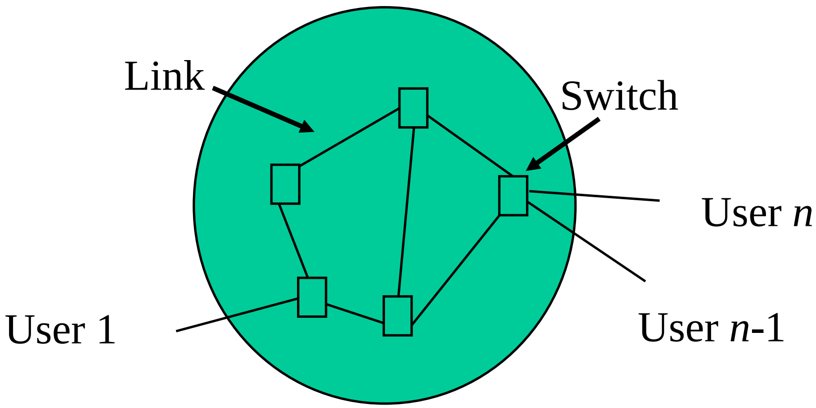
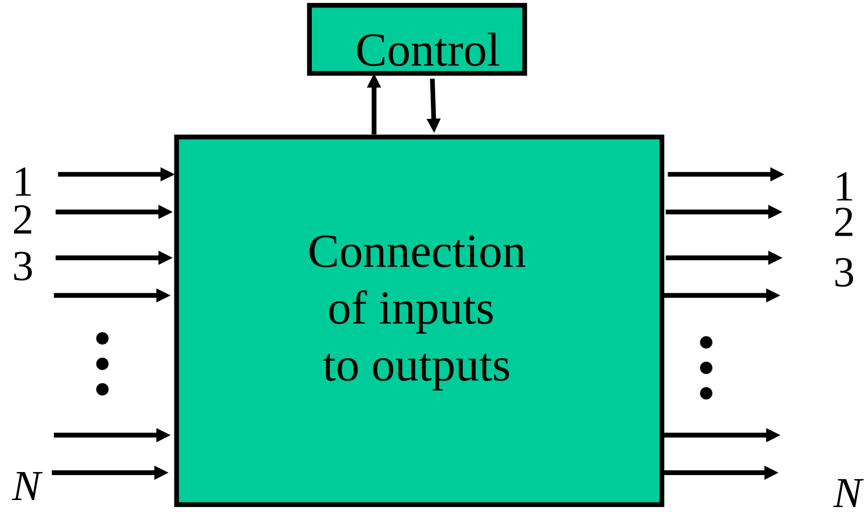
Circuit Switches

- Providing connectivity between users across a network





  – a sequence of switches must be set across the network to set up a circuit

  – cases:

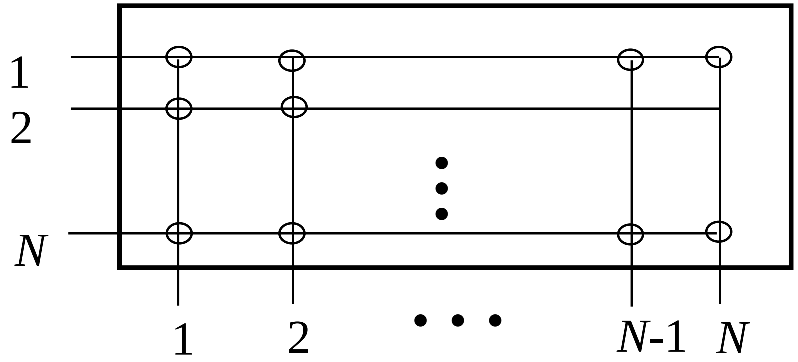
    » switching one input to one output

    » switching a flow of multiplexed signals

      - must be demultiplexed first, in principle

      - but switching time-division multiplexed signals possible on-the-fly

- Space-Division switches : a Crossbar switch:



» an N x N array of crosspoints

» can connect any input to any available output

» when a connection request received, correspond crosspoint closed

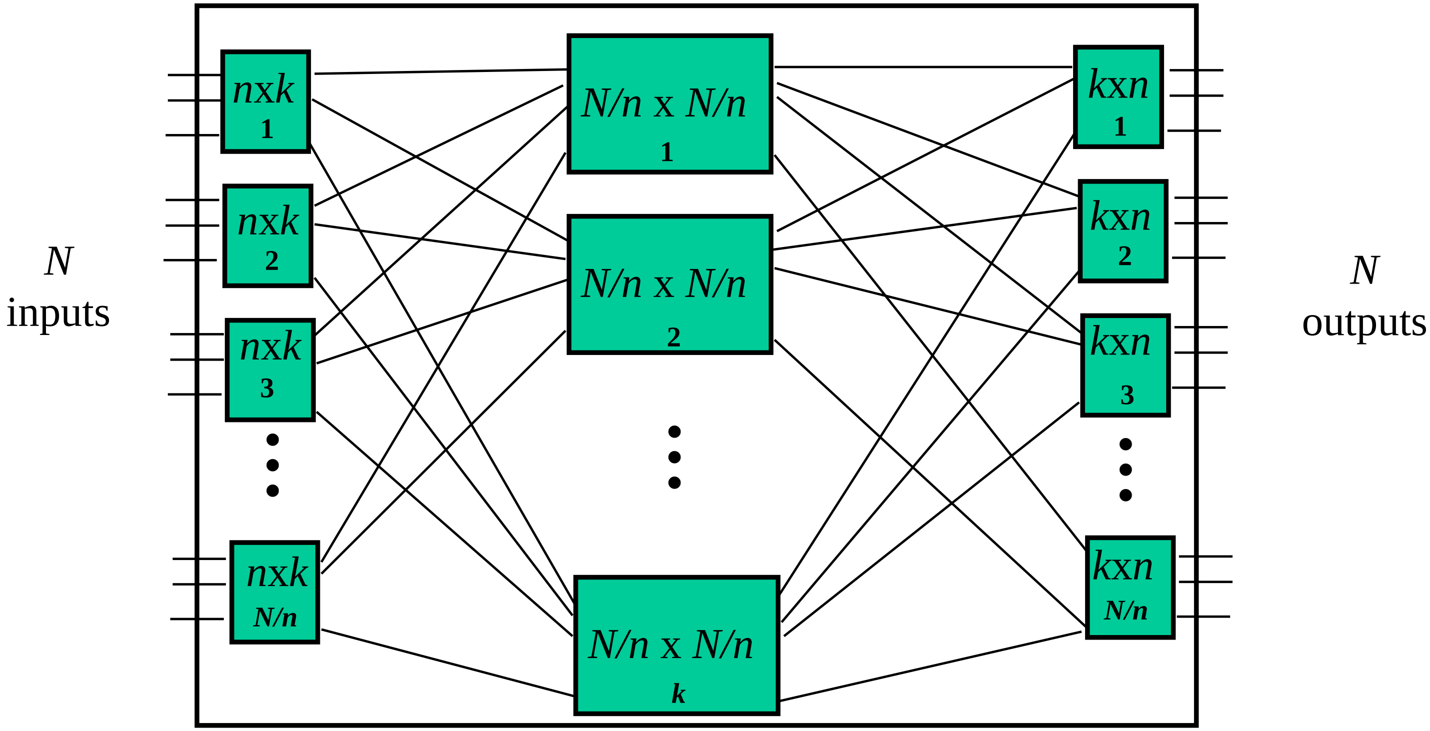
» *nonblocking* – connection requests never need to be denied through lack of connectivity resources

- only denied when outgoing line already busy

» complexity in terms of the number of crosspoints = N^2

- grows very quickly with number of input and output ports
- complexity can be reduced by using multistage switches

- Multistage switches
  - e.g. a 3-stage switch:



  - *N* inputs grouped into *N/n* groups of *n x k* switches
  - each of the *n x k* first-stage switch output ports is connected to an input port of one of the *N/n x N/n* intermediate switches
  - the output ports of an intermediate-level switch are connected to each of the *k x n* third-stage switches

– in effect, each set of *n* input lines shares *k* possible paths to any one of the switches at the last stage

» 1st path goes through 1st intermediate switch

» 2nd path goes through 2nd intermediate switch etc.

– not necessarily non-blocking

» if $k<n$, as soon as a first-stage switch has *k* connections, its other connections will be blocked

– when is a multistage switch non-blocking?

