Transmission
Data Plane
Control Plane
#2

Outline

- Physical transmission of information
- Multiplexing
- Data plane-control of movement of data
- Packet Switching
- Control plane-routing and signaling

Elements of a Communications System

- Transmission of Bits
- Data Plane
- Control Plane

Transmission

- Bit transmission is the process of sending digital information (in the form of bits) from one device to another over a communication channel.
  - Source: Transmitter encodes the digital information into a series of electrical or optical signals, (or even acoustic) that can be transmitted through the communication channel.
  - Channel: The communication channel carries the signals from the transmitter to the receiver. Often the channel is a ***shared*** resource.
  - Receiver: Decodes the signals back into the original digital information

Links: physical media

- bit: propagates between transmitter/receiver pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Twisted pair (TP)

- two insulated copper wires
  - Category 5: 100 Mbps, 1 Gbps Ethernet
  - Category 6: 10Gbps Ethernet

Links: physical media

Coaxial cable:

- two concentric copper conductors
- bidirectional
- broadband:
  - multiple frequency channels on cable
  - 100's Mbps per channel

Fiber optic cable:

- glass fiber carrying light pulses, each pulse a bit
- glass fiber carrying light pulses, each pulse a bit
- Security-hard to tap
- high-speed operation:
  - high-speed point-to-point transmission (10's-1000's Gbps)
- low error rate:
  - repeaters spaced far apart
  - immune to electromagnetic noise

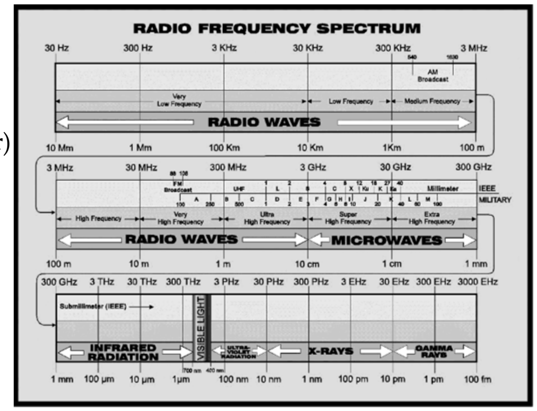
Links: physical media

Wireless signal carried in electromagnetic spectrum

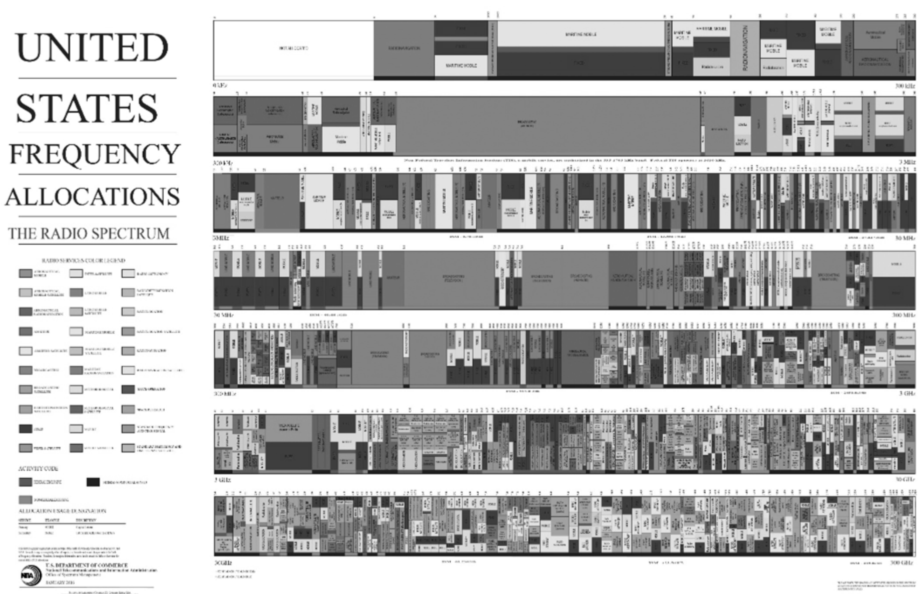
- no physical "wire"
- broadcast and "half-duplex" (sender to receiver)
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

Radio link types:

- terrestrial microwave
- Wireless LAN (WiFi)
- wide-area (e.g., cellular)
- satellite

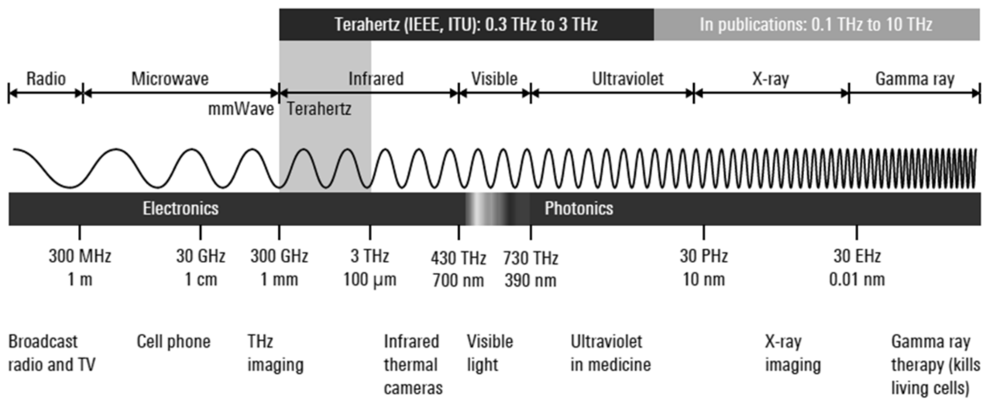


Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020



See: http://www.ittc.ku.edu/~frost/EECS_562/us-frequency-allocations.jpg

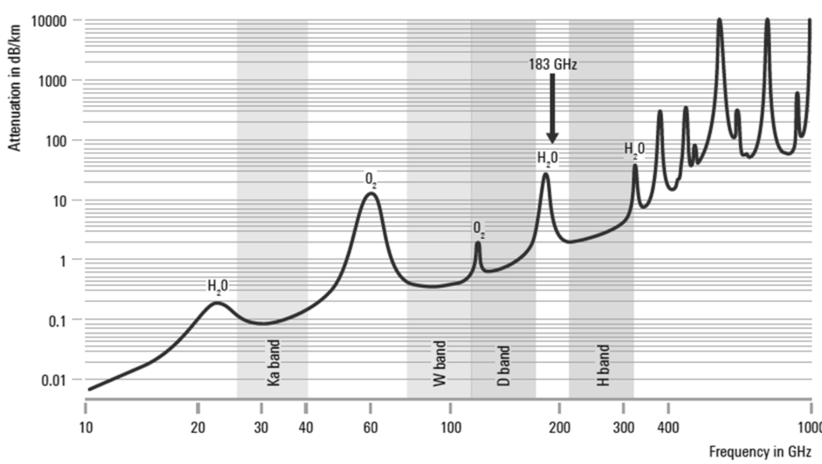
Figure 6: The electromagnetic spectrum and applications with the terahertz spectrum on the borderline between electronics and photonics



