Computer Networks: Multiplexing

EE1001

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Outline

- EE 4321
- Multiplexing
- NFC
EE 4321: Computer Networks

• EE Technical Elective Course, 3 credits
• Network Lab (MWAH 60)
• Course Objective: to learn characteristics of network transmission media, protocol architectures, routing algorithms, various LAN technologies, WAN technologies, and network programming.
Multiplexer (Mux)

\[ y = \begin{cases} x_0 & \text{if } S_1 S_0 = 00 \\ x_1 & \text{if } S_1 S_0 = 01 \\ x_2 & \text{if } S_1 S_0 = 10 \\ x_3 & \text{if } S_1 S_0 = 11 \end{cases} \]
Demultiplexer (Demux)

<table>
<thead>
<tr>
<th>$S_1$ $S_0$</th>
<th>$x_3$</th>
<th>$x_2$</th>
<th>$x_1$</th>
<th>$x_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>y</td>
</tr>
<tr>
<td>0 1</td>
<td>-</td>
<td>-</td>
<td>y</td>
<td>-</td>
</tr>
<tr>
<td>1 0</td>
<td>-</td>
<td>y</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1 1</td>
<td>y</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Mux/Demux
Multiplexing

$\text{n inputs} \quad \text{MUX} \quad 1 \text{ link, n channels} \quad \text{DEMUX} \quad \text{n outputs}$
Multiplexing Forms

- **Time Division Multiplexing (TDM)**
  - Synchronous TDM – Each signal source is interleaved using a fixed time slot assigned.
  - Statistical TDM -- Time slots are not preassigned. Rather, data are transmitted using the available time slots.

- **Frequency Division Multiplexing (FDM)** – A number of signals are carried simultaneously on the same medium by allocating to each signal a different frequency band.
Synchronous Time Division Multiplexing (TDM)

- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals interleaved in time
- May be at bit level of blocks
- Time slots preassigned to sources and fixed
- Time slots allocated even if no data
- Time slots do not have to be evenly distributed amongst sources
Time Division Multiplexing
TDM System

(a) Transmitter

Time slot: may be empty or occupied

(b) TDM Frames

(c) Receiver
TDM Link Control

- No headers and trailers
- Data link control protocols not needed
- Flow control
  - Data rate of multiplexed line is fixed
  - If one channel receiver can not receive data, the others must carry on
  - The corresponding source must be quenched
  - This leaves empty slots
- Error control
  - Errors are detected and handled by individual channel systems
Data Link Control on TDM

(a) Configuration

Input1: F1 f1 f1 d1 d1 d1 C1 A1 F1 f1 f1 d1 d1 d1 C1 A1 F1
Input2: F2 f2 f2 d2 d2 d2 d2 C2 A2 F2 f2 f2 d2 d2 d2 d2 C2 A2 F2

(b) Input data streams

... F1 d2 f1 d2 f1 d2 d1 d2 d1 C2 d1 A2 C1 F2 A1 f2 F1 f2 f1 d2 f1 d2 f1 d2 d1 d2 d1 C2 C1 A2 A1 F2 F1

(c) Multiplexed data stream

Legend:
F = flag field
d = one octet of data field
A = address field
f = one octet of FCS field
C = control field
Digital Carrier Systems

- Hierarchy of TDM
- USA/Canada/Japan use one system
- ITU-T use a similar (but different) system
- US system based on DS-1 format
- Multiplexes 24 channels (64Kbps/channel)
- Each frame has 8 bits per channel plus one framing bit
- 193 bits per frame (24x8 +1 =193)
- Single voice channel =8KHz (Nyquist rate=2B, 4Kx2=8K Samples per sec, 8bit per sample)
Digital Carrier Systems

- For voice each channel contains one word of digitized data
  - PCM at 8000 samples per sec
  - Data rate $8000 \times 193 = 1.544 \text{Mbps}$ (193=24x8+1) $\rightarrow$ DS1, T1