» consider any desired input and any desired output

» worst case for the desired input is when all the other $(n-1)$ inputs in its group have already been connected

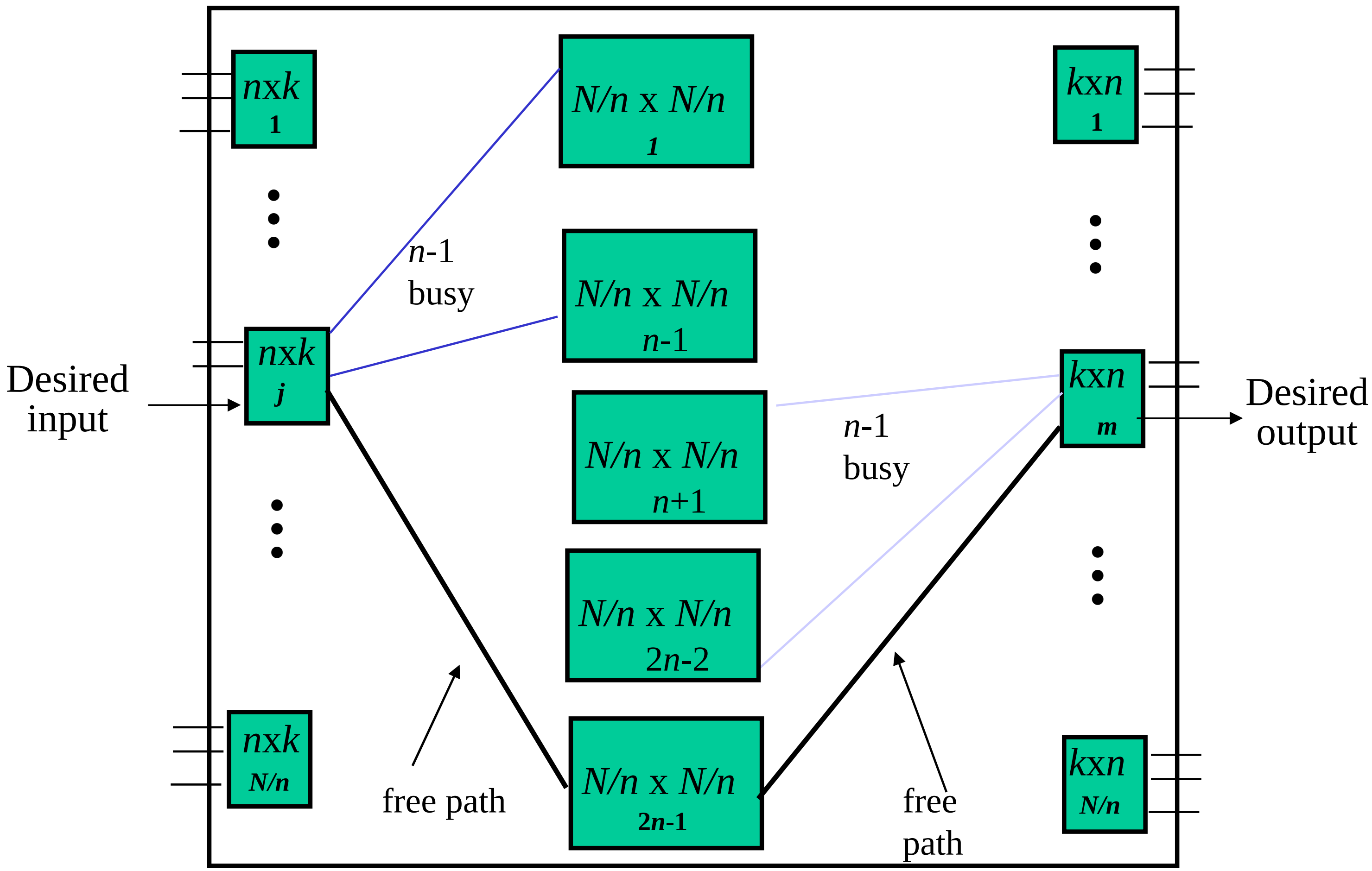
» worst case for the desired output is when all the other $(n-1)$ outputs in its group have already been connected

» the worst-case situation that maximises the number of intermediate-level switches is when each existing connection uses a different intermediate switch

» i.e. maximum number of intermediate switches not available to connect the desired input to the desired output is $2(n-1) = 2n-2$

» if $k = 2n-1$, a single path is still available for the desired connection

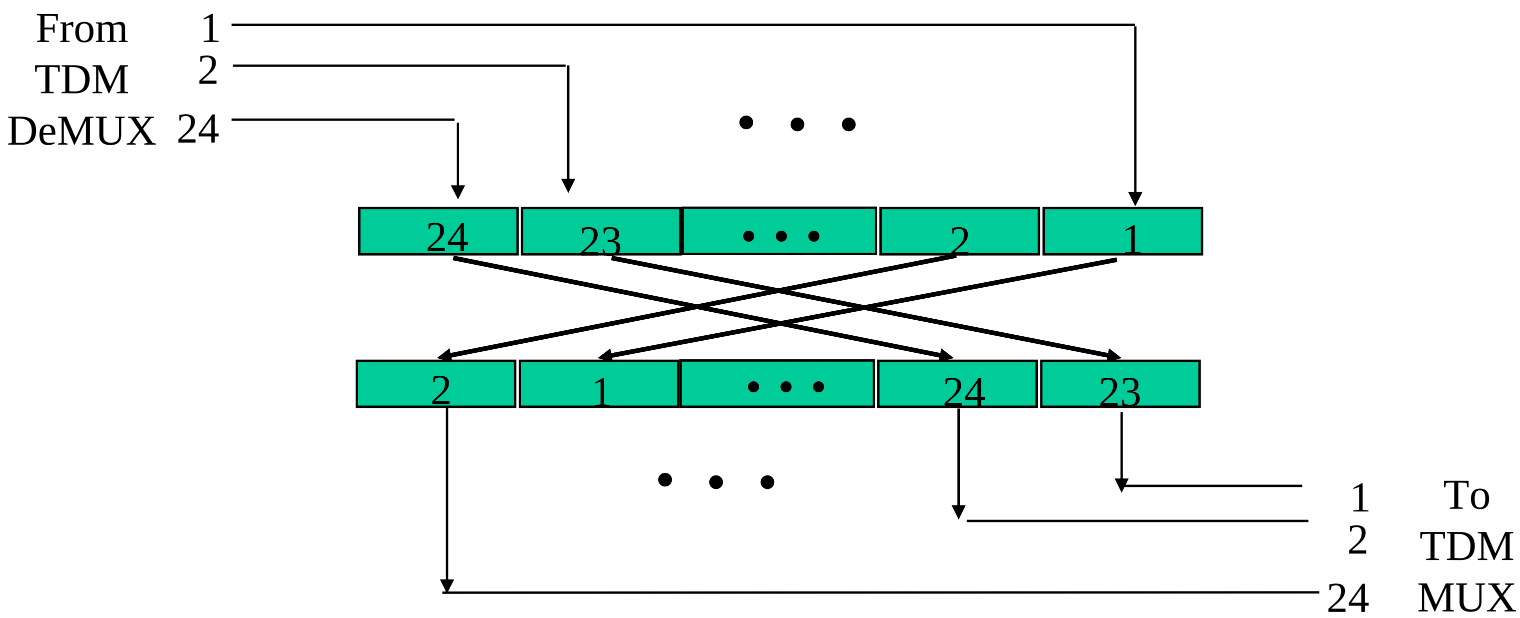
- *i.e.* $k = 2n-1$ *is non-blocking*



nxk
1
nxk
j
nxk
N/n
N/n x N/n
1
N/n x N/n
n-1
N/n x N/n
n+1
N/n x N/n
2n-2
N/n x N/n
2n-1
kxn
1
kxn
m
kxn
N/n
n-1
busy
n-1
busy
Desired
input
Desired
output
free path
free
path

