18-345 – Fall 08

Lecture 9

Telephone Networks Overview

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Chapter 4

Announcements

- Homework 2 has been posted
  - Due on Monday (not graded)
  - Next quiz is next week Wednesday
- Project 2 deadline has been moved to Monday October 6
  - Demos will be October 10

Topics

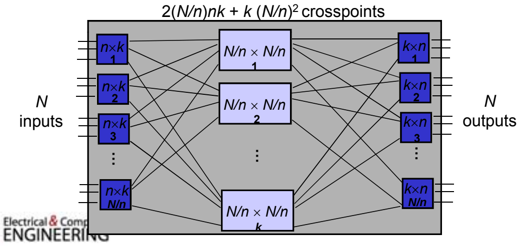
- Multiplexing
- SONET
- Transport Networks
- Circuit Switches
- Telephone Network

Circuit Switches Continued

Multistage Space Switch

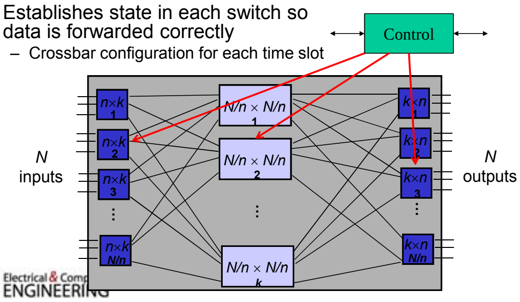
- Large switch built from multiple stages of small switches
- The n inputs to a first-stage switch share k paths through intermediate crossbar switches
- Condition for non-blocking: $k \geq 2n-1$
- Complexity scales as $4\sqrt{2}N^{1.5}$ which is slower than N^2

$2(N/n)nk + k(N/n)^2$ crosspoints



Control of a Multistage Space Switch

- Circuits are established using a signaling protocol (control plane)
- Establishes state in each switch so data is forwarded correctly
  - Crossbar configuration for each time slot

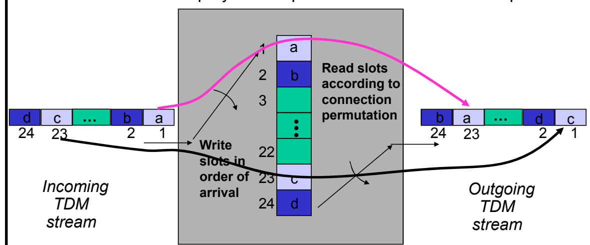


How Do We Build the Switch?

- Simplest solution is to use crossbars (space switches) for all switches
- Can also use Time-Slot Interchange
  - Effectively uses memory for switching
  - Explain first for one flow, then for multiple
- Next step is to run the lines inside the switch at a higher rate to reduce hardware cost

Time-Slot Interchange (TSI) Switching

- Write bytes from arriving TDM stream into memory
- Read bytes in permuted order into outgoing TDM stream
- Permutation set up by control plane when circuits are set up



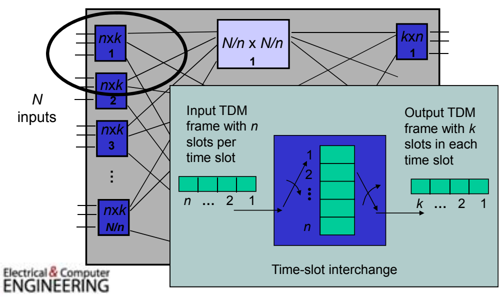
Time-slot interchange

TSI Switching Discussion

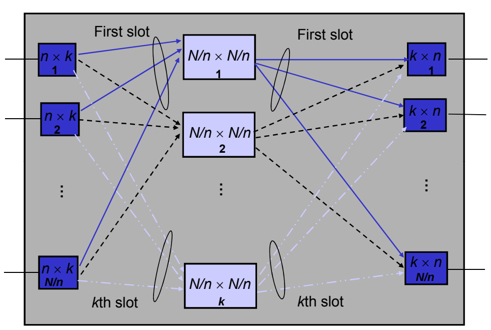
- TSI can be used as the basis for a switch
- n input ports write their frames to memory
- n output ports read frames in permuted order:
  - In each time slot they pick a frame from an input port, time slot pair
    - Permutation will typically be different for each time slot
  - Need fast memory:
    - Max # slots = 125 μsec / (2 x memory cycle time)
- Different numbers of input and output slots
  - May run at different rates

