Evolution, Organization and Standards

Network Evolution, Standards, and Layered Architectures

#2

Outline

- **Network Evolution**
  - What makes communication systems work?
  - How the network evolved?
  - How network provided more services for less cost?
  - Predict where technology is going.

- **Standards**
  - Organization Objectives
  - Standards Organizations

- **Layered Architectures**
  - OSI reference (layered) model
  - TCP/IP network architecture (layered) model
  - Goal: Understand how networks are described
Elements of Current Communication Paradigm
Session Initiation Protocol (SIP) for Voice over IP (VoIP)

INVITE sip: tom@startup.com
c= IN IPv4 192.168.12.5
m=audio 35092 RTP/AVP 0

INVITE sip: tom@192.168.15.17
c= IN IPv4 192.168.12.5
m=audio 35092 RTP/AVP 0

(1) INVITE sip: tom@startup.com
(2) INVITE sip: tom@192.168.15.17
(3) ringing
(4) SIP/2.0 200 OK
(5) proxy
(6) proxy
(7) SIP/2.0 200 OK
(8) ACK
(9) ACK

Elements of a Communications System

- Transmission
- Switching/Routing
- Signaling
Transmission Network Resources

- **Time**
  - When and how long a user gets to talk

- **Frequency**
  - What part of the spectrum (channel) is used
  - What “code” is used.

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**TDM**

*Time Division Multiplexing*

- Normally, fixed allocation of time slot or channel spectrum

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**FDM**

*Frequency Division Multiplexing*

- Typical for analog voice

TDM Example

- Frame time = 1/8000 = 125 μs
- Number of slots/frame = 24
- Number of bits/slot = 8
  - Number of bits/frame = 24*8 = 192
  - Slot time = 125 μs/24 = 5.2 μs
  - Bit rate = (number of bits transmitted)/(time to transmit those bits) = 24*8/125 μs = 1.536 Mb/s
  - Bit time = slot time/(number bits/slot) = frame time/(number bits/frame) = 1/bit rate = 0.651 μs
  - Add one bit/frame for synchronization → bit rate = (193/125 μs) = 1.544 Mb/s

FDMA and TDMA:

Multiple Access (MA) is a channel access method; allowing several users to share the resource in time or frequency. The users transmit in “order”, each using his own frequency channel(s)/time slot(s).

Example:

- 4 users

Normally, in MA networks there is dynamic allocation of resource allocation.

Transmission Network Resources

- **Downlink/Downstream**, e.g., base station → smartphone
- **Uplink/Upstream**, e.g., smartphone → base station
- **Frequency-division duplexing (FDD)**
  - Downlink on frequency carrier \( f_1 \)
  - Uplink on frequency carrier \( f_2 \)
- **Time-division Duplexing (TDD)**
  - Downlink is time slots \( k \)
  - Uplink in time slots \( k+1 \), \( M \)
Evolution, Organization and Standards

Table 5.2 UTRA operating bands (3G 25.990 [11] Table 5.5.1)