- number of crosspoints in a three-stage switch:
  - » N/n input switches x nk crosspoints/switch
  - » k intermediate switches x $(N/n)^2$ crosspoints/switch
  - » N/n output switches x nk crosspoints/switch
  - » $= 2Nk + k(N/n)^2$
- to make switch non-blocking, $k = 2n-1$
  - » i.e. number of crosspoints = $2N(2n-1) + (2n-1)(N/n)^2$
- number of crosspoints can be minimised by choice of group size n
  - » differentiating wrt n gives a minimum when $n \approx (N/2)^{½}$
  - » then minimum number of crosspoints = $4N((2N)^{½} - 1)$
  - » grows at a rate proportional to $N^{1.5}$
  - » i.e. less than the N^2 of the crossbar switch
- when $k < 2n-1$, a nonzero probability that a connection request will be blocked

- Time-Division switches : Time-Slot interchange (TSI)
  - replaces crosspoint switches with reading and writing of a slot in memory
  - consider a T-1 time-division multiplexed signal carrying 24 voice channels
    - » 8000 bytes/sec per channel interleaved byte-by-byte
  - suppose voice assigned to slot 1 is talking to voice assigned to slot 23
    - » need to route incoming slot 1 to outgoing slot 23 and incoming slot 23 to outgoing slot 1, in each frame of 24 slots
    - » similarly if another pair of speakers assigned to slots 2 and 24



– each incoming byte is written into an array in memory as it arrives

– call setup procedure sets up a *permutation* table that controls the order in which bytes are read out of the array

– outgoing frame begins by reading contents of slot 23, then slot 24 and so on until slots 1 and 2 are read

– this procedure can connect any input to any available output

– frames come 8000 times/sec

– the time-slot interchange for the whole frame requires *one* write and *one* read per slot

– hence, maximum number of slots that can be handled is:

$$\frac{125\mu s}{2 \text{ x memory cycle time}}$$

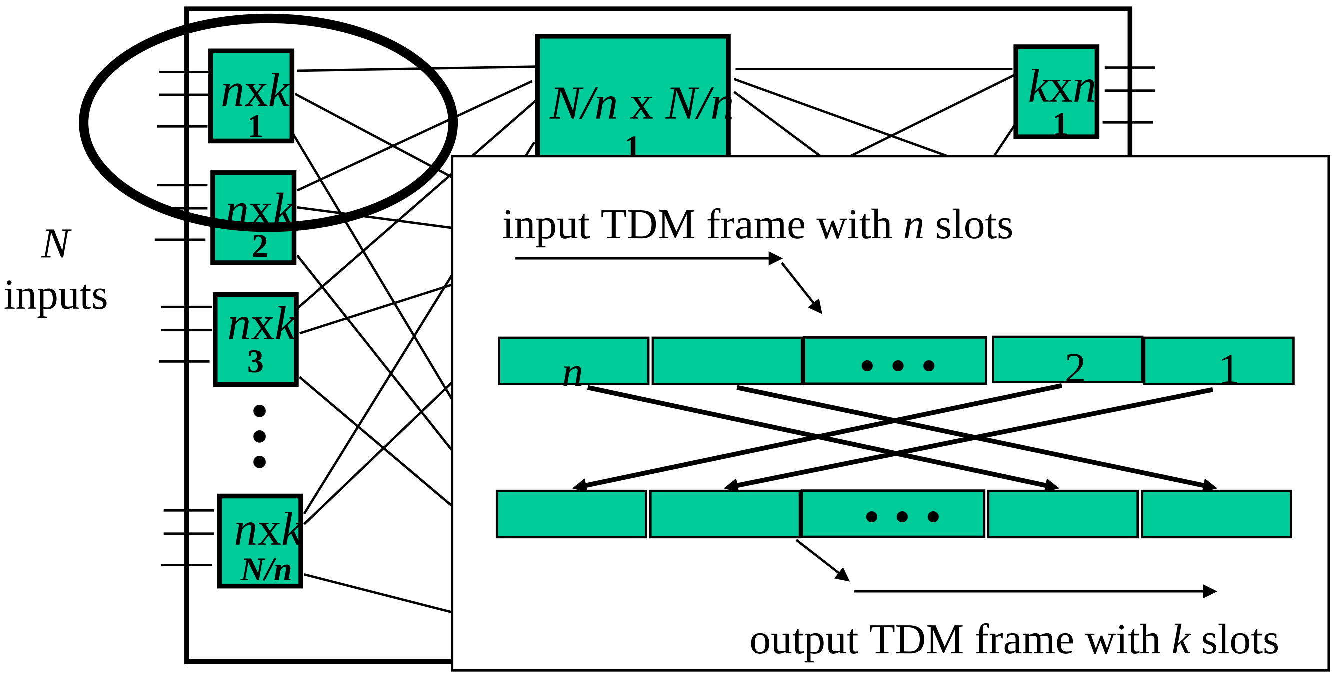
– e.g. cycle time of 50ns gives a maximum of 1250 slots i.e. 625 connections

– telephone exchanges initially used space-division switches

» introduction of TSI switches led to significant cost savings

» crucial in the development of all-digital telephone switching networks

- Time-Space-Time switches
  - – a hybrid design of multistage switch
    - » TSI switches at input and output stages
    - » a crossbar space switch at the intermediate stage
  - – design approach is to establish an exact correspondence between the input lines in a space-division switch in the first stage and time-slots in a TSI switch
  - – each *n x k* first-stage switch is replaced by an *n x k* TSI switch:



– each input line corresponds to a slot

» i.e. the TSI has input frames of size *n* and *k* output slots

– operation of the the TSI switch:

» writes the *n* slots of the incoming frame into memory

» reads them out from memory into a frame of size *k* slots according to some preset permutation

– for the system to operate in a synchronous fashion:

» transmission time of an input frame must equal that of the output frame

» e.g. if $k = 2n-1$, internal speed is nearly double that of the incoming signal

– consider the flow of slots between the first stage and the intermediate stage:

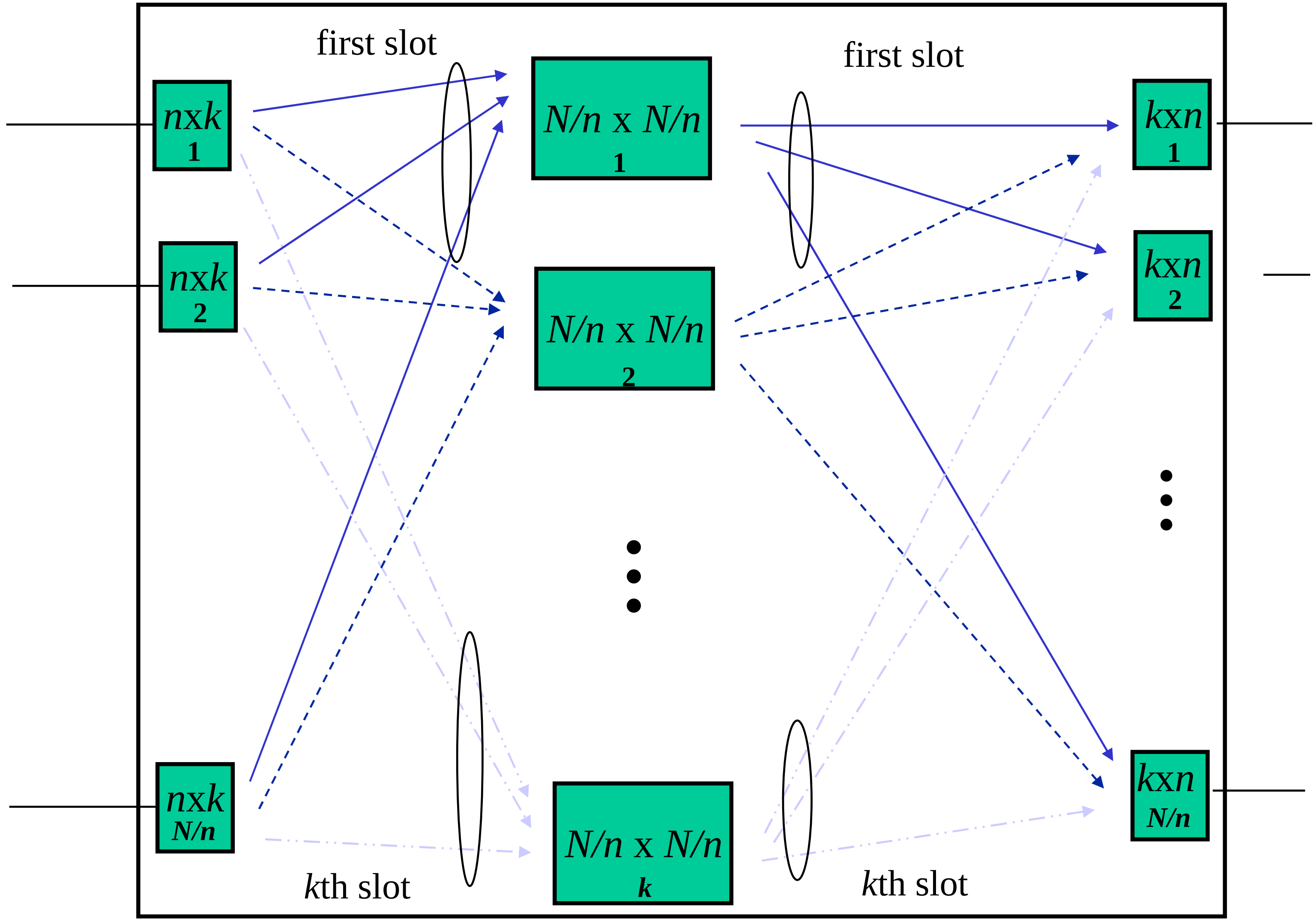
» assume TSI frames in the first stage are all *synchronised*

