1.264 Lecture 32

Telecom: Basic technology

Next class: Green chapter 4, 6, 7, 10. Exercise due <u>before</u> class

Exercise 1

- **Communications at warehouse**

  A warehouse scans its inventory with RFID readers that read every item every 15 minutes. There are 100,000 items in inventory. The sweep takes one minute to complete, so the data is bursty. The data is sent to the data center 3 km away as it is read. Each RFID tag transmits 256 bits of information, and is read four times per sweep (either by different readers or multiple times by the same reader). TCP/IP and HTTP headers double the size of the data.

  - **What is the total bandwidth required?**
  - **Would 10 Mbps Ethernet work?**
  - **Would 100 Mbps Ethernet work?**
  - **Would cellular 500 kbps link work?**
  - **Maximum Ethernet copper cable length is 100 meters.**
    - **How would you connect points 3 kilometers apart if you have right of way?**
    - **Don't have right of way?**

Solution

- **Communications at warehouse**
  - **What is the bandwidth required?**
    - **100 000 x 4 x 256 bits / 60 sec x 2 ~= 3.4 Mbps**
  - **Would 10 Mbps Ethernet LAN work?**
    - **Yes**
  - **Would 100 Mbps Ethernet LAN work?**
    - **Yes**
  - **Would cellular 500 kbps link work?**
    - **No. Bandwidth too low.**
    - **Unless you send data over 15 minutes, which is possible if you store it and/or process it (with a server) at warehouse**
    - **This is a typical business/ops decision affected by telecom**
  - **The maximum Ethernet copper cable length is 100 meters. How would you connect points 3 kilometers apart?**
    - **If you have right of way: use fiber adapter and fiber optic cable**
    - **If you don't have right of way: obtain carrier Ethernet service**
    - **Or use 4G wireless, if available, but it's often more expensive**

Exercise 2

- **Why do we bother with wired telecommunications?**
  - **Why not use wireless everywhere?**
- **Why do companies design and manage their own networks?**
  - **Local area network**
  - **Wide area network**
- **When do companies build their own network, versus lease facilities, versus buy carrier solution? Why?**
- **For each these companies, indicate whether they probably build their own, lease facilities or buy a carrier solution, and briefly explain why:**
  - **MBTA, UPRR, MITFCU, Bertucci, Citibank, NBC, AA**

Solution

- **Why do we bother with wired telecommunications?**
  - Bandwidth hugely greater; reliability, latency much better
- **Why do companies design and manage their own networks?**
  - Local area network: Inexpensive, easy, no exotic skills reqd
  - Wide area network: Security, control, quality of service
- **When do companies build their own network, versus lease facilities, versus buy carrier solution?**
  - MBTA: Builds own. Has row, hard to manage
  - UPRR: Builds own. Has row, easy to manage
  - MITFCU: Carrier: Small, lease expensive, no row
  - Bertucci: Carrier: Small, lease expensive, no row
  - Citibank: Lease: Large, manage own facilities, no row
  - NBC: Lease + satellite: Large, manage own net, no row
  - AA: Lease: Large, manage own facilities, no row
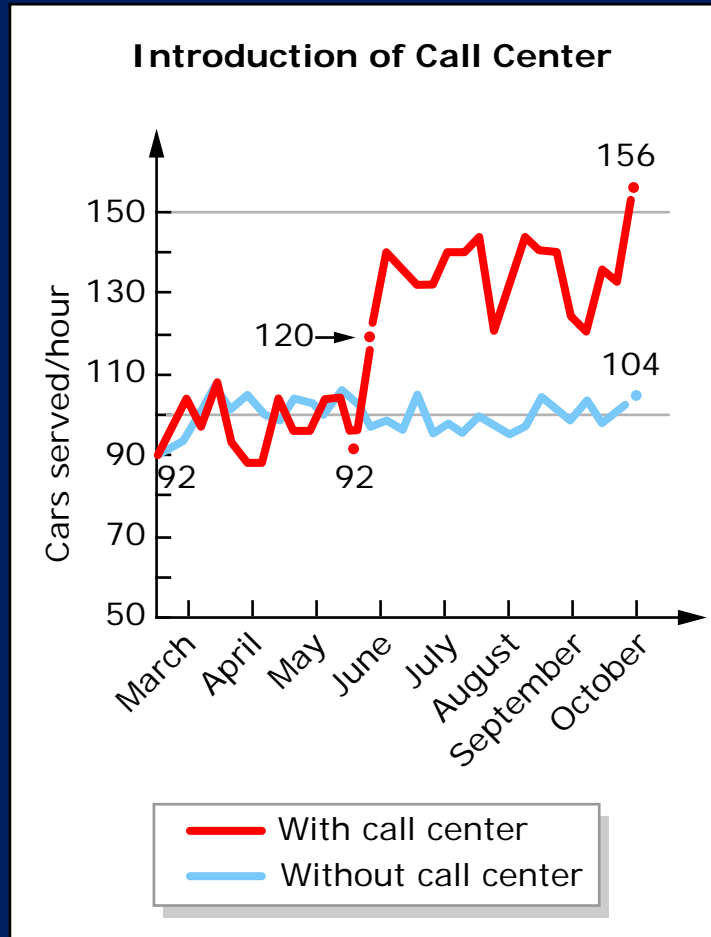
Telecom can enable supply chain innovation

