitting loss: $l_{pwr\ split}$**
  - **Connector loss: l_C**
  - **System margin: l_M**
  - **Fiber loss: αL**
- **Power from XMTR to RCVR**
  - **P_F in fiber at transmitter (in dBm), less...**
  - **Fiber loss, αL, from transmitter to star**
  - **Loss of l_C at fiber/coupler connectors**
  - **Splitting loss of $l_{pwr\ split}$ = log N**
  - **Excess loss of star (l_{excess})**
  - **Loss of l_C at coupler/fiber connectors**
  - **Fiber loss of αL to receiver**
- **Adding dB losses, power budget is**

$$10\log\left(P_f/P_R\right)=10\log\left(N\right)+\alpha\left(2L\right)+2l_c+l_{\text{excess}}+l_M$$

  - **dB-losses in star increase as 10log N**

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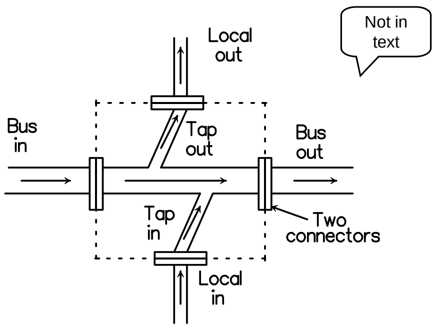
Linear Bus: Power Budget

- **Linear data bus made up of tee couplers**
- **Each station has two couplers:**
  - **"Tap out": couples fraction C_T into "local out" arm**
  - **"Tap in": adds fraction C_T of "local in" signal to bus**



- **Losses:**
  - **Transmission past either tap:**
    - » $l_{thru} = -10 \log(1 - C_T)$
    - » **Total transmission loss:** $2l_{thru}$
  - **Bus to "Local out"**
    - » $l_{tap} = -10 \log(C_T)$ **dB**
  - **"Local in" to bus**
    - » $l_{tap} = -10 \log(C_T)$ **dB**
  - $2l_C$ **for coupler connectors (pair)**
  - **Excess loss** l_{excess} **for coupler**

Linear Bus: Power Budget (cont.)

- **Consider *N* stations separated by *L***
- **Smallest loss: station to nearest-neighbor station (*L* away)**
- **Largest loss: station to *N*-th station**
  - **XMTR power in fiber: P_F**
  - **Connector loss entering coupler #1: l_C**
  - **Power onto bus with C_T efficiency: l_{tap}**
  - **Connector pair leaving coupler #1: l_C**
  - **Excess loss for "local in" to "bus out" path: l_{excess}**
  - **N-1 pieces of fiber, length L: $(N-1)\alpha L$**
  - **N-2 couplers between first and last station: $l_{excess} + 2l_C + 2l_{thru}$ (each)**
  - **Connector pair entering coupler #N: l_C**
  - **Coupling into "local out" of coupler #N: l_{tap}**
  - **Connector pair leaving coupler receiver arm: $2l_C$**
  - **Tap loss l_{tap} "bus in" to "local out": l_{tap}**
- **Power budget**

$$10\log\left(P_f / P_R\right)$$

$$= l_c + l_{\text{tap}} + l_c + l_{\text{excess}} + (N-1)\alpha L + (N-2)\left(l_{\text{excess}} + 2l_c + 2l_{\text{thru}}\right) + l_c + l_{\text{tap}} + 2l_c + l_{\text{excess}}$$

$$= N\left(\alpha L + 2l_c + l_{\text{excess}} + 2l_{\text{thru}}\right) - \alpha L - 4l_{\text{thru}}$$

- **Losses increase *linearly* with *N***

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Bus Comparison: Power Budget Example

- **Star network: I_C = 1.5 dB; insertion loss (for each channel) = 0.75 dB**
- **Linear data bus: Taps 10% into arms; excess loss per coupler = 0.5 dB**