From FUNDAMENTALS OF THz TECHNOLOGY FOR 6G,
White Paper, Version 01.02, Dr. Taro Eichler, Robert Ziegler, Rohde & Schwarz

Figure 7: Specific atmospheric attenuation within the millimeterwave and THz spectrum

At air pressure of 1013 hPa, temperature of +15 °C and water vapor density of 7.5 g/m³. The rotational excitations of different molecules present in the atmosphere (i.e. water, oxygen) are reflected in the absorption spectra.



From FUNDAMENTALS OF THz TECHNOLOGY FOR 6G,
White Paper, Version 01.02, Dr. Taro Eichler, Robert Ziegler, Rohde & Schwarz

Wireless Channels

- Usable transmission bandwidth for a wireless communication system is limited by
  - Carrier frequency f_c (Hz) (wavelength $\lambda=c/f_c$ were c speed of propagation in free space)
  - The available frequency spectrum; the allocated bandwidth
  - Physical characteristics of the transmission medium
  - As the carrier frequency increases, the usable transmission bandwidth also increase, but
    - Typically, the usable transmission bandwidth is on the order of 10% (= f_c /10) of the carrier frequency.
    - Increased propagation loss at higher frequencies
    - Signal penetration through obstacles, e.g., walls, is limited at higher frequencies

Wireless Channels

- Carrier frequencies in the range of 700 MHz to 900 MHz are better suited for providing wider coverage and better penetration through buildings and other obstacles, higher value spectrum.
- Higher frequency bands such as 2.5 GHz and bands in the millimeter-wave (mmWave) range (24 GHz and above) offer increased usable bandwidth.
- mmWave technology allows for increased usable bandwidth and thus higher data transfer rates compared to legacy networks, making it suitable for high-bandwidth applications such as video streaming and virtual reality. Millimeter-wave (mmWave) technology is an important component of wireless system deployments for 5G and beyond.

Wireless Channels

- Millimeter-wave (mmWave) carrier frequencies are in the range of 24 GHz to 300 GHz. The mmWave spectrum lies between microwave and infrared frequencies. The mmWave wavelengths range from about 1 mm to 12.5 mm.
- Attributes of mmWave technology include but are not limited to:
  - Atmospheric effects: mmWave transmissions are attenuated by rain and fog.
  - Shadowing: Shadowing is a term used in wireless communication to describe the attenuation of a signal due to obstacles and other physical obstructions in the signal's path. In mmWave transmissions, shadowing can have a significant impact on the signal strength and quality, as the shorter wavelength of mmWave signals makes them more susceptible to blockage and attenuation.
  - Antenna Size: The shorter wavelength used for mmWave transmissions results in physically smaller antennas.

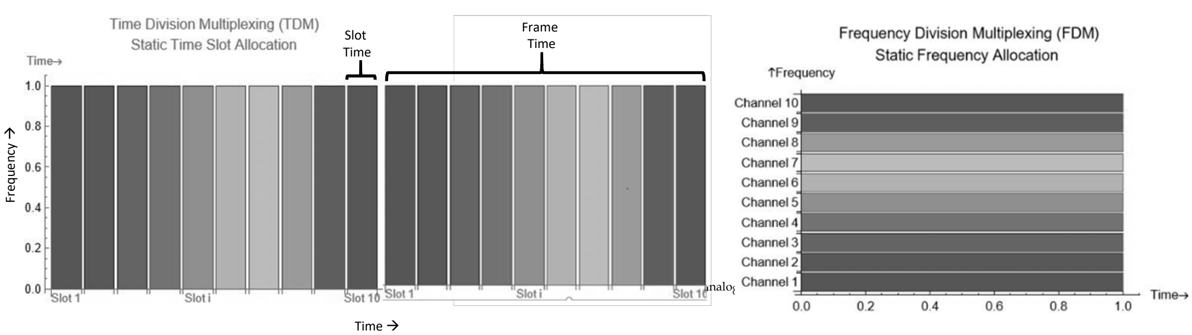
Wireless Channels

- Continued-Attributes of mmWave technology include but are not limited to:
  - Greater network capacity: mmWave system can support more devices and higher data traffic due to their wider bandwidth and higher frequency range, making them well suited for densely populated areas such as stadiums, convention centers, and airports.
  - Reduced adjacent channel interference: mmWave networks operate in a higher frequency range than legacy networks, which reduces interference from other devices and networks.
  - Enhanced security: When mmWave systems use beamforming and other advanced techniques to transmit signals in tightly constrained physical directions, the risk of unauthorized access is reduced.

Sharing Transmission Resources

- Time
  - When and how long a user gets to talk
- Frequency
  - What part of the spectrum (channel) measured in Hz is used.
  - A spectrum allocation is given a bandwidth (Hz)
  - 1 Hz ≠ 1 bit/sec (WiFi 7 ~12 bits/Hz)

Transmission Network Resources



Normally, fixed allocation of time slot or channel spectrum

FDM Example

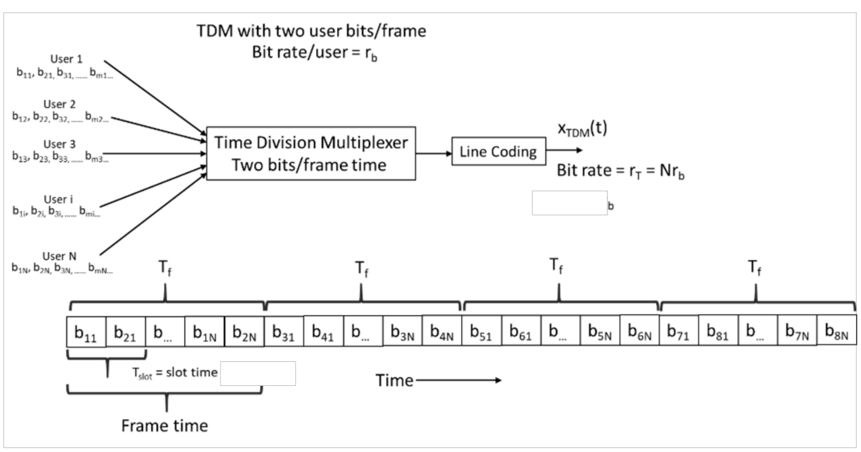
- The FM radio in the US is assigned a frequency band 88.0 MHz to 108.0 MHz. The band is divided into 100 channels, each 200 kHz (200 kHz) wide.