– first time-slot corresponds to first output line of each of the first-stage switches

– recall that the first output line of each first-stage switch is connected to the inputs of the first intermediate switch

» the *first intermediate switch* therefore operates on the *first time-slot outputs* from the first-stage switches

» the other intermediate switches are *idle* while the first one is busy


first slot
first slot
nxk
1
nxk
2
nxk
N/n
N/n x N/n
1
N/n x N/n
2
N/n x N/n
k
kxn
1
kxn
2
kxn
N/n
kth slot
kth slot

– the intermediate switch is a crossbar switch

» transfers *N/n* inputs to *N/n* outputs according to the crosspoint settings

– the second output line of each first-stage switch is connected to the inputs of the second intermediate switch

» the *second intermediate switch* therefore operates on the *second time-slot outputs* from the first-stage switches

» the other intermediate switches are *idle* while the second one is busy

– the third output line/time-slot connected to third intermediate switch

» the other intermediate switches are *idle* while the third one is busy

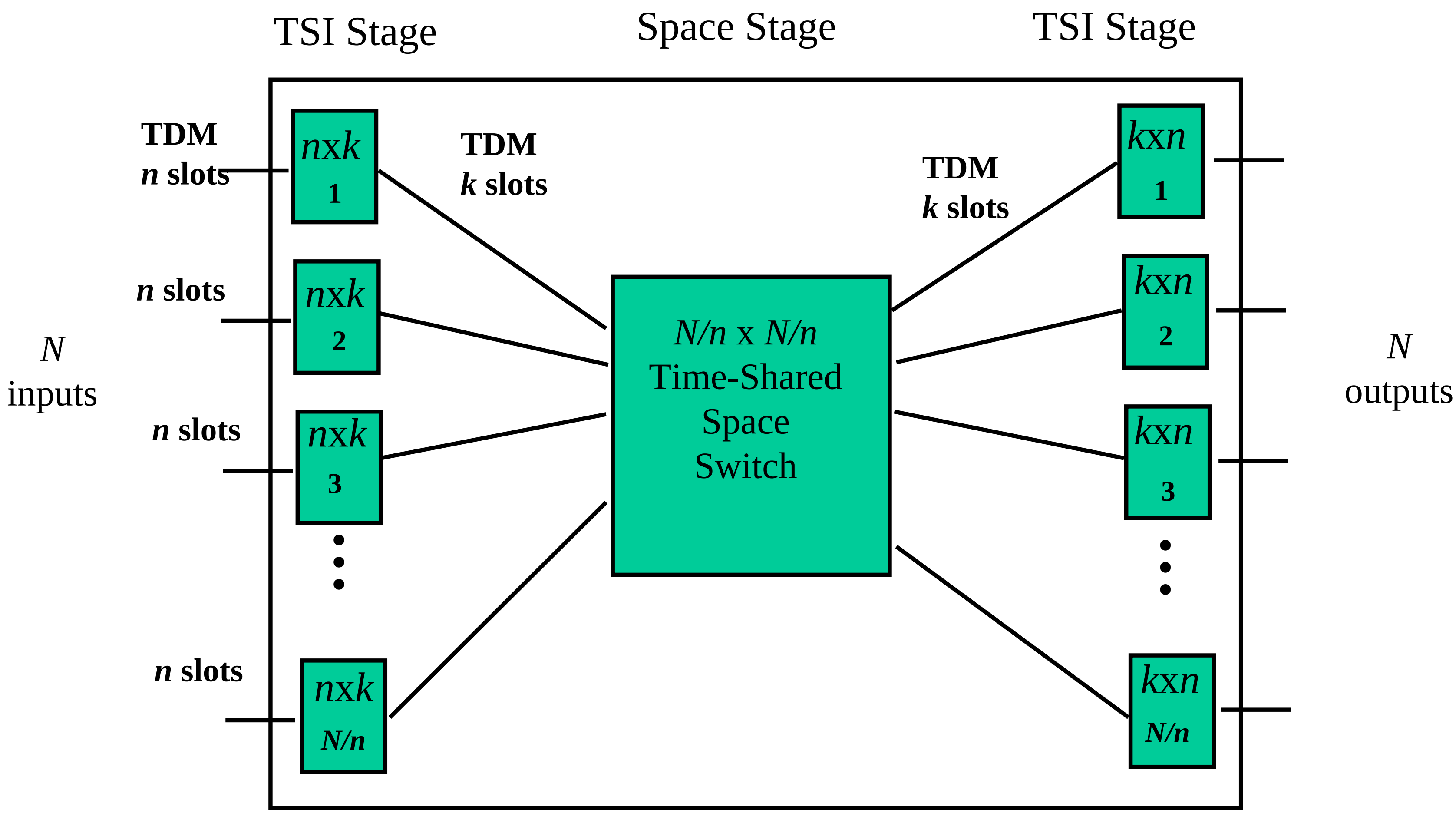
– only one of the intermediate switches is busy during any one time-slot