Image by MIT OpenCourseWare.

Supply chain analyzes time, space, things, people. Consolidation is a key tool in improving supply chain. Telecom allows location flexibility.

Telecom equipment is reliable

- **99.9%: " 3 9s"**
  - **Downtime 9 hours per year (rounded to 10)**
  - **Typical of older or unmanaged wired local area nets (LANs), and wireless wide area nets (WANs- 2G data)**
- **99.99%: " 4 9s"**
  - **Downtime of 0.9 hours per year (rounded to 1)**
  - **Typical of modern, managed, wired LANs and WANs, and wireless LANs**
- **99.999%: " 5 9s"**
  - **Downtime of 0.09 hours per year (rounded to 5 minutes)**
  - **Typical of individual telecom switches, routers, fiber links**
    - **Downtime often 1 minute or less per year**
- **And downtime is expensive:**
  - **$200,000/hr for Amazon, $6 million/hr for brokerage**

Telecom in business

- **Open Internet is not generally usable for business:**
  - **Limited or no service level guarantees: "best effort"**
  - **Security is difficult**
    - **Exposes your servers to criminal organizations**
- **Businesses use or build their own networks using Internet standards**
  - **Private networks, using leased lines**
  - **Shared business networks provided by carriers**
    - **Physical security and/or encryption**
    - **Isolated from open Internet**
  - **Encrypted "tunnels" over Internet if necessary**
  - **Consumer contact via open Internet, of necessity**
  - **Wireless connectivity is open, of necessity**

Data communications

- **Elements: sender, receiver, message, transmission medium, protocol (rules/process)**
- **Data representation: data (text, numbers/binary, images), voice, video**
- **Data flow: simplex (one-way), duplex (two-way)**
- **Network type: local (LAN), wide-area (WAN), metro area (MAN), interconnected as Internet**
  - **LAN, MAN, WAN serve different distances**
- **Addressing: Ethernet, IP, port, URL, email, …**
- **Standards: ISO, ITU-T, ANSI, IEEE, EIA, Internet**

Analog bandwidth

- **Analog bandwidth= (highest – lowest) frequency of signal. Hz= 1 cycle/second**
  - **Voice telephony: 300 Hz- 3300 Hz or 3000 Hz or 3 kHz**
  - **AM radio: 10 kHz bands. 950 AM is 945 kHz to 955 kHz**
  - **FM radio: 200 kHz bands. 95.3 is 95.2 MHz to 95.4 MHz**
  - **Analog black-and-white TV: 6 MHz bands**
    - **TV is 525 by 700 lines, or 367,500 pixels**
    - **Scan 30 times/second: send 30*367,500, or 11 Mpixels/sec**
    - **Send 2 pixels/cycle: min amplitude for 1 color, max for other**
    - **Need ½ *11 Mpixels/sec, or 5.5 MHz= 5,500,000 cycles/sec**
    - **Alternating pixels is worst case; can send color in 6MHz too, with sophisticated coding**

