Resource Sharing: Multiplexing

Method 1 - Circuit-switching

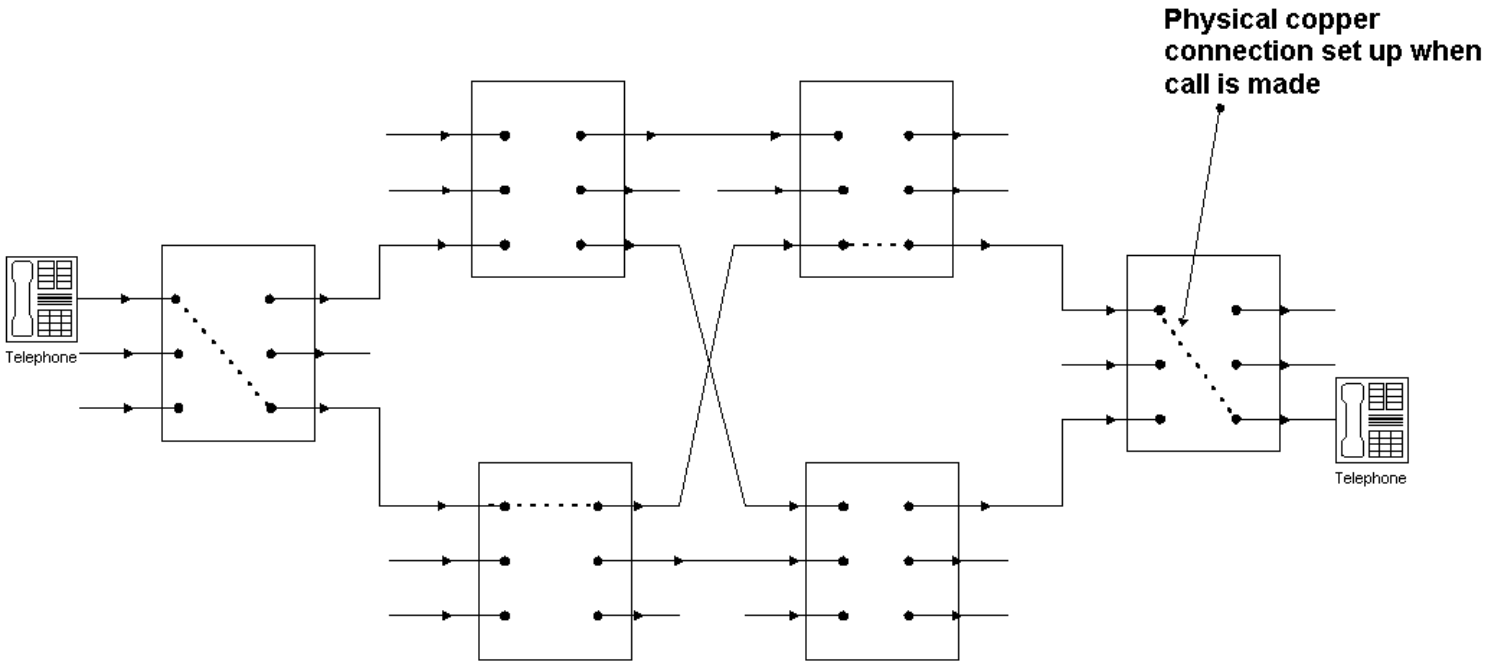


Fig. 2-34. (a) Circuit switching

"circuit-switching" refers to creating an electrical circuit for the duration of each telephone call.

Tanenbaum fig. 2-34(a)

Telephone switches

Wikipedia Commons

Telephone crossbar switch

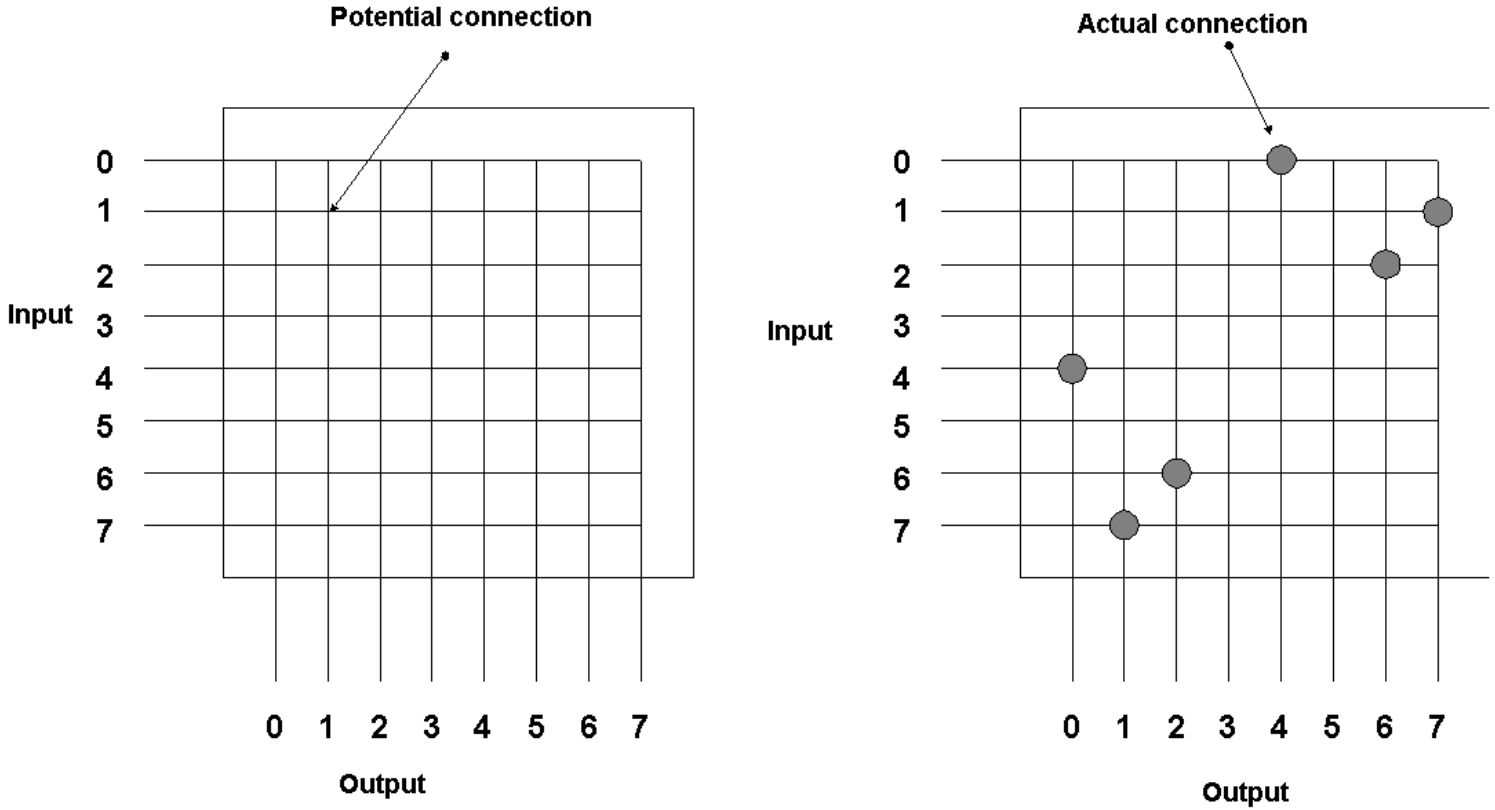


Fig. 2-38. (a) A crossbar switch with no connections. (b) A crossbar switch with three connections set up: 0 with 4, 1 with 7, and 2 with 6.

Tanenbaum fig. 2-38

Telephone switches often connect 10,000 lines (not 8 as shown).

Telephone space division switch

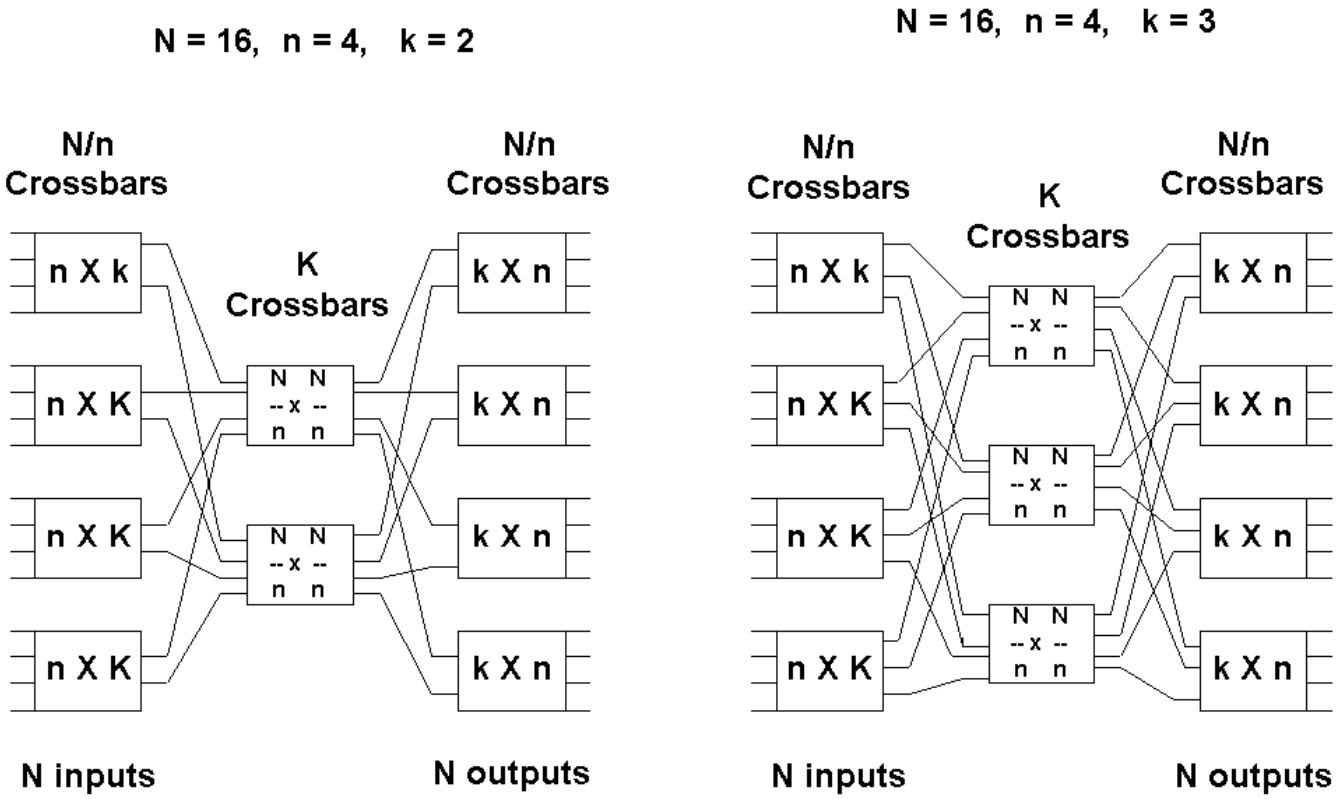
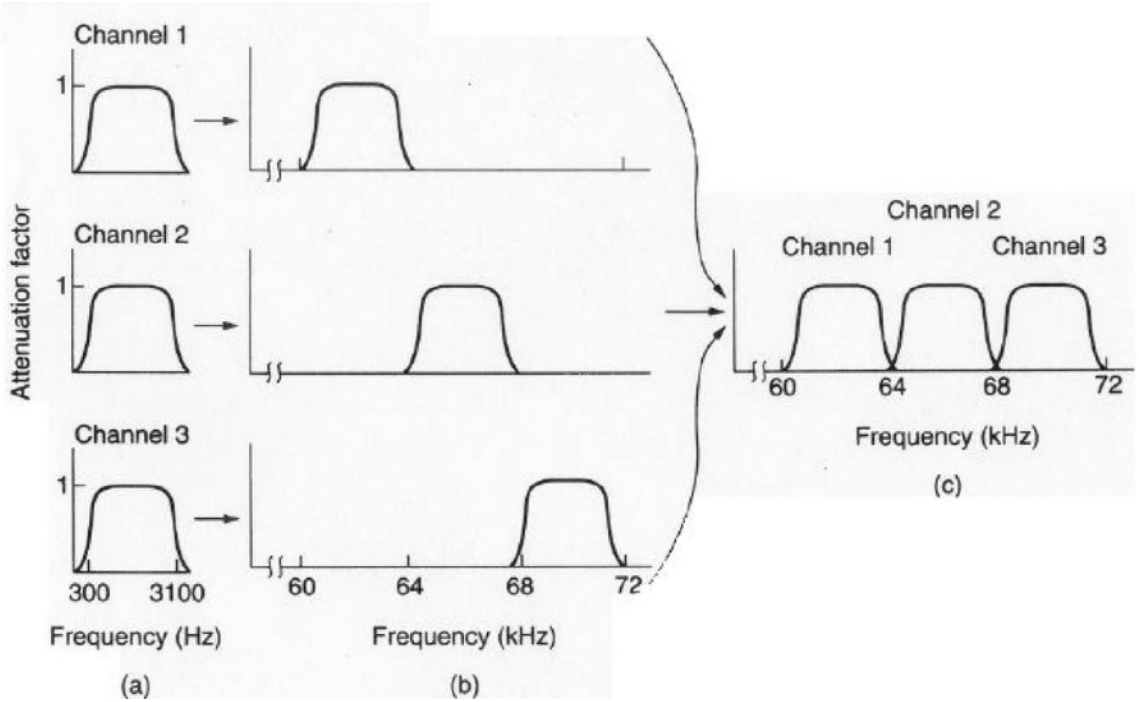


Fig. 2-39. Two space division switches with different parameters

Telephone switches often connect 10,000 lines (not 16 as shown).