Call Sign	Freq.	Dist./Signal	City
KJTY	88.1 FM	11.9 mi.	Topeka, KS
[illegible]JNW	88.5 FM	41.9 mi.	Kansas City, MO
KGLV	88.9 FM	42.8 mi.	Manhattan, KS
KCUR	89.3 FM	42.3 mi.	Kansas City, MO
KKFI	90.1 FM	42.4 mi.	Kansas City, MO
KBUZ	90.3 FM	42.9 mi.	Topeka, KS
KJHK	90.7 FM	1.0 mi.	Lawrence, KS
KCIU (LPFM)	91.1 FM	1.3 mi.	Lawrence, KS
KANU	91.5 FM	1.0 mi.	Lawrence, KS
KCCV	92.3 FM	22.0 mi.	Olathe, KS
KMXN	92.9 FM	22.1 mi.	Osage City, KS
KMXV	93.3 FM	40.3 mi.	Kansas City, MO

From: Radio Locator

Transmission Network Resources: TDM

Example:
2 bits/time slot

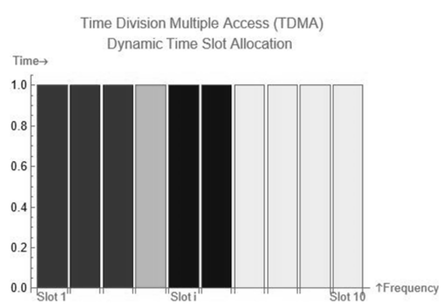


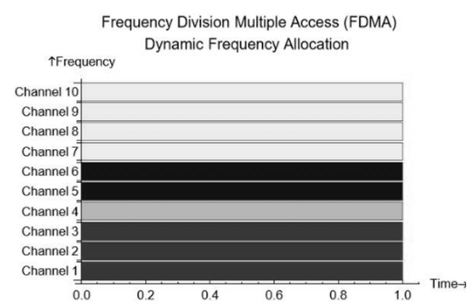
TDM Example

- 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 = 1.536Mb/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

Transmission Network Resources

Dynamic allocation of time slots/channels performed by the "network"





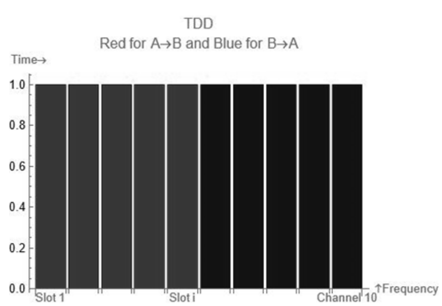
Time slot assignments can change every frame time

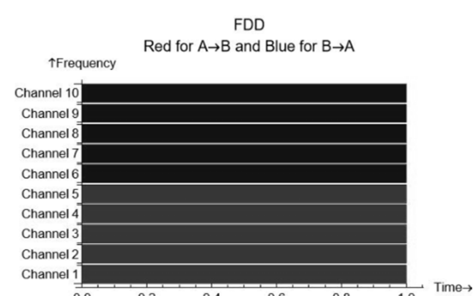
Transmission Network Resources: Duplexing

- Simplex: One way communications, e.g., broadcast radio
- Half duplex if A talks to B or B talks to A but A and B cannot both send at the same time.
- Full duplex if A talks to B and B talks to A simultaneously. Meaning both A and B have the capability to send data to the other at any time.

Transmission Network Resources: Duplexing

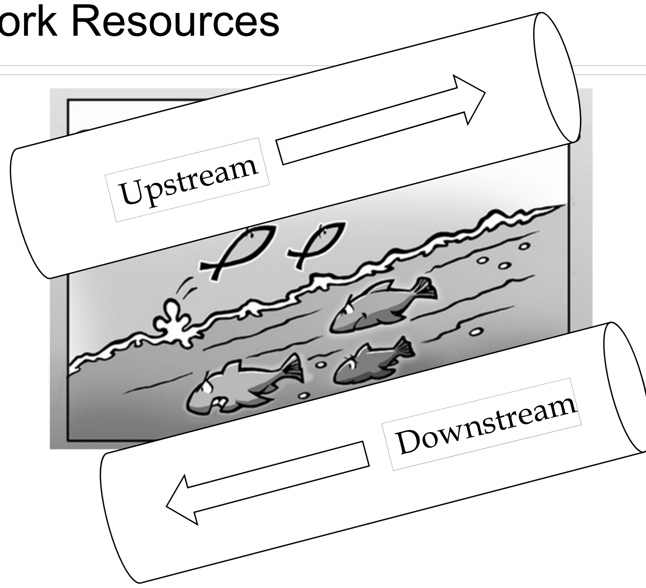
- Frequency division duplex (FDD) assigns some of the channels for A to B communications and a separate set of channels for B to A communications, enabling full duplex communications.
- Time division duplex (TDD) assigns some of the time slots for A to B communications and a separate set of time slots for B to A communications, enabling full duplex communications.





