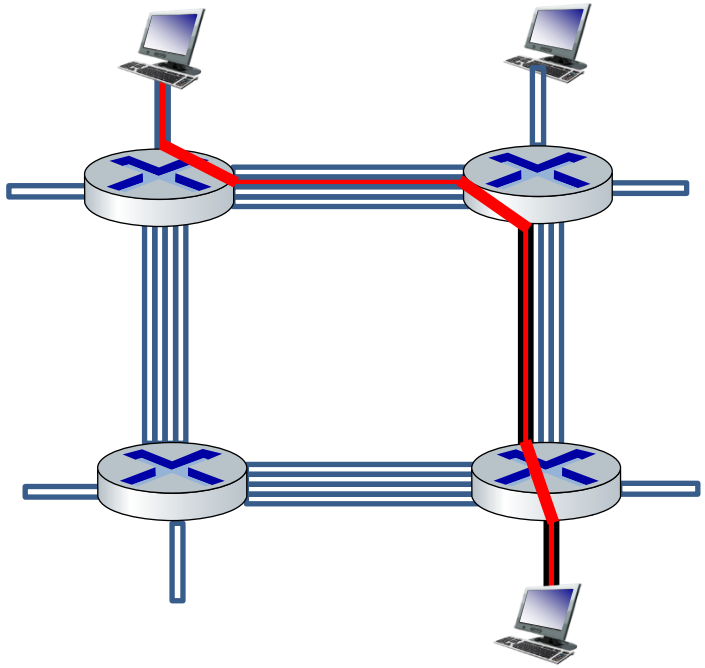
Alternative to packet switching: circuit switching

end-end resources allocated to, reserved for "call" between source and destination

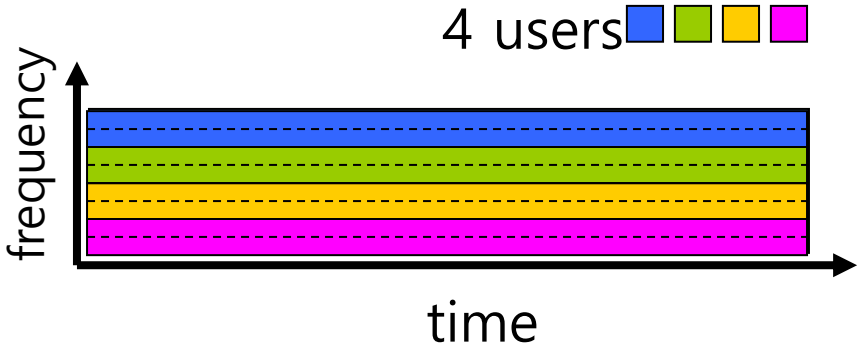
- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks



Circuit switching: FDM and TDM

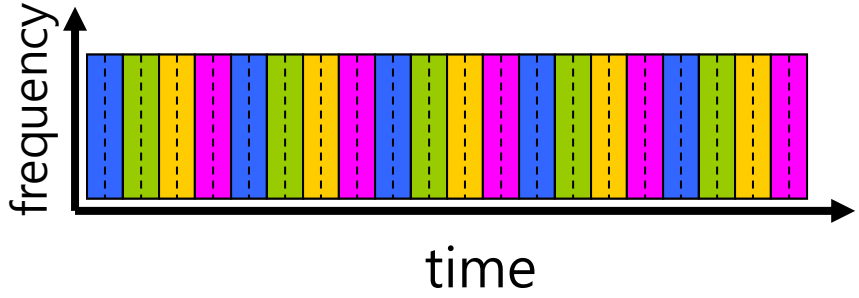
Frequency Division Multiplexing (FDM)

- optical, electromagnetic frequencies divided into (narrow) frequency bands
- each call allocated its own band, can transmit at max rate of that narrow band