Digital bandwidth

- **Digital bandwidth= bits per second. Examples:**
  - **Text at 100 pages/second: 24 lines * 80 columns * 8 bits/character * 100= 1,536,000 bps= 1.5 Mbps**
  - **Digitized voice: 4000 Hz * 2 samples/Hz * 8 bits= 64 kbps**
  - **HDTV: 1920 * 1080 pixels * 30 frames/second *24 bit (each color pixel)= 1,492,992,000 bps= 1.5 Gbps**
    - **Reduced to 20 to 40 Mbps by compression (factor of 38-75)**
- **Digital signals carried over analog links**
  - **Digital bandwidth~= analog bandwidth *SNR/3**
    - **Where SNR= signal/noise power ratio in decibels (base 10)**
      - **SNR= 10 $\log_{10}$(signal power/noise power)**
  - **Phone line: 3000 Hz, SNR= 35**
    - **Digital capacity= 3000 * 35/3= 35,000 bps**
    - **This is capacity of dialup modem upstream**
    - **Tweaks are used to get 56,000 bps downstream**

Exercise 3: Bandwidth

- **A wireless LAN has analog bandwidth=2 MHz and SNR= 30. Compute the digital bandwidth (Mbps)**

- **This LAN must connect 9 devices, each transmitting to the LAN access point at 2 Mbps.**
  - The LAN should operate at 70% capacity or less
  - Is the LAN capacity sufficient?

- **If the SNR is raised to 36, what is the digital bandwidth? Is this sufficient?**
  - This can be done by increasing signal strength or lowering the noise

Solution

- **A wireless LAN has analog bandwidth=2 MHz and SNR= 30. Compute the digital bandwidth (Mbps)**
  - **20 Mbps= 2 MHz * 30/3**
- **This LAN must connect 9 devices, each transmitting to the LAN access point at 2 Mbps.**
  - **The LAN should operate at 70% capacity or less**
  - **Is the LAN capacity sufficient?**
  - **Capacity required= 9 * 2= 18 Mbps**
  - **Practical capacity= 20 Mbps*0.7= 14 Mbps. Not sufficient**
- **If the SNR is raised to 36, what is the digital bandwidth?**
  - **At SNR=36, digital bandwidth= 24 Mbps= 2 MHz*36/3**
  - **Practical capacity= 24 Mbps*0.7= 16.8 Mbps. Almost ok.**