<table>
<thead>
<tr>
<th>E-UTRA operating band</th>
<th>Uplink (UL) operating band</th>
<th>Downlink (DL) operating band</th>
<th>Duplex mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f_2,n - f_1,n</td>
<td>f_1,m - f_2,m</td>
<td>FDD</td>
</tr>
<tr>
<td>1</td>
<td>1900 - 1910 MHz</td>
<td>2110 - 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1930 - 1990 MHz</td>
<td>1890 - 1890 MHz</td>
<td>FDD</td>
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<tr>
<td>3</td>
<td>1710 - 1755 MHz</td>
<td>1805 - 1805 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>4</td>
<td>1770 - 1785 MHz</td>
<td>2110 - 2170 MHz</td>
<td>FDD</td>
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<tr>
<td>5</td>
<td>824 - 849 MHz</td>
<td>880 - 885 MHz</td>
<td>FDD</td>
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<tr>
<td>6</td>
<td>870 - 880 MHz</td>
<td>875 - 895 MHz</td>
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<td>7</td>
<td>2570 - 2670 MHz</td>
<td>2620 - 2690 MHz</td>
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<tr>
<td>8</td>
<td>698 - 713 MHz</td>
<td>925 - 960 MHz</td>
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<td>9</td>
<td>1706 - 1780 MHz</td>
<td>1094 - 1097 MHz</td>
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<tr>
<td>11</td>
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<tr>
<td>12</td>
<td>698 - 713 MHz</td>
<td>746 - 760 MHz</td>
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<td>13</td>
<td>777 - 797 MHz</td>
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<td>734 - 740 MHz</td>
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<td>33</td>
<td>1930 - 1995 MHz</td>
<td>1930 - 1995 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>34</td>
<td>2010 - 2055 MHz</td>
<td>2010 - 2055 MHz</td>
<td>TDD</td>
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<tr>
<td>35</td>
<td>1830 - 1915 MHz</td>
<td>1830 - 1915 MHz</td>
<td>TDD</td>
</tr>
<tr>
<td>36</td>
<td>1920 - 1990 MHz</td>
<td>1920 - 1990 MHz</td>
<td>TDD</td>
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<tr>
<td>37</td>
<td>1910 - 1930 MHz</td>
<td>1910 - 1930 MHz</td>
<td>TDD</td>
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<td>38</td>
<td>2070 - 2090 MHz</td>
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<td>1900 - 1970 MHz</td>
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</tr>
<tr>
<td>40</td>
<td>2300 - 2400 MHz</td>
<td>2390 - 2490 MHz</td>
<td>TDD</td>
</tr>
</tbody>
</table>

- **LTE definitions**
  - **UE** = User Equipment, e.g., smartphone
  - **eNB** = Evolved NodeB = Base station

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Transmission Network Resources

- Code Division Multiple Access (CDMA)
- Assume three users share same medium in time and frequency
- Users are synchronized & use different 4-bit orthogonal codes: 
  \{-1,-1,-1,-1\}, \{-1,+1,-1,+1\}, \{-1,-1,+1,+1\}, \{-1,+1,+1,-1\}

![Diagram of code division multiple access (CDMA)](image)
Evolution of Transmission

- Access Technology
  - Twisted pair copper
  - Coax
  - Fiber
  - Wireless
  - Others
    - Powerline
    - Satellite

Switching

- Switching
  - Information in on “Port” $i$
  - Information out on “Port” $j$
- Manual
- Step-by-step
- Crossbar with stored program control
- Digital Switching
- Packet Switching
- Optical Switching
- Quantum Internet?

Physicists transmit data via Earth-to-space quantum entanglement
Phys.org, July 11, 2017
- World’s first link layer protocol brings quantum internet closer to a reality, Phys.org, August 20, 2019
Step-by-Step Switch

Crossbar Switch
From: Engineering Operations in the Bell system

Digital Switching
Using TDM
Packet Switching (Statistical Multiplexing)

- Packet switching provides flexibility and the dynamic allocation of bandwidth
- The Internet is a packet switched network
- Packet switching has lead to the integration of all services on one infrastructure

Optical Switching

- All current switches are electronic
- Current switches require photon-to-electron and electron-to-photon conversions--optical to electronic (O/E) and E/O interfaces
- Optical switching will eliminate these interfaces:
  - Faster
  - Cheaper
  - Lower power required
  - Still “slow”
Signaling

- Signaling/Control: Governs network elements, e.g., telephone switches or packet switches (routers)
  - Sets-up a communications capability, request for resources
  - Maintains a communications capability
  - Ends (tears down) a communications capability
- The signaling network carries the messages that controls the network elements
  - Pulses \( \rightarrow \) In the same transmission path as voice signal
  - Tones \( \rightarrow \) In the same transmission path as voice signal
  - Computer Messages \( \rightarrow \) Outside of the transmission path.
    - Common Channel interoffice signaling (CCIS)
    - Signaling System #7 (SS7)
    - Session Initiation Protocol (SIP) for VoIP
    - H.323
    - Others.....
  - IP routing protocol messages, packets sent between processors in routers that set up forwarding tables