– the *k* intermediate switches can therefore be replaced by one switch

» time-shared among the *k* slots in the frame

» the single intermediate switch must be reconfigured for each time-slot

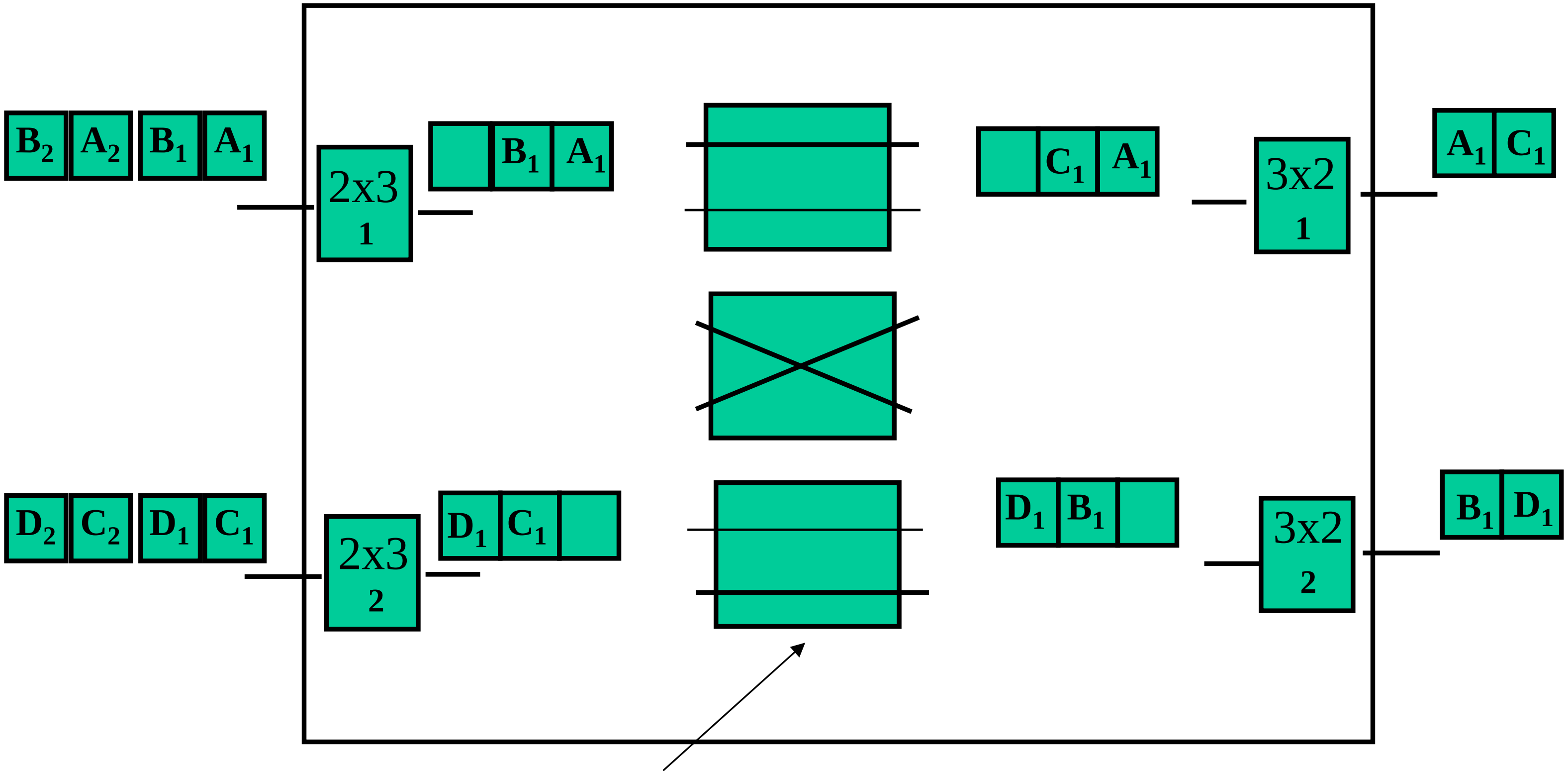
» known as *time-division* switching


TSI Stage
Space Stage
TSI Stage
TDM
n slots
nxk
1
TDM
k slots
TDM
k slots
kxn
1
n slots
nxk
2
kxn
2
N
inputs
N/n x N/n
Time-Shared
Space
Switch
N
outputs
n slots
nxk
3
kxn
3
n slots
nxk
N/n
kxn
N/n

– example: a 4 x 4 switch configured for the connection pattern (A, B, C, D) to (C, A, D, B)

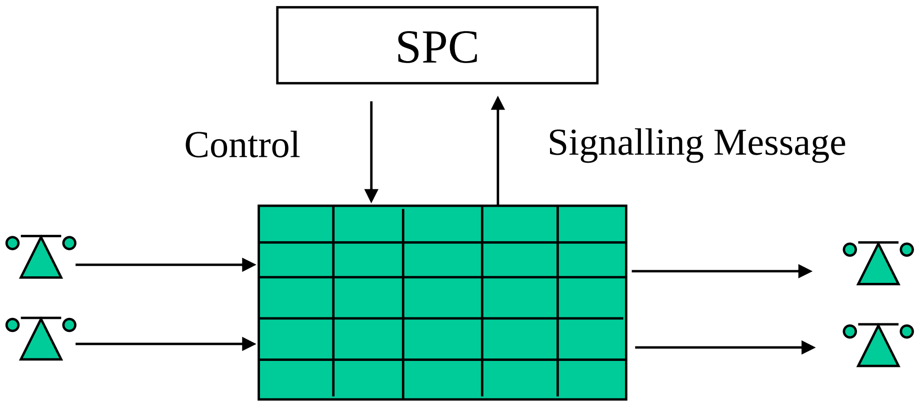
» using 2 x 3 input TSI switches

» i.e. 2-slot input frames and 3-slot output frames at the first stage switches

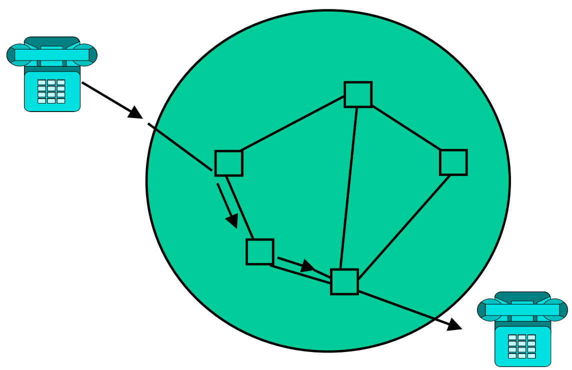


successive switch configurations

- Switching in the Telephone Network
  - switches between users must be configured to make the desired connections
    - » under Stored Program Control (SPC) i.e. computer control, in digital exchanges



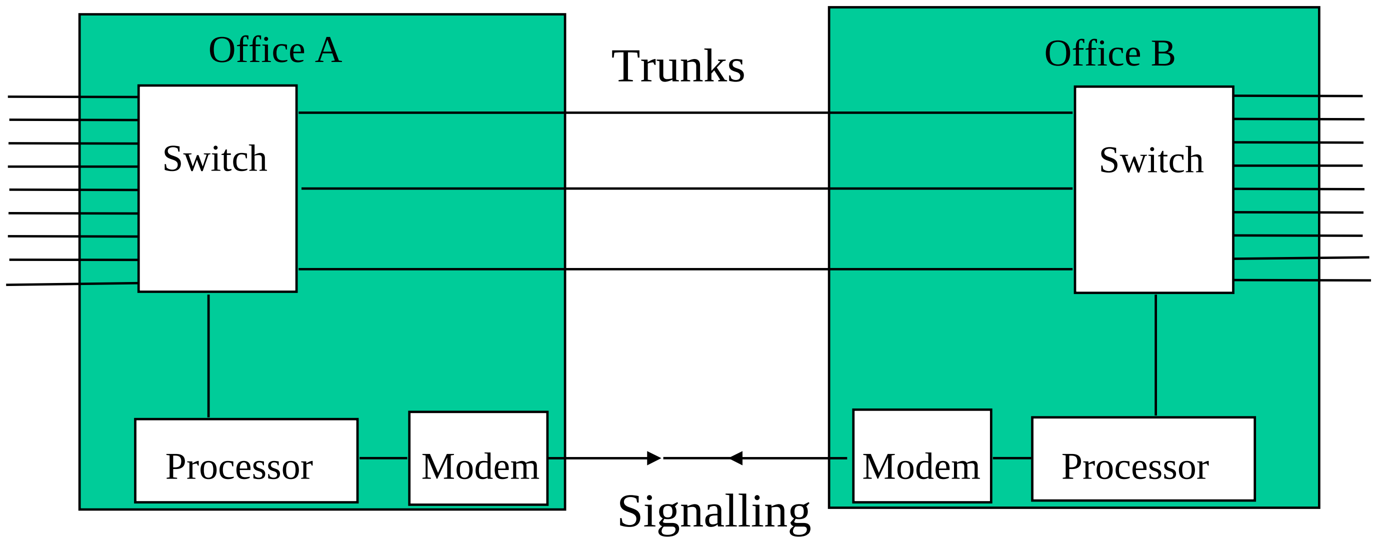
  - straightforward if switching in the same local exchange
  - switch reconfiguration needed in several exchanges *en route* for remote calls



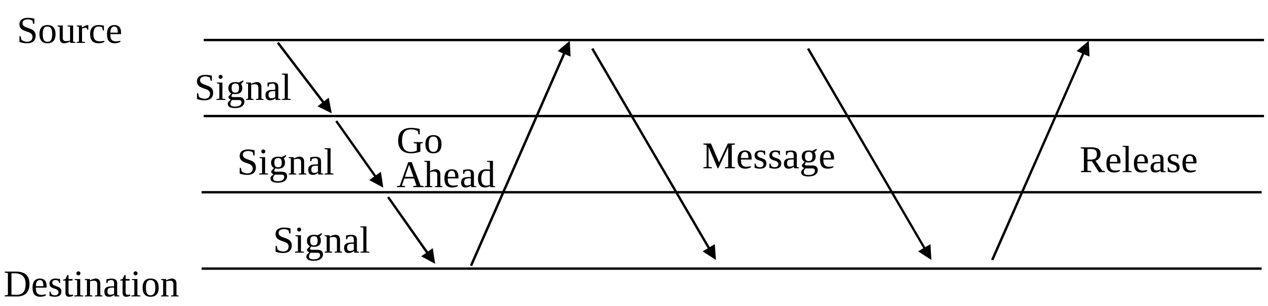
– a signalling system between exchanges is used to set switch configurations

