4.4 Circuit Switches

- The function of a circuit switch is to transfer the signal that arrives at a given input to an appropriate output.
  1) From one incoming line to one outgoing line (physical path) First telephone switches
  2) From a specific sub-flow of an input line to a specific sub-flow of a given output line. Modern telephone switches.

4.4.1 Space-Division Switches

- Provide a separate physical connection between inputs & outputs (separated in space).
- Crossbar switch: consists of $N \times N$ cross-points
  ( $N$: number of input lines = number of output lines)
- Non-blocking switch: connection requests are never denied because of lack of connectivity resources (cross-points)
  - Denied only when the requested outgoing line is engaged in another connection.
- Complexity: $N^2$
  - Can be reduced by using multi stage switches
Crossbar Space Switch

---

**Multistage switches**

- Fig 4.35
- First stage: $N/n \times nxk$ switches
- Intermediate stage: $k \times N/n \times N/n$ switches
- Third stage: $N/n \times kxn$ switches
- If $k < n$, obviously, the switch is not non-blocking (in fact, if $k < 2n-1$, not non-blocking)

$$2(N/n)n + k (N/n)^2$$ crosspoints
Multistage switches

– If $k=2n-1$, the multi-stage switch is non-blocking
– Fig 4.36: worst case
  • The max number of intermediate switches not available to connect the desired input to the desired output is $2(n-1)$. So if $k=2(n-1)+1=2n-1$, $\Rightarrow$ non-blocking

Multistage switches

Total number of cross-points in a multistage switch.

– Input switches: $\frac{N}{n} \times nk = Nk$
– Intermediate switches: $k \left( \frac{N}{n} \right)^i$
– Output switches: $\frac{N}{n} \times kn = Nk$

$\Rightarrow 2Nk + k \left( \frac{N}{n} \right)^i$, when $k = 2n-1 \Rightarrow 2N(2n-1)+(2n-1)\left( \frac{N}{n} \right)^i$

When $n \approx \left( \frac{N}{2} \right)^{\frac{1}{i}}$, the number of cross-points is minimized

$$4N((2N)^{\frac{1}{i}}-1) \sim N^{1.5}$$
4.4.2 Time-Division Switches

- TSI: time-slot interchange
  - *Fig 4.37:* write slots in order of arrival
  - Read slots according to connection permutation.
  - If 8000 frame/sec, the max no. of slots per frame:
    \[ = 125 \mu \text{sec} / (2 \times \text{memory cycle time}) \]

Time-Space-Time switches

- Multistage switch: switches in input and output stages are replaced by TSI switches
  - Input stage: nxk TSI switches
  - Output stage: kxn TSI switches

If \( k=2n-1 \), the internal speed is nearly double the speed of incoming line
- The first slot out of the input stage ↔ the first output line in the original multistage switch
  ⇒ the first slot will be directed to intermediate switch 1, all other intermediate switches are idle during the first time slot.
  similarly, in time slot \( i \ (1 \leq i \leq k) \), all intermediate switches are idle except the \( i \)th intermediate switch
- During any time slot, only one intermediate switch is active
Flow of time slots between switches

- Only one space switch active in each time slot

Time-Space-Time switches

- We can replace the k intermediate switches with a single crossbar switch that is time-shared among the k slots
- Result in much more compact design than space switches
  e.g: 4096 x 4096 time-space-time switch, $N=4096$
  128 slots/input frame $n=128$
  Input stage: $\frac{N}{n}=32$, input TSI switches $(n \times k)$
  $K=2n-1=255$, internal speed $\geq 2 \times$ input speed.
  Intermediate stage: one 32x32 time-shared crossbar switch
  Output stage: $32 \times n$ TSI switches
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) 3-stage Space Switch

(b) Equivalent TST Switch
4.5 The Telephone Network

- Three phases of connection-oriented communications:
  1. User pick up the phone → a current flow goes to the switch at the local telephone office indicating a call request → the switch prepares to accept the dialled digits → user dials the dest phone number (a sequence of pulses or a sequence of tones) → the switch convert these pulses or tones to telephone numbers → the source switch uses telephone-signalling network to find a route to the destination office → the dest office ringing the dest user → conversation begins when the dest phone is picked up
  2. Message transfer phase
  3. When users hang up phones, call is terminated, resources released

- LECs (Local Exchange Carriers) provide local phone service in LATAs (Local Access and Transport Areas).
- IXC (Interchange Carriers) provide communications between LATAs, long distance service
- User phone to local telephone office: twisted pair of copper wires, analog signals, “last mile”
- Between telephone offices: optical fibers, digital signal.
4.5.1 Transmission Facilities.

