# CSIS 4222

Ch 11: Multiplexing and Demultiplexing

*Multiplexing*: combining information streams from multiple sources for transmission over a shared medium
*Demultiplexing:* separating a combination back into individual information streams

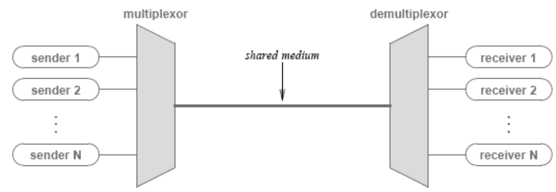



**Figure 11.1** The concept of multiplexing in which independent pairs of senders and receivers share a transmission medium.

## Basic Types of Multiplexing

- Frequency Division Multiplexing (FDM)
- Wavelength Division Multiplexing (WDM)
- Time Division Multiplexing (TDM)
- Code Division Multiplexing (CDM)
  – TDM and FDM are widely used
  – WDM is a form of FDM used for optical fiber
  – CDM is a mathematical approach used in cell phone mechanisms

## Frequency Division Multiplexing

- Radio stations can transmit signals without interference provided, they each use a separate channel (i.e., carrier frequency)
- It is also possible to send multiple carrier waves simultaneously over a single copper wire
- A demultiplexor applies a set of filters that each extract a small range of frequencies near one of the carrier frequencies
- The FDM mechanism will separate the frequency from others without otherwise modifying the signal

## Frequency Division Multiplexing

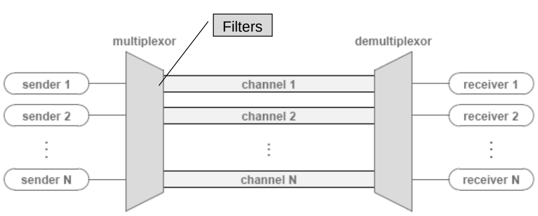



**Figure 11.3** The conceptual view of Frequency Division Multiplexing (FDM) as providing a set of independent channels.



## Frequency Division Multiplexing

| Channel | Frequencies Used |
|---|---|
| 1 | 100 KHz - 300 KHz |
| 2 | 320 KHz - 520 KHz |
| 3 | 540 KHz - 740 KHz |
| 4 | 760 KHz - 960 KHz |
| 5 | 980 KHz - 1180 KHz |
| 6 | 1200 KHz - 1400 KHz |

Carrier waves on separate frequencies don't interfere

**Figure 11.4** An example assignment of frequencies to channels with a guard band between adjacent channels.

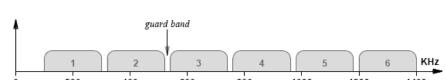
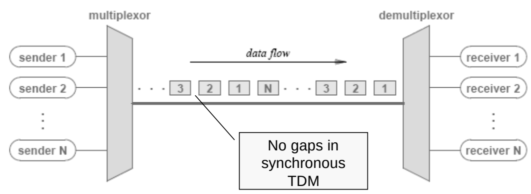



**Figure 11.5** A frequency domain plot of the channel allocation from Figure 11.4 with a guard band visible between channels.

## Time Division Multiplexing

TDM does not rely on special properties of electromagnetic energy

– Just transmit an item from one source, then transmit from another source, etc.




## Telephone System TDM

Synchronous TDM multiplexes digital streams from multiple phone calls with an extra framing bit between rounds

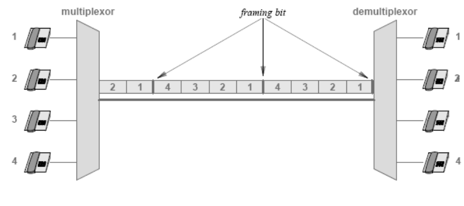



**Figure 11.10** Illustration of the synchronous TDM system used by the telephone system in which a framing bit precedes each round of slots.