– a *separate* `out-of-band' signalling network connecting exchanges

» designed for high reliability

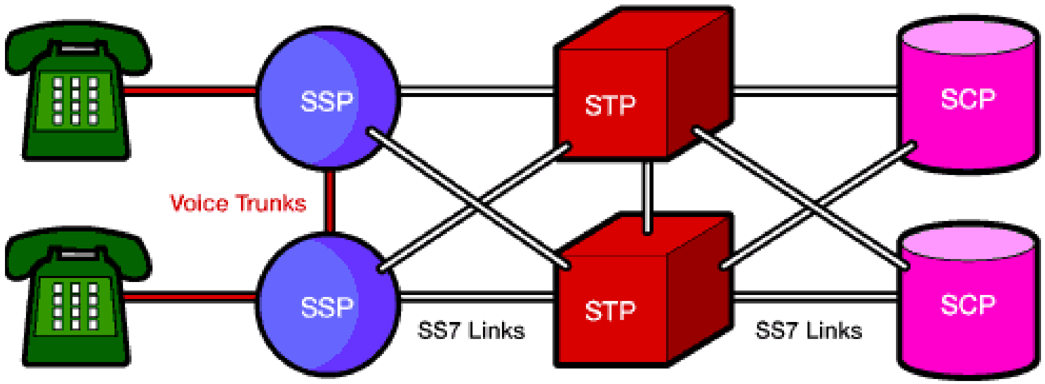


– e.g. call setup:



- The Common Channel Signalling System No. 7 (SS#7)
  - ref. http://www.pt.com/tutorials/ss7
  - an ITU global standard for defining the protocol for telephone network elements to exchange information
    - » used for: call setup, `tear-down', routing and control
    - » enhanced services: freephone (0800), premium lines, call forwarding, calling party name/number display, credit-card calls, conferencing etc.
    - » wireless mobile roaming
  - out-of-band signalling claims to give:
    - » faster call setup times compared with in-band multi-tone signalling
    - » more efficient use of voice circuits
    - » support for intelligent network services
      - e.g. requiring database accesses
    - » better control over fraudulent use

- Signalling points and networks
  - each signalling point is uniquely identified by a numeric *point code*
    - » source and destination point codes carried in signalling messages



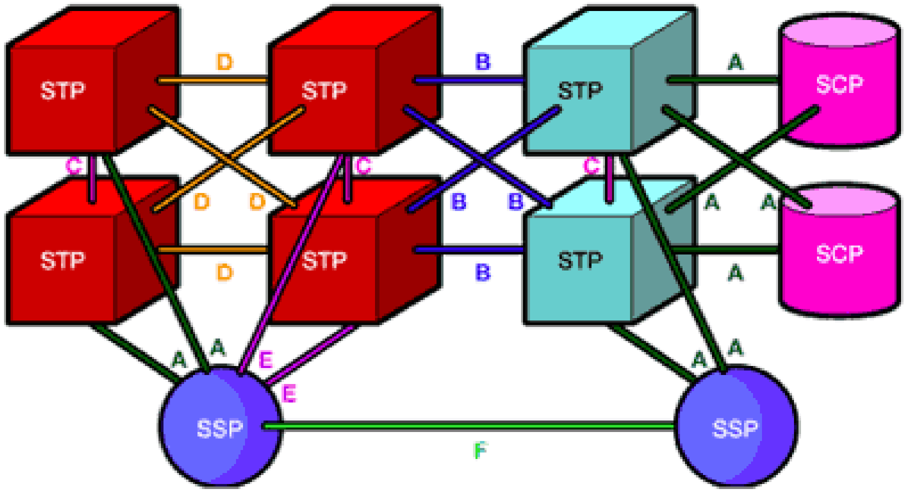
  - SSP : Service Switching Point
    - » switches that originate and terminate calls
    - » sends messages to other SSPs to setup, manage and release voice circuits
    - » may also send query messages to a centralised database (SCP) to determine how to route a call e.g. 0800 calls, or alternate call number if busy/unanswered
  - SCP : Service Control Point
  - STP : Signal Transfer Point
    - » message packet routing between SSPs, STPs and SCPs

– STPs and SCPs deployed in mated pairs for resilience in event of failure

» housed at physically separate places

» links between signalling points also deployed in pairs

– alternate pairs of STPs also possible if cost of extra resilience justifiable

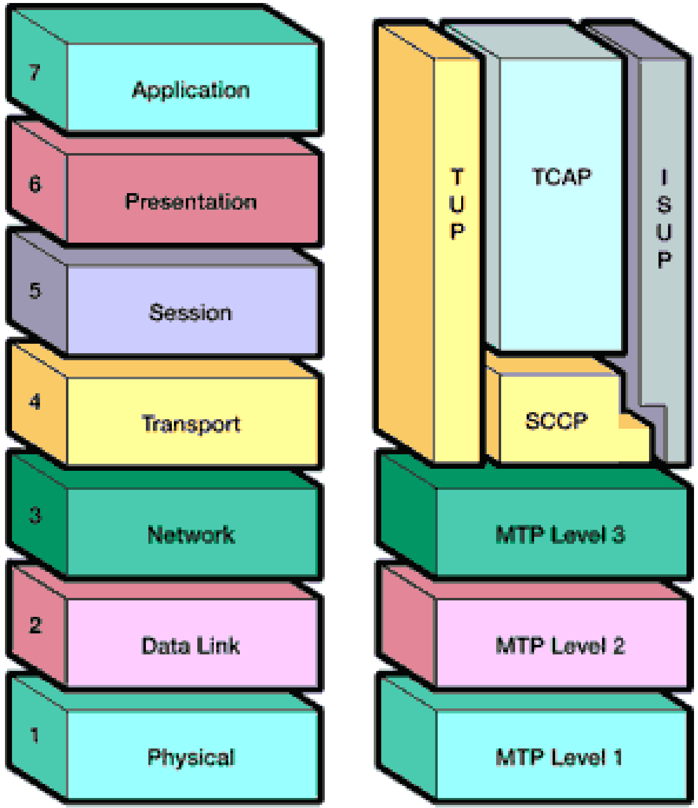


– various link types for interconnecting different types of signalling points

» A : Access link, B : Bridge link, C : Cross link, D : Diagonal link etc.

– links are bidirectional

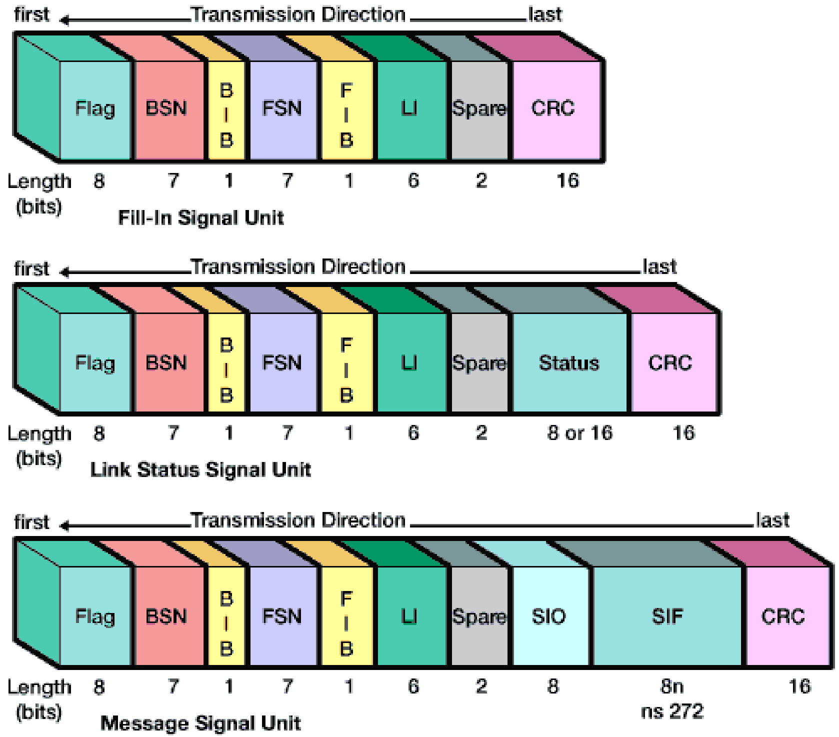
- SS#7 Protocol Stack
  - comparison with OSI 7-layer model :