Trunks: multiplexing

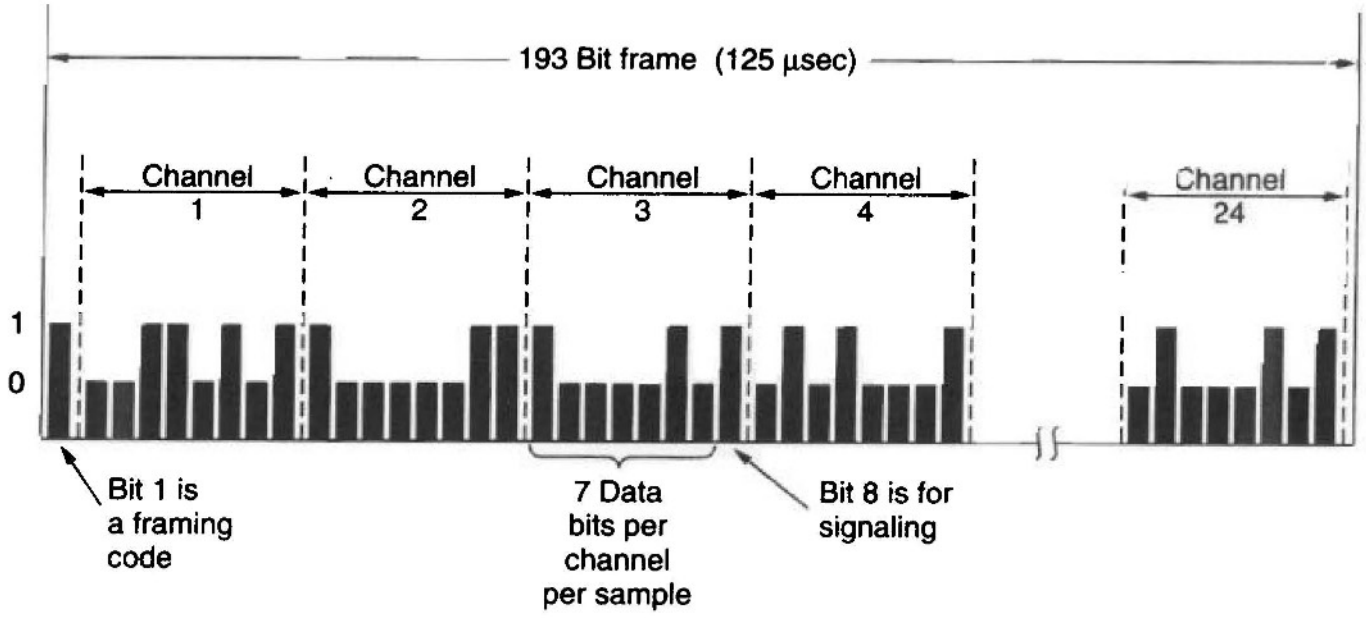
- Method 2 -- Frequency Division Multiplexing (FDM):



Tanenbaum fig. 2-24

Trunks: multiplexing

- Method 3 – Time Division Multiplexing (TDM):
  - Sample each 125 μsec. Quantize each sample into 7 bits. Combine 24 telephone calls



Tanenbaum fig. 2-26

Trunks for TDM streams

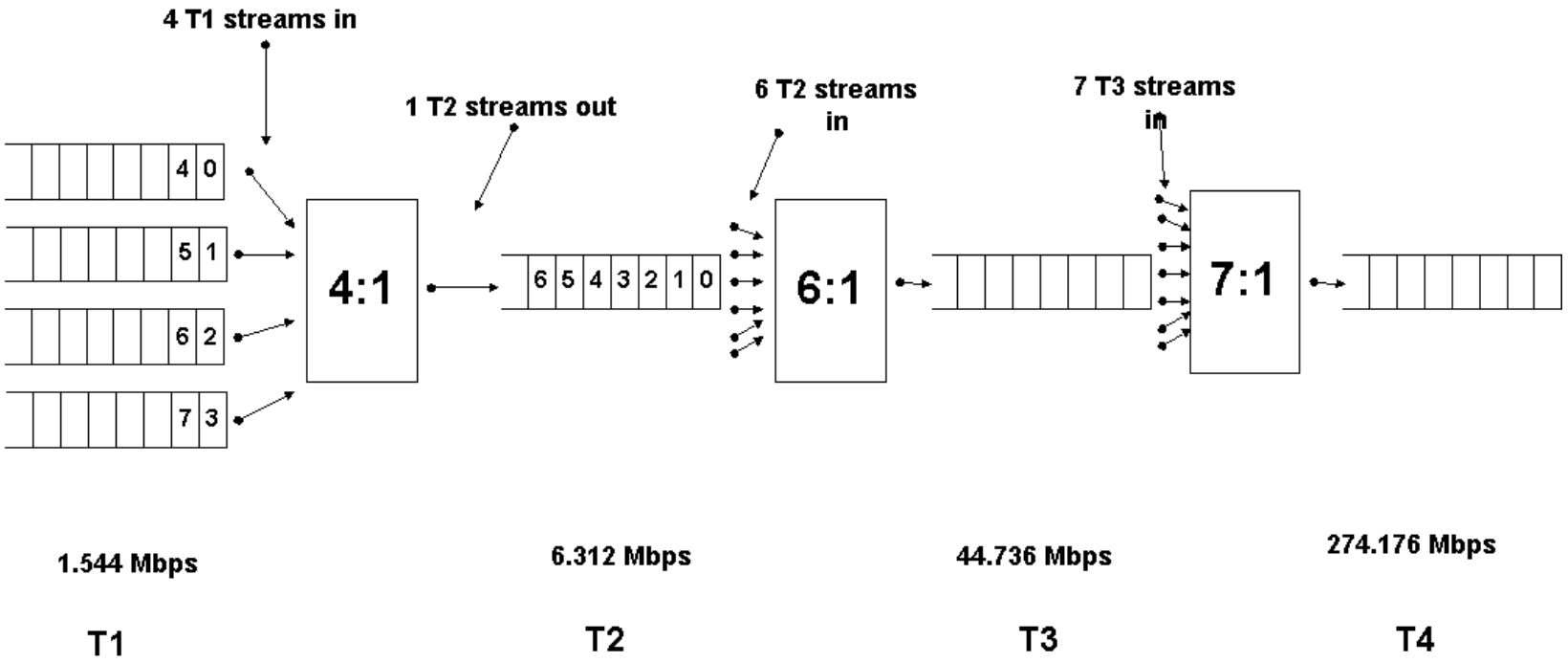
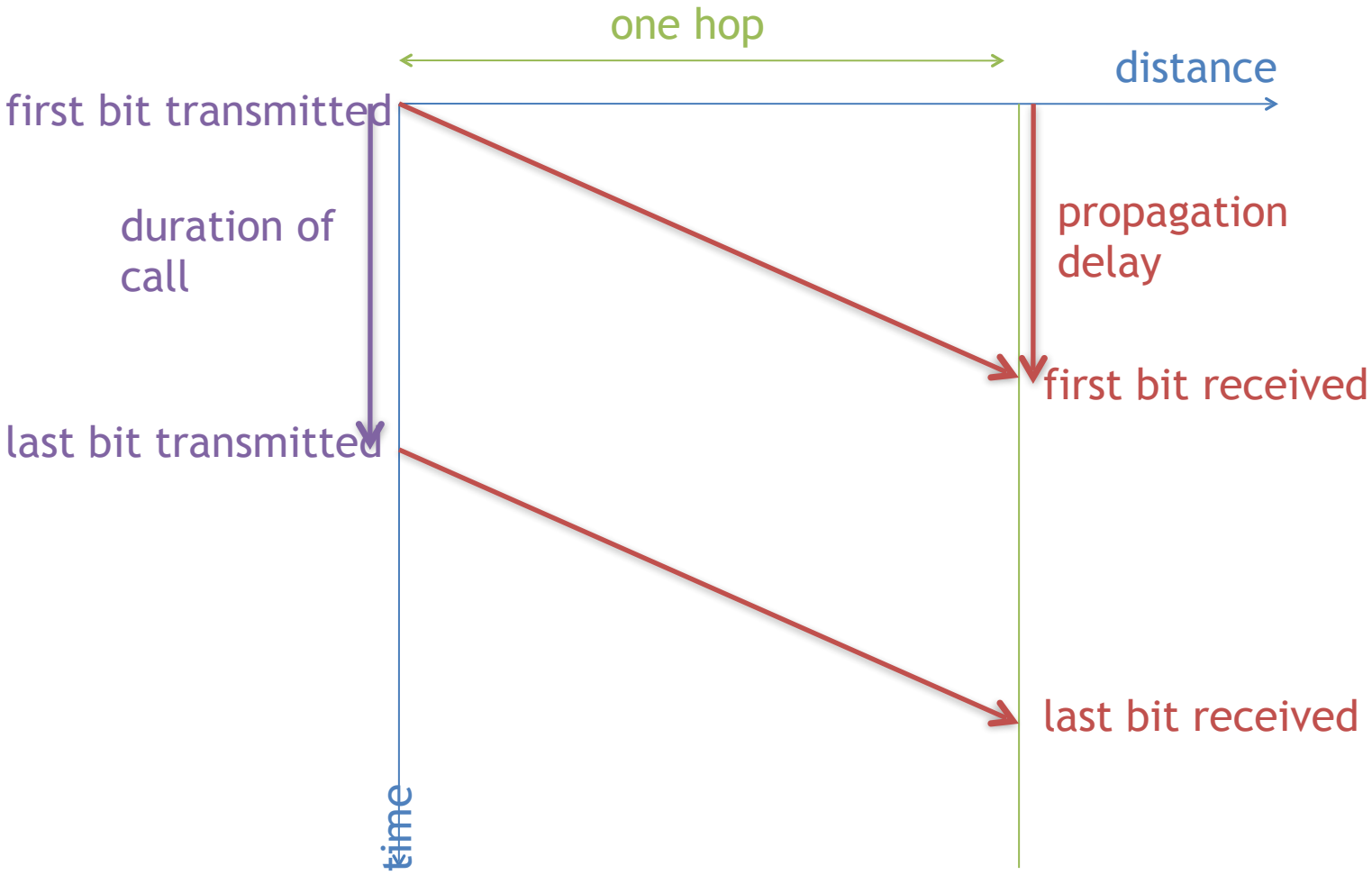


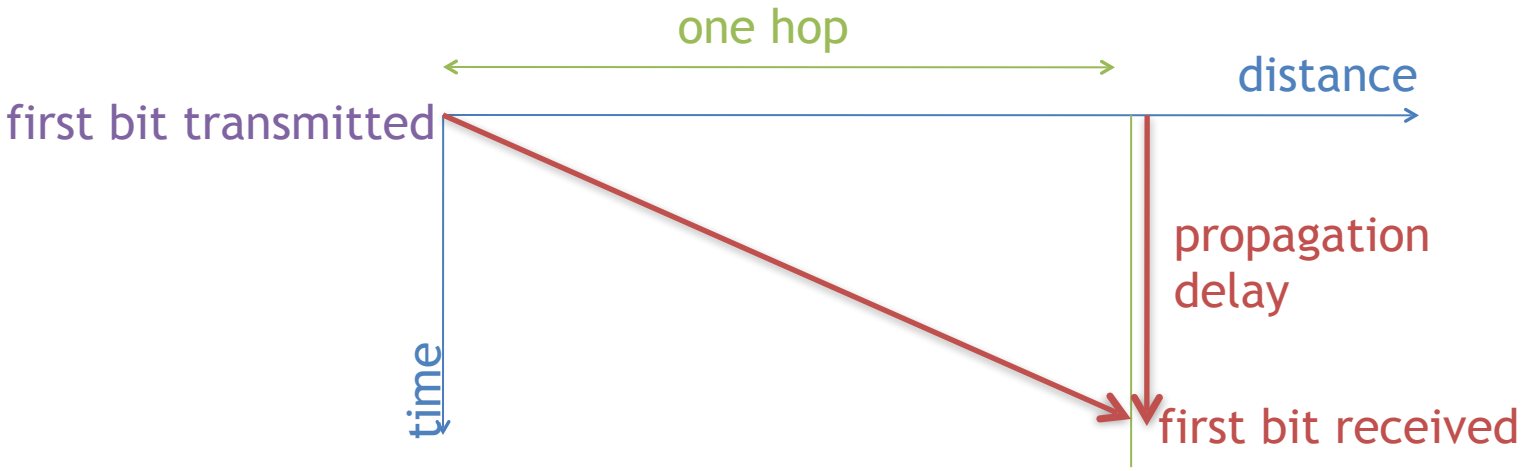
Fig. 2-28 Multiplexing T1 streams onto higher carriers