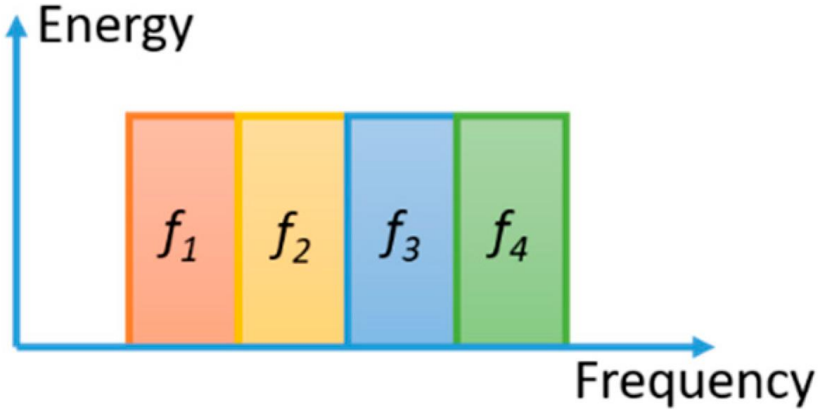


Time Division Multiplexing (TDM)

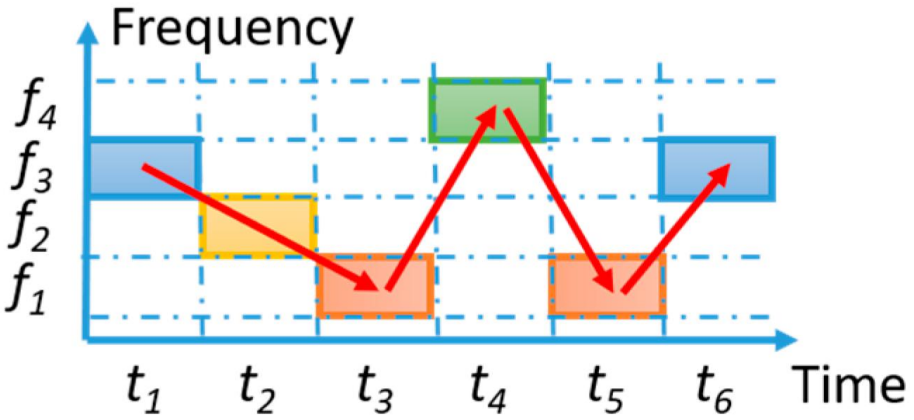
- time divided into slots
- each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band, but only during its time slot(s)



Frequency hopping



(a)



(b)

CDMA (Code Division Multiple Access)

- CDMA a.k.a. spread spectrum technique
- Used in some 2G and most 3G cellular systems

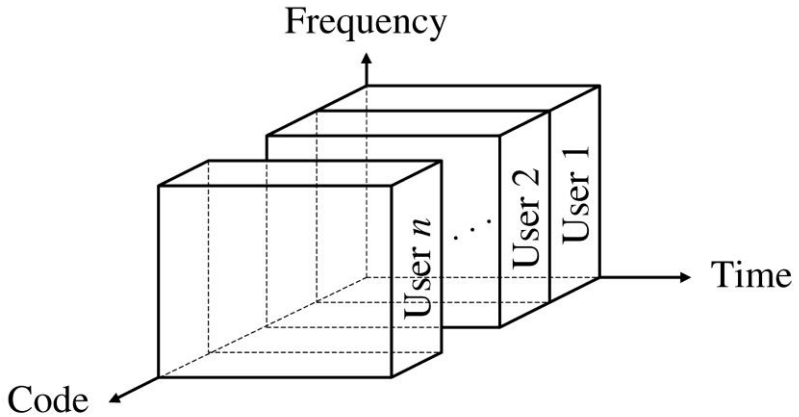
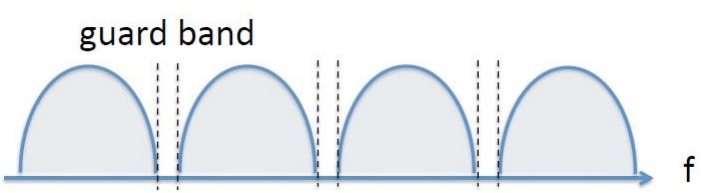
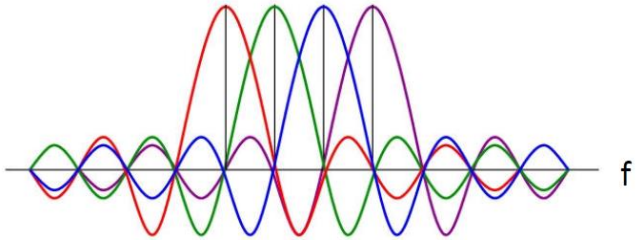


Figure 1.13 Code division multiple access (CDMA).