  - Message Transfer Part (MTP) level 1
    - » equivalent to OSI physical layer
    - » defines physical & electrical characteristics of the link
      - includes interfaces for DS-1 (1.5Mbps), DS-0 (64kbps), etc.
  - MTP level 2
    - » ensures accurate end-to-end transmission of a message across a link
    - » implements flow control. message sequence validation, error checking
      - message retransmission on error
    - » nominally equivalent to OSI Data Link Layer
      - but also performs higher level functions

– an SS#7 message is called a *signal unit*

» Fill-in Signal Units (FISUs), Link Status Signal Units (LSSUs), Message Signal Units (MSUs),



» FISUs are transmitted continuously in both directions in absence of other messages

» can include acknowledgment of signal unit receipt by a remote signalling point

» CRC checksum included, so link quality continuously checked

– LSSUs carry status information regarding signalling points at ends of a link

– MSUs carry all call control, database query/response, network management and maintenance data

» in the Signalling Information Field (SIF), 1-63 bytes long

– Flag field indicates start of a message = 01111110

» 0 bit-stuffing after successive 11111 sequences in rest of message

– BSN : Backward Sequence Number

» used to acknowledge receipt of a message

» contains the sequence number of the message being acknowledged

– BIB : Backward Indicator Bit

» the negative acknowledgment indicator

– FSN : Forward Sequence Number

» the sequence number of the message being sent

– FIB : Forward Indicator Bit

» error indicator, like BIB

– uses a *Go-Back-N ARQ* (Automatic Repeat Request) protocol (*later lecture*)

– MTP levels 1 and 2 may be replaced by the ATM (Asynchronous Transfer Mode) protocol in future implementations

– MTP level 3

» provides message routing between signalling points

» equivalent to OSI Network layer

» source and destination routing labels (point codes) in messages

» message fed up to higher level protocol handler at its destination

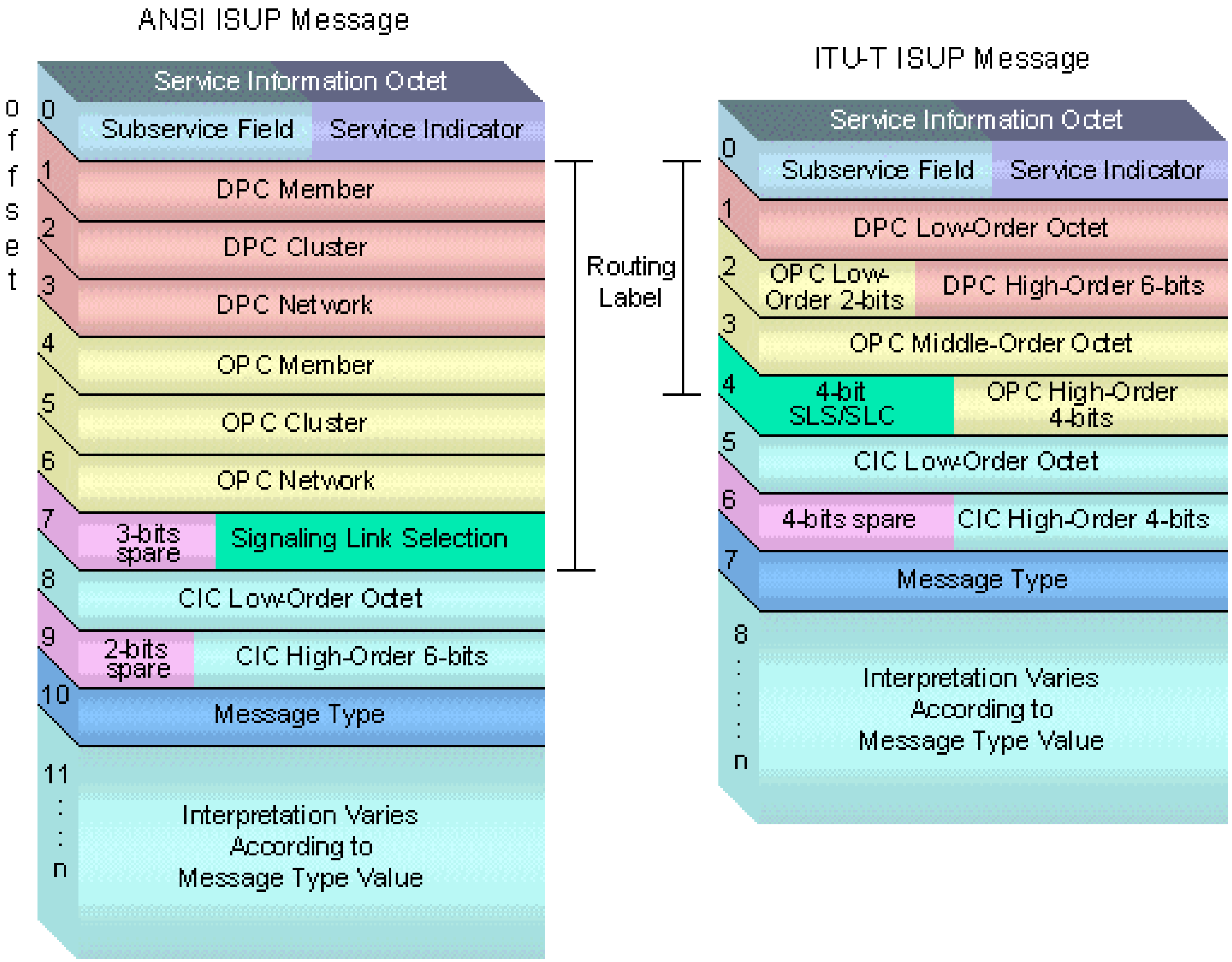
» passed on along the network if not destined for this point

– ISUP : ISDN User Part

» used for call setup, management and call release

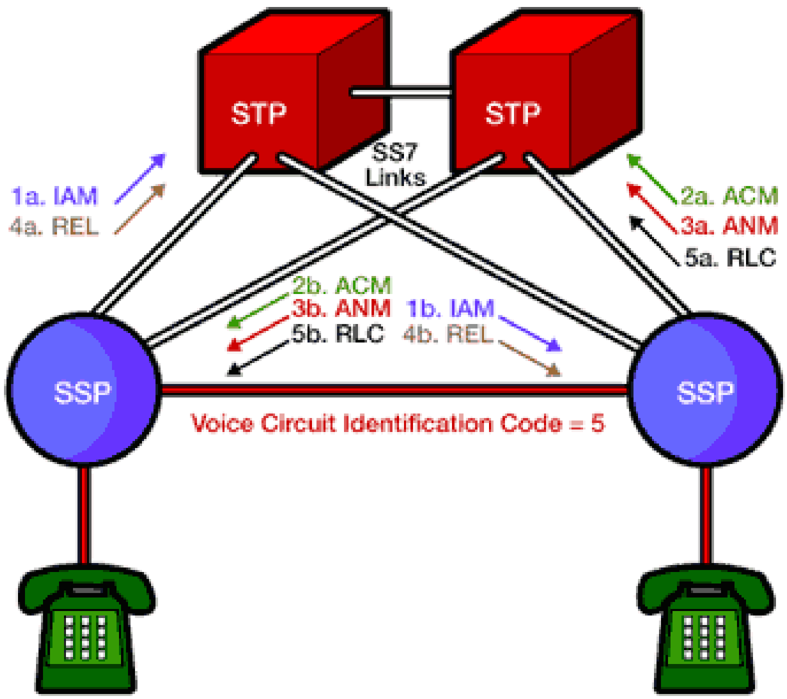
» used for both ISDN (Integrated Services Digital Network) and non-ISDN

- ISDN provides 2 x 64 kbps digital interface at the home/small business level
- predecessor of broadband



- hierarchical point codes
  - » as in IP addresses
  - » different variants in US and rest of world

- Basic ISUP Call Control : example :



1. Originating SSP transmits an ISUP Initial Address Message (IAM)
   – to reserve an idle trunk circuit from origin to destination switch (*1a*)
   – message includes circuit identification code, dialled digits and (optionally) the calling party number and name
   – IAM routed, via home STP of originating SSP, to destination SSP (*1b*)
   – same signalling links used for call duration unless a failure occurs

2. Destination switch examines dialled number

– checks that called line is available for ringing

– puts ring-tone onto called party's line

– transmits an ISUP Address Complete Message (ACM) back to originating switch (*2a*), via its home STP

– to indicate that remote end of trunk circuit has been reserved

– destination's home STP routes the ACM to the originating switch (*2b*)

– originating switch puts ring-tone onto calling party's line

– and connects it to the trunk to complete the voice circuit

– if originating and destination switches not directly connected with trunks:

– originating switch transmits an IAM to reserve a trunk to an intermediate switch

– intermediate switch sends an ACM acknowledging the circuit reservation request

– then transmits an IAM to reserve a trunk circuit to another switch in the route

– process continues until all the trunks required to complete the voice circuit from the originating switch to the destination switch are reserved

3. When called party picks up the phone

– destination switch terminates the ring-tone

– transmits an ISUP Answer Message (ANM) to originating switch via its home STP (*3a*)

– STP routes the ANM to originating switch (*3b*)

  – verifies that calling party’s line is connected to the reserved trunk

  – initiates billing!