Tanenbaum fig. 2-28

Time versus distance



Propagation delay



Propagation delay
= distance / propagation speed

Example:
Hop = 100 km

Propagation delay
= 100 km / (3 * 10^8 m/s)
= 333 μsec

Time and distance

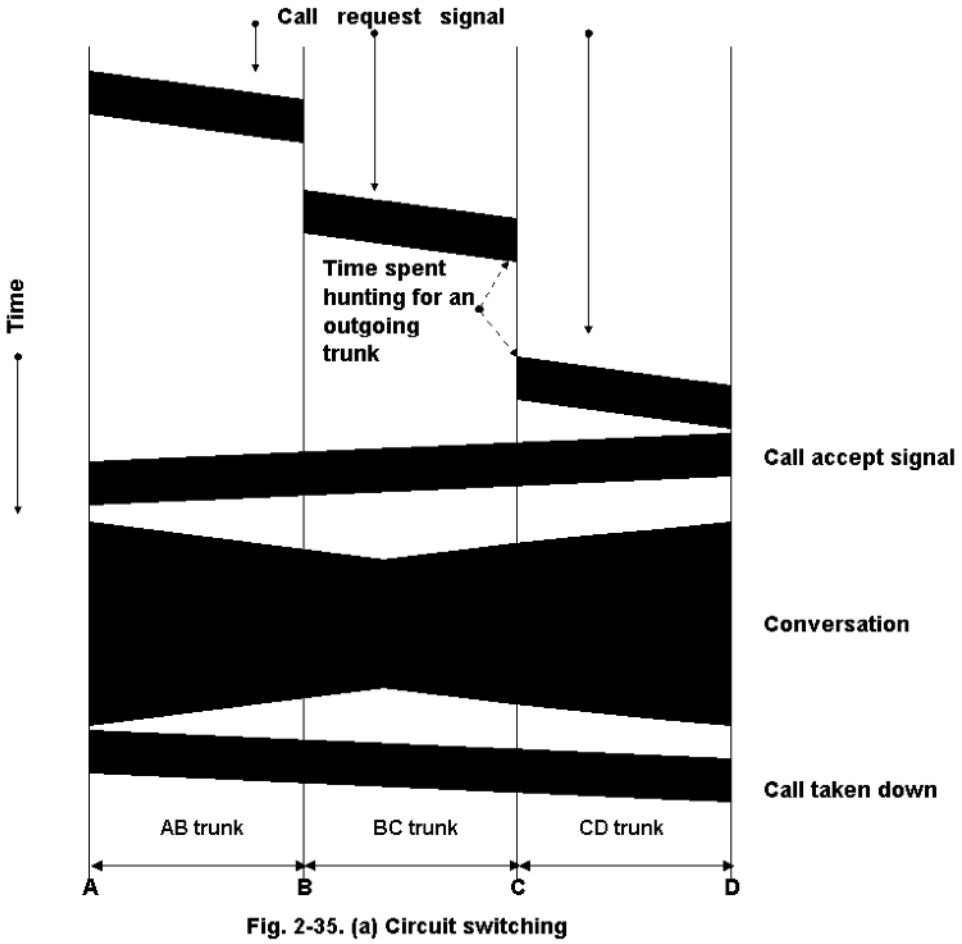


Fig. 2-35. (a) Circuit switching

Tanenbaum fig. 2-35(a)

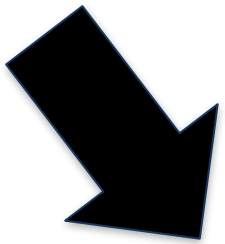
Horizontal axis is distance: source = A, destination = D.

Vertical axis is time, starting with the beginning of the call at the top.

Lines slope according to propagation delay from one location to another.

Design comments

- 1 Application
- Constant generation rate
- Long unicast sessions
- Sparse calls



- Circuit switching
- Resource reserved for the entire call
- Delay to set up a path

Internet and Packet switching

Key notions:

- Topology
  - Hierarchy: motivation
  - Structure of the network (offices, lines, trunks)
- Multiplexing (trunks)
  - FDM
  - TDM
- Circuit switching
  - Physical switching
  - TDM switching
  - Delay

Telephone network design

- 1 Application (voice)
- Constant traffic generation rate
- Long unicast sessions
- Sparse calls

- Circuit switching
- Resource reserved for the entire call
- QoS guaranteed (once the connection is established)

Internet design

- Multiple applications (e.g., file transfer, email)
- Bursty traffic generation
- Short (frequent) connections

- Packet switching
- Resource sharing
- Best effort (design variable)

Packet Switching

- Idea: decompose message into packets
  - Transmit the packets one by one.
- Packet switches/routers replace telephone routers.
  - Instead of setting up “circuits” for each call, route packets one by one.
  - Packets are buffered, first in first out.
- Efficient for bursty traffic

Terminology

- synchronous
  - all packets experience same delay from source to destination
- vs. asynchronous
  - packets experience different delays from source to destination, depending on queuing in routers

- connection-oriented
  - packets arrive in sequence sent
- vs. connectionless
  - packets don't necessarily arrive in sequence sent; need packet ordering

- reliable
  - no packets are dropped
- vs. unreliable
  - some packets dropped by routers; may need packets retransmission

Circuit switching vs. packet switching

- Circuit switching
  - synchronous
  - connection-oriented
  - reliable
- Datagram packet switching (without additional mechanisms, e.g. UDP)
  - asynchronous
  - connectionless
  - unreliable
- Datagram packet switching (with additional mechanisms, e.g. TCP)
  - To get synchronous, add buffering before playout (e.g. streaming programs)
  - To connection-oriented, add resequencing (e.g. TCP or in application)
  - To get reliable, add retransmissions (e.g. TCP or in application)

Topologies

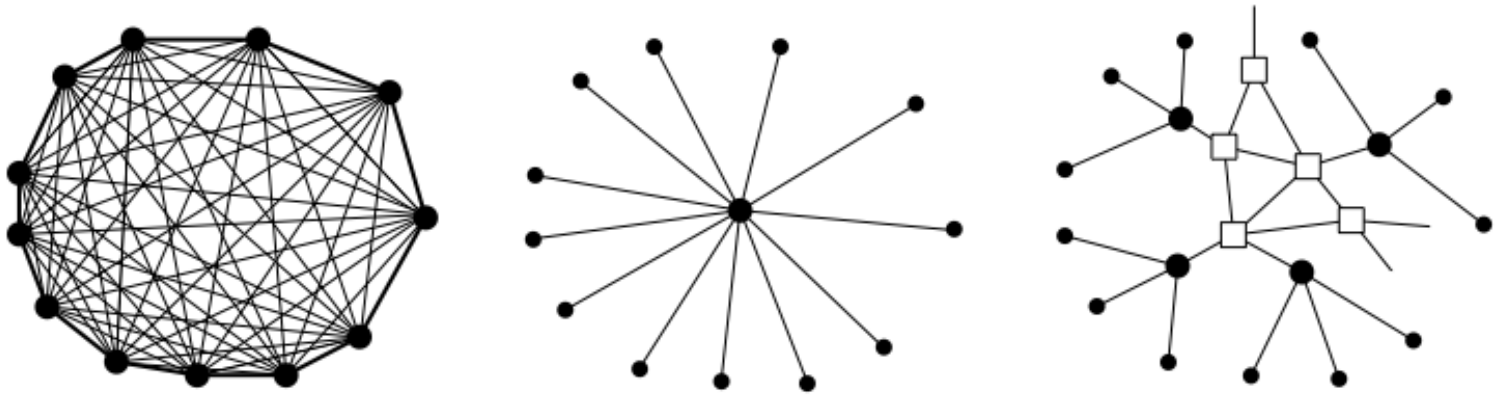
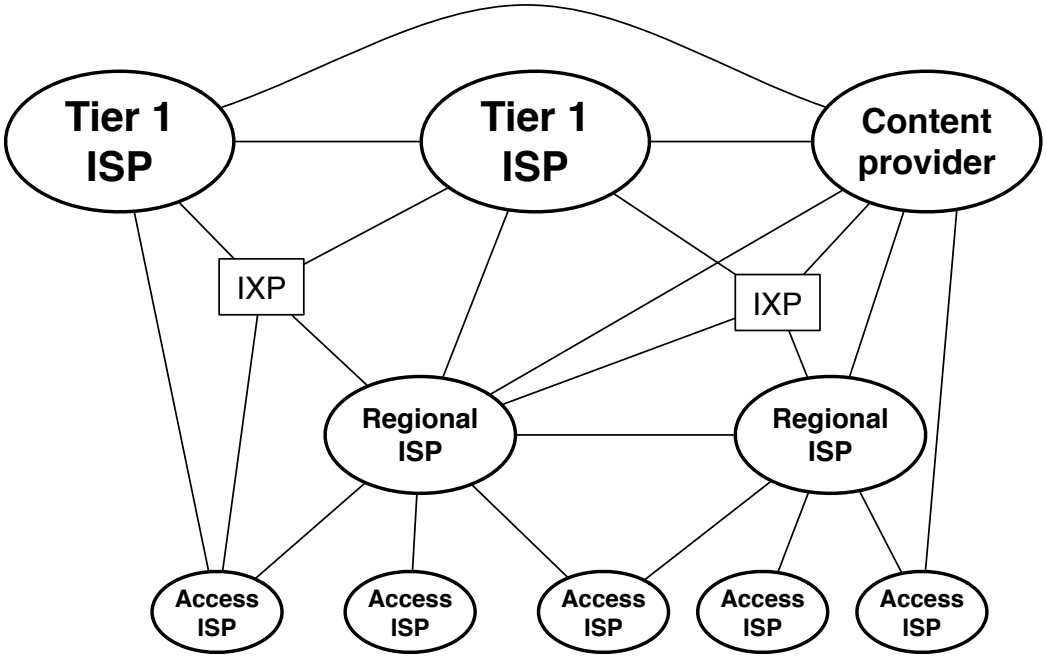


Figure 2-29. (a) Fully interconnected network. (b) Centralized switch. (c) Two-level hierarchy.

Tanenbaum fig. 2-29

Topology: network of networks



ISP: internet service provider

IXP: internet exchange points

Tier 1 ISP: AT&T, Sprint, NTT, etc.

Hierarchal structure of networks (sub-level tier is a costumer of the higher level tier)
Hosts connect to ISP via some access network

ARPANET 12/69

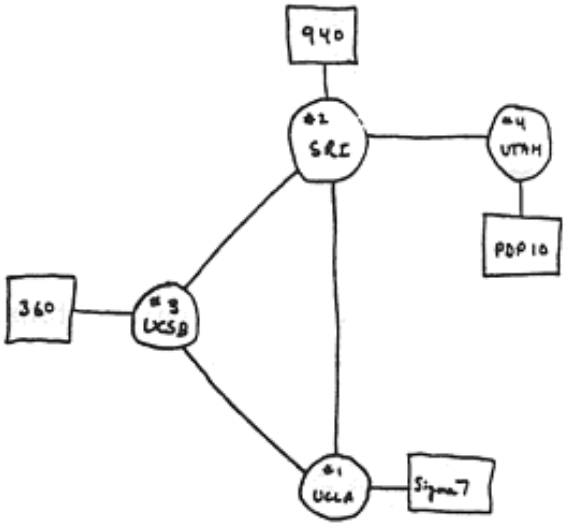
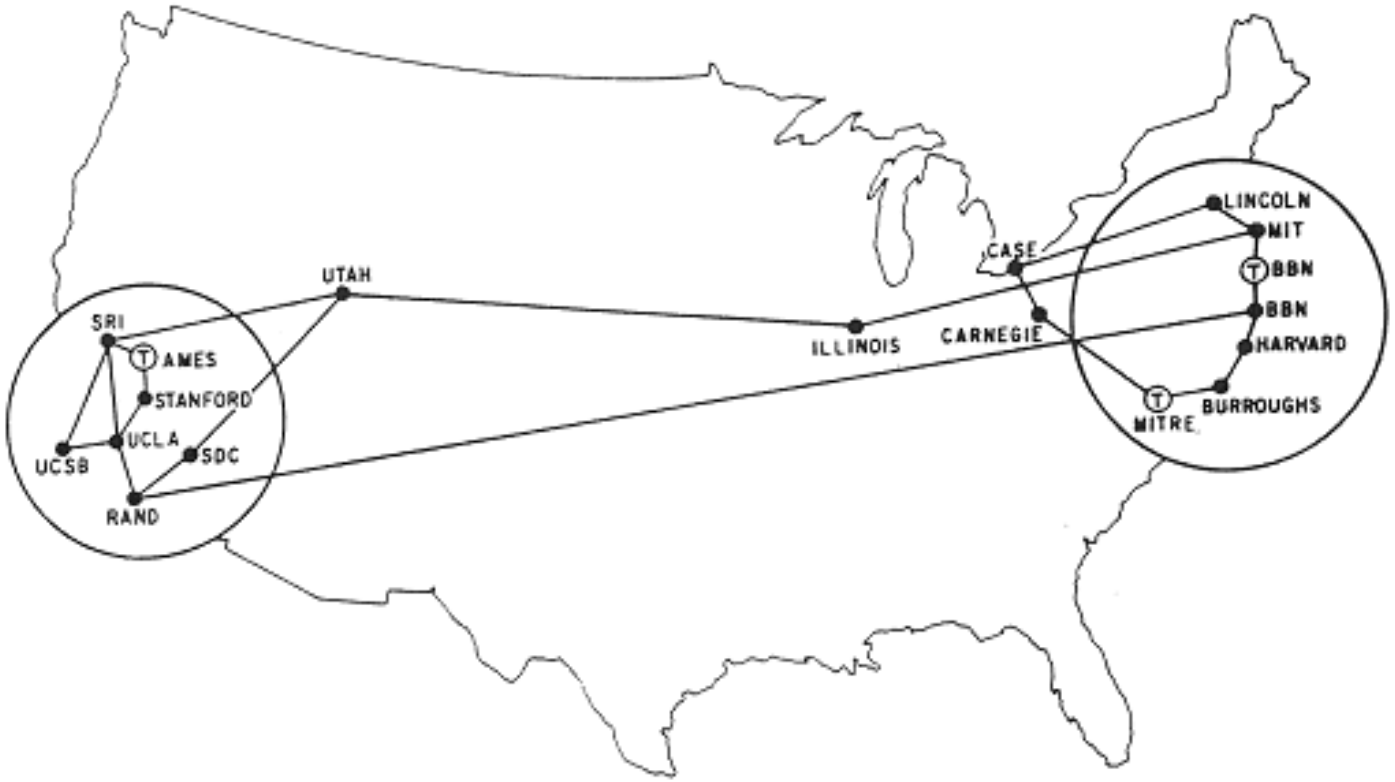