Time-Space-Time Hybrid Switch

- Use TSI in first & third stage; Use crossbar in middle
- Replace n input x k output space switch by TSI switch that takes n-slot input frame and switches it to k-slot output frame

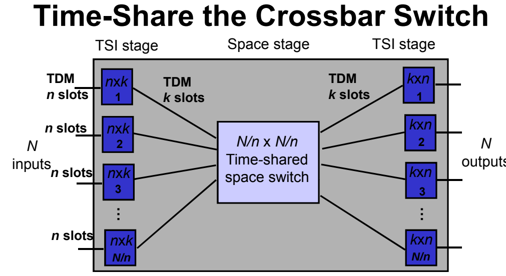


Flow of Time Slots between Switches



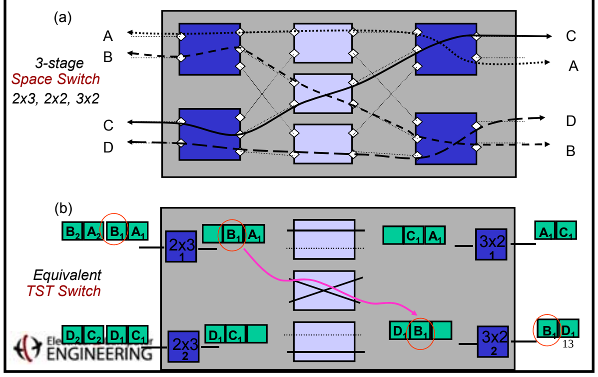
- Only one space switch active in each time slot

Time-Share the Crossbar Switch



- Interconnection pattern of space switch is reconfigured every time slot
- Very compact design: fewer lines because of TDM & less space because of time-shared crossbar

Example: A→2, B→4, C→1, D→3



Example: T-S-T Switch Design

For N = 960

- Single stage space switch ~ 1 million crosspoints
- T-S-T
  - Let n = 120 N/n = 8 TSIs
  - k = 2n – 1 = 239 for non-blocking
  - Pick k = 240 time slots
  - Need 8x8 time-multiplexed space switch

For N = 96,000

- T-S-T
  - Let n = 120 k = 239
  - N / n = 800
  - Need 800x800 space switch

Available TSI Chips circa 2002

- OC-192 SONET Framer Chips
  - Decompose 192 STS1s and perform (restricted) TSI
- Single-chip TST
  - 64 inputs x 64 outputs, i.e., N/n = 64
  - Each line @ STS-12 (622 Mbps), i.e., n = 12
  - Equivalent to 768x768 STS-1 switch, i.e., N = 768

Pure Optical Switching

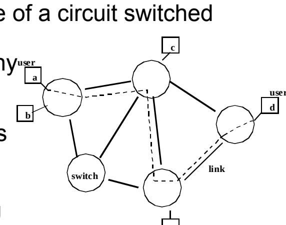
- Pure Optical switching: light-in, light-out, without optical-to-electronic conversion
- Space switching theory can be used to design optical switches
  - Multistage designs using small optical switches
  - Typically 2x2 or 4x4
  - MEMs and Electro-optic switching devices
- Wavelength switches
  - Very interesting designs when space switching is combined with wavelength conversion devices

Summary

- Multiplexing
- SONET
- Transport Networks
- Circuit Switches
- Telephone Network

Telephone Network

- Objective: to introduce digital telephone networks
- An important example of a circuit switched network
- The Network Hierarchy
  - Post-divestiture U.S. Network
- Transmission facilities
- Signaling System
  - In-Band Signaling
  - Out-of-Band Signaling