Transmission Network Resources

- Downlink/Downstream,
- e.g. , base station → smartphone
- Uplink/Upstream,
- e.g., smartphone → base station



Long Term Evolution (LTE) Operating Bands:
15 bands use FDD and 8 bands use TDD

LTE definitions

UE = User Equipment, e.g., smartphone

eNB = Evolved NodeB
=Base station

TDD: Same Band for:
BS→UE &
UE → BS

Table 4. EUTRA operating bands (TS 36.101 [6] Table 5.5-1)

E-UTRA operating band	Uplink (UL) operating band BS receive UE transmit	Downlink (DL) operating band BS transmit UE receive	Duplex mode
	$F_{UL\_low} - F_{UL\_high}$	$F_{DL\_low} - F_{DL\_high}$	
1	1920 – 1980 MHz	2110 – 2170 MHz	FDD
2	1850 – 1910 MHz	1930 – 1990 MHz	FDD
3	1710 – 1785 MHz	1805 – 1880 MHz	FDD
4	1710 – 1755 MHz	2110 – 2155 MHz	FDD
5	824 – 849 MHz	869 – 894 MHz	FDD
6	830 – 840 MHz	875 – 885 MHz	FDD
7	2500 – 2570 MHz	2620 – 2690 MHz	FDD
8	880 – 915 MHz	925 – 960 MHz	FDD
9	1749.9 – 1784.9 MHz	1844.9 – 1879.9 MHz	FDD
10	1710 – 1770 MHz	2110 – 2170 MHz	FDD
11	1427.9 – 1452.9 MHz	1475.9 – 1500.9 MHz	FDD
12	698 – 716 MHz	728 – 746 MHz	FDD
13	777 – 787 MHz	746 – 756 MHz	FDD
14	788 – 798 MHz	758 – 768 MHz	FDD
...			
17	704 – 716 MHz	734 – 746 MHz	FDD
...			
33	1900 – 1920 MHz	1900 – 1920 MHz	TDD
34	2010 – 2025 MHz	2010 – 2025 MHz	TDD
35	1850 – 1910 MHz	1850 – 1910 MHz	TDD
36	1930 – 1990 MHz	1930 – 1990 MHz	TDD
37	1910 – 1930 MHz	1910 – 1930 MHz	TDD
38	2570 – 2620 MHz	2570 – 2620 MHz	TDD
39	1880 – 1920 MHz	1880 – 1920 MHz	TDD
40	2300 – 2400 MHz	2300 – 2400 MHz	TDD

Example: T-Mobile
- Band 2 (1900 MHz)
- Band 5 (850 MHz)
- Band 4 (1700/2100 MHz)
- Band 66

(Extension of band 4 on 1700/2100 MHz).
From: https://www.t-mobile.com/support/coverage/t-mobile-network

Allocated LTE frequency bands in USA are found at: http://anisimoff.org/eng/lte_bands/usa.html

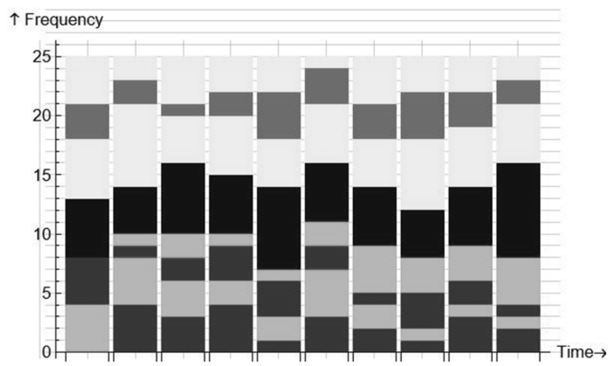
Agilent, 3GPP Long Term Evolution:
n Overview, Product Development, and Test Challenges, Application Note

Transmission Network Resources

Allocation of time slots/channels performed by the “network”

Combined TDMA & FDMA

Different colors represent resources assigned to different users

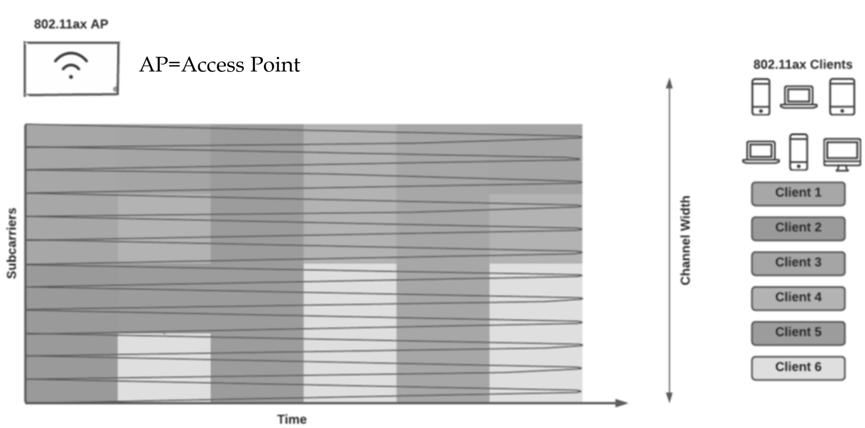


Time/Frequency assignments can change every frame time

Transmission Network Resources

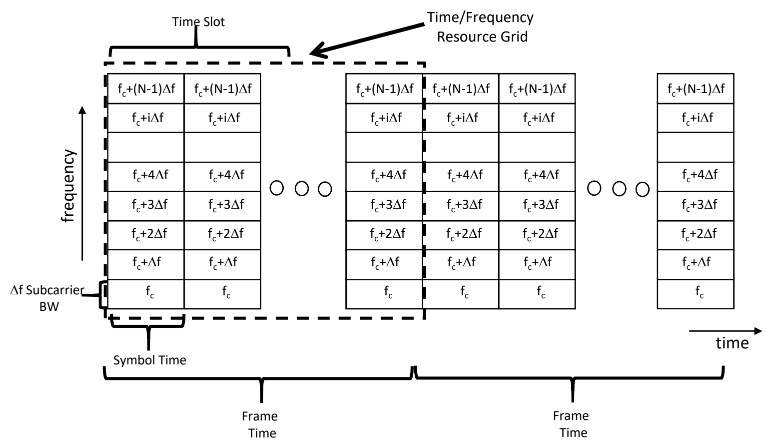
Allocation of time slots/channels in WiFi 6 aka IEEE 802.11ax

OFDMA = Orthogonal Frequency Division Multiple Access



Modified from : Wi-Fi 6 (802.11ax) Technical Guide, Cisco, https://documentation.meraki.com/MR/Wi-Fi_Basics_and_Best_Practices/Wi-Fi_6_(802.11ax)_Technical_Guide

Downlink Physical Channel for Long Term Evolution (LTE-4G/5G)
Orthogonal Frequency Division Multiple Access (OFDMA)