FIGURE 6.2 Drawing of 4 Node Network
(Courtesy of Alex McKenzie)

www.cybergeography.org

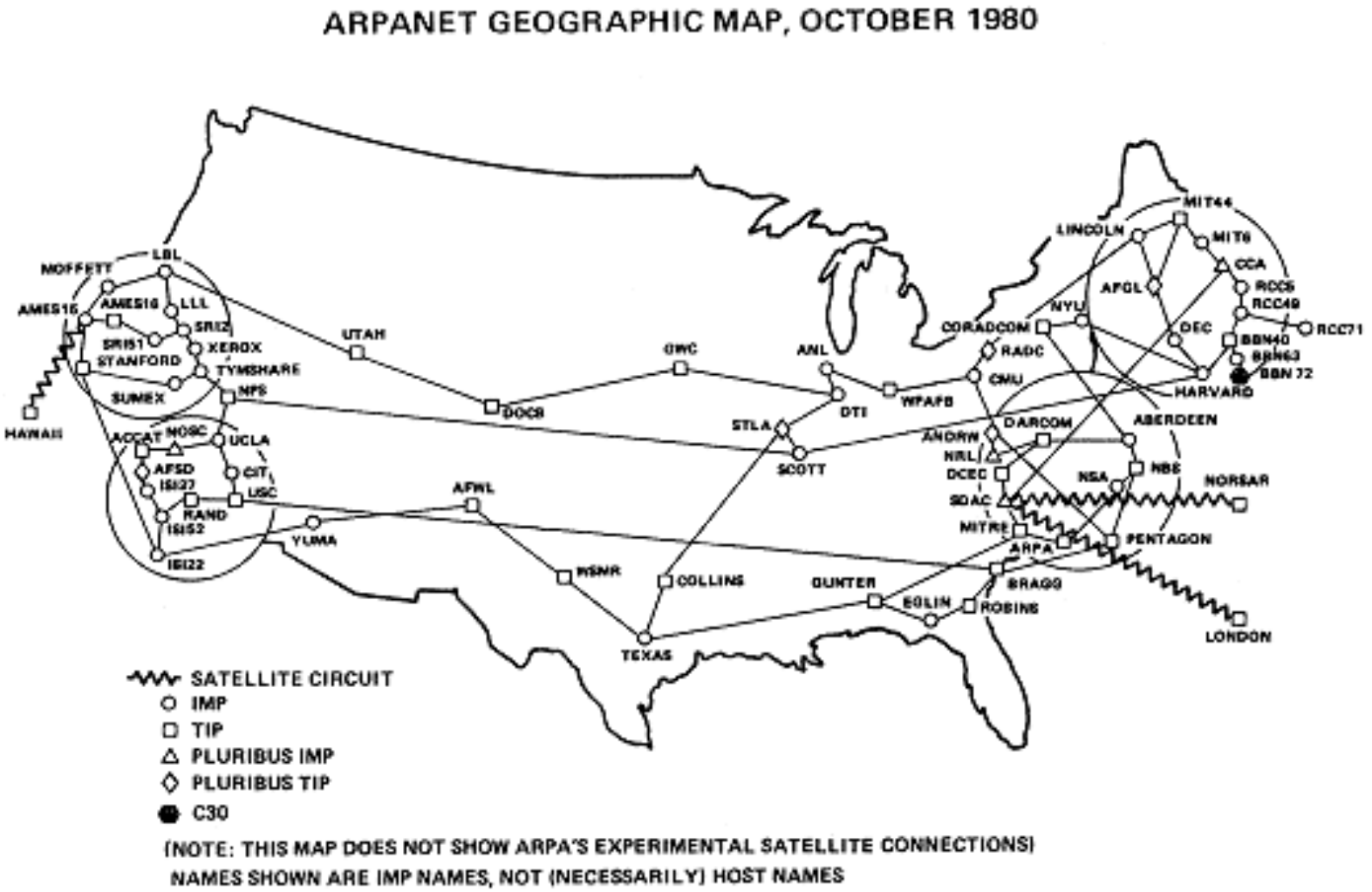
ARPANET 9/71



MAP 4 September 1971

www.cybergeography.org

ARPANET 10/80



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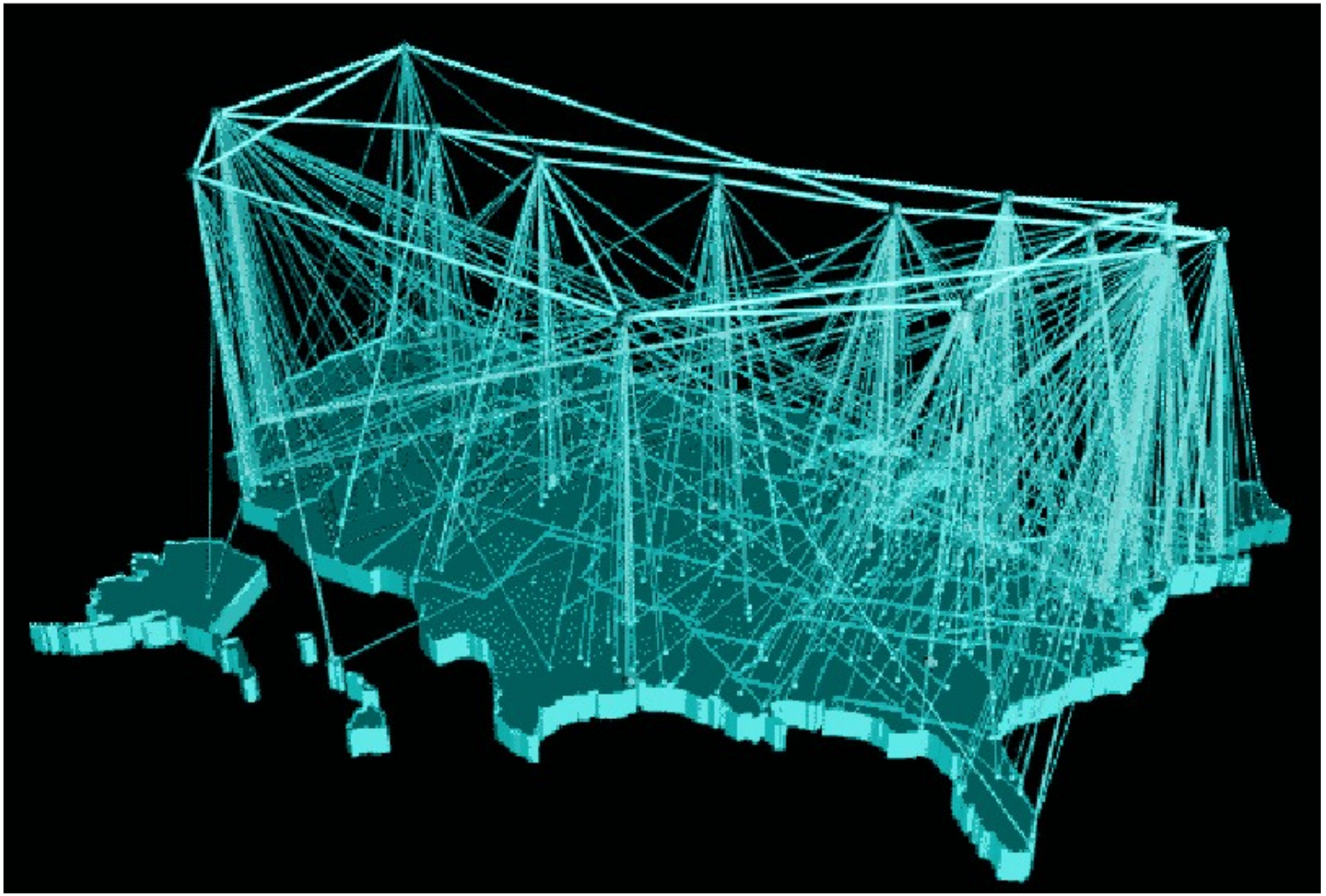
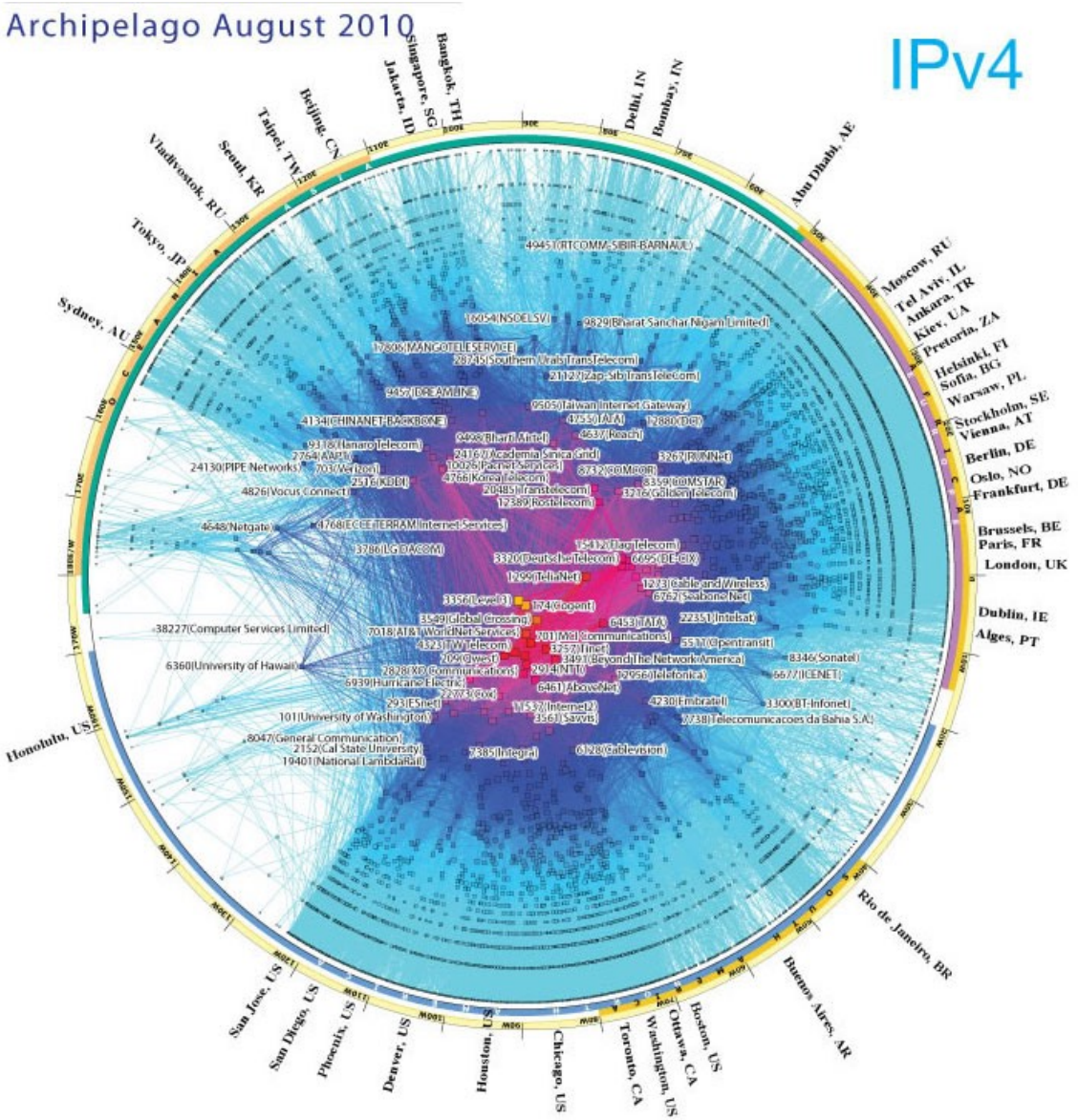
Internet (USA part) 1990



