PSTN

The first large network

The **P**ublic **S**witched **T**elephone **N**etwork

- was the first communications network, and thus worthy of study
- was not planned, but rather grew by mergers and acquisitions
- is not a network, but rather an internetwork of regional networks

The PSTN was originally an analog network
but when digital communications
- was proven better (Shannon theory)
- became practical (invention of transistor)

the PSTN migrated to become a digital core with analog subscriber lines

Many innovations were invented for the PSTN, including:
- multiplexing
- network planning, addressing
- OAM, control and management planes, billing

The PSTN is presently being phased out (being replaced by the Internet)
but many issues remain before it will be completely shut down

Multiplexing

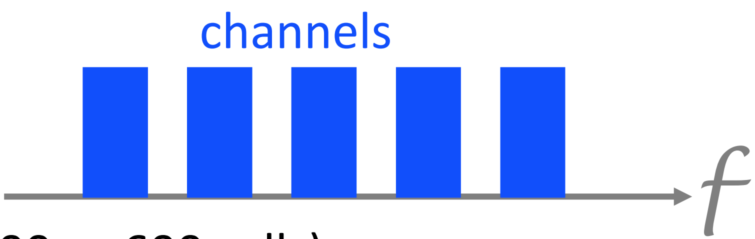
In 1900, 25% of telephony revenues went to copper mines

- standard was 18 gauge (about 1.2mm), long distance even heavier
- two wires per loop to combat cross-talk

A method was needed to place multiple calls on a single link (trunk)

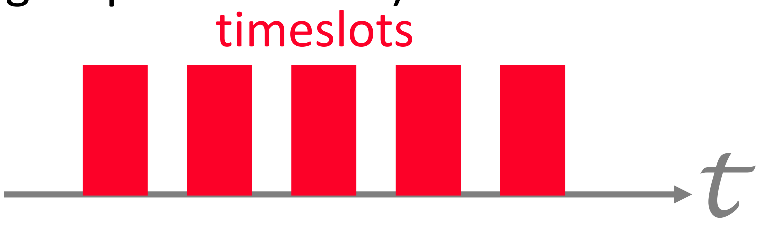
from 1918: "Carrier system" (FDM)

- group: 12 calls on a single trunk
- supergroup: 5 groups (60 calls)
- master group: 5 or 10 supergroups (300 or 600 calls)
- supermaster groups, jumbo groups, etc.



from 1963: T-carrier system (TDM)

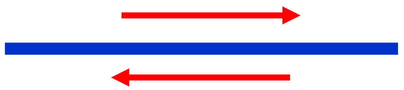
- T1 = 24 conversations per trunk (two groups on 2 trunk)
- PDH hierarchy
- SDH hierarchy



Multiplexing terminology

There are mechanisms to efficiently utilize *links* in a *network*

- Duplexing (half/full duplex)
  sending information in both directions on same link
  examples: FDD, TDD



- Multiplexing
  sending multiple flows of information on same link
  examples: FDM, TDM

- Inverse multiplexing
  sending a single flow of information on multiple links
  examples: LAG, link bonding, ECMP, VCAT

- Multiple Access
  multiplexing uncoordinated users
  examples, FDMA, TDMA, CDMA

The old PSTN

The PSTN was originally an **analog** network

Analog voltages travel end-to-end over copper wires

Voice signals arrive at destination (attenuated, distorted, and noisy)

- Amplifiers can be used to combat attenuation
- Loading coils can be used to combat distortion

Routing was originally performed *manually* at *exchanges*

Routing became mechanical and then electrical

Digitization of the PSTN

The FDM hierarchy was based on 4 KHz voice channels
- not because that is really sufficient for speech
- rather since that was the output of microphones in the early 1900s

When migrating to digital, the channels were digitized at 8000 samples/sec.