Signaling Example
Survivability → Resilience

- **FIBER CUT**
  - Jan., 4, 1991 - New York metro area
    - 6 million homes without long-distance service
    - New York Mercantile Exchange and New York Commodity Exchange shut down
    - Fiber cuts are common

- **Survivability - SS7 FAILURE**
  - June, 10, 1991 - California 2 million homes without phone service
  - June, 26, 1991 - Baltimore-10 million homes in 4 states without service & U.S. government phones affected

- **Survivability-SWITCH and POWER FAILURE**
  - September, 17, 1991 - New York metro area
    - 2 million homes without long-distance service
    - 3 major New York airports close for 6 hours
Physical Architecture of the Internet

What's the Internet: “nuts and bolts” view: how do packet flow over the internet

- billions of connected computing devices: hosts, end-systems
  - PCs workstations, servers
  - Smartphones,
  - IoT (Machine-to-machine: M2M), running network apps
- communication links
  - fiber, copper, radio, satellite
  - transmission rate = bits/sec
    Sometimes called bandwidth*
- routers: forward packets (chunks of data)
Internet structure: network of networks

- "Tier-2" ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs

Tier-2 ISP pays tier-1 ISP for connectivity to rest of Internet
- tier-2 ISP is customer of tier-1 provider

Tier-2 ISPs also peer privately with each other, interconnect at NAP

Internet structure: network of networks

- "Tier-3" ISPs and local ISPs
  - last hop ("access") network (closest to end systems)

Local and tier-3 ISPs are customers of higher tier ISPs connecting them to rest of Internet
Internet structure: network of networks

- a packet passes through many networks!

How do you make it all work given:

- Hardware from different vendors
- Software from different vendors
- Different computer operating systems
- Rapid change in enabling technologies, more:
  - CPU power
  - Memory
  - Link Capacity
  - New radios
- Rapid introduction of new applications
- Multiple owners
Network Standards and Open Systems: **Need for Standards**

- Enable interoperability of equipment/software from different vendors
- Facilitate the building of a large market to reduce prices
- Standards lead to “**Open Systems**”
- With open systems customers are not locked into one vendor’s solution
- Open systems lead to a “**seamless**” user environment, e.g., www

Network Standards and Open Systems: **Objectives for Standards**

- Create standards by:
  - Development
  - Establishment
  - Promulgation
- Co-ordinate activity
- Assure consensus
- Information focal point
- Mechanism for management
  - Why do standards need to be managed?
Network Standards and Open Systems: Standards Organizations

- **American National Standards Institute (ANSI)**
  - Manufacturers
  - Organizations
  - Government
  - Users

- **Internet Engineering Task Force (IETF)**
  - Request for Comment (RFC)

- **Electronic Industries Association (EIA)**
  - Electronic manufacturers

- **International Telecommunications Union (ITU) [Formerly: Consultative Committee International Telegraph Telephone CCITT]**
  - National PTT's
  - Scientific organizations

- **IEEE**, e.g. IEEE 802.11

Network Standards and Open Systems: Problems with Standards

- freezes technology
- Multiple standards evolve for same system
- Standards take a long time to be established
- Difficult to evolve to meet rapidly changing needs
- Often standards are complex
- De-facto standards often emerge
### Network architectures and the Reference Models

- Standards require description and organization of network functionality
- Open systems are build upon a **Layered Architecture** of the network
- Layered Architecture is the “structuring” of network functions
- Note that network protocols are one example of real-time distributed processing

### Network architectures and the Reference Models

- Reference models provide:
  - A conceptual framework to characterize networks
  - A mechanism to control/describe the complexity of networks
  - Required for open systems
Network architectures and the Reference Models

