Part 1: Common network/protocol functions

Goals:
- identify, study common architectural components, protocol mechanisms
- **synthesis:** big picture
- **depth:** important topics not covered in an intro course

Overview:
- signaling: telephone net, Internet, ATM net
- state management (signaling)
- randomization
- indirection
- multiplexing
- virtualization
- design for scale
Common but already covered...

- error control
  - ARQ (ACK, NAK), FEC, hybrid
  - checksum, CRC
- flow control
- congestion control
- routing
- timers
- concerns: fairness, stability
- naming and addressing
- others?
Signaling

**signaling**: exchange of messages among network entities to enable (provide service) to connection/call

- **before, during, after connection/call**
  - call setup and teardown (state)
  - call maintenance (state)
  - measurement, billing (state)
- **between:**
  - end-user <-> network
  - end-user <-> end-user
  - network element <-> network element
Examples

- SS7 (Signaling System no. 7): telephone network
- Q.2931: ATM
- RSVP (Resource Reservation Protocol): Internet
Telephone Network

- Created 1876
- Currently a global infrastructure

Diagram:

- Central office
- Long haul Network
- Toll switch (Backbone Switch)
- Subscriber access lines (twisted pair)
- PBX

Legend:

- Central office
- Voice "trunk" lines
Central Office and Local Loop

- each phone user (subscriber) has direct connection to switch in central office (local loop)
- local loop has length 1 - 10 km
- switches in central office called (local) exchanges
- company providing local telephone service called local exchange carrier or LEC (e.g., Bell Atlantic)
**PBX**

- **PBX (Private Branch Exchange)** telephone system within enterprise that switches calls on local lines; allows users to share fixed number of external lines to central office
- saves cost of line per user to central office
Long-haul network

- toll switches provide long-distance connectivity over long distance trunks
- ~500 toll switches in US
- toll switch runs 100,000+ phone calls
How is voice transmitted?

Two ways:

- **analog voice transmission**: voice channel allocated bandwidth of 3.5 kHz
- **digital voice transmission**: analog voice stream converted to digital stream
  - standard scheme: 8000 8 bit samples
Until 1960s:
- analog telephone network
- frequency-division multiplexing

Today:
- local loop analog
- rest of network digital (based on TDM)

When do we get all digital network?
- ISDN (Integrated services Digital Network) is all digital circuit switching technology. available since the early-1990s (in Europe) or mid-1990s (US). No wide deployment in US

Another all digital - but not circuit-switched - telephony solution is IP telephony.
All analog telephone network

- first telephone switch digitizes voice call (8000 8-bit samples per second)
  - switching method is TDM.
- switch multiplexes calls, interleaving samples in time. call receives one 8-bit slot every 125 µs
Analog local loop / digital network

- telephone at subscriber digitizes voice, sends one 8-bit sample every 125 µs
Digital Multiplexing

- Digital Signaling (DS) transmission hierarchy used in US for multiplexing digital voice channels

<table>
<thead>
<tr>
<th></th>
<th>Number of voice circuits</th>
<th>Bandwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0</td>
<td>1</td>
<td>64 kbps</td>
</tr>
<tr>
<td>DS1</td>
<td>24</td>
<td>1.544 Mbps</td>
</tr>
<tr>
<td>DS2</td>
<td>96</td>
<td>6.312 Mbps</td>
</tr>
<tr>
<td>DS3</td>
<td>672</td>
<td>44.736</td>
</tr>
</tbody>
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Addressing and Routing

- Each subscriber has address (telephone number)
  - Hierarchical addresses
  - Example: Antonio’s Pizza in downtown Amherst

- Telephone address used for setting up route from caller to callee
Telephone network: services

- point-to-point POTS calls
- special telephone numbers:
  - 800 (888) number service: free call to customer
  - 900 number service: bill caller
  - numbers for life
- caller ID
- calling card/third part charging
- call routing (to end user): prespecified, by time-of-day
- “follow me” service
- incoming/outgoing call restrictions
- support for cellular roaming: “home” number routed to current cell location
Telephone network: AIN

AIN: Advanced Intelligent (phone) Network: migration from service-in-the-switch to service logic external to (on top of) switching systems

- looks like Internet philosophy:
  - e.g., DNS is at application layer; (RIP, OSPF, BGP above IP)
- AIN advantages:
  - introduce new services rapidly
  - open interfaces: vendor customization, vendor independence of services
Telephone network: circuit-switched voice trunks (data plane)
Telephone network: data and control planes
SS7: telephone signaling network

Note: redundancy in SS7 elements
Signaling System 7: telephone network signaling

- **out-of-band signaling**: telephony signaling carried over separate network from telephone calls (data)
  - allows for signaling between any switches (not just directly-connected)
  - allows for signaling during call (not just before/after)
  - allows for higher-than-voice-data-rate signaling
  - security: in-band tone signaling helps phone phreaks; out of band signaling more secure