With logarithmic quantization, 8 bits per sample is sufficient
- leading to a basic digital voice channel (DS0) of 64 kbps (*timeslot*)

The rate of 8000 frames per second defines all later PSTN digital signals
- network is **C**onstant **B**it **R**ate (bit rate consumed even when no information)
- and synchronous (accurate timing needed for bit recovery)

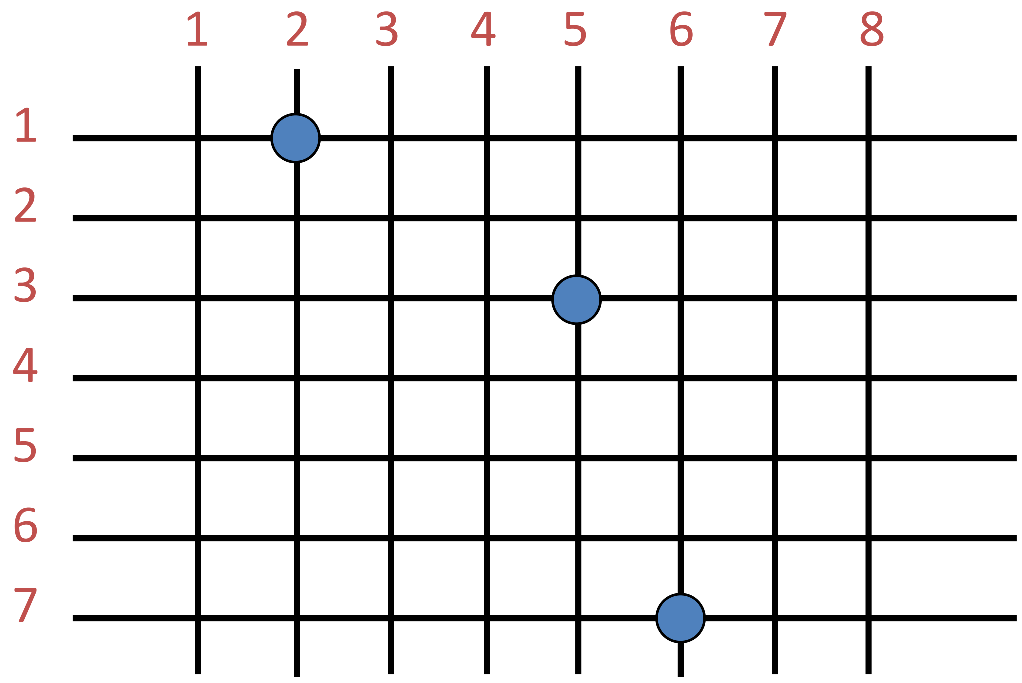
The first multiplexed level (DS1) is Time Division Multiplexing is **synchronous**
- all DSOs are sampled simultaneously

The following levels (DS2, DS3, DS4) are **plesiochronous** (PDH)
- multiplexed lower levels are only nominally of the same frequency

The higher levels are once again synchronous (SDH)
- multiplexed lower levels float in virtual containers

Analog switching

Analog Crossbar switch



Complexity increases rapidly with number of timeslots

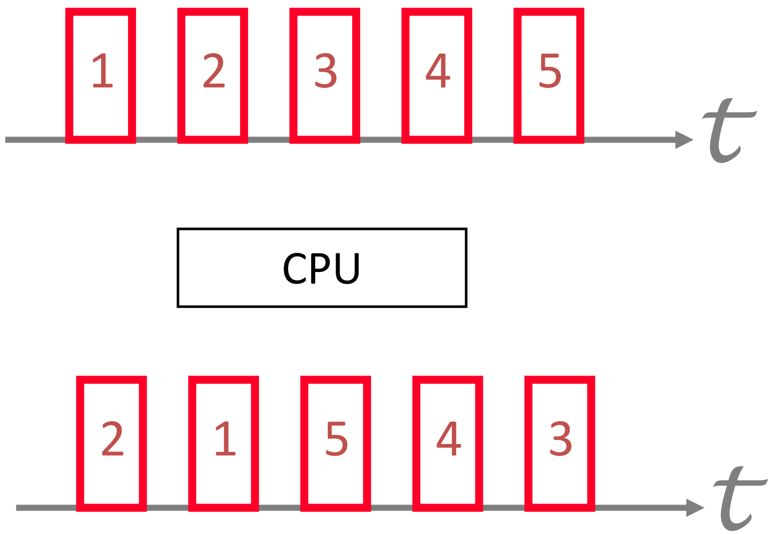
Switch introduces no transit delay

so end-to-end propagation time is time-of-flight (@ 200 meters / μsec)