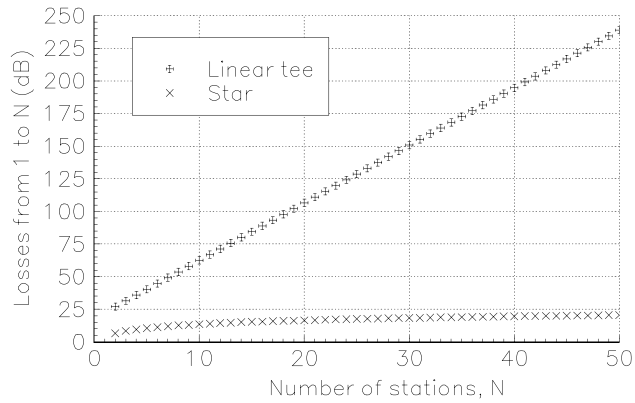

Fig. 8.4
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- **Systems with large number of stations should use star configuration**
  - **Value of *N* where star becomes advantageous depends on actual loss values**

Networks: Receiver Dynamic Range

- LANs susceptible to dynamic range problems
- Wide range of possible distances between stations
  - Next neighbor
    - » $P_{R,2}$: maximum power received
  - Furthest neighbor
    - » $P_{R,N}$: minimum power received
- *Dynamic range* DR of receiver
  - Ex., dynamic range of linear bus is

$$DR = 10\log\left(P_{R,2}/P_{R,N}\right) = 10\log\left(P_{R,2}\right) - 10\log\left(P_{R,N}\right)$$
$$= -2\alpha L + 4l_{\text{excess}} + 4l_C - N\left(\alpha L + l_{\text{excess}} + 2l_C + 2l_{\text{thru}}\right)$$

- Assuming each receiver on net is same
  - ☞ Each receiver must have this dynamic range to avoid
    - ✳ Being saturated by nearby transmitter or
    - ✳ Underdriven by far-away transmitter

Proposed Standard Fiber Networks: US *Telecommunications* Standards

- **Pre-1984: Bell system set *de facto* standards**
- **Post-1984: US standards-setting different**
- **Players:**
  - **Operating companies**
  - **Long-distance service suppliers**
  - **Equipment manufacturers**
- **Committee T1 of American National Standards Institute (ANSI)**
  - **Proposes and discusses US standards**
    - » **Develops North American telecom standards**
    - » **Develops reports and American recommendations for ITU**
  - **Developed...**
    - » **Integrated Services Data Network (ISDN) standard**
    - » **SS7 switch services**
    - » **Synchronous Optical Network (SONET) standard**

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International Telecommunications Standards

- **Set by International Telecommunications Union (ITU)**
- **Deals only with governmental bodies**
  - **US Department of State has US National Committee for ITU (US ITU)**
- **T1 committee proposals...**
  - **Studied by one of US ITU's four study groups**
  - **Once approved, State Department submits to ITU as official US proposal**
- **ITU deliberates, discusses pros and cons, and, if approved, issues official Recommendation**
- **Recommendations can have legal status that varies from mandatory observance to voluntary observance**

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- In US, observance of ANSI standards and ITU standards is voluntary
  - ☞ Failure to follow standard at company's risk

Computer Network Standards Setting

- **Computer standards set by industry**
  - **No government interaction**
  - **Problem: Data networks merging with telecommunications network**
- **In US, computer network standards developed by Committee X3 of Computer Business Manufacturers Association**
- **LAN standards set by Institute of Electrical and Electronic Engineers (IEEE) Committee 802**
  - **Ethernet LAN, token-ring network, Gigabit Ethernet**
- **Committee 802, IEEE, and ANSI work with International Standards Organization (ISO) to develop international computer standards**

- Close cooperation between standards-setting groups
  - ☞ Usually obtained by overlapping memberships

Standard Fiber Networks

- Two fiber-optic network international standards
  - Fiber Distributed Data Interface (FDDI)
    - » Computer LAN
    - » 100 Mb/s
  - Synchronous Optical NETwork (SONET in US)
    - » International standard: Synchronous Digital Hierarchy (SDH)
    - » Wide-area telecom network
    - » Interconnection of WANs into seamless global network
    - » 155 Mb/s to many Gb/s