- Same format for digital data
  - 23 channels of data
  - 24th channel is reserved for a special sync byte
<table>
<thead>
<tr>
<th>Digital Signal Designation</th>
<th>Bandwidth/data rate</th>
<th>Channels (DS0s)</th>
<th>Carrier designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>64 kbps</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>DS1</strong></td>
<td>1.544 Mbps</td>
<td>24</td>
<td><strong>T1</strong></td>
</tr>
<tr>
<td>DS1C</td>
<td>3.152 Mbps</td>
<td>48</td>
<td><strong>T1c</strong></td>
</tr>
<tr>
<td>DS2</td>
<td>6.312 Mbps</td>
<td>96</td>
<td><strong>T2</strong></td>
</tr>
<tr>
<td><strong>DS3</strong></td>
<td>44.736 Mbps</td>
<td>672</td>
<td><strong>T3 = 7xT2</strong></td>
</tr>
<tr>
<td><strong>DS4</strong></td>
<td>274.176 Mbps</td>
<td>4032</td>
<td><strong>T4 = 6xT3</strong></td>
</tr>
<tr>
<td>DS5</td>
<td>400.352 Mbps</td>
<td>5760</td>
<td><strong>T5 = 60 xT2</strong></td>
</tr>
</tbody>
</table>
SONET/SDH (1)

- Synchronous Optical Network (SONET)
  - An optical transmission interface originally proposed by Bellcore and standardized by ANSI

- Synchronous Digital Hierarchy (SDH)
  - SONET compatible standard published by ITU-T
SONET/SDH (2)

- **Signal Hierarchy**
  - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) = 51.84 Mbps, 
    \(51.88 \times 10^6 / 65K = 810\) DS0 channels
  - STS-3/OC-3, 155.52 Mbps = 51.84 x 3 Mbps
  - STS-192/OC-192, 9953.28 Mbps = 51.84 x 192 Mbps
  - STS-768/OC-768, 40 Gbps = 51.84 x 768 Mbps
    \(= 622,080\) x DS0
  - ITU-T lowest rate is 155.52 Mbps (STM-1)
Statistical TDM

- In Synchronous TDM many slots are wasted
- Statistical TDM allocates time slots dynamically based on demand
- Multiplexer scans input lines and collects data until frame full
- Data rate on line lower than aggregate rates of input lines
Synchronous Vs. Statistical TDM

Synchronous TDM

A B C D A B C D A B C D

Statistical TDM

A B A D C
Statistical TDM Frame Formats

(a) Overall frame

(b) Subframe with one source per frame

(c) Subframe with multiple sources per frame
Performance

- Output data rate is less than aggregate input rates (the average amount of input is less than the capacity of the multiplexed line).

- May cause problems during peak periods
  - Buffer inputs
  - Keep buffer size to minimum to reduce delay
Buffer Size and Delay

(a) Mean buffer size versus utilization

(b) Mean delay versus utilization

- $M = 25$ kbps
- $M = 50$ kbps
- $M = 100$ kbps
Cable Modem Outline

- Two channels from cable TV provider dedicated to data transfer. One in each direction.
- Each channel is shared by a number of subscribers.
  - Scheme needed to allocate capacity
  - Statistical TDM
Cable Modem Operation

- **Downstream**
  - Cable scheduler delivers data in small packets
  - If more than one subscriber active, each gets fraction of downstream capacity
    - May get 500kbps to 20Mbps
  - Also used to grant (allocate) upstream time slots to subscribers

- **Upstream**
  - User requests timeslots on shared upstream channel. Dedicated slots are allocated for this request.
  - Headend scheduler sends back assignment of future time slots to subscriber using downstream
Cable Modem Scheme

- **Grant:** Station A can send 1 minislot of data.
- **Data:** for Station X.
- **Grant:** Station B can send 2 minislots of data.
- **Data:** for Station Y.
- **Data:** from Station X.
- **Data:** from Station A.
- **Request from Station C.**
- **Data:** from Station B.
Frequency Division Multiplexing
FDM System
Wavelength Division Multiplexing