Numbering System

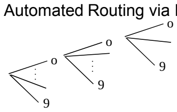
Hierarchical Number System

North-American Number System :

0/1 – AreaCode – CentralOffice - Station

1-412-268-yyyy

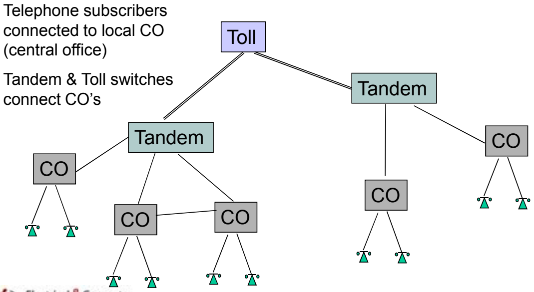
Automated Routing via Dial Pulses



Hierarchical Network Structure

Telephone subscribers connected to local CO (central office)

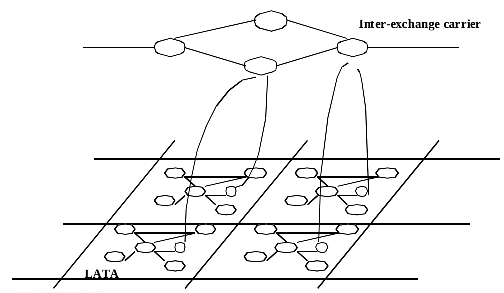
Tandem & Toll switches connect CO's



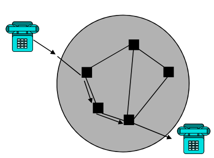
Post-divestiture U.S. Network

- AT&T monopoly's divestiture resulted in partitioning of telephone network into :
  - IEC(Inter-Exchange Carrier)
  - LEC (Local Exchange Carrier)
- IEC (i.e. AT&T, Sprint, MCI) provides long-distance service
- LEC (i.e. Bell Atlantic (Verizon), Southwestern Bell, Bell South, etc.) provides local service (Local Access & Transport Area - LATA)
  - More than 200 LATAs in the US

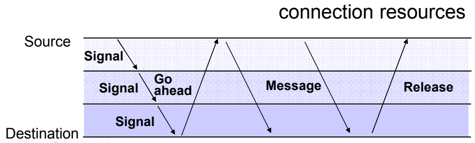
Post-divestiture U.S. Network



Telephone Call

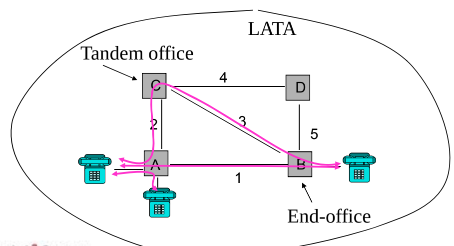


- User requests connection
- Network signaling establishes connection
- Speakers converse
- User(s) hang up
- Network releases connection resources



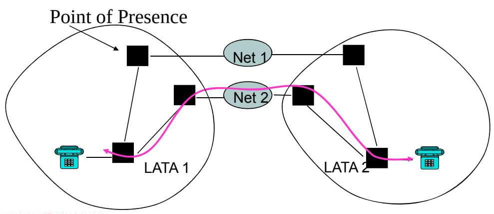
Call Routing - local

- Local calls routed through local network (In U.S., this is called LATA)
  - Local calls are toll-free
  - But, if the call requires a tandem office (for large LATA), it pays toll



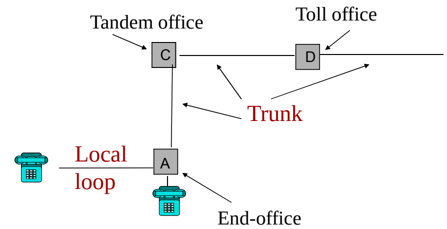
Call Routing – long-distance

- Long distance calls routed to one of the long distance service providers
  - LEC and IECs meet at the Point of Presence switch