TDM switching

Digital Crossconnect (DXC)

(depicted for a single TDM trunk)



The crossconnect switch

- extracts a byte
  - from timeslot N
  - in TDM trunk S
- places the byte
  - in timeslot M
  - in TDM trunk T

Complexity increases linearly with number of timeslots

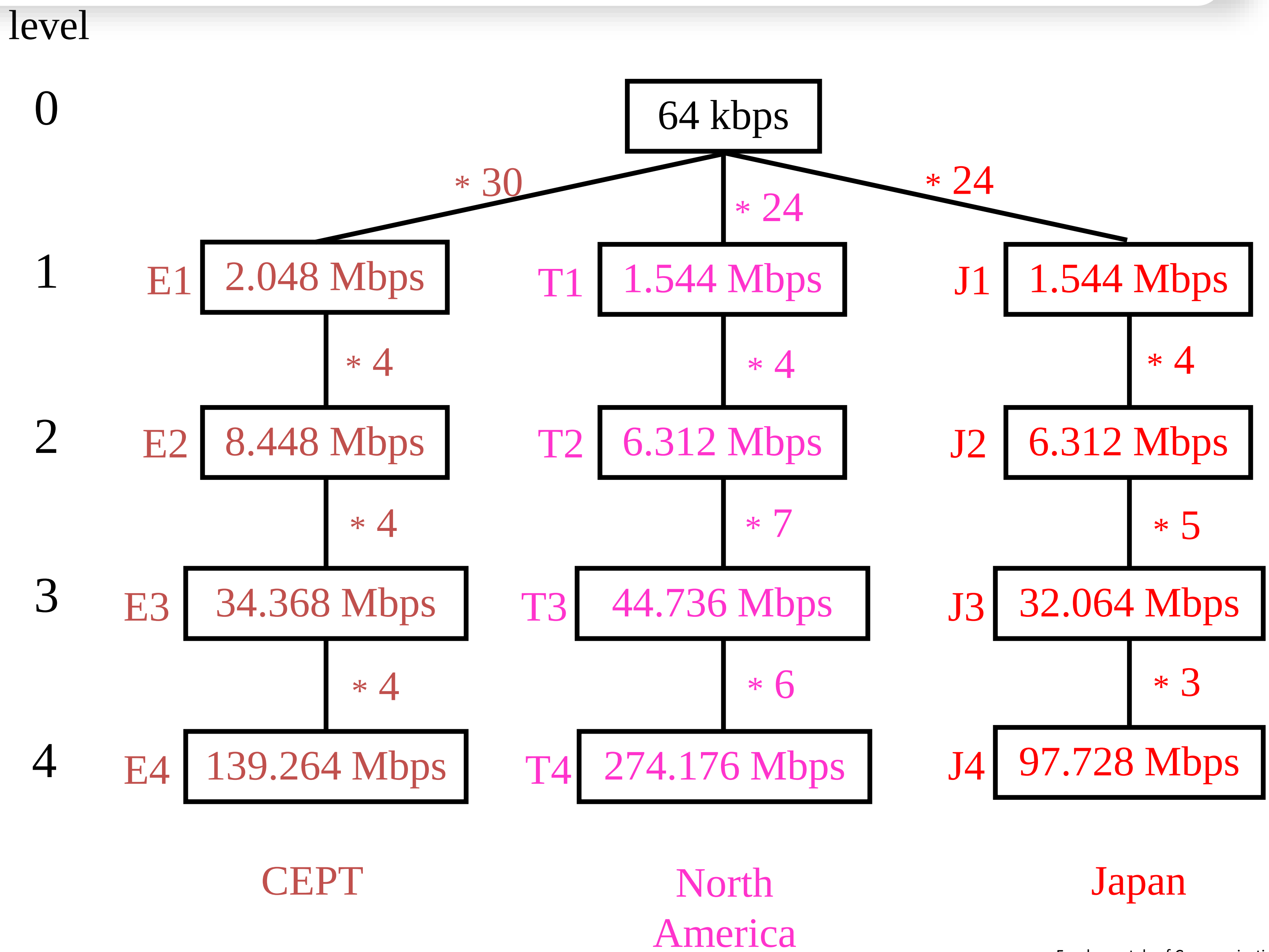
Switching time is theoretically 1 frame duration ($\frac{1}{8000}$sec = 125 μsec)