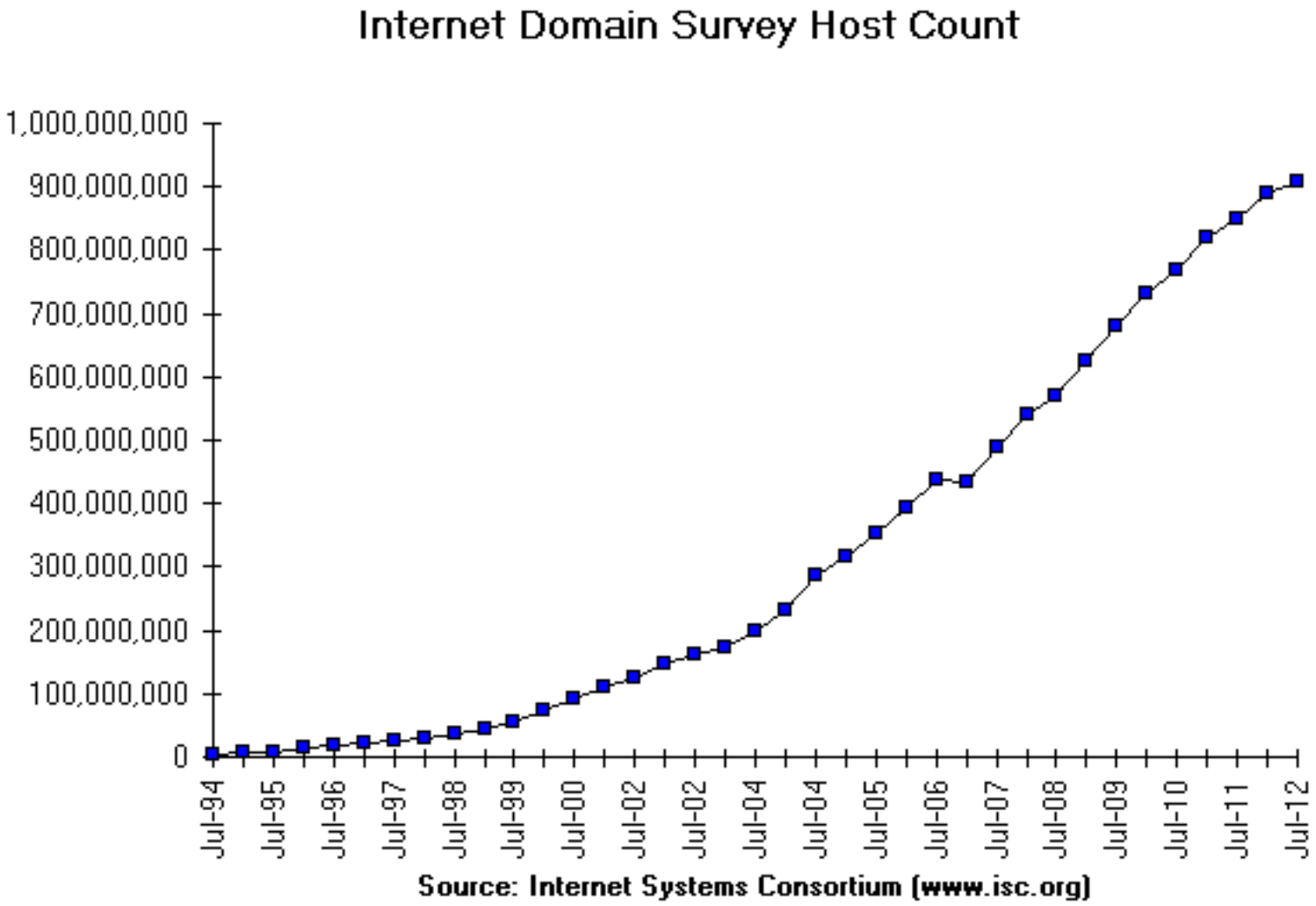
Walrand fig. 3.1

Internet core 8/10



CAIDA / UC Regents

Internet host count



Time and distance

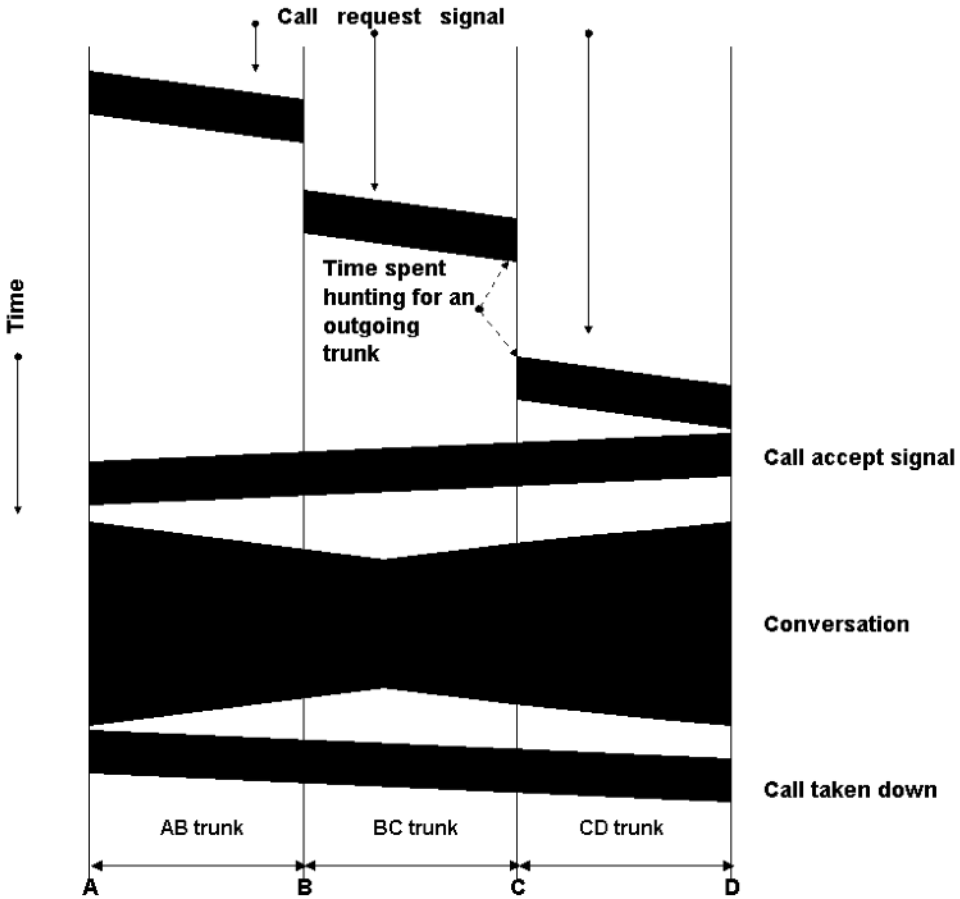


Fig. 2-35. (a) Circuit switching

Horizontal axis is distance: source = A, destination = D.

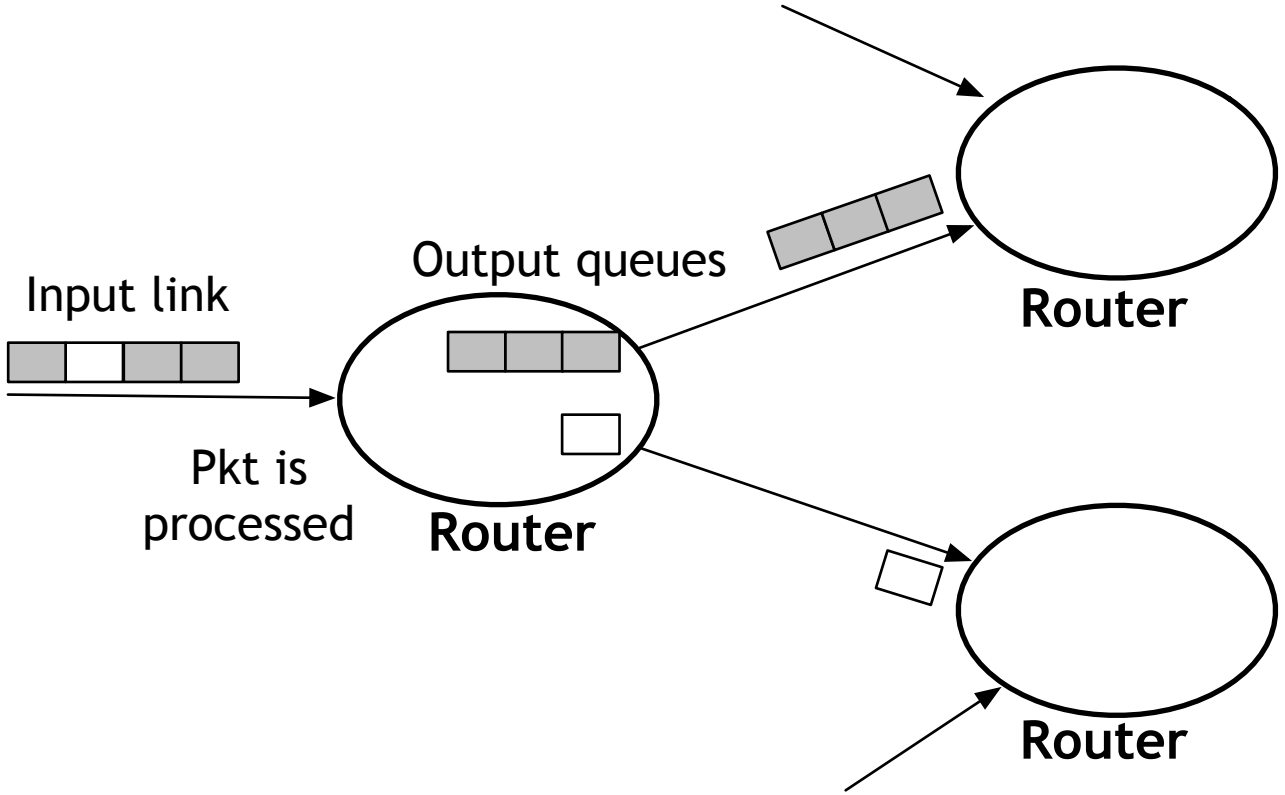
Vertical axis is time, starting with the beginning of the call at the top.

Lines slope according to propagation delay from one location to another.

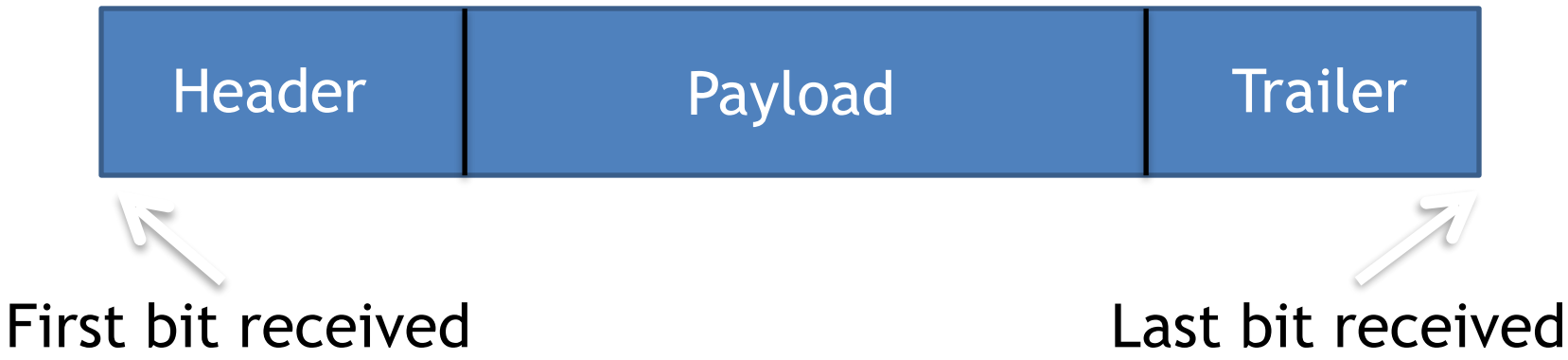
Tanenbaum fig. 2-35(a)

Queueing

Packet is processed, then sent to the output queue



Why is the entire packet processed before it is forwarded?