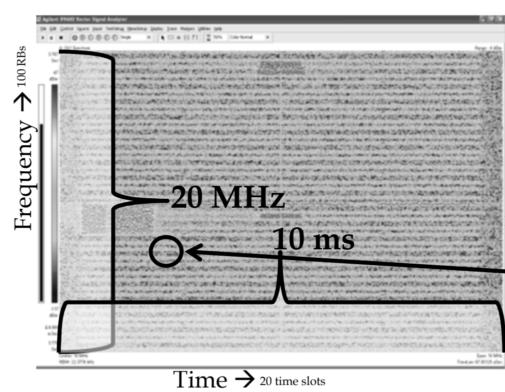
OFDMA with TDMA/FDMA

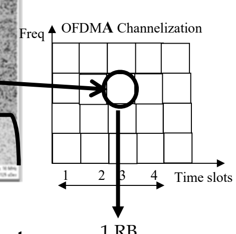
Transmission Network Resources

Spectrogram of Downlink Physical Channel for Long Term Evolution (LTE/4G)

Subcarrier BW=15kHz
Time Slot = 0.5ms
Resource Block = RB
12-subcarriers
1-Time Slot
RBs are allocated to specific users

Example:
1 RB=336kb/s
- User 1 assigned 5 RB = 1.68Mb/s
- User 2 assigned 3 RB = 1.008Mb/s
- User 3 assigned 7 RB = 2.352Mb/s





OFDMA is used in both 4G and 5G (and in the the developing 6G) systems

Modified from: Peter Cain, Using Wireless Signal Decoding to Verify LTE Radio signals, Agilent Technologies, July 2011

G's Generations

- Mobile network technology has evolved through several generations, each marked by significant advancements in capabilities. The main generations of mobile network technology are:
  - 1G: The first generation of mobile networks introduced analog voice communication. It began in the early 1980s and was primarily based on Advanced Mobile Phone System (AMPS) technology.
  - 2G: emerged in the late 1980s and early 1990s, introduced digital voice communication and provided better voice quality, encryption, and new features like text messaging (SMS). Technologies like GSM (Global System for Mobile Communications) and CDMA (Code Division Multiple Access) were prevalent in 2G networks.
  - 3G: deployed around the early 2000s, marked the transition to high-speed data services. They provided faster data transfer rates, enabling features like mobile internet access, video calling, and higher-quality multimedia. Technologies like UMTS (Universal Mobile Telecommunications System) and CDMA2000 were part of 3G.
  - 4G: introduced in the late 2000s, 4G networks offered significantly faster data transfer rates, low latency, and improved network efficiency. Technologies like LTE (Long-Term Evolution) **is a** key component of 4G.
  - 5G : the latest generation, with deployments starting around 2019. It brings even higher data speeds, lower latency, increased network capacity, and support for a massive number of connected devices. New technologies like millimeter-wave spectrum and massive MIMO (Multiple-Input, Multiple-Output).
  - 6G developing mobile network standards for cellular technology. 6G will operate on higher radio frequencies, providing more bandwidth and lower latency at microsecond speeds. **Not yet deployed, expected launch 2030.**
- Each new generation builds upon the capabilities of the previous one, aiming to meet the growing demands for connectivity, data services, and emerging technologies.

Data Plane

- The data plane, also known as the forwarding plane or user plane, is responsible for the actual movement of user data through a network. It is the part of the network architecture that is responsible for receiving and forwarding data between devices on the network.
- In general, the data plane is responsible for the following functions:
  - Forwarding: This involves forwarding data from one network device to another.
  - Quality/Class of Service: The data plane also may plays a role in quality of service by prioritizing certain types of traffic based on their service level agreements (SLA).
  - Traffic Filtering: The data plane can also be responsible for filtering out certain types of traffic, such as malicious traffic, or traffic that doesn't meet certain criteria.
  - Error Detection and Correction: The data plane can also be responsible for detecting and correcting errors in data packets, such as checksum errors or corrupted packets.

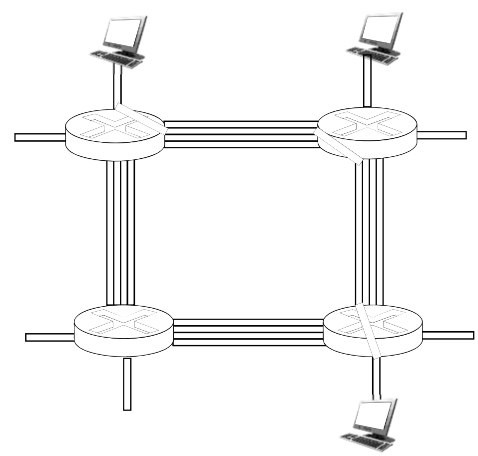
Data Plane

- Examples of types of user data
  - User data requiring end-to-end resources reserved between source and destination for duration of transmission
    - For example, reserving a "wavelength" (color of light) on a fiber from LA to NYC for the time it takes to back-up an entire data center.
      - Suppose the data center holds 1 Petabyte (PB-$1x10^{15}$ bytes) of information.
      - Data rate = 1 Tb/s
      - Backup time=Holding time = ($1x10^{15}$ bytes)(8bits/byte)/$1x10^{12}$ bits/sec = 8000 sec = 2.2 hours
  - User data that can tolerate (or recover from) information loss and some random delay
    - For example, voice & video
- Data Plane approaches
  - Circuit switching for exclusive reserved recourses for duration of "call"
  - Packet Switching
  - Virtual Circuit Packet Switching

Circuit switching

end-end resources allocated to, reserved for "call" between source and destination

- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- "Signaling" used to allocate resources, call set-up
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- Customers can not use idle channels, →unused capacity is wasted
- commonly used in traditional telephone networks and Dense Wavelength Division Multiplexing (DWDM) Systems



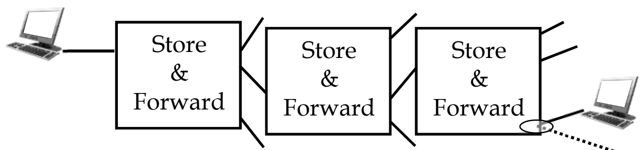
In circuit switching network resources are easily defined:

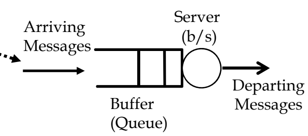
Voice line

Wavelength (color) in DWDM systems

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

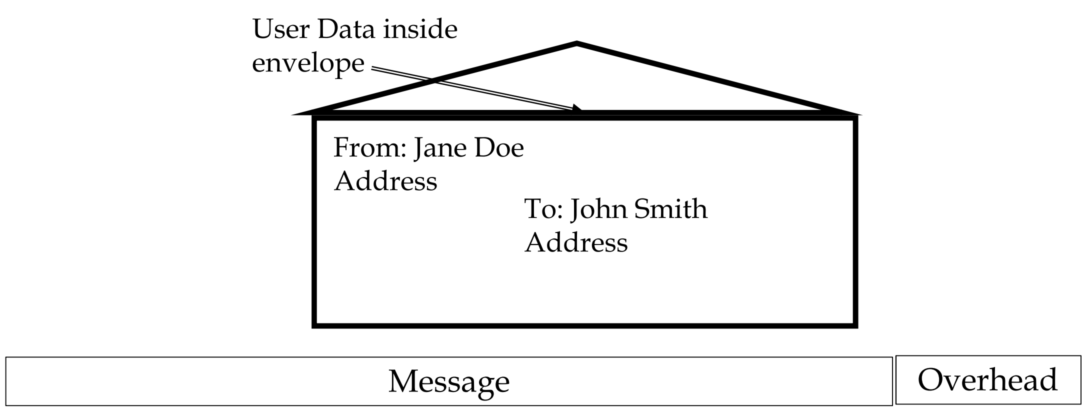
Message Switching (a step toward packet switching)





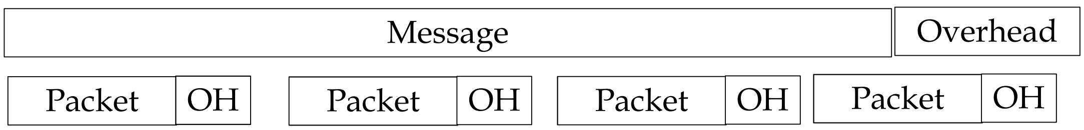
- No Dedicated path
- Address information is added to the message
- Store if output port is busy
- Trade off delay for blocking
- If message is corrupted then retransmit entire message

Packet Switching: Header Information - Overhead



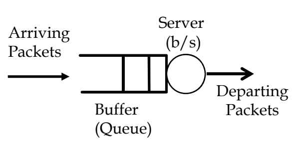
Packet Switching

- Break up large messages into smaller units: **Packets**
- The process of *"breaking up"* larger information units into smaller parts is called: **Segmentation or Fragmentation**
- The process of *"putting together"* smaller parts into larger information units is called: **Reassembly**
- **Segmentation and Reassembly (SAR) can happen multiple times to the same information stream, or flow**



Statistical Multiplexing

- Packets arrive at random times
- Arriving packets have random lengths
- If arrives to empty system then it is transmitted at the **FULL LINE RATE**
- If a message arrives to a busy system it waits
- If a message arrives to a full system it is dropped/lost
- Transmission at the **FULL LINE RATE is *statistically* shared among the all the users**



This is called a Statistical Multiplexer

TDM vs Statistical Multiplexing

- Example:
  - Link rate = 1 Mb/s
  - Message size = 5000 bits
  - TDM
    - Frame size = 10 ms (1 Mb/s * 10 ms =10,000 bits/frame)
    - 10 times slots /frame (slot time = 1 ms, 1000 bits/slot)
    - Time to transmit 5000 bit message = 5 slot times @ 1 slot /frame = 50 ms
  - Statistical Multiplexing
    - "*Assume*" arriving message finds the system empty
    - Time to transmit 5000 bit message = 5000 bits/(1Mb/s) = 5 ms

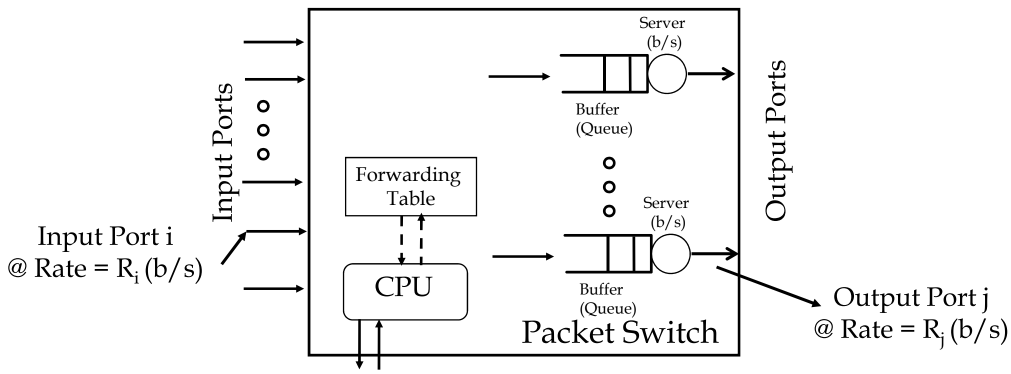
Packet Switching in the network

- mesh of interconnected network devices, switches/routers (the technical difference to be defined later)
- packet-switching: hosts break application-layer messages into *packets*
  - forward packets from one router to the next, across links on path from source to destination
  - each packet transmitted at full link capacity

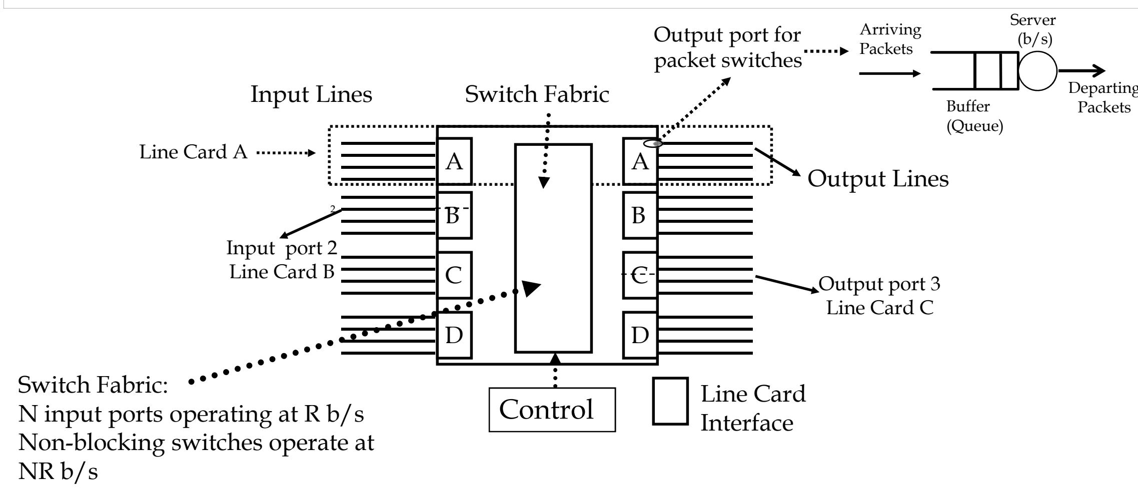
- Packet switching provides flexibility and the dynamic allocation of bandwidth
- The Internet is a packet switched network
- Packet switching has resulted in the integration of all services on one infrastructure