constant and independent of bit-rate

So that end-to-end propagation time is

- time-of-flight (@ 200 meters / μsec)
- number of switches * 125 μsec

PDH hierarchies



PDH switching

Because tributaries are plesiochronous
with each other
and with the higher order trunk
PDH multiplexing must perform (positive or negative) bit-justification

Because of this, demultiplexing must be performed on stages

For example, in order to extract a DS0 timeslot from an E4, one must

- demux the E4 into 4 E3s
- demux the particular E3 into 4 E2s
- demux the particular E2 into 4 E1s
- extract from the particular E1 the appropriate timeslot

Conversely, in order to insert a timeslot into an E4, one must

- insert the bytes into the appropriate timeslot in the particular E1
- mux 4 E1s into an E2
- mux 4 E2s into an E3
- mux 4 E3s into an E4

Switching time is constant and can be 2 frame times (250 μsec)

SONET/SDH hierarchy

SONET	SDH	rate	T1	T3	E1	E3	E4
OC-1		51.84M	28	1	21	1	
OC-3	STM-1	155.52M	84	3	63	3	1
OC-12	STM-4	622.080M	336	12	252	12	4
OC-48	STM-16	2488.32M	1344	48	1008	48	16
OC-192	STM-64	9953.28M	5376	192	4032	192	64

PDH couldn't scale to higher rates due to overhead increasing

SONET/SDH is still based on 8000 frames per second

higher data-rates are achieved by larger frames

The newer (non-PSTN) OTN has constant frame size

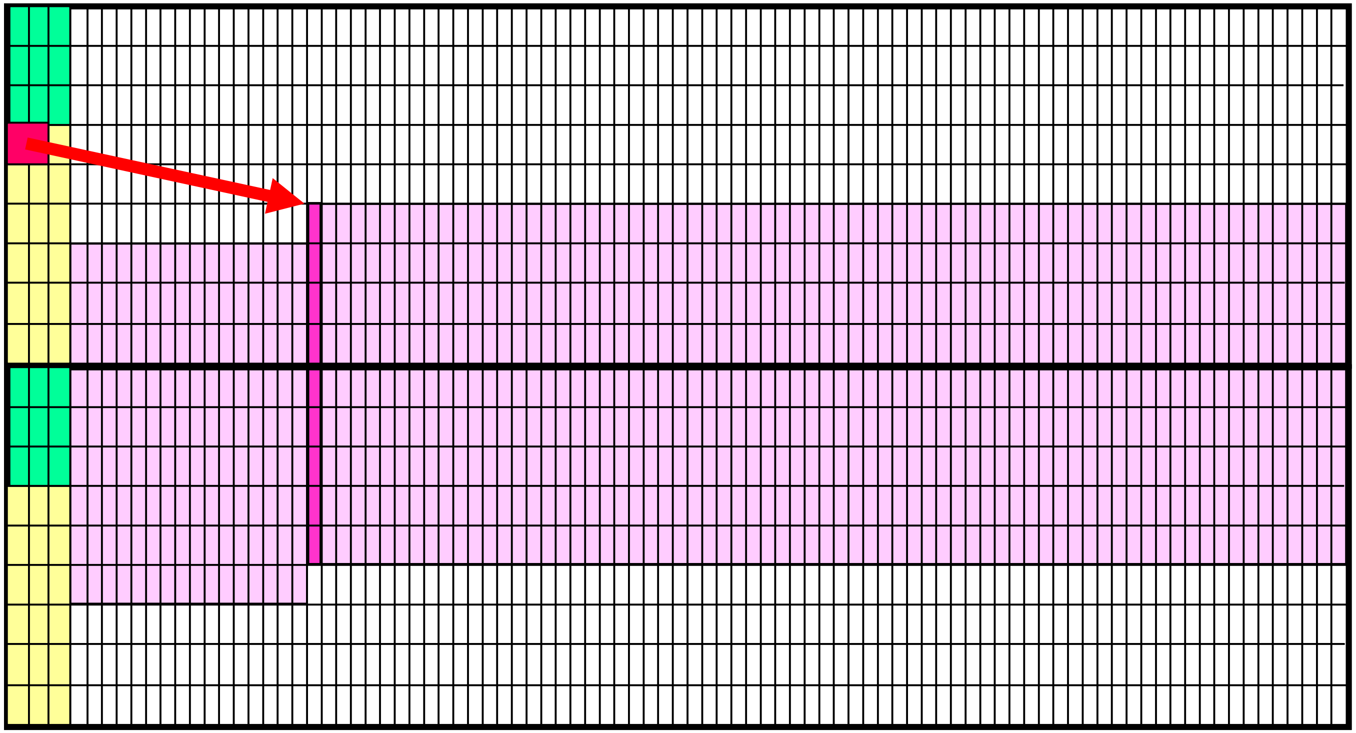
higher data-rates are achieved by more frames per second