Error correction performed at each hop

Packet regeneration (two steps: demodulation/ remodulation, and error correction)

Multiplexing: TDM streams

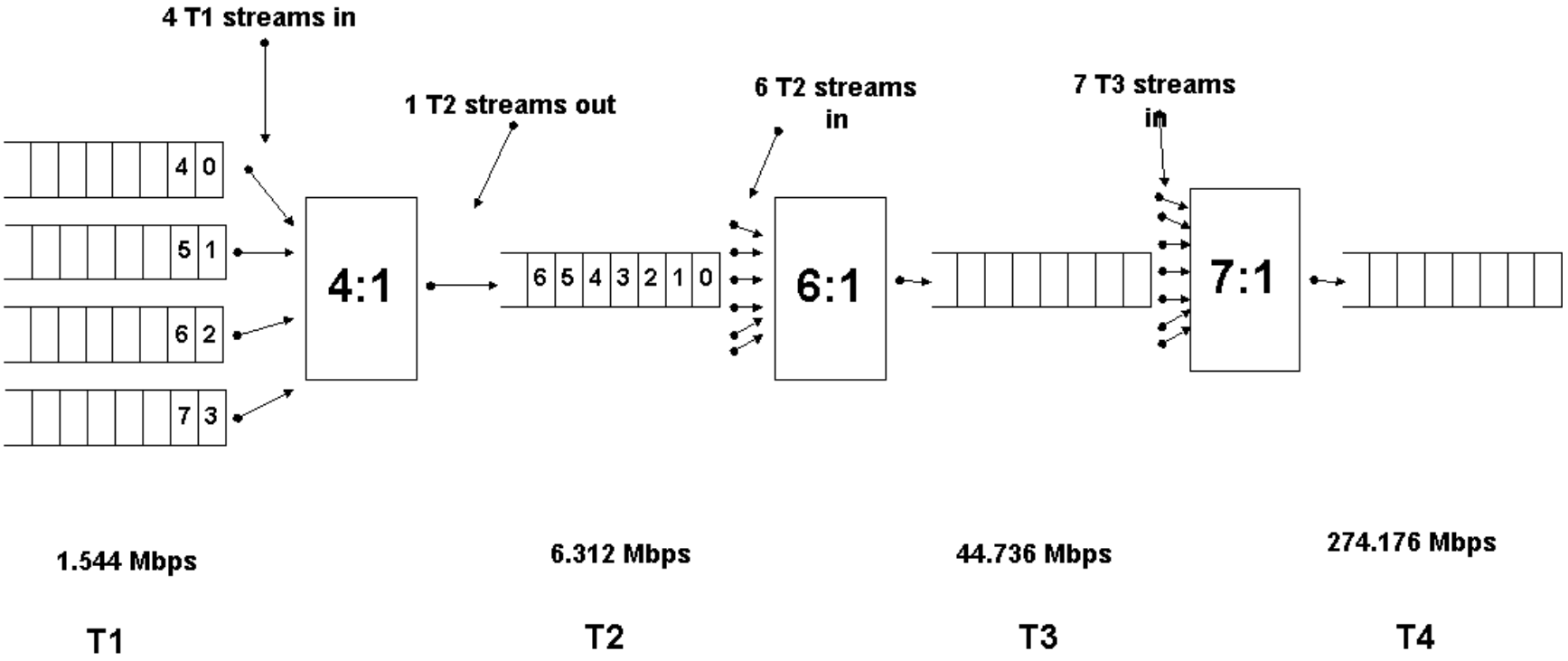
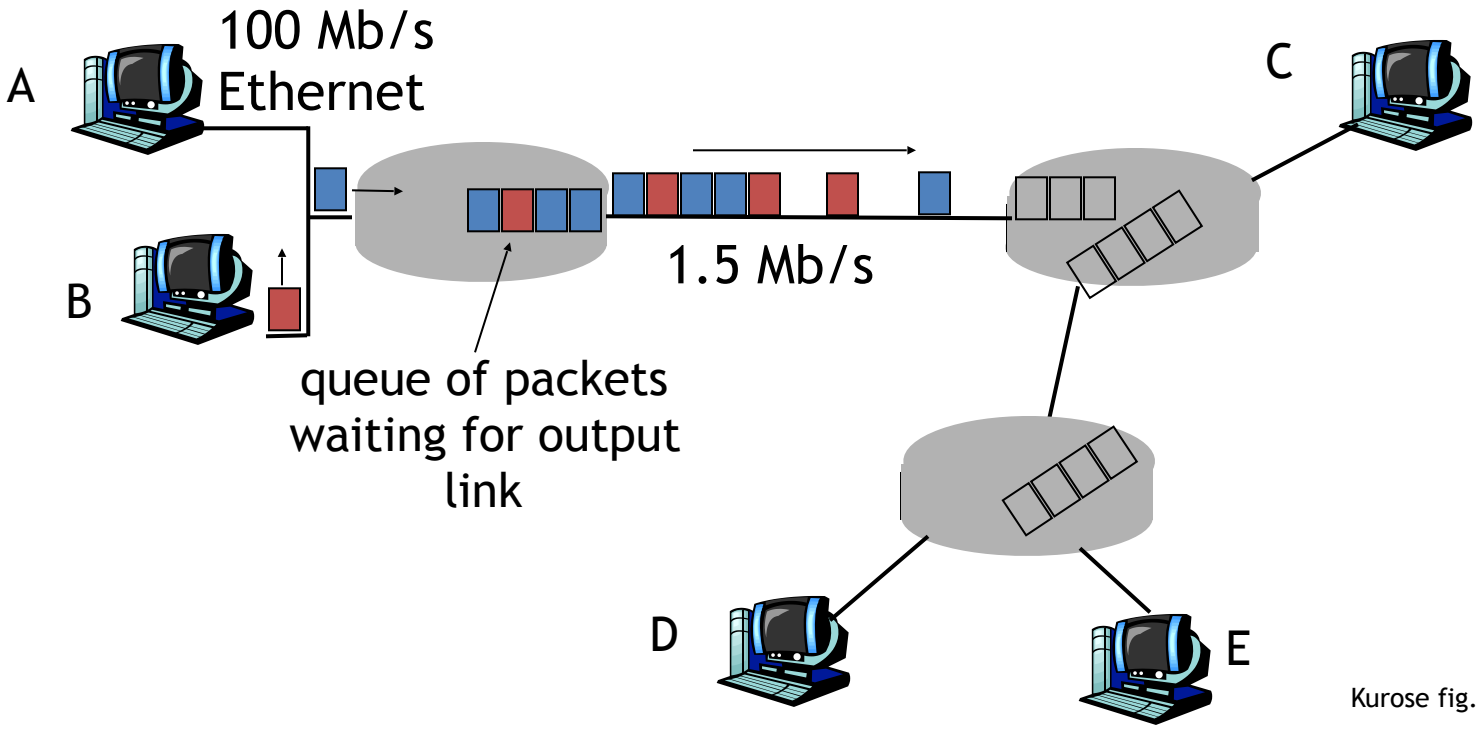


Fig. 2-28 Multiplexing T1 streams onto higher carriers

Tanenbaum fig. 2-28

Multiplexing



Kurose fig. 1.14

Statistical (vs deterministic) TDM multiplexing

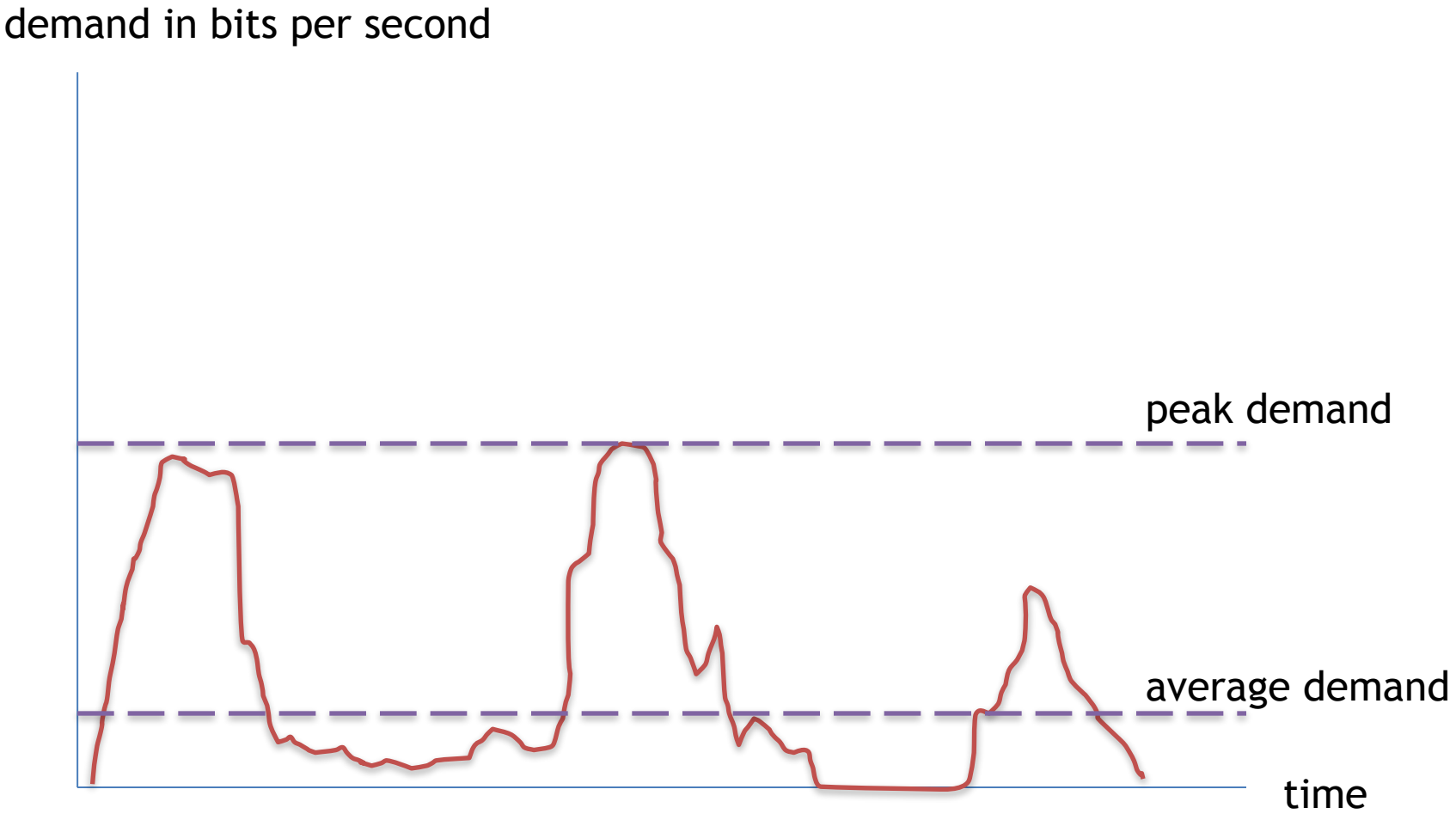
Function of: traffic rate of other nodes, congestion (tx speed), etc.

Consequence

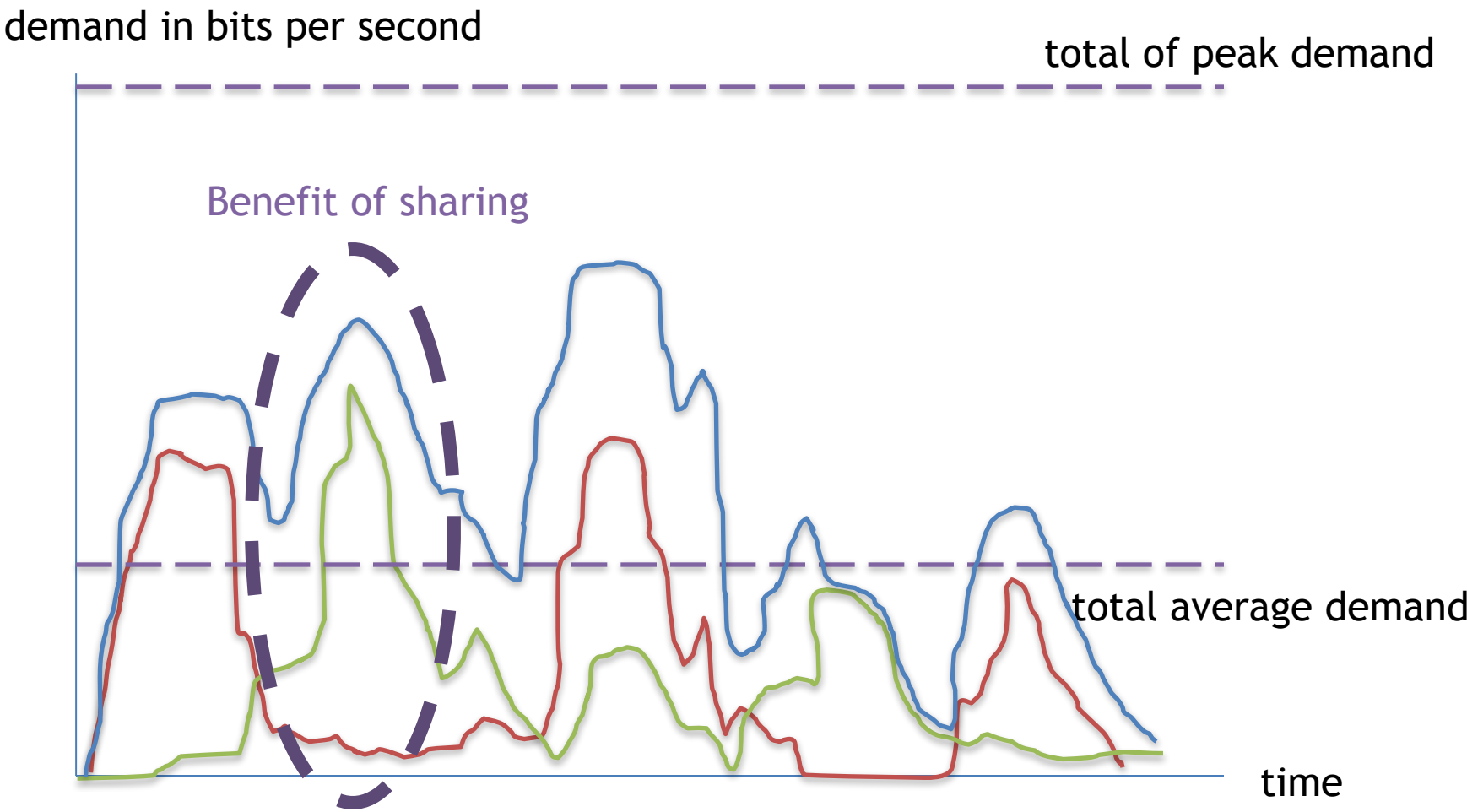
Performance metrics (delay, throughput, packet loss probability) of an individual packet are:

Random variables!