4. If calling party hangs up first

– originating switch sends an ISUP Release Message (REL)

  – to release the trunk circuit between the switches (*4a*)

– STP routes the REL to the destination switch (*4b*)

If called party hangs up first, or if the line is busy,

– destination switch sends an REL back to the originating switch

  – indicating the cause of the release e.g. *normal* release of *busy*

5. Upon receiving the REL

- destination switch disconnects trunk from called party's line
- sets trunk state to *idle*
- transmits an ISUP Release Complete Message (RLC) to originating switch (*5a*)
  - acknowledges the release of the remote end of the trunk circuit

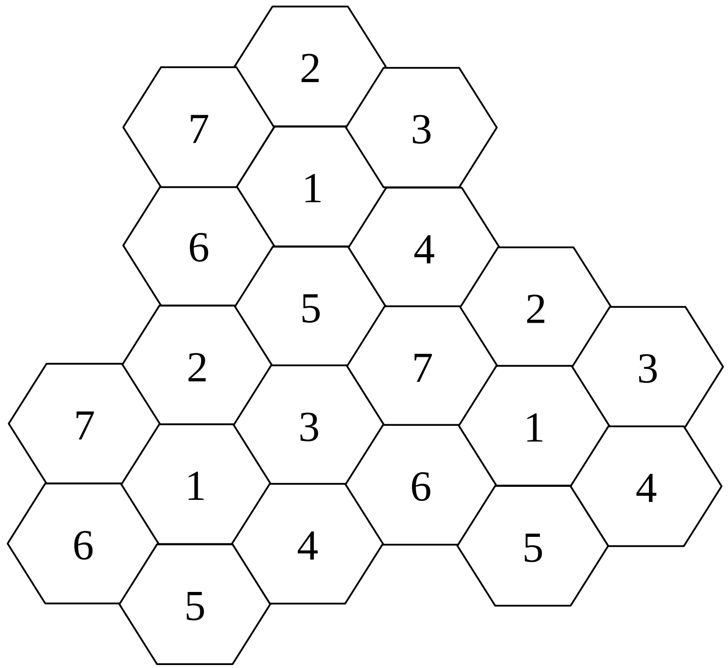
When originating switch receives, or generates, the RLC (*5b*)

- it terminates the billing
- sets the trunk to *idle* in preparation for the next call

- SCCP : Signalling Connection Control Part
  - provides connectionless and connection-oriented services above MTP level 3
  - allows messages to be addressed to specific applications and services at signalling points
  - used as the *transport layer* for TCAP services

- TCAP : Transaction Capabilities Application Part
  - enables intelligent network services
  - e.g. a query to an SCP to determine the routing address of 0800 numbers and the response from the SCP
  - e.g. when a mobile subscriber roams into a new Mobile Switching Centre area
    - » the Visitor Location Register requests the service profile information from the subscriber's Home Location Register
    - » for validation of service requested etc.

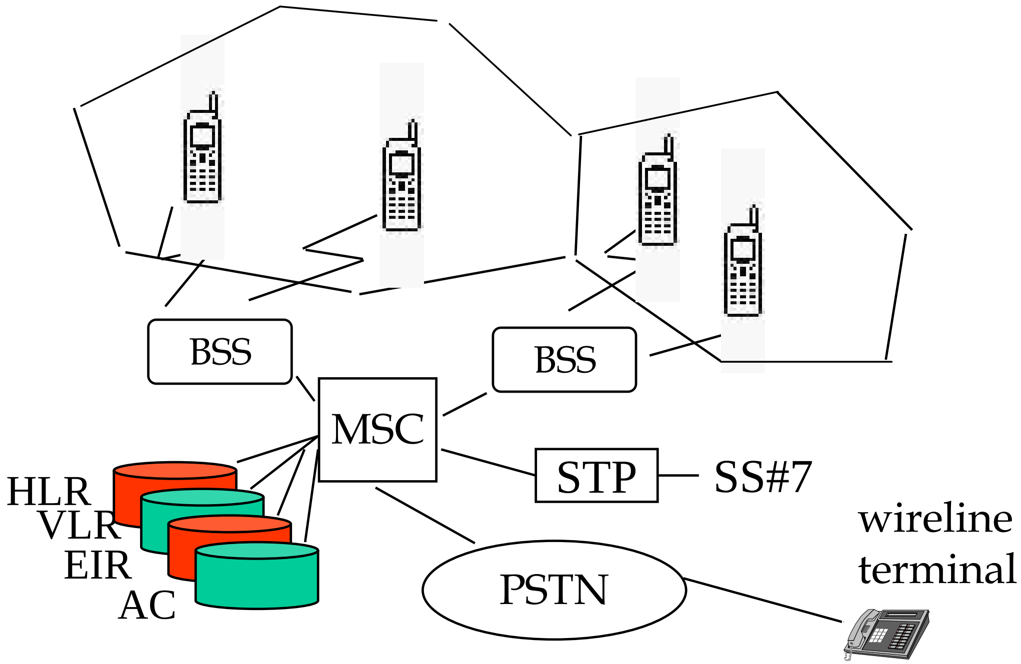
- Cellular Telephone networks
  - – a region divided up into *cells*
  - – each cell has a *base station* receiving and transmitting into that cell
    - » in practice, directional transmitters placed at meeting points of three cells
  - – different radio frequencies used in adjacent cells
    - » frequencies can be re-used in non-adjacent cells



– base stations are connected to the Mobile Switching Centre (MSC) via land-line or microwave links

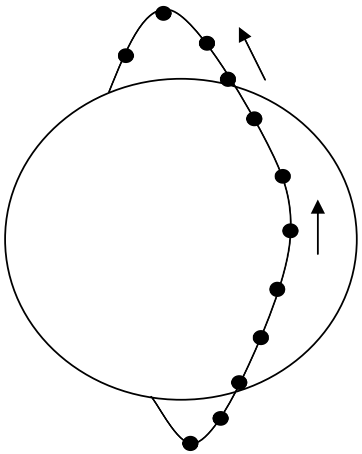
– MSC handles connections between cells and also to the public switched telephone network via STPs

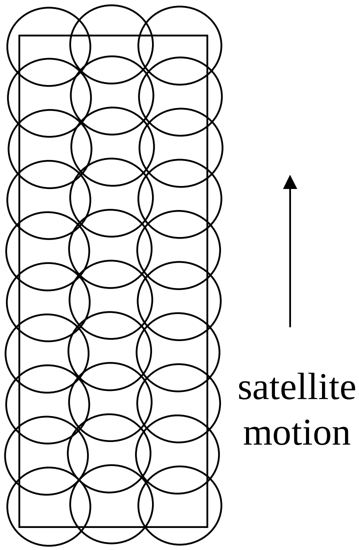
– also handles *hand-off* as users move from cell to cell



AC = authentication center
BSS = base station subsystem
EIR = equipment identity register
HLR = home location register
MSC = mobile switching center
PSTN = public switched telephone network
STP = signal transfer point
VLR = visitor location register

- Satellite Phones
  - geostationary satellites have too long a round-trip time for conversation
  - low-earth orbit needed – 750-2000km height
  - in polar orbits to cover whole earth surface





  - either satellite-fixed (cells defined relative to satellite) or earth-fixed
  - ground stations to connect to PSTN + intersatellite links for information relay
  - Iridium (Boeing, Motorola, DoD) – 66 satellites in 780Km LEO
  - Teledesic (Bill Gates, Craig McCaw) – not off the ground yet