- Layered Architectures must have
  - Structure
  - Symmetry
  - Peer protocols
- Structure is the collection of related processing functions into layers
- Symmetry requires compatible functions exist in source/destination systems
- Peer Protocols are the set of rules that govern the processing between peer entities, i.e., the source/destination

Network architectures: Underlying Principles

- Minimize the number of layers thus simplifying the tasks of describing and integrating different layers.
- Establish boundaries at points where the description of services is small and the number of interactions is minimum.
- Create layers that include different functions.
Network architectures:
Underlying Principles

- Establish boundaries where history demonstrates that the implementation can be partitioned.
- Engineer layers so that they can be redesigned to take advantage of new technology without changing the services and interfaces of adjacent layers.
- Allow for the bypassing of sublayers.
- Each layer should add value.

Layered Architecture
PDUs and SDUs

- Protocol Data Units (PDU) = packets between Peer entities
- Service Data Units (SDU) = packets between layers

Layered Architecture: International Organization for Standardization (ISO)
Open Systems Interconnection Model (OSI)

<table>
<thead>
<tr>
<th>OSI reference (layered) model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Layer</td>
</tr>
<tr>
<td>Presentation Layer</td>
</tr>
<tr>
<td>Session Layer</td>
</tr>
<tr>
<td>Transport Layer</td>
</tr>
<tr>
<td>Network Layer</td>
</tr>
<tr>
<td>Data Link Layer</td>
</tr>
<tr>
<td>Physical Layer</td>
</tr>
</tbody>
</table>

- Each layer adds “information” e.g., a header, to support processing packets at that layer.
- Protocols are partially described by defining the header information, e.g., the meaning of specific bits in the header.
Physical Layer (PHY)

- DTE/DCE interface
  - Data Terminal Equipment (PC)
  - Data Communications Equipment (Modem)
- Electrical/optics/radio connections, modulation formats
- Mechanical connections
- Functional Requirements
  - Procedural protocol
  - Bit transmission

How many PHY interfaces are on your smartphone?

Data Link Layer (DLL)
aka Data Link Control (DLC) layer

- Point-to-point
- Manage the link connection
- Supervise data interchange
- Synchronize and delimit
- Frame (block) sequencing
- Link flow control
- Link error control
- Abnormal condition recovery
- Identification and parameter exchange
Network Layer

- Routing and switching
- Network connections
- Logical channel control
- Segmenting and blocking
- Error recovery
- Sequencing and flow control

Network Layer

- May provide guaranteed delivery
- May provide delivery with delay bound
- For packet flows if defined:
  - In-order delivery
  - Guaranteed minimal data rate (e.g. in b/s)
  - Guaranteed minimal jitter
  - Security

Packet Arrival at dest. jitter
Transport Layer

- End-to-end
- Mapping
- Multiplexing
  - Multiple sessions on one transport pipe
- End-to-end error control
- Flow regulation
- Manage concatenated networks

Session Layer

- Administrative services
  - Binding connections
  - Unbinding connections
- Dialog Services
  - Control data exchange
  - Interaction and synchronization
  - Exception reporting
Presentation Layer

- Interpretation of data
- Data transformation
- Data formatting
- Syntax selection
- Structuring of data

Application Layer

- Highest layer
- Serves as window to OSI
- Functions to provide all services
- Comprehensible to the user e.g.
  - Identification
  - Availability of resources
  - Authority
  - Authentication
  - Agreement on syntax
- Layer management function
Layered Architecture: End-to-End Perspective & Encapsulation

Protocol layering and data

Each layer takes data from above
- adds header information to create new data unit
- passes new data unit to layer below

Example of Encapsulation

TCP Header contains source & destination port numbers

IP Header contains source and destination IP addresses; transport protocol type

Ethernet Header contains source & destination MAC addresses; network protocol type

FCS = Frame Check Sequence

Another Example of Encapsulation: IP over SONET

HTTP Request

TCP Header contains source & destination port numbers

IP Header contains source and destination IP addresses; transport protocol type

HDLC framing of PPP-encapsulated packets

SONET

HDLC = High-Level Data Link Control
PPP = Point-to-Point Protocol
SONET = Synchronous Optical Network
Putting it all together