SDH multiplexing

SDH solves PDH's overhead-explosion problem
by having constant overhead percentage

SDH solves the timing problem by using pointers

The tributary is placed in a container that floats inside the payload envelope



SDH switching

SDH is byte-oriented, unlike PDH which is bit-oriented

Lower order components can be extracted

- by pointer indirection
- without full demuxing

For example, one can (warning – very simplified explanation ...)

- locate a particular STM16 inside an STM64 by following the pointer
- locate a particular STM4 inside the STM16 by following another pointer
- locate a particular STM1 inside the STM4 by following another pointer
- locate a particular PDH payload inside the STM1 by following a pointer

Switching time is constant and low

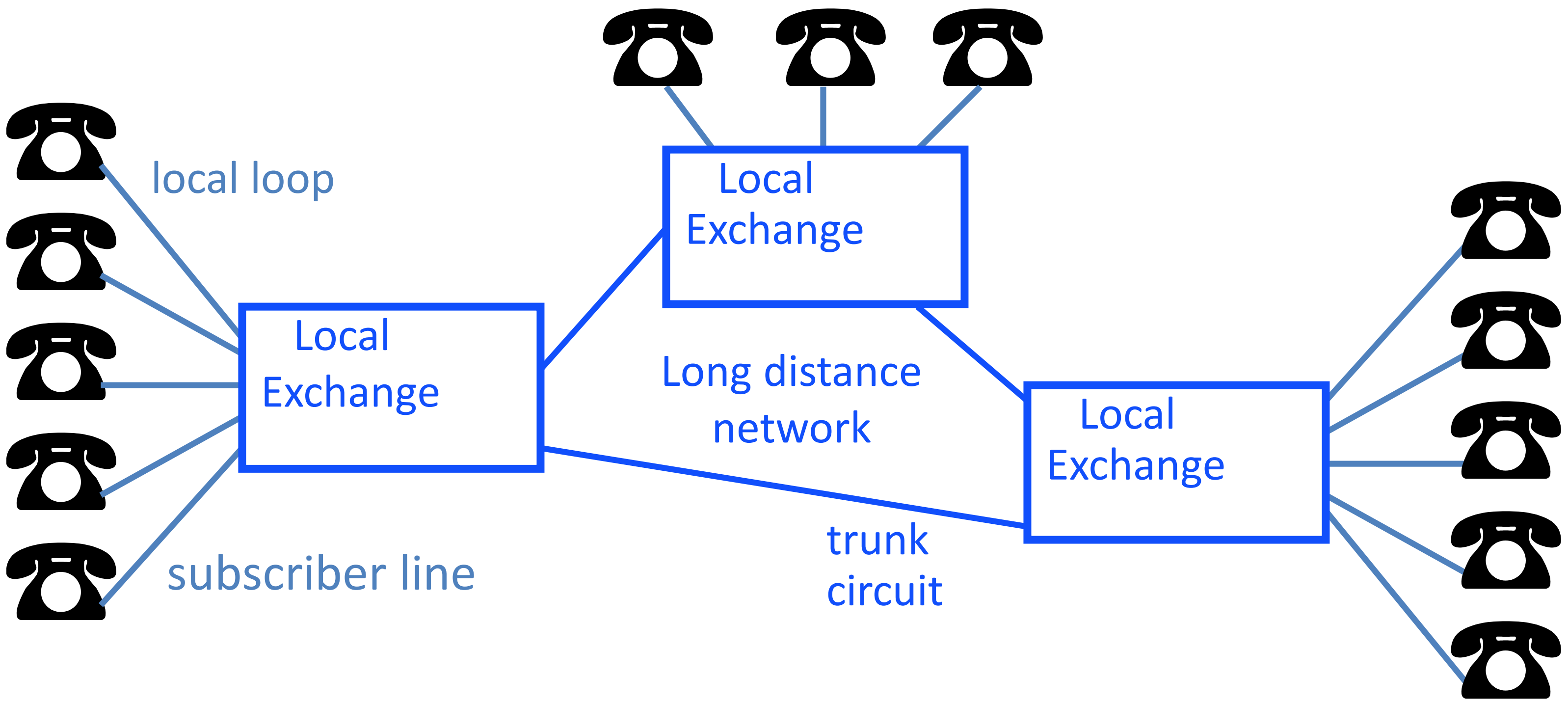
- path terminations (source and sink) contribute 250 μsec
- SDH cross-connects contribute less than 50 μsec