- Multiple beams of light at different frequency
- Carried by optical fiber
- A form of FDM
- Each colour of light (wavelength) carries separate data channel
- 1997 Bell Labs
  - 100 beams
  - Each at 10 Gbps
  - Giving 1 terabit per second (Tbps)
- Lab systems (Alcatel) 256 channels at 39.8 Gbps each
  - 10.1 Tbps
  - Over 100km
Frequency Hopping Spread Spectrum (FHSS)

- signal is broadcast over seemingly random series of frequencies
- receiver hops between frequencies in sync with transmitter
- eavesdroppers hear unintelligible blips
- jamming on one frequency affects only a few bits
Frequency Hopping Example

(a) Channel assignment

(b) Channel use
Code Division Multiple Access (CDMA)

- a multiplexing technique used with spread spectrum
- given a data signal rate $D$
- break each bit into $k$ chips according to a fixed chipping code specific to each user
- resulting new channel has chip data rate $kD$ chips per second
- can have multiple channels superimposed
CDMA Example

- Code
- Message "1101" Encoded

User A

User B

User C
Near-field communications, an extremely short-range wireless technology, will soon revolutionize payment and access systems.
NFC in Train, Subway Pay Applications

Using an NFC-enabled phone to exit a London train station

Japan’s subway entry
NFC Parking Applications

Using NFC to pay parking

Parking meters equipped with NFC stickers
NFC in Public Transportation
NFC Applications

Tokyo, a candy store
NFC Enabled Washer/Dryer
NFC-Enabled Action Figures

An NFC tag in the action figure contains the strengths and attributes of each character, while the portal that reads the NFC tag can bring those characters back into the video game.
NFC-Enabled Headphone

Pair, download, and play music from an NFC-Compatible device with a tap of the headphone.
User merely swipe their phone when entering the house to turn on Wi-Fi or launch an app. Entering the car with a SmartTag initiates GPS and navigation.
Mobile Wallet

Google Play store, T-Mobile, At&T, Verizon
Apple Pay

iPhone 6 and iPhone 6 Plus
Near/Far Field

- Far field: the orthogonal electric and magnetic fields extend out from the antenna beyond several wavelengths. The field strength decreases by a factor of $1/d^2$.

- Near field: the field is within one wavelength or less from the antenna. Magnetic field is more dominant. The signal strength decreases by $1/d^6$. 
<table>
<thead>
<tr>
<th>NFC-Forum standard</th>
<th>Polling or listening</th>
<th>Coding</th>
<th>Modulation</th>
<th>Data rate</th>
<th>Carrier frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>NFC-A</td>
<td>Polling</td>
<td>Modified Miller</td>
<td>ASK 100%</td>
<td>106 kbits/s</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>NFC-A</td>
<td>Listening</td>
<td>Manchester</td>
<td>Load (ASK)</td>
<td>106 kbits/s</td>
<td>13.56 MHz + 848-kHz sub-carrier</td>
</tr>
<tr>
<td>NFC-B</td>
<td>Polling</td>
<td>NRZ-L</td>
<td>ASK 10%</td>
<td>106 kbits/s</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>NFC-B</td>
<td>Listening</td>
<td>NRZ-L</td>
<td>Load (BPSK)</td>
<td>106 kbits/s</td>
<td>13.56 MHz + 848-kHz sub-carrier</td>
</tr>
<tr>
<td>NFC-F</td>
<td>Polling</td>
<td>Manchester</td>
<td>ASK 10%</td>
<td>212/424 kbits/s</td>
<td>13.56 MHz</td>
</tr>
<tr>
<td>NFC-F</td>
<td>Listening</td>
<td>Manchester</td>
<td>Load (ASK)</td>
<td>212/424 kbits/s</td>
<td>13.56 MHz (no subcarrier)</td>
</tr>
</tbody>
</table>
Figure 3.2: Modified Miller Code
NFC Modes
NFC Applications

- Mobile payment device: restaurants, parking lots, theaters, ports stadiums, buses, taxies, airlines,…
- Electronic key: home access, secure buildings, car doors, computers,…
- Pairing: peer-to-peer data exchange
- Reading of smart stickers or tags: provides specifications, features, price, sales, web link, etc.
NFC Chips for Projects, AS3911