## Synchronous TDM: Unfilled Slot Problem

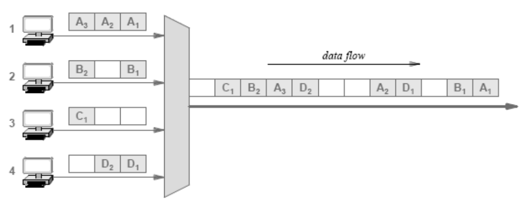



**Figure 11.12** Illustration of a synchronous TDM system leaving slots unfilled when a source does not have a data item ready in time.

## Statistical TDM

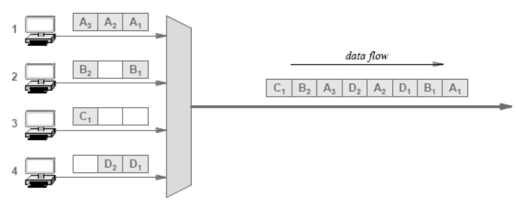



**Figure 11.13** Illustration that shows how statistical multiplexing avoids unfilled slots and takes less time to send data.



## Inverse Multiplexing

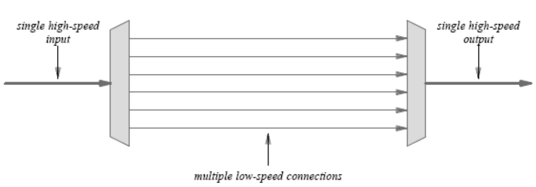



**Figure 11.14** Illustration of inverse multiplexing in which a single high-speed digital input is distributed over lower-speed connections for transmission and then recombined to form a copy of the input.

Complex, but widely used in the Internet

## Code Division Multiplexing

- CDM is used in parts of the cellular telephone system and for some satellite communication
  - Cell phone version called Code Division Multi-Access (CDMA)
- CDM does not rely on physical properties
  - such as frequency or time
- CDM uses mathematical ideas based on orthogonal vectors

## Internet Access Technology: Upstream and Downstream

- Most Internet users follow an asymmetric pattern
  - subscribers receives more data from the Internet than they send
- *Downstream*: data traveling from an ISP to a subscriber
- *Upstream*: data traveling from a subscriber to an ISP

## Narrowband and Broadband Access Technologies

Narrowband Technologies

- deliver data up to 128 Kbps

Broadband Technologies

- high data rates

| Broadband |
| --- |
| DSL technologies |
| Cable modem technologies |
| Wireless access technologies |
| Data circuits at T1 speed or higher |

## Digital Subscriber Line (DSL)

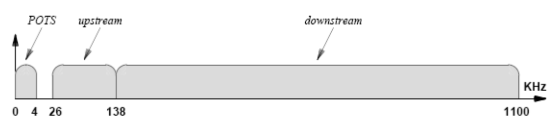
One of the main technologies for high-speed data communication over a *local loop*
(the physical connection between a telephone company Central Office (CO) and a subscriber)

| Name | Expansion | General Use |
| --- | --- | --- |
| ADSL | Asymmetric DSL | Residential customers |
| ADSL2 | Asymmetric DSL version 2 | Approximately three times faster |
| SDSL | Symmetric DSL | Businesses that export data |
| HDSL | High bit rate DSL | Businesses up to 3 miles away |
| VDSL | Very-high bit rate DSL | Proposed version for 52-Mbps |

## Digital Subscriber Line (DSL)

ADSL is the most widely deployed variant

- Uses FDM to divide bandwidth of the local loop into three regions
  - one region for traditional analog phone service, ie. Plain Old Telephone Service (POTS)
  - two regions for data communication




## ADSL Data Rate

How fast can ADSL operate?

- downstream rate of 8.448 Mbps on short local loops
- upstream rate of 640 Kbps
  - But network control channel uses 64 Kbps so the effective upstream rate for user data is 576 Kbps

- Adaptation has an interesting property
  - ADSL can only guarantee to do as well as line conditions allow
- Distance from a CO (or local loop interference) affects data rates
  - downstream rate varies from 32 Kbps to 8.448 Mbps
  - upstream rate varies from 32 to 640 Kbps

## Cable Modem Technologies

- Uses cable television wiring (high bandwidth and is less susceptible to interference than twisted pair)
- FDM used to deliver TV signals for many channels over coaxial cable
  - bandwidth is insufficient to extends a separate channel for each user