However, switch transit times do not decrease with increasing bit-rate

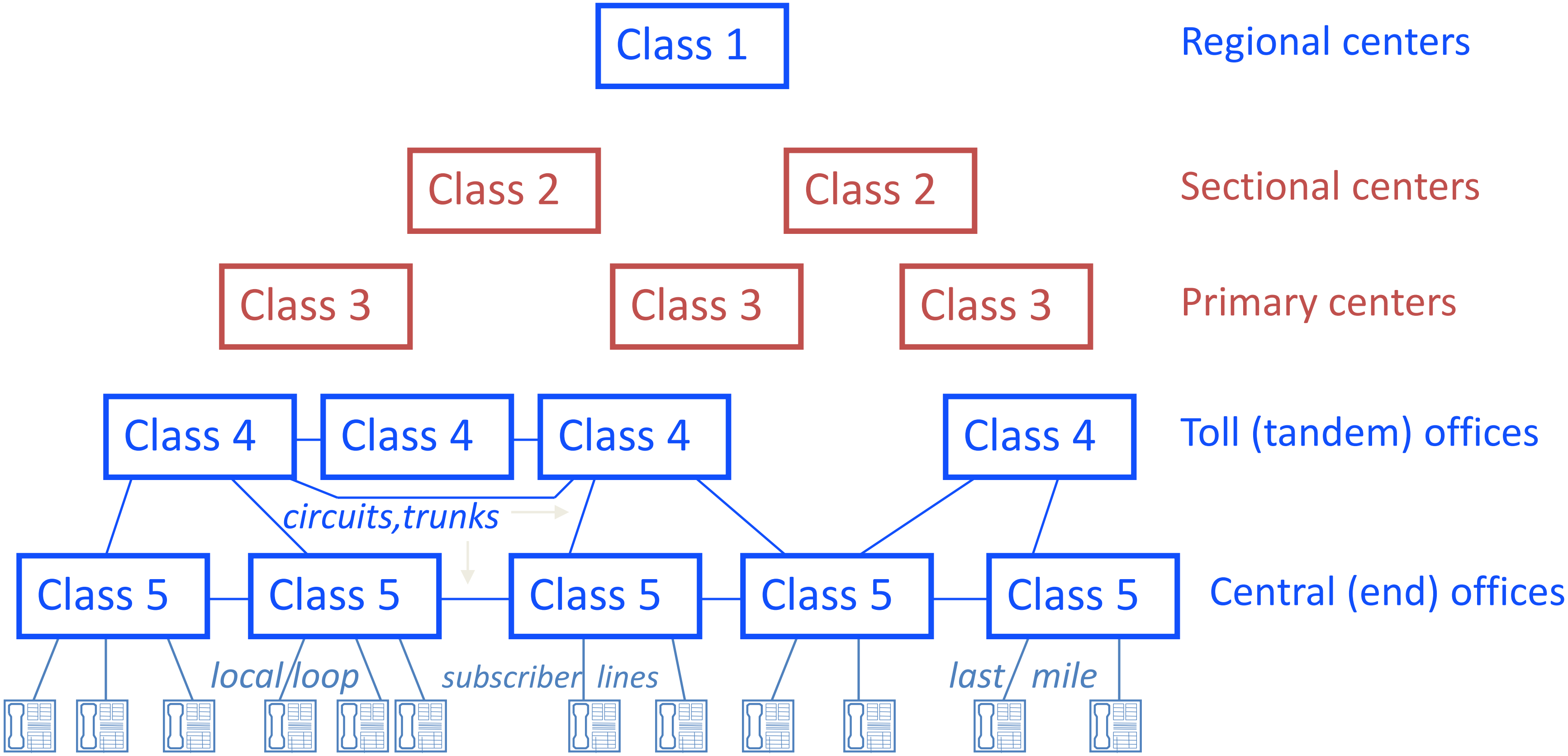
PSTN Topology

Many local telephone exchanges had sprung up

Bell Telephone acquired them
and interconnected them for long distance