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

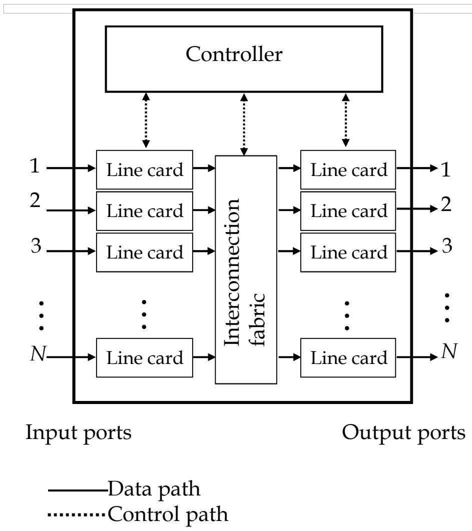
Packet Switches



Packet Switches



Generic Packet Switch

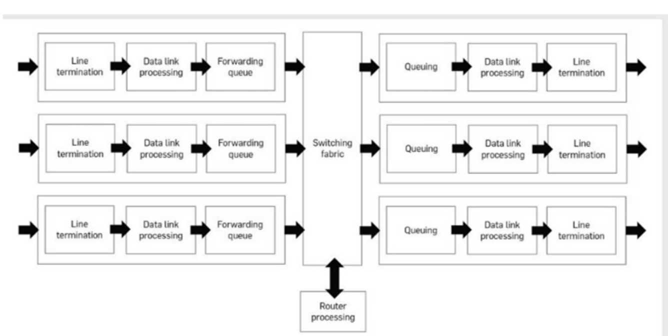


"Unfolded" View of Switch

- Ingress Line Cards
  - Header processing
  - Demultiplexing
  - Routing in large switches
- Controller
  - Routing in small switches
  - Signaling & resource allocation
- Interconnection Fabric
  - Transfer packets between line cards
- Egress Line Cards
  - Scheduling & priority
  - Statistical Multiplexing

Modified from: Leon-Garcia & Widjaja: *Communication Networks*

Generic Packet Switch

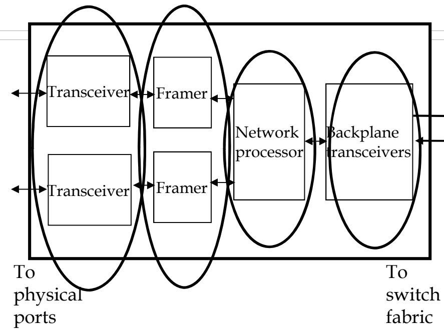


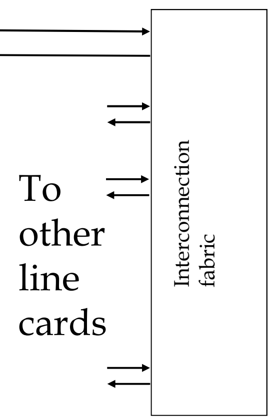
Another View of Switch

- Ingress Line Cards
  - Header processing
  - Demultiplexing
  - Routing in large switches
- Controller
  - Routing in small switches
  - Signaling & resource allocation
- Interconnection Fabric
  - Transfer packets between line cards
- Egress Line Cards
  - Scheduling & priority
  - Statistical Multiplexing

Modified from: Buffer-Bloated Router? How to Prevent It and Improve Performance, Philippa Harrison
Communications of the ACM Volume 66Issue 624 May 2023pp 73–77

Line Cards

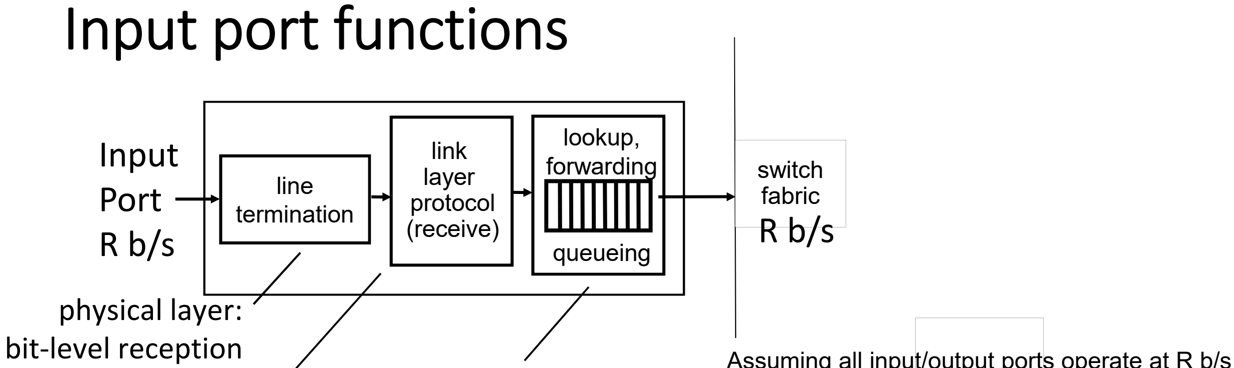




Folded View
- 1 circuit board is ingress/egress line card
  - Physical layer processing
  - Data link layer processing
  - Network header processing
  - Physical layer across fabric + framing

Modified from: Leon-Garcia & Widjaja: *Communication Networks*

Input port functions

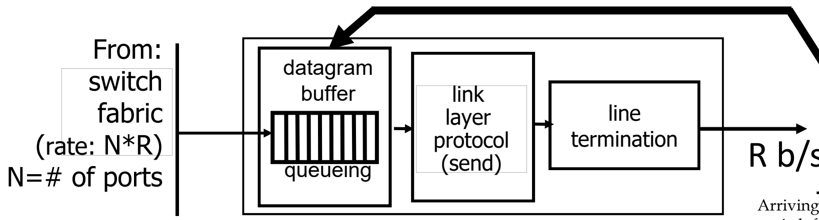


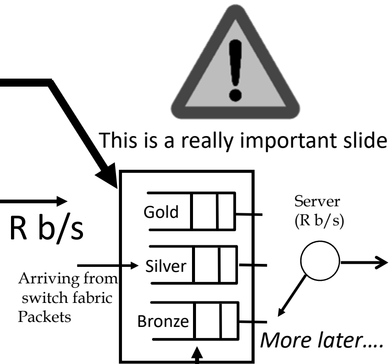
link layer:
e.g., Ethernet

decentralized switching:
- using header field values, lookup output port using forwarding table in input port memory
- destination-based forwarding: forward based only on destination IP address (traditional)
- goal: complete input port processing at ‘line speed’
- input port queuing: if datagrams arrive faster than forwarding rate into switch fabric (if switches operate at > NR b/s no input port queuing)

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

Output port queuing





- *Buffering* required when datagrams arrive from fabric faster than link transmission rate. *Drop policy:* which datagrams to drop if no free buffers?