Modified from: Leon-Garcia & Widjaja: Communication Networks

Evolution, Organization and Standards
Layering: *logical* communication

E.g.: transport
- take data from app
- add addressing, reliability check info to form packet
- send datagram to peer
- wait for peer to ack receipt
- analogy: post office

Layering: *physical* communication

Layered Architecture:

- Presentation: What does the peer look like?
- Sessions: Who is the Peer?
- Transport: Where is the Peer?
- Network: What is the route to the peer?
- Link: How is each step along the route taken?
- Physical: How is the transmission medium used?

Layered Architecture: TCP/IP

TCP/IP network architecture (layered) model

<table>
<thead>
<tr>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application Layer</td>
</tr>
<tr>
<td>Transport Layer</td>
</tr>
<tr>
<td>(host-to-host)</td>
</tr>
<tr>
<td>Internet Layer</td>
</tr>
<tr>
<td><strong>Network Access</strong></td>
</tr>
<tr>
<td>Layer</td>
</tr>
<tr>
<td>Physical</td>
</tr>
</tbody>
</table>
Layered Architecture: TCP/IP

- Physical layer is same as in OSI
- Network Access Layer:
  - Interaction between end-systems and network
  - Source provides destination address through network layer
  - Makes higher layer software “independent” of underlying networking technology

Layered Architecture: TCP/IP:

- Internet Layer
  - Routing between networks
  - Implemented in end systems
  - Implemented in routers
  - Internet Protocol (IP)
Layered Architecture: TCP/IP:

- Transport Layer
  - Reliable end-to-end transport
    - Transport Control Protocol (TCP)
  - User datagram protocol (UDP)
  - Others, e.g., Real Time Protocol (RTP)

Layered Architecture: TCP/IP:

- Application Layer
  - ftp
  - telnet
  - Mail
  - www
Common Protocol Functions

- Encapsulation
  - adding control information, e.g.,
    - Address
    - Error detection/correction bits
    - Protocol control
- Fragmentation and reassembly
  - Max packet size
### Common Protocol Functions

- **Connection control**
  - Not all protocols use connections
  - Connection oriented
  - Signaling
  - Graceful set-up and tear-down

- **Ordered delivery**
  - Deal with reordering
  - Lost packets

- **Flow control**
  - Match transmit and receiving rates
  - Prevent over running buffers

- **Error control**
  - Error detection
  - Error correction
  - Adds bits to packets
  - Detected errors sometimes causes retransmissions
Common Protocol Functions

- **Addressing**
  - Different layers contain different addressed, e.g., MAC, link layer, IP addresses, and socket

<table>
<thead>
<tr>
<th>Application Interface (TCP/UDP)</th>
<th>Socket Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internetwork Interface</td>
<td>IP address</td>
</tr>
<tr>
<td>Physical Interface</td>
<td>MAC address</td>
</tr>
</tbody>
</table>

- **Multiplexing**
  - Enables multiple customers to use one “pipe”
    - MAC address allows sharing on LAN
    - In TDM address is the time slot
    - In the internet host id is the IP address
    - Socket addresses allow multiple applications to use the same IP address

- **Transmission services,**
  - QoS, CoS
  - Security
  - Other “layer” specific services, e.g., framing
Example: LTE Protocol Stack

- Protocol Data Units (PDU) = packets between Peer entities
- Service Data Units (SDU) = packets between layers


Implementation of Layered Architecture: OSI and TCP/IP

Summary

- Elements of a Communications System
  - Signaling
  - Transmission (Time, Frequency, and Code)
  - Switching/Routing
- Internet Architecture
- Standards
  - Who makes them?
  - Why? (Advantages/disadvantages)
- Layered Architecture
  - OSI reference (layered) model
  - TCP/IP network architecture (layered) model
  - Encapsulation
- Common Protocol Functions