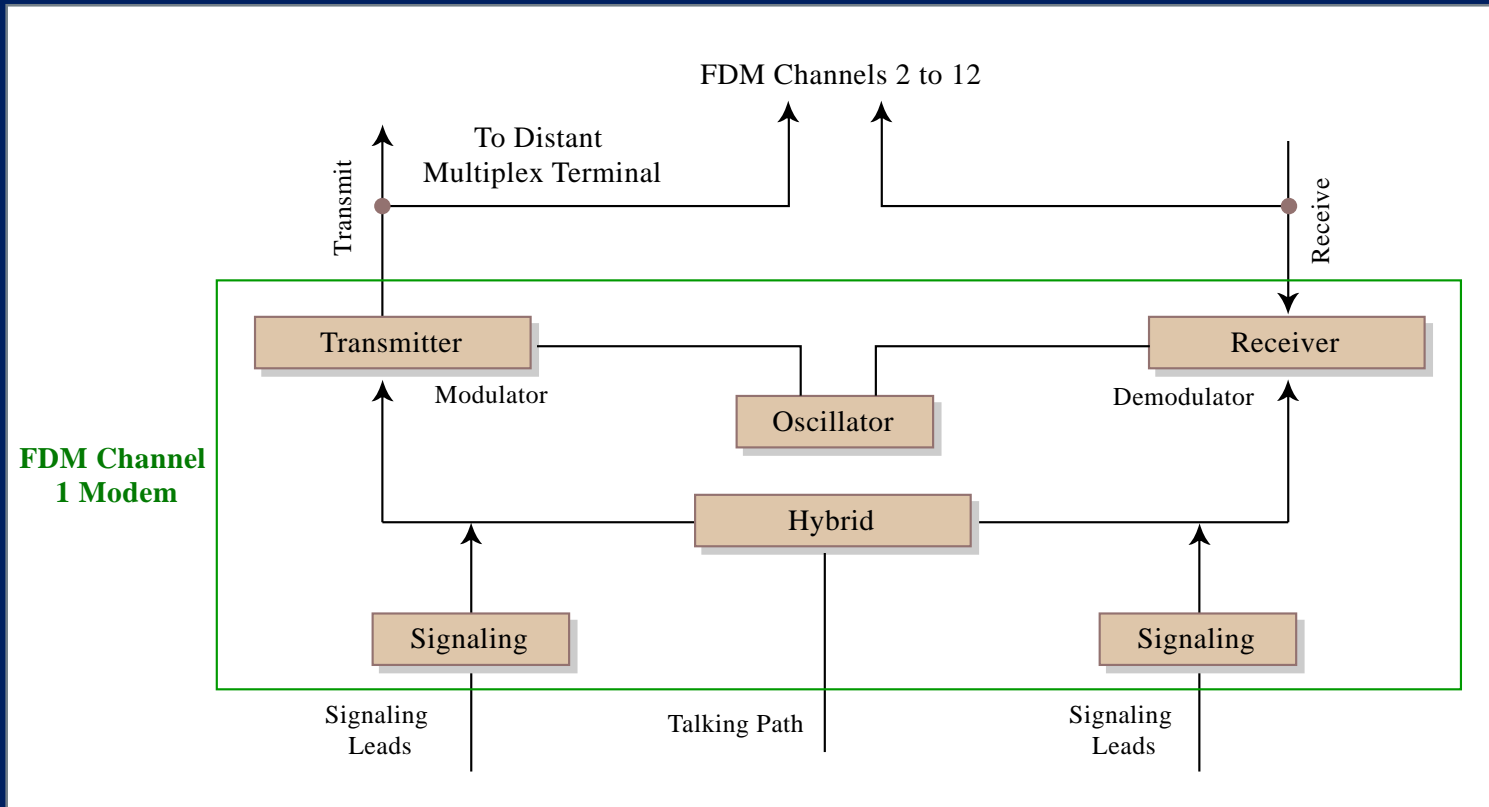# Frequency division multiplexing

Image by MIT OpenCourseWare.

Traditional method of carrying multiple channels on a cable
Similar to radio broadcasting with stations at different frequencies
Being used again in ADSL, CATV, satellite, …
Basic frequency is 4kHz band, based on voice needs
Voice hears from 20 to 20,000 Hz, but mostly 300 to 3500 Hz
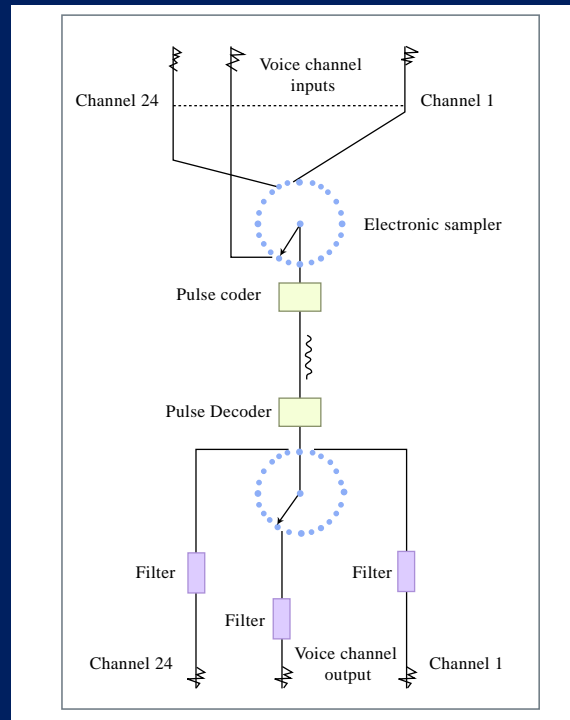
Transmission: Time division multiplexing (TDM)

Image by MIT OpenCourseWare.