Demand



Sharing

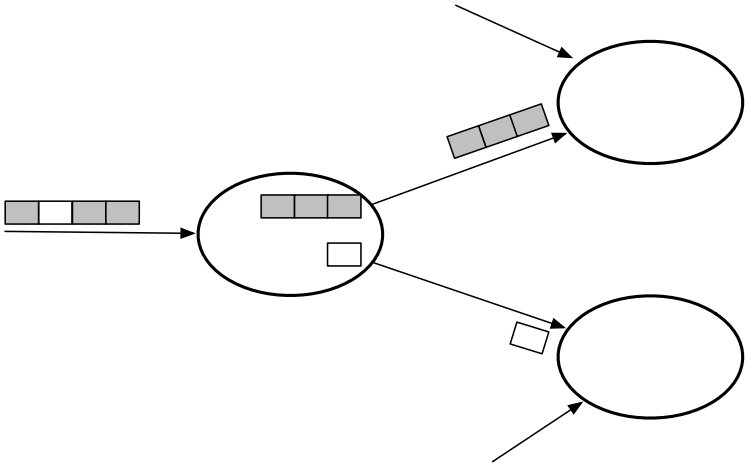

demand in bits per second
total of peak demand
Benefit of sharing
total average demand
time

Cell phone networks

- 1G – circuit-switched analog voice
- 2G – circuit-switched digital voice & rudimentary data
- 3G – circuit-switched digital voice & packet switched data
- 4G – packet switched digital voice (VoIP) & packet switched data

Wired vs Wireless

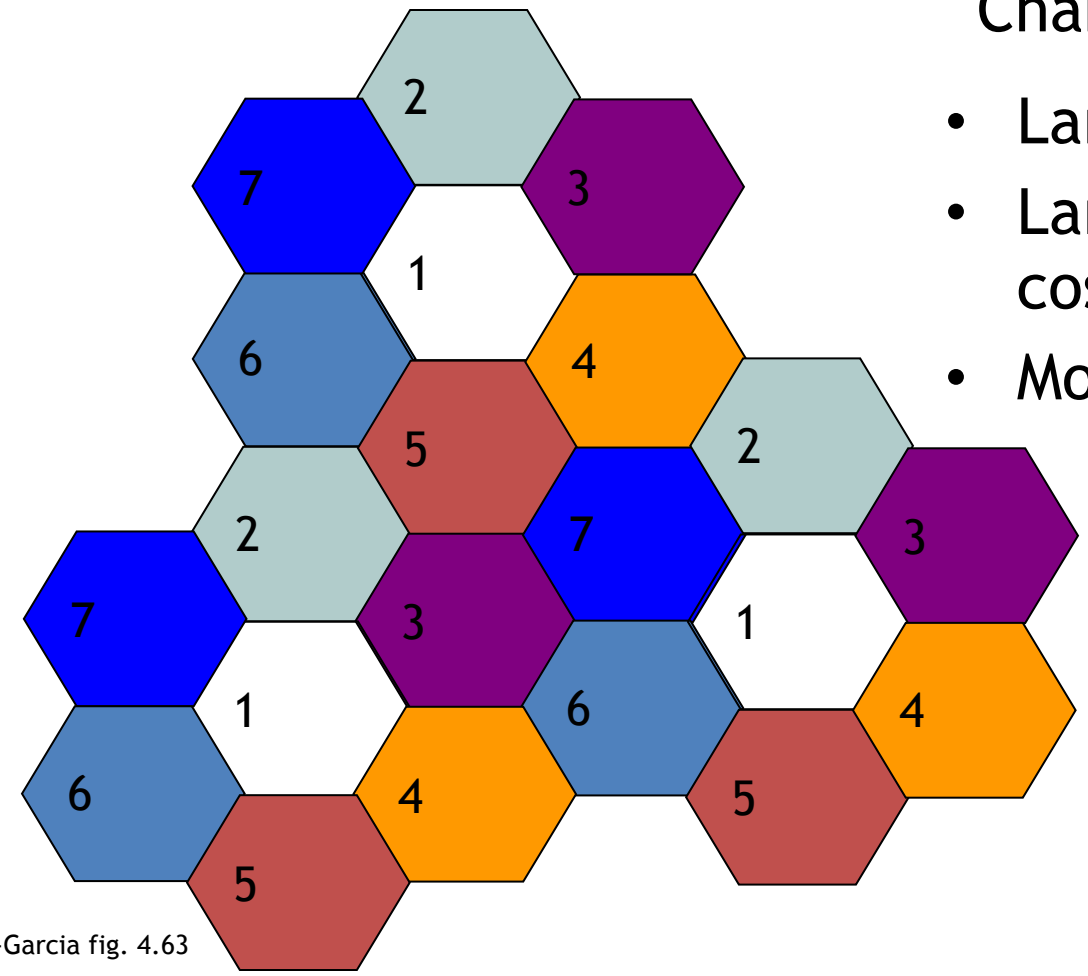
Wired: spatial multiplexing



Wireless: broadcast channel

Interference

Cell structure



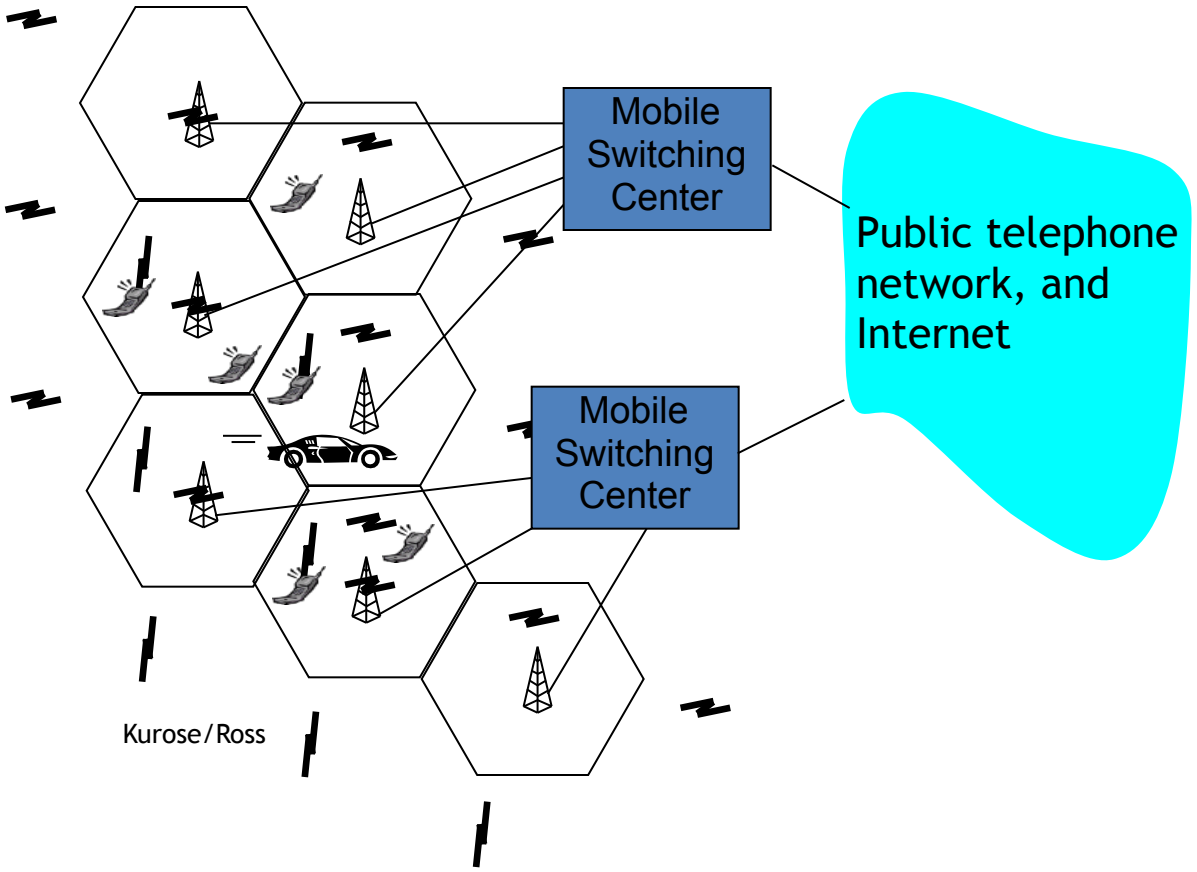
Leon-Garcia fig. 4.63

Channel reuse

- Larger capacity
- Larger infrastructure cost
- More Uniform coverage

Cell phone networks

MSCs control end-to-end connection, channel assignment and handoff, and are connected to the PTN and internet

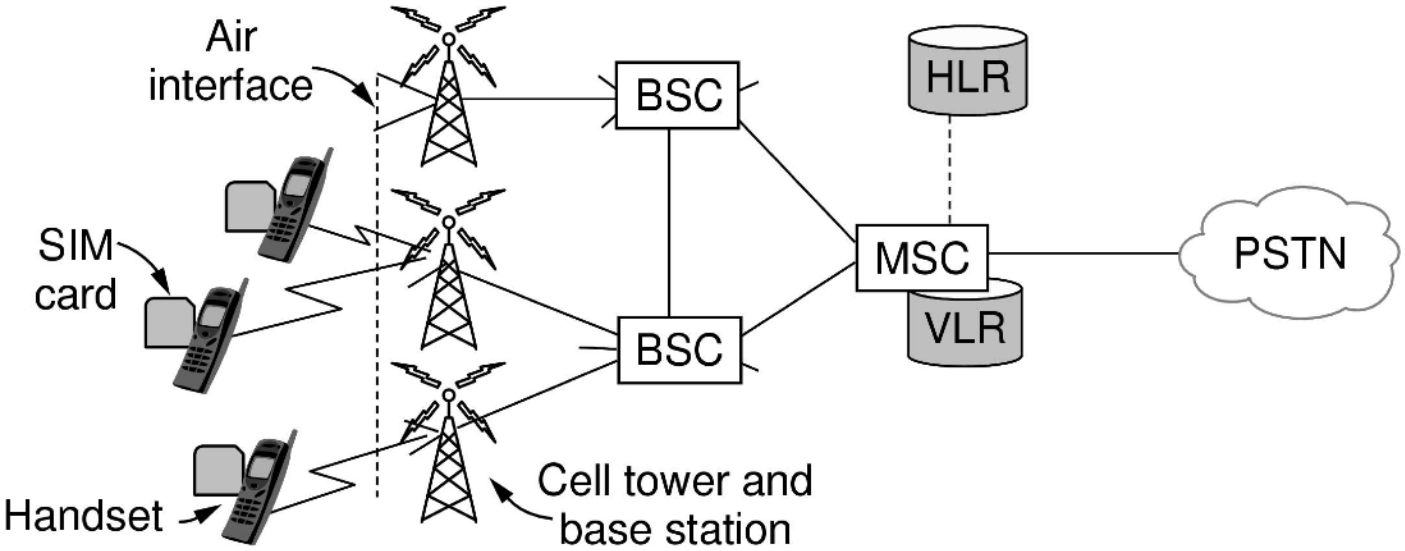


To make calls:
Access channel (contention based)

Incoming calls:
paging channel

GSM

TDM: channels are assigned to multiple users



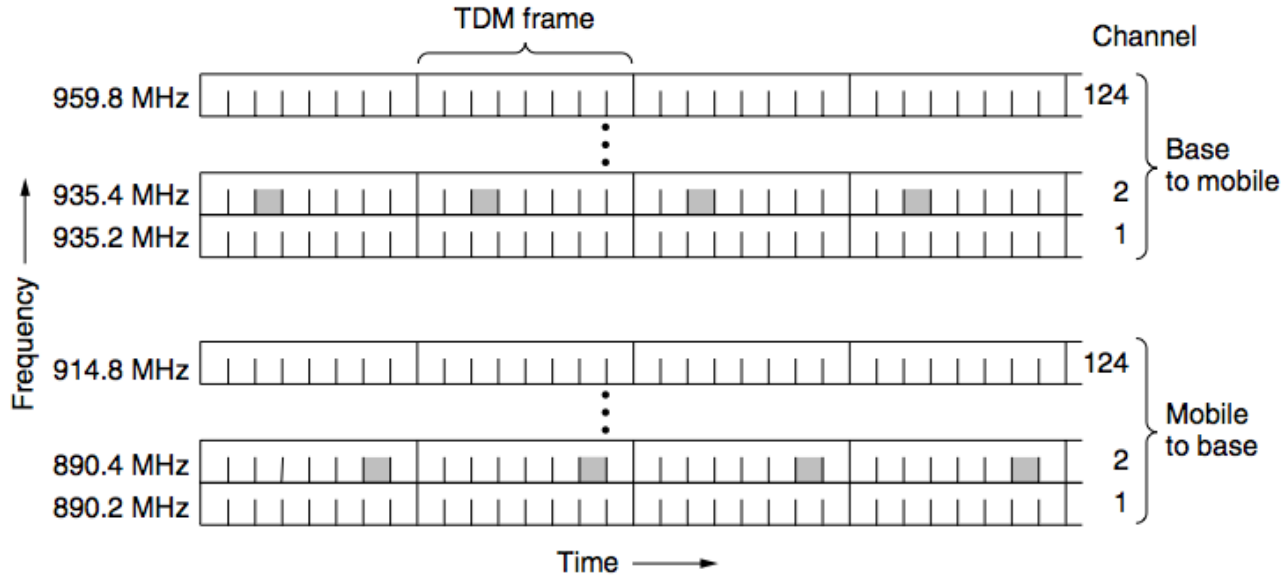
Tanenbaum

The BSC (Base station controller) control channel resource and handoff

The MSC (Mobile Switching Center) routes calls using the Visitor Location Register (local users) and the Home Location Register (last known location)