## Cable Modem Data Rate

- In theory, cable can support 52 Mbps downstream and 512 Kbps upstream
- In practice, the rate can be much less
- The bandwidth is shared among a set of *N* subscribers (size controlled by provider)
  - effective data rate available to each individual subscriber varies over time
  - the amount of capacity available to an individual subscriber will be 1/N

## Optical Fiber Access Technologies

Fiber To The Curb (FTTC)
- Optical fiber for high capacity trunks
- and then use copper for the feeder circuits

Fiber To The Building (FTTB)
- Optical fiber for high upstream data rates for businesses

Fiber To The Home (FTTH)
- Optical fiber for high downstream data rates to residential subscribers (entertainment and video)

- Fiber To The Premises (FTTP)
  - Generic term for FTTB and FTTH

## Wireless Access Technologies

How to provide access in rural areas?
- E.g., a farm or remote village many miles from the nearest city
- Too far for ADSL and least likely to have cable television service

- Even in suburban areas, technologies like ADSL may have technical restrictions on the type of line they can use
- Local loop technology may not work on all lines

## Wireless Access Technologies

| Technology | Description |
|---|---|
| 3G services | Third generation cellular telephone services for data (e.g., EVDO) |
| WIMAX | Wireless access technology up to 155 Mbps using radio frequencies |
| Satellite | Various commercial vendors offer data services over satellite |

**Figure 12.9** Examples of wireless access technologies.

## High-Capacity Connections at the Internet Core

- Access technologies handle the *last mile* problem
  - The connection to a residential subscriber or a small business
  - Small Office Home Office (SOHO)
- Connections to large businesses or connections among providers require substantially more bandwidth

## High-Capacity Connections at the Internet Core

- Core refers to connections at the backbone of Internet
- Core technologies are high-speed
- What technology can move data long distances at a rate of 10 Gbps?
  - A point-to-point digital circuit leased from a telephone company
  - High-capacity digital circuits are available for a fee depending on data rate and distance

## Telephone Standards for Digital Circuits

- A digital circuit leased from a telco follows the same digital transmission standards that the telco uses to transport digital phone calls
- In the USA, standards for digital telephone circuits were given names that consist of the letter T followed by a number
  - One of the most popular is known as T1 (used by many small businesses)

## Telephone Standards for Digital Circuits

| Name | Bit Rate | Voice Circuits | Location |
|---|---|---|---|
| basic rate | 0.064 Mbps | 1 | |
| T1 | 1.544 Mbps | 24 | North America |
| T2 | 6.312 Mbps | 96 | North America |
| T3 | 44.736 Mbps | 672 | North America |
| E1 | 2.048 Mbps | 30 | Europe |
| E2 | 8.448 Mbps | 120 | Europe |
| E3 | 34.368 Mbps | 480 | Europe |

**Figure 12.11** Examples of digital circuits and their capacity.

Fractional T1 circuits can also be leased

## Highest Capacity Circuits (Synchronous Transport Signal Standards)

| Copper Name | Optical Name | Bit Rate | Voice Circuits |
|---|---|---|---|
| STS-1 | OC-1 | 51.840 Mbps | 810 |
| STS-3 | OC-3 | 155.520 Mbps | 2430 |
| STS-12 | OC-12 | 622.080 Mbps | 9720 |
| STS-24 | OC-24 | 1,244.160 Mbps | 19440 |
| STS-48 | OC-48 | 2,488.320 Mbps | 38880 |
| STS-192 | OC-192 | 9,953.280 Mbps | 155520 |

**Figure 12.12** Data rates of digital circuits according to the STS hierarchy of standards.

Called digital trunk circuits by telephone companies

## Synchronous Optical NETwork (SONET)

- Telcos defined a broad set of standards for digital transmission
  - In North America, the standards are called Synchronous Optical NETwork (SONET)
  - In Europe the Synchronous Digital Hierarchy (SDH)
- SONET specifies details, such as
  - how data is framed
  - how lower-capacity circuits are multiplexed into a high-capacity circuit
  - how synchronous clock information is sent