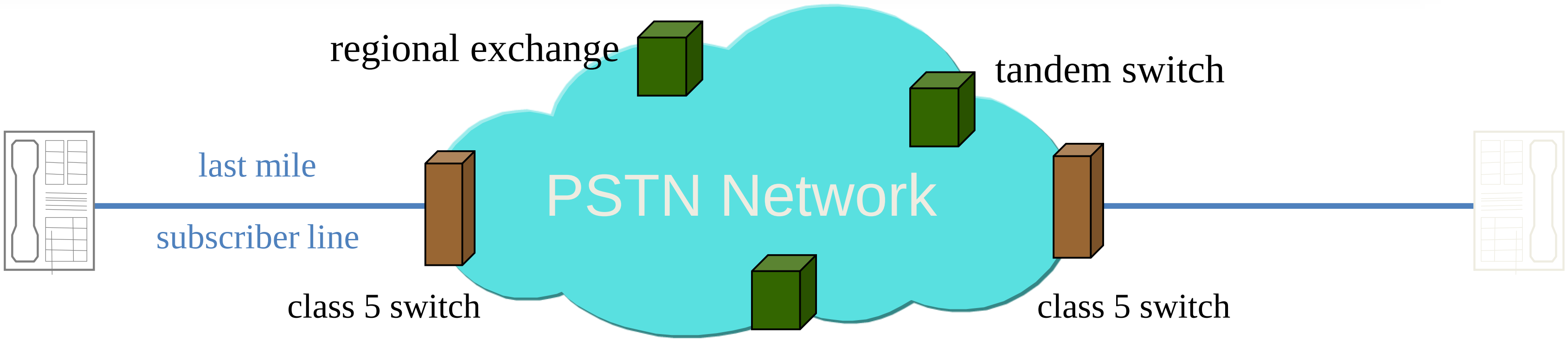


Old US PSTN



Class 5 switch is the sole interface to the subscriber lines

The PSTN after 1960



Analog voltages and copper wire used only in "last mile",
but core designed to mimic original situation