GSM

FDM + TDM: channels are assigned to multiple users



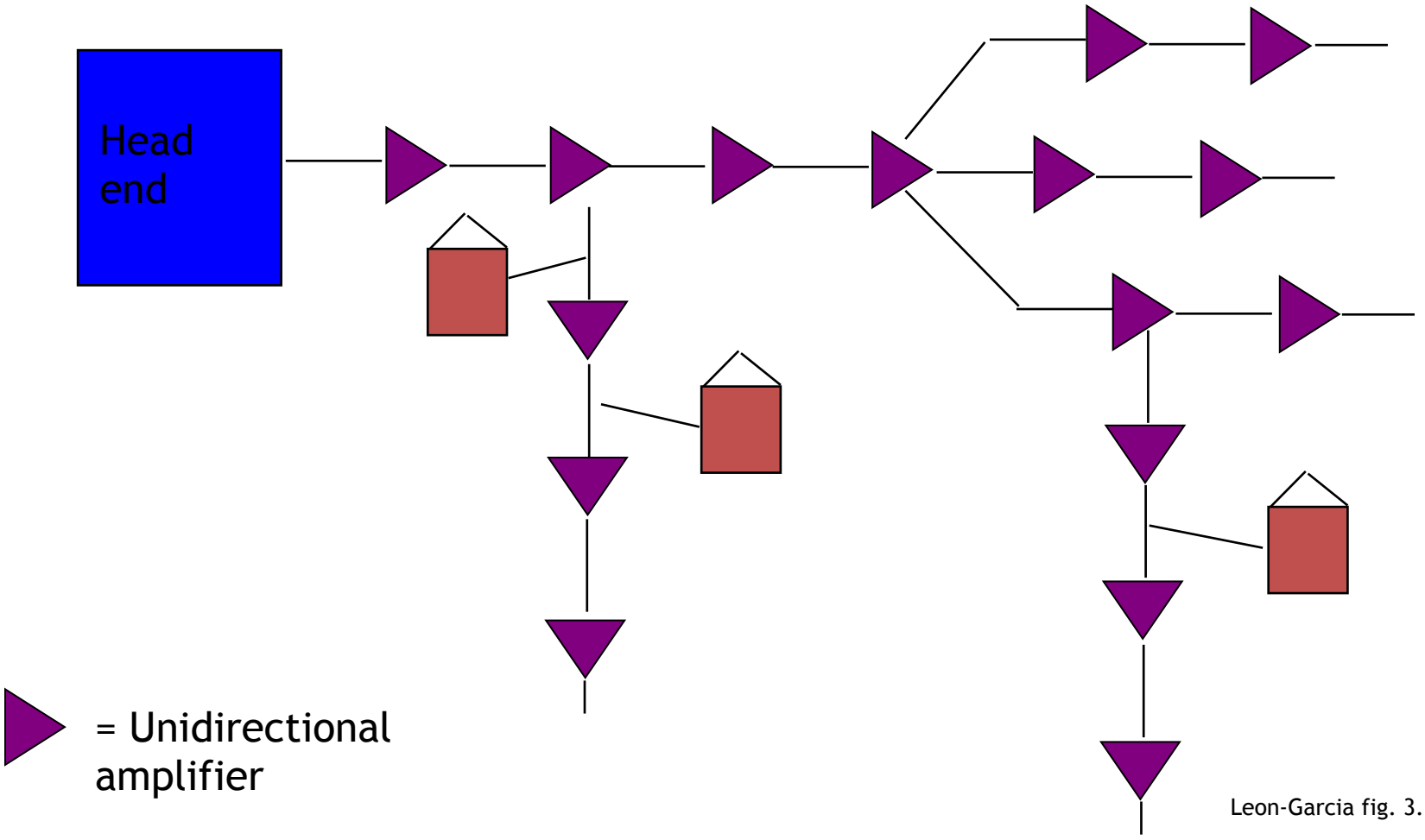
Tanenbaum

Downstream/upstream in different slots (half-duplex)

Cell phone Internet access

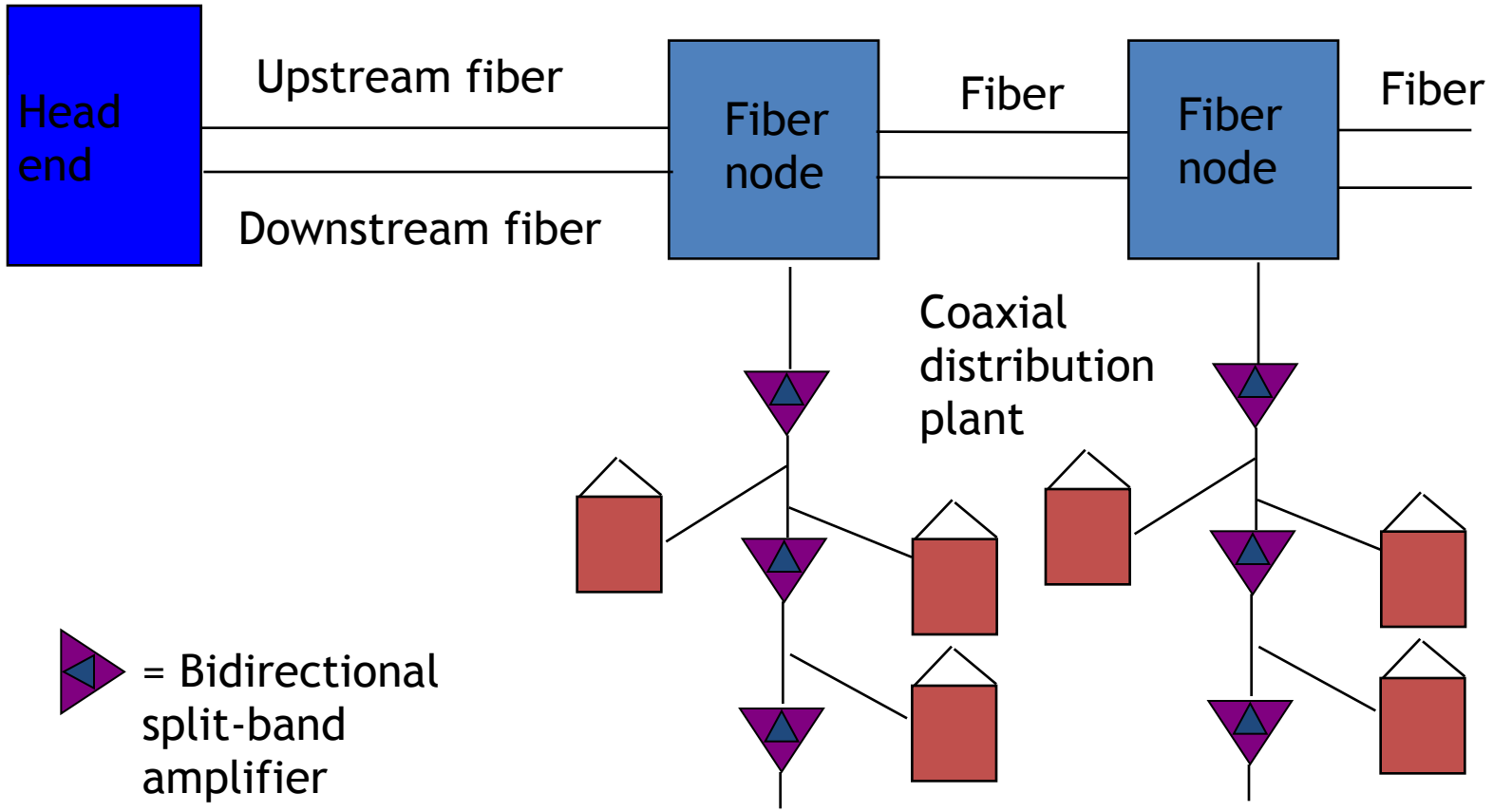
- 2 merging families of standards (GSM, CDMA)
- FDM/TDM/CDMA used to define “channels”
- downstream (base station to mobile)
  - packet switching
  - no contention!
- upstream (mobile to base station)
  - contention!
  - typically use a version of slotted ALOHA to reserve timeslots
  - also uses power and rate allocation

Cable TV networks



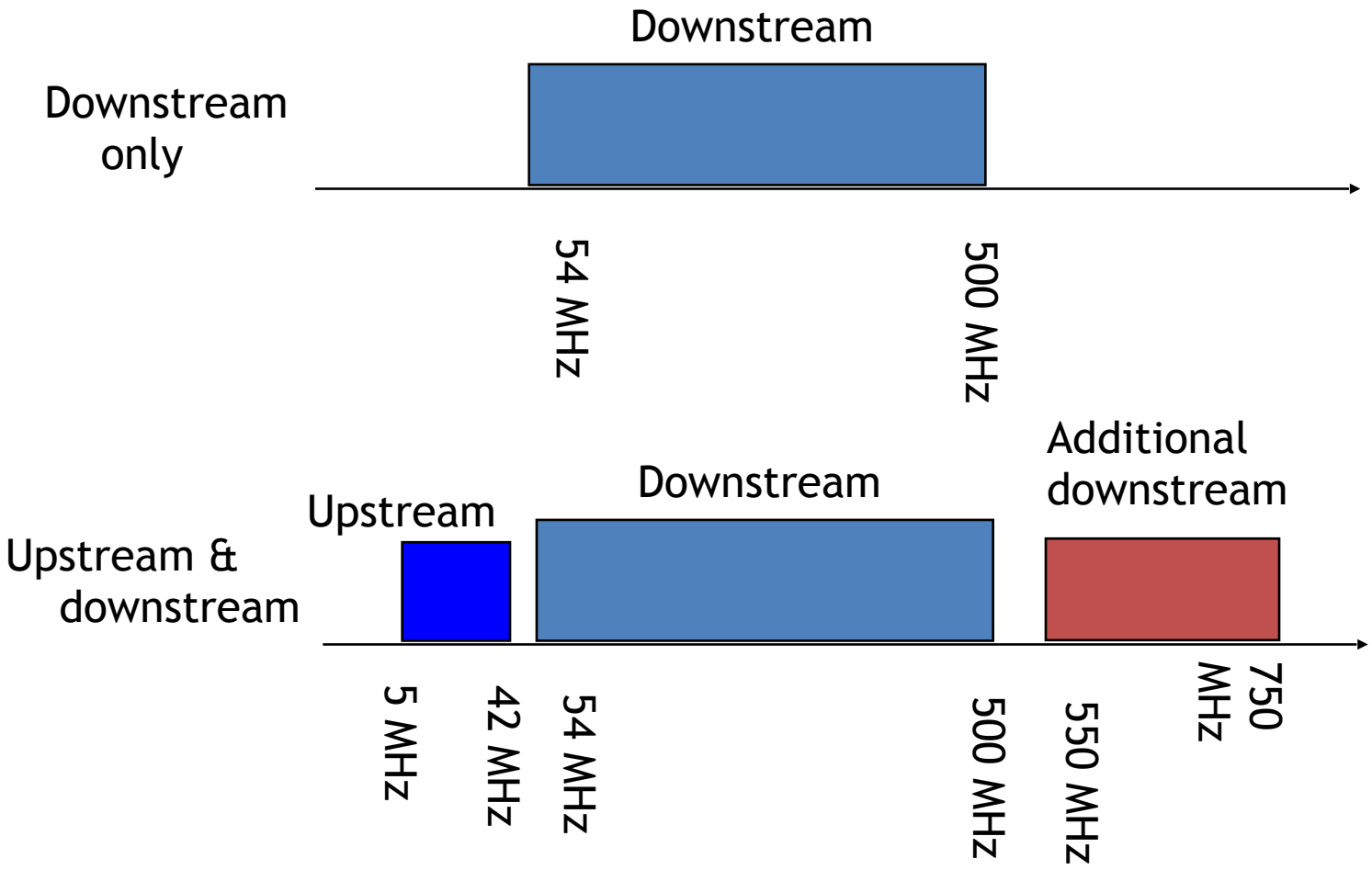
Leon-Garcia fig. 3.51

Cable TV networks



Leon-Garcia fig. 3.52

Cable TV networks



Leon-Garcia fig. 3.53