Time division multiplexing (TDM) samples each 4kHz channel
Nyquist's theorem: Sample at twice the bandwidth to code and decode all
      possible information
So, sample 8000 times/second at 8 bits per second (or 256 levels)
Yields 64kb/sec channel, which is the basic rate of voice and data comm
24 64kb/sec channels is a T-1 (32 64 kb/sec channels in Europe form an E-1)
TDM used in fiber optic technologies; lasers can do both TDM and FDM (colors)

Transmission: T-1 (copper or fiber)

8,000	samples per second
x 8	bits per sample
64,000	bits per channel
x 24	channels
1,536,000	bits per second
+ 8,000	framing bits per second (not enough!)
1,544,000	bits per second total in T-1 circuit

Framing used to keep sync between ends of circuit. If all 24 circuits are quiet, only framing bits keep the clocks at both ends of the circuit in sync (several framing systems used)

T-1 is often the backbone for both voice and data, carries both

T-1s operate over both copper and fiber.

Higher bandwidth than T-1 is fiber or digital radio only.

Transmission: SONET (fiber)

Mb/s

SONET & SDH LINE RATES

SONET	SDH	SPEED (Mb/s)
STS-1		51.840
STS-3	STM-1	155.520
STS-9	STM-3	466.560
STS-12	STM-4	622.080
STS-18	STM-6	933.120
STS-24	STM-8	1,244.160
STS-48	STM-16	2,488.370
STS-192	STM-64	9,953.280

Image by MIT OpenCourseWare.

Fiber bandwidth, beyond T-1
STS-1, or OC-1, is same as T-3, or 28 T-1s
SONET can be divided into channels as small as 64kbps
    Voice carried at 64kbps or less (mobile as low as 9 kbps)
    Data carried at many rates
    Video carried at MPEG-1 (1.5Mb/sec) or MPEG-2 (6+Mb/sec); these are highly compressed
SONET superseded by OTN at 10 Mb/sec and above. More flexible frame, etc.

Exercise 4: Transmission

- **What is the bandwidth (digital) of an E1 channel? Ignore the framing bits. Give the result in both kbps and Mbps.**

- **How many E1 channels can be carried in an STS-1 (or OC-1) channel?**
  - **Round down by about 10% to allow for overhead.**
  - **The result must be an integer.**

- **How many voice calls (64 kbps) can be carried on the STS-1 channel over the E1s it contains?**

Solution

- **What is the bandwidth (digital) of an E1 channel? Ignore the framing bits.**
    - 32 * 64 kbps= 2048 kbps, or 2.048 Mbps
- **How many E1 channels can be carried in an STS-1 (or OC-1) channel?**
    - Round down by about 10% to allow for overhead.
    - The result must be an integer.
    - Bandwidth after overhead= 0.9*51.84= 46.66 Mbps
    - Channels= 46.66/2.048= 22+
    - Round down to either 22 or 20.
- **How many voice calls (64 kbps) can be carried on the STS-1 channel over the E1s it contains?**
    - 20 * 32= 640 (or 22 * 32= 704)

Glossary

- **RFID: Radio frequency ID**

- **SNR: Signal-to-noise ratio (decibels)**

- **T-1: 1.5 Mbps transmission circuit (US)**

- **E-1: 2 Mbps transmission circuit (Europe)**

- **SONET: Synchronous optical network, fiber optic transmission standard**

- **OTN: Optical Transport Network, for bandwidths beyond SONET using WDM (FDM)**

- **MPEG-1, -2: Motion Picture Experts Group standards for video transmission, compression**

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