- Voice signal filtered to 4 KHz at input to digital network

Time Division Multiplexing of digital signals in the network

- Extensive use of fiber optic and wireless physical links
- T1/E1, PDH and SONET/SDH "synchronous" protocols

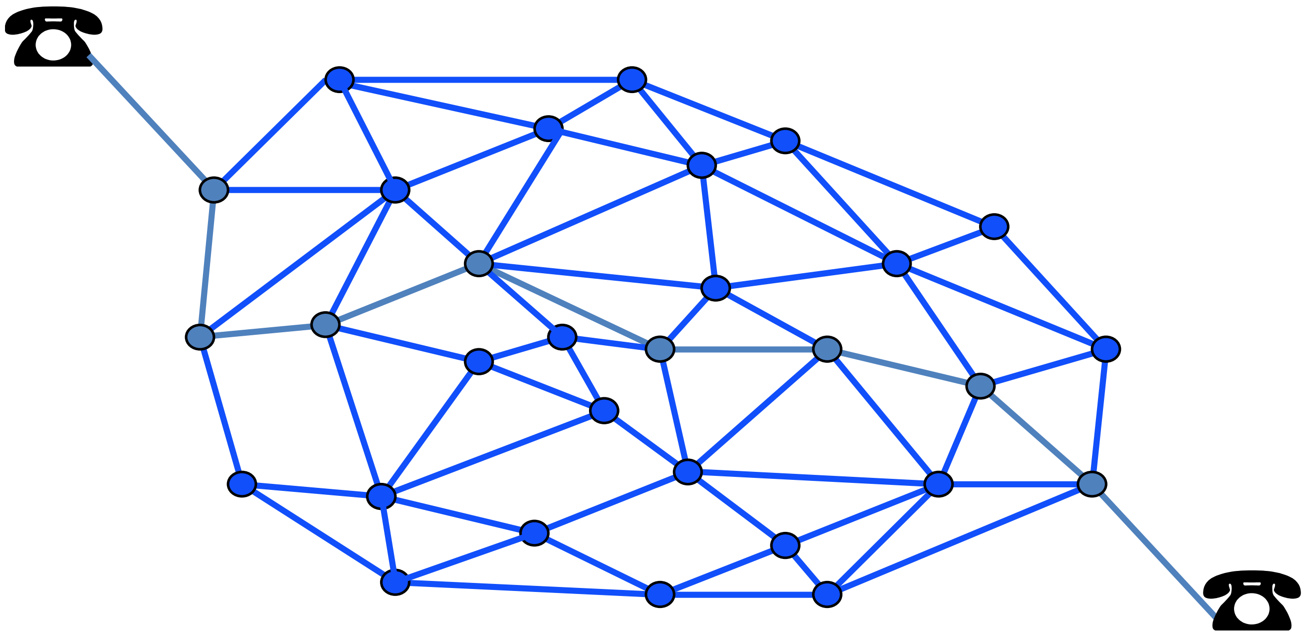
Universal dial-tone and automatic switching

Signaling can be channel/trunk associated or via separate network (SS7)

Automatic routing

- Circuit switching (route is maintained for duration of call)
- Complex routing optimization algorithms (LP, Karmarkar, etc)

Optimized Telephony Routing



Circuit switching (route is maintained for duration of call)

Call duration consists of ***set-up***, ***voice*** and ***tear-down*** phases

Route set-up is an expensive operation, just as it was for manual switching

Computation is performed globally by a *God-box*

Complex *least cost routing* algorithms (e.g., Karmarkar's algorithm) are used

Research topics

- Sunsetting of the PSTN :
  - who will be responsible for phone numbers ?
  - who will provide life-line services ?
  - who will provide location-enabled emergency services ?
  - who will inherit the physical resources ?
- Circuit switched networks provide physical layer frequency distribution
  - how can they distribute **T**ime **o**f **D**ay ?
  - how can PSNs provide timing services ?
- Circuit switched networks provide minimal propagation latency needed for interactive services such as VoIP, gaming, on-line music
  - how can PSNs networks reduce delay while maintaining the statmux advantage?