1) Fig 4.45 Local loop
   - Local Telephone office \textit{Feeder cable} serving area
     \textit{interface} \textit{Distribution cable} \textit{pedestals} —— user telephone
   - User to local switch: a single pair of wires
   - Inside the networks, 2 pairs: one transmit pair, one receive pair
   - Hybrid Transformer: echo cancellation
   - DCC: Digital cross-connect (Fig 4.47)

2) Between Switches: SONET-based optical networks.
   - SONET: ADM. or DCC

Switch and DCC

- Switch is generally configured using signaling to establish paths (dynamic)
- Digital Cross Connect is similar to switch except that is is semi-permanent, usually configured manually by network operators rather than signaling process.
4.5.2 End-to-End Digital Service

- “last mile” analog
- Early 1980s, ISDN: Integrated Service Digital Network
  - BRI: 2B+D  B: 64kbps  D: 16 kbps.
  - PRI: 23B+D
- BISDN:
  Broadband ISDN →
  ATM: Asynchronous Transfer Mode →
  Adopted Very Slowly, few service can use it

4.6 Signalling

- In very earliest telephone systems, operator manually set up the connections. (still used in set up SONET paths):
  - Long distance: more than one operators involved, may take 20-30 mins to set up
- SPC: (stored-program control) switches can be controlled by computers. (Fig 4.50)
  - Long Distance: more than one computers involved → signalling network (Fig 4.51)
  - Intelligent network: provide credit-card call, 800 calls etc. to enhance the basic telephone service.
4.6.2 Signalling system #7

- User or data plane: physical layer connections for voice signals
- Control plane: SS7 network

SS7: a packet switching computer network.

- Fig 4.54 MTP: message transfer part
  - MTP 1 physical layer
  - MTP 2 Data link layer
  - MTP3 Network layer
- ISUP (ISDN user port)/TUP (Telephone user part): basic phone call set-up, management and release.
- SCCP Transport layer
- TCAP Database queries, intelligent networks
Traffic concentration

- Traffic fluctuates as calls initiated & terminated
  - Driven by human activity
- Providing resources so
  - Call requests *always* met is too expensive
  - Call requests met *most of the time* cost-effective
- Switches concentrate traffic onto *shared* trunks
  - Blocking of requests will occur if no trunks available
- Traffic engineering provisions resources to meet blocking performance targets (e.g. < 1%)
4.7.1 Concentration

• Arrivals: Poisson process with \( \lambda \) calls/sec
• Holding Time: Time a user maintains a connection \( X \) a exponential random variable with average \( E[X] \)
• Offered load: rate at which work is offered by users
  \[ a = \lambda \text{ calls/sec} \times E[X] \text{ secs/call (Erlangs)} \]
• 1 Erlang: offer load that occupy 1 trunk 100% of the time
• Erlang B formula:
  \[ P_b = B(c,a) = \frac{a^c / c!}{\sum_{k=0}^{c} a^k / k!} \]
  Where \( C \): number of trunks. \( a \): offered load.
• Utilization \( = \lambda (1 - P_b) E[X]/C = (1 - P_b) a/c \)

<table>
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<th>Load</th>
<th>Trunks@1%</th>
<th>Utilization</th>
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<tbody>
<tr>
<td>1</td>
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<tr>
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<td>7</td>
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<td>0.85</td>
</tr>
<tr>
<td>100</td>
<td>117</td>
<td>0.85</td>
</tr>
</tbody>
</table>

4.7.1 Concentration

• Quality of Service (Qos): \( \leq 1\% \) blocking probability.
• Table 4.2: size of system (or offered load) ↑ utilization ↑
  – Multiplexing gain
• Example: Fig 4.58 10 Erlangs A, B, C ↔ D, E, F.
  a) 9 pairs of (src, dest). 10 Erlangs (1%) → 18 trunks/pair. 9x18 = 162 trunks
  b) 90 Erlangs (1%) → 106 trunks
18 trunks for 10 Erlangs
9x18 = 162 trunks
Efficiency = \( \frac{90}{162} \times 100 = 56\% \)

90 Erlangs when combined
106 trunks for 90 Erlangs
Efficiency = 85%

4.8 cellular telephone Networks

- Regulation: governments regulate the use and allocation of freq. bands. → frequency spectrum be a precious resource
- Frequency reuse: by reducing the power level, the coverage area is reduced and frequency bands can be reused in other areas ⇒ cellular radio communications
  - Fig 4.63 hexagonal cells, Frequency reuse pattern, Frequency reuse factor
4.8 cellular telephone Networks

• Base station: (BSS) centre of each cell.
  – Forward channel: base station → mobile users
  – Reverse channel: mobile users ← base station
• BSSs are connected to MSC (Mobile switch center)
  MSC handles connections between cells as well as to the public
  switched telephone network (PSTN).
• Handoff: when a user moves from one cell to another, a hand off
  procedure is carried out to transfer the connection from one base
  station to the other, without interrupting the call
• In Chap 6, we will discuss more details about: AMPS, GSM, and
  CDMA