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=r IN IPv4 192.168.12.5
m=audio 35092 RTP/AVP 0

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

(1) (2) (3)

(4) (5) ringing

(6)

(7)
SIP/2.0 200 OK

(8)
ACK

(9)

modified from: Communication Networks:
Fundamentals Concepts and Key Architectures
Authors: A. Leon-Garcia and I. Widjaja

Evolution, Organization and Standards

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.

![Diagram of TDM and FDM](image)

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 their own frequency channel(s)/time slot(s).

FDMA = Frequency Division Multiple Access

TDMA = Time Division Multiple Access

Example:

4 users

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


Transmission Network Resources

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

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 4**: EUTRA operating bands (TS 36 813-1; Table 5.5.1)

<table>
<thead>
<tr>
<th>E-UTRA operating band</th>
<th>Uplink (UE) operating band BS receiver</th>
<th>Downlink (BS) operating band UE transmit</th>
<th>Duplex mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1920 - 1980 MHz</td>
<td>2110 - 2170 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>2</td>
<td>1980 - 2040 MHz</td>
<td>2170 - 2130 MHz</td>
<td>FDD</td>
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<td>3</td>
<td>2040 - 2100 MHz</td>
<td>2130 - 2190 MHz</td>
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<td>4</td>
<td>2100 - 2160 MHz</td>
<td>2190 - 2250 MHz</td>
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<td>5</td>
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<td>8</td>
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<td>2430 - 2490 MHz</td>
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<td>15</td>
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<td>16</td>
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<td>19</td>
<td>3000 - 3060 MHz</td>
<td>3090 - 3150 MHz</td>
<td>FDD</td>
</tr>
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<td>20</td>
<td>3060 - 3120 MHz</td>
<td>3150 - 3210 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>21</td>
<td>3120 - 3180 MHz</td>
<td>3210 - 3270 MHz</td>
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<tr>
<td>22</td>
<td>3180 - 3240 MHz</td>
<td>3270 - 3330 MHz</td>
<td>FDD</td>
</tr>
<tr>
<td>23</td>
<td>3240 - 3300 MHz</td>
<td>3330 - 3390 MHz</td>
<td>FDD</td>
</tr>
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<td>24</td>
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<td>3870 - 3930 MHz</td>
<td>FDD</td>
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<td>33</td>
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<td>3930 - 3990 MHz</td>
<td>FDD</td>
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<td>3990 - 4050 MHz</td>
<td>FDD</td>
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<td>35</td>
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<td>4050 - 4110 MHz</td>
<td>FDD</td>
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<tr>
<td>36</td>
<td>4020 - 4080 MHz</td>
<td>4110 - 4170 MHz</td>
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<td>37</td>
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<td>40</td>
<td>4260 - 4320 MHz</td>
<td>4350 - 4410 MHz</td>
<td>FDD</td>
</tr>
</tbody>
</table>

### UE 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

Transmission

Evolution of Transmission

- Twisted pair copper
- Coax
- Wireless
- Others
  - Powerline
  - Satellite

Transmission Media:
- Copper Wire
- Microwave Radio
- Satellite
- Fiber Optic

Time Division Multiplexing

Analog Transmission

Digital Transmission
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
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
  - Tones → 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
Survivability

- **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
  - PDAs phones,
  - 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)
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 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!

The Internet is a network of networks

Интернет — это сеть из сетей

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
  - 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

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**

---

### Network architectures and the Reference Models

- **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.

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 Host → Source Entity → Protocol Entity → Destination Entity → Destination Host

Message Flow

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)

OSI reference (layered) model

<table>
<thead>
<tr>
<th>Layer</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
- Mechanical connections
- Functional Requirements
- Procedural protocol
- Bit transmission
### 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

- Guaranteed Delivery (eventually)
- Guaranteed 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
- 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 over WDM-Packet over SONET

HTTP Request

- Header contains source and destination port numbers

TCP Header

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

IP Header

HDLC framing of PPP-encapsulated packets

HDLC

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

- End host
- Network
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 (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

Encapsulation: adding control information
  - 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

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 addressed, e.g., MAC, link layer, IP addresses, and socket

- **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

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

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