2 - Network Evolution, Standards and Layered Architectures
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 a 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

registrar

proxy

(1) SIP/2.0 200 OK
(7) SIP/2.0 200 OK
(8) ACK
(9) Media Flow

(2) (3) (4) (5) ringing

Modified From: Communication Networks: Fundamentals Concepts and Key Architectures
Authors: A. Leon-Garcia and I. Widjaja
Elements of Communication Systems

● Transmission
  ○ Source and channel coding, Packetization, Protocols
  ○ Waveform, spectrum, etc.

● Switching/Routing
  ○ Shortest path, adhoc networks, mobile

● Signaling
Transmission Network Resources

**TDM**
Time Division Multiplexing

**FDM**
Frequency Division Multiplexing*

Normally, fixed allocation of time slot or channel spectrum

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).

FDMA = Frequency Division Multiple Access

Example:
4 users

TDMA = Time Division Multiple Access

Transmission Network Resources

Spectrogram of Downlink Physical Channel for Long Term Evolution (LTE)

Subcarrier BW = 15kHz
Resource Block = 12 subcarriers (180kHz)
Time Slot = 0.5 ms

From: Peter Cain, Using Wireless Signal Decoding to Verify LTE Radio signals, Agilent Technologies, July 2011
Transmission Network Resources

- Downlink, e.g., base station → smartphone
- Uplink, e.g., smartphone → base station
- Frequency-division duplexing (FDD)
  - Downlink on frequency carrier 1, $f_1$
  - Uplink on frequency carrier 2, $f_2$
- Time-division Duplexing (TDD)
  - Downlink is time slots 1, k
  - Uplink in time slots k+1, M
LTE Operating Bands: 15 use FDD and 8 use TDD

<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>BS receive</td>
<td>BS transmit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UE transmit</td>
<td>UE receive</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1920 - 1980 MHz</td>
<td>2110 - 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1850 - 1910 MHz</td>
<td>1930 - 1990 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>3</td>
<td>1710 - 1785 MHz</td>
<td>1805 - 1880 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>4</td>
<td>1710 - 1755 MHz</td>
<td>2110 - 2155 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>5</td>
<td>824 - 849 MHz</td>
<td>869 - 894 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>6</td>
<td>830 - 840 MHz</td>
<td>875 - 885 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>7</td>
<td>2500 - 2570 MHz</td>
<td>2620 - 2690 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>8</td>
<td>880 - 915 MHz</td>
<td>925 - 960 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>9</td>
<td>1749.9 - 1794.9 MHz</td>
<td>1834.9 - 1879.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>10</td>
<td>1710 - 1770 MHz</td>
<td>2110 - 2170 MHz</td>
<td>FDD</td>
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<tr>
<td>11</td>
<td>1427.9 - 1452.9 MHz</td>
<td>1475.9 - 1500.9 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>12</td>
<td>688 - 716 MHz</td>
<td>728 - 746 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>13</td>
<td>777 - 787 MHz</td>
<td>746 - 756 MHz</td>
<td>FDD</td>
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<tr>
<td>14</td>
<td>788 - 798 MHz</td>
<td>758 - 768 MHz</td>
<td>FDD</td>
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<tr>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>17</td>
<td>704 - 716 MHz</td>
<td>734 - 748 MHz</td>
<td>FDD</td>
</tr>
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<td>...</td>
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<td>...</td>
</tr>
</tbody>
</table>

- TDD: Same Band for: BS→UE & UE → BS

- LTE definitions

  UE = User Equipment, e.g., smartphone

  eNB = Evolved NodeB = Base station

From: Agilent, 3GPP Long Term Evolution: System Overview, Product Development, and Test Challenges, Application Note
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\}

Section 6.4.3 Modified From: Communication Networks: Fundamentals Concepts and Key Architectures Authors: A. Leon Garcia and I. Widjaja
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
Step-by-Step Switch
Crossbar Switch
Stored Program Control System

(from Engineering Operations in the Bell System)
Packet Switching (Statistical Multiplexing)

- Packet switching provides flexibility and the dynamic allocation of bandwidth
- The Internet is a packet switched network
- Packet switching is leading to the integration of all services on one infrastructure: One infrastructure for voice, data, video
- Examples: VoIP and Video over IP (over the top)
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
  - Maintains a communications capability
  - Ends (tears down) a communications capability
- The signaling network carries the messages that controls the network elements
  - Pulses → In the same transmission path as voice signal
  - Computer Messages → 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 that control IP routers
Signaling Example
Signaling Example - LTE

Figure 2  Attach sequence for LTE radio
Physical Architecture of the Internet

What’s the Internet: “nuts and bolts”

- billions of connected computing devices: *hosts, end-systems*
  - PCs workstations, servers
  - Smartphones,
  - Machine-to-machine (M2M), e.g., toasters, smart meters running network apps

- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate = bits/sec
    Sometimes called *bandwidth*

- *routers*: forward packets (chunks of data)

---

The Internet: Network of networks

- “Tier-2” ISPs: smaller (often regional) ISPs
  - Connect to one or more tier-1 ISPs, possibly other tier-2 ISPs
The Internet: Network of networks

The Internet is a network of networks

The Internet: Network of 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
- Institute of Electrical and Electronics Engineers (IEEE)
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 built 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 is 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

Source

Message Flow

DATA

CONTROL

ENTITY

PROTOCOL

ENTITY

Message Flow

Destination

State Information

Processing

Layer

Interface

Source Host

Destination Host
**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><strong>Application Layer</strong></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
- 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
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 and 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.

Diagram illustrates the encapsulation process from HTTP Request to Ethernet header.
Putting it all together

Router

End System

Transmission Medium

Network

Division of Labor
- End host
- Network

1. Physical layer entity
2. Data link layer entity
3. Network layer entity
4. Transport layer entity

Modified from: Leon-Garcia & Widjaja: Communication Networks
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

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 rout 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><strong>Application Layer</strong></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 Layer</strong></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
- Fragmentation and reassembly
- Connection control
- Ordered delivery
- Flow control
- Error control
- Addressing
- Multiplexing
- Transmission services
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
  - Connection oriented
  - Signaling
  - Graceful set-up and tear-down

- Ordered delivery
  - Deal with reordering
  - Lost packets

Not all protocols use connections
Common Protocol Functions

- **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 addresses, 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>

Modified from: Computer Networks: Performance and Quality of Service. Ivan Marsic, Rutgers University, http://www.ece.rutgers.edu/~marsic/books/CN/
Common Protocol Functions

● **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 Protocol Stack:
Universal Mobile Telecommunications System (UMTS) Protocol Architecture - User Plane

GPRS = General Packet Radio Service; FP= Framing Protocol; SGSN= Serving GPRS Support Node
GTP-U= GPRS Tunneling Protocol-User; GGSN=Gateway
PDCP =Packet Data convergence Protocol; RLC=Radio Link Control; GTP-U=GPRS tunneling protocol (GTP)-User

From: Geert Heijenk, wwwhome.cs.utwente.nl/~heijenk/mwn/slides/Lecture-5%20slides%20per%20page.pdf
Example Protocol Stack: High Speed Data Packet Access (HSDPA)

GTP-U = GPRS tunneling protocol: GTP-U is used for carrying user data within the GPRS core network and between the Radio Access Network and the core network.

Implementation of Layered Architecture: OSI and TCP/IP