- FDM vs. OFDM
  - FDM needs guard bands between adjacent frequency bands
    - Extra overhead and lower throughput



FDM



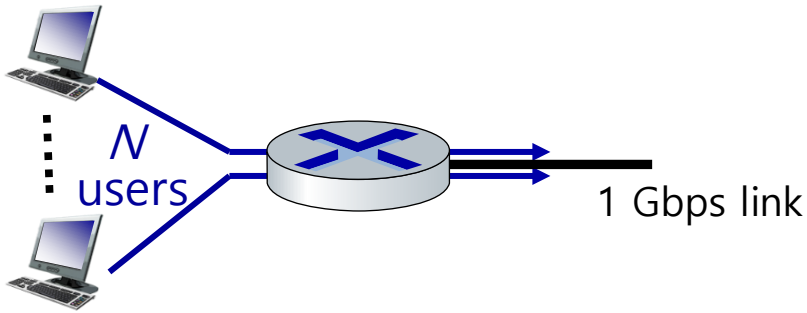
OFDM

Packt eswitching versus circuit switching

packet switching allows more users to use network!

Example:

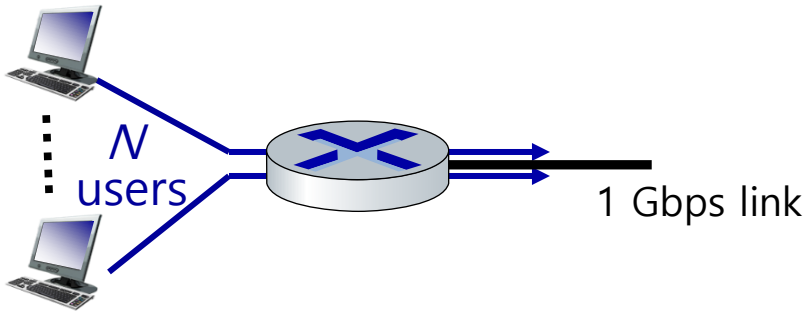
- 1 Gb/s link
- each user:
  - 100 Mb/s when "active"
  - active 10% of time



- *circuit-switching:* 10 users
- *packet switching:* with 35 users, probability > 10 active at same time is less than .0004 *

Q: how did we get value 0.0004?

Q: what happens if > 35 users ?



$$\binom{35}{n} p^n (1-p)^{35-n}$$

$$1 - \sum_{n=0}^{10} \binom{35}{n} p^n (1-p)^{35-n}$$

packet switching: with 35 users, probability > 10 active at same time is less than .0004 *

Q: how did we get value 0.0004?

sol) p = 0.1

- N = 35 users
- Prob (# active users > 10) = 1 – Prob (#active = 10)
  – Prob (#active = 9)
  – Prob (#active = 8)
  …
  – Prob (#active = 0)
- Prob (#active = 10) = C(35, 10) * 0.1^{10} x 0.9^{25}

Packet switching versus circuit switching

Is packet switching a "slam dunk winner"?

- great for "bursty" data – sometimes has data to send, but at other times not
  - resource sharing
  - simpler, no call setup
- excessive congestion possible: packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control
- *Q:* How to provide circuit-like behavior?
  - bandwidth guarantees traditionally used for audio/video applications

Q: human analogies of reserved resources (circuit switching) vers us on-demand allocation (packet switching)?

Internet structure: a "network of networks"

- Hosts connect to Internet via access Internet Service Providers (ISPs)
  - residential, enterprise (company, university, commercial) ISPs
- Access ISPs in turn must be interconnected
  - so that any two hosts can send packets to each other
- Resulting network of networks is very complex
  - evolution was driven by economics and national policies
- Let's take a stepwise approach to describe current Internet structure

announcements

- Quiz 1: avg 51.3/100 (top: 86/100, last place: 14)
- Midterm exam 1: 4/17 (Wed)