Types of transmission links

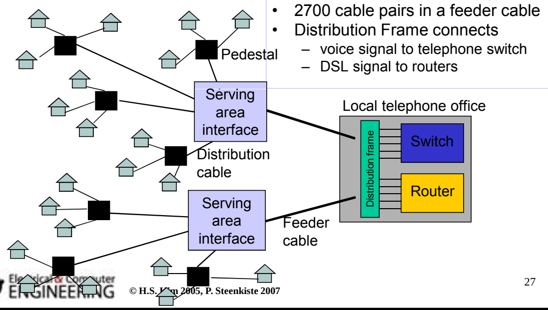
- Local loop : Subscriber to End-office link
- Trunk : Inter-office links



Telephone Local Loop

Local Loop: "Last Mile"

- Copper pair from telephone to CO
- Intermediate nodes to bundle wires. Creates "star topology"
- 2700 cable pairs in a feeder cable
- Distribution Frame connects
  - voice signal to telephone switch
  - DSL signal to routers

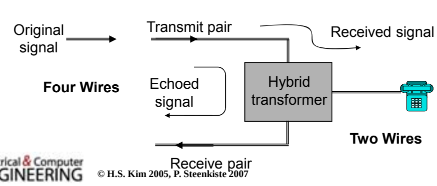


Telephone local loop wire

- "Unshielded twisted pair" (UTP) copper wire
- Thicker UTP has lower loss
- Similar wire can also be used for ethernet

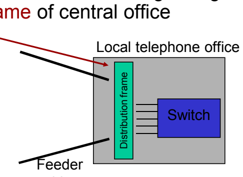
Two- & Four-wire connections

- From telephone to CO, two wires carry signals in both directions
- Inside network, 1 wire pair per direction
- Conversion from 2-wire to 4-wire occurs at hybrid transformer in the CO
- Signal reflections can occur causing speech echo
- Echo cancellers used to subtract the echo from the voice signals



Trunk links

- Trunk links
  - To connect central offices
  - For long distance links
- Modern trunk links are almost totally all-digital
- Conversion of analog voice in UTP into digital signal occurs at Distribution frame of central office

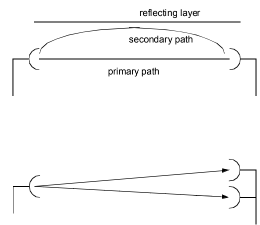


Trunk links

- Coaxial cable used in early systems.
  - Less prevalent now
- Microwave links used later
- Satellite links for very long distance (since 1960s)
- Optical fiber – most of trunk links are nowadays optical fiber

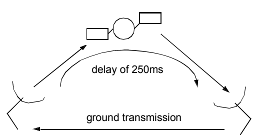
Microwave Radio

- Cheaper than coaxial cables since no digging, purchasing right of way, etc.
- Problems
  - limited bandwidth due to FCC regulation (bandwidth for TV, Radio, etc.)
  - atmospheric induced multipath fading
  - equipment failures
  - rain attenuation (11 GHz and above)



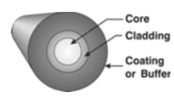
Satellite

- Geostationary orbit – 22000 miles above earth
- Great coverage of earth !
- Problem:
  - Propagation delay > 500 ms for up and down link total
  - partial solution is to use ground transmission for other direction of call



Fiber optic link

- Fiber optic : Light transmission in glass fiber
- Outer "cladding" reflects light and keeps it inside glass
- Very low loss : Thus long links possible without repeaters (100 km)
- Very high bandwidth : Thus, very high data rate (100 Gbps) possible