- SS7 network: *packet-switched*
  - calls circuit-switched

- lots of redundancy (for reliability) in signaling network links, elements
**Signaling System 7: telephone network**

- **signaling between telephone network elements:**
  - **signaling transfer point (STP):**
    - packet-switches of SS7 network
    - send/receive/route signaling messages
  - **signaling control point (SCP):**
    - “services” go here
    - e.g., database functions
  - **signaling switching point (SSP):**
    - attach directly to end user
    - endpoints of SS7 network
Example: signaling a POTS call

1. caller goes offhook, dials callee. SSP A decides to route call via SSP B. Assigns idle trunk A-B

2. SSP A formulates Initial Address Message (IAM), forwards to STP W

3. STP W forwards IAM to STP X

4. STP X forwards IAM SSP B
Example: signaling a POTS call

5. B determines it serves callee, creates address completion message (ACM[A,B,trunk]), rings callee phone, sends ringing sound on trunk to A

6. ACM routed to Z to Y to A

7. SSP A receives ACM, connects subscriber line to allocated A-B trunk (caller hears ringing)
Example: signaling a POTS call

8. Callee goes off hook, B creates, sends answer message to A (ANM[A,B,trunk])

9. ANM routed to A

10. SSP A receives ANM, checks caller is connected in both directions to trunk. *Call is connected!*
**Example: signaling a 800 call**

800 number: logical phone number

- translation to physical phone number needed, e.g., 1-800-CALL_ATT translates to 162-962-1943

1. Caller dials 800 number, A recognizes 800 number, formulates translation query, send to STP W

2. STP W forwards request to M

3. M performs lookup, sends reply to A
Example: signaling a 800 call

800 number: logical phone number
- translation to physical phone number needed

1. A begins signaling to set up call to number associated with 800 number
Example: SS7 protocol stack

TCAP: application layer protocols:
- 800 service,
- calling card,
- call return,
- cellular roaming

SCCP: demultiplexing to multiple upper layer applications

SS7-specific network, link, physical layer protocols
- move to IP (RFC 2719)?

ISDN end-user signaling
Asynchronous Transfer Mode: ATM

- 1990's/00 standard for high-speed (155Mbps to 622 Mbps and higher) Broadband Integrated Service Digital Network architecture

- **Goal**: integrated, end-end transport to carry voice, video, data
  - meeting timing/QoS requirements of voice, video (versus Internet best-effort model)
  - “next generation” telephony: technical roots in telephone world
  - packet-switching (fixed length packets, called “cells”) using virtual circuits
ATM networks
ATM Layer: Virtual Channels

- **VC transport**: cells carried on VC from source to dest
  - call setup, teardown for each call before data can flow
  - each cell carries VC identifier (not destination ID)
  - every switch on source-dest path maintain “state” for each passing connection
  - link, switch resources (bandwidth, buffers) may be allocated to VC: to get circuit-like perf.

- **Permanent VCs (PVCs)**
  - long lasting connections
  - e.g., “permanent” route between two IP routers

- **Switched VCs (SVC)**:
  - dynamically set up on per-call basis
ATM Signaling: Q.2931
ATM Signaling: Q.2931

- point to point and point-to-multipoint
- symmetric/asymmetric BW requirements
- QoS negotiation
- error recovery mechanism
ATM Q.2931 Call Setup Signaling

VCI=5; VPI=0 used as signaling channel

user

UNI

ATM network

UNI

user

setup

call proc

connect

conn ack

user-user data

call reference addresses
traffic spec
QoS

call reference VPI/VCI

setup
call proc
connect
conn ack
ATM Q.2931 Call Release Signaling
ATM UNI Connection control messages

SETUP: initiate call estab
CALL PROCEEDING: call estab begun
CONNECT: call accepted
CONNECT ACK: call accept ACK

RELEASE: initiate call clearing
RELEASE COMPLETE: call cleared

STATUS ENQUIRY: req. status
STATUS: requested status info

RESTART: restart all VC’s
RESTART ACK: ACK RESTART

ADD PARTY: add party to existing connection
ADD PARTY ACK: ACK of ADD PARTY
ADD PARTY REJECT: REJECT of ADD PARTY
DROP PARTY: drop party from existing connection
DROP PARTY ACK: ACK of DROP PARTY
ATM Q.2931 Call Setup: Timers

- timers used to recover from problems
  - 10 timers at user side, 10 timers at network side
ATM Q.2931 Call Release Signaling
“...at a specific link, one switching system plays the role of the user side, and the other plays the role of the network side, as defined in the UNI 3.1 Specification.” ATM Forum af-pnni-0026.000

**PNNI Signaling:**