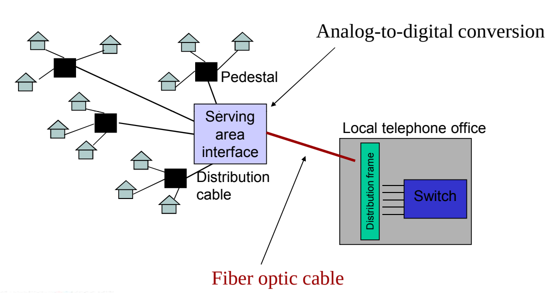


Fiber optic cable

Digital Loop Carrier (DLC)

- Since fiber optic has much higher bandwidth than UTP, it can carry many voice signals, as opposed to one voice signal in UTP
- Trend to extend fiber optics closer to homes (rather than stop at central office)
- Thus, UTP is digitized closer to home and the resulting digital signals are multiplexed into a fiber optic (or coax) link sent to central office
- This is called DLC
- Appearing in new residential communities

DLC



Benefits of reducing UTP length

Table 3.5 Data rates of 24-gauge twisted pair

Standard	Data Rate	Distance
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

- Fiber is more expensive but has much higher bandwidth than copper
- Table shows DSL data rates possible over copper wire of various lengths
- Shorter copper lengths possible if fiber is brought closer to home

"Bell" Telephone Loop Plant Today

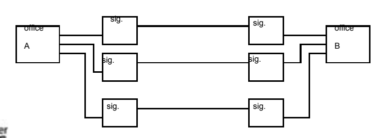
- Copper wire twisted pair loops = about 120 million lines
  - Length : 0 to at least 25 miles; average 11,000 feet.
- Digital Loop Carrier derived loops = about 5 million
  - 15% projected growth, about 50% of total growth
- $100 Billion invested
- $2.8 Trillion estimate for complete fiber overlay
- Independent telephone companies have about another 80 million lines
  - About 1400 others

Signaling functions

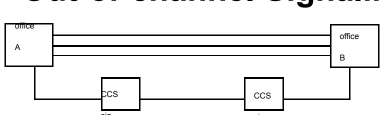
- Supervisory : Convey status or control of network elements. E.g. request for service (off-hook), ready to receive (dial tone), call alerting (ringing), call termination (on-hook), and busy tones.
- Information bearing : Convey data such as Called party address, calling party address, toll charges
- Network management : monitoring network, equipment failure, congestion, etc.
- Two methods to send signaling information:
  - In-channel Signaling
  - Out-of-channel Signaling

In-channel Signaling

- Signaling over same path as voice path
  - DTMF (Dual Tone Multi Frequency) from push button telephone to communicate dialed numbers
  - MF (Multi Frequency) signaling between switching offices
  - dial pulses by a rotary dial., 10 pulses per second
- Susceptible to fraud because signaling is easy to generate artificially

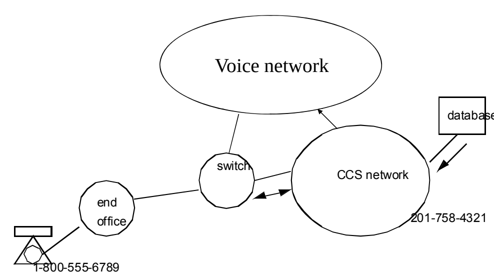


Out-of-channel Signaling



- Signaling over separate path instead of voice path
- Example : CCIS (Common Channel Interoffice Signaling) aka Signaling System # 7
- Common channel = All calls use same signaling lines

Signaling System # 7



Out-of-channel Signaling

- Advantages:
  1. Only one set of signaling facilities are need for each associated trunk group instead of separate facility for each individual circuit.
  2. no mutual interference of voice and control signal
  3. control channel inaccessible to user (no more blue box fraud)
  4. faster connection since direct link between offices rather than circuit path set up of voice channel

- Disadvantages:
  1. high degree of reliability required for both physical facility and error in control data
  2. no automatic voice circuit test since voice circuit independent of signaling links

Summary

- The Network Hierarchy
  – Post-divestiture U.S. Network
- Transmission
- Signaling System
  – In-Band Signaling
  – Out-of-Band Signaling