- *Scheduling discipline* chooses among queued datagrams for transmission

Priority scheduling – who gets best performance

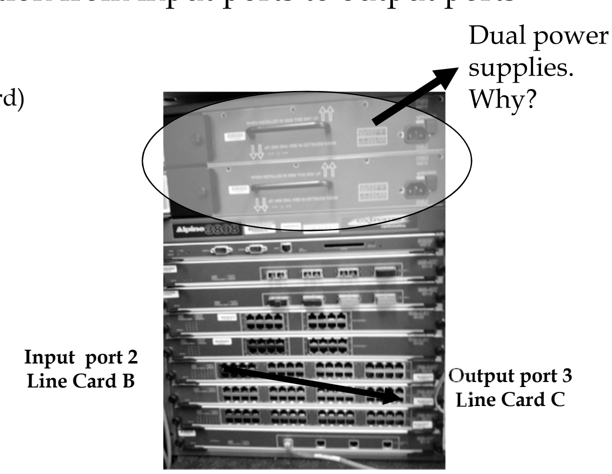
Datagrams can be lost due to congestion, lack of buffers

Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

Network Switching Technologies

- Switching transfers information from input ports to output ports

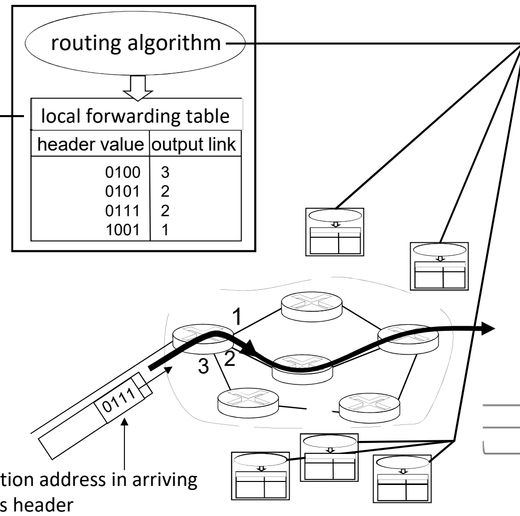
- Elements of Switches
  - Line cards (multiple interfaces/card)
  - Switch fabric
  - Control
  - Management
  - Billing



Two key network-core functions

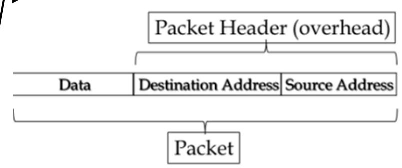
Forwarding (data plane):

- *local* action: move arriving packets from router's input link to appropriate router output link



Routing (control plane):

- *global* action: determine source-destination paths taken by packets
- routing algorithms

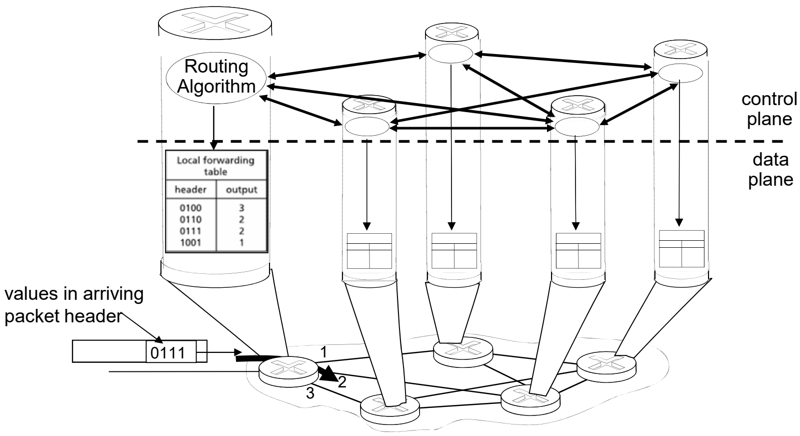


Control Plane

- The control plane is responsible for managing and controlling network devices and protocols.
- In general, the control plane is responsible for the following functions:
  - Routing: This includes determining the best path for data to flow through the network, and managing routing protocols (to be discussed later).
  - Manages network traffic, load balancing
  - Learns and maintains network topology, i.e., recovers from link and switching failures.
  - Connection management.
    - Set up connections
    - Tear down connections
    - Commonly called "Signaling"

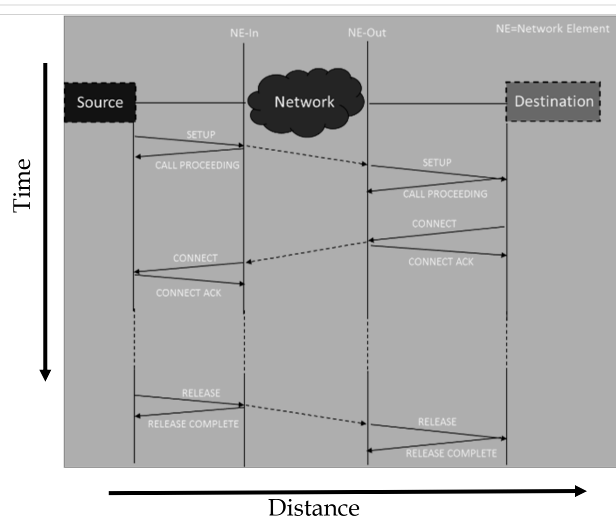
Per-router control plane

Individual routing algorithm components *in each and every router* interact in the control plane



Modified from: 8th edition Jim Kurose, Keith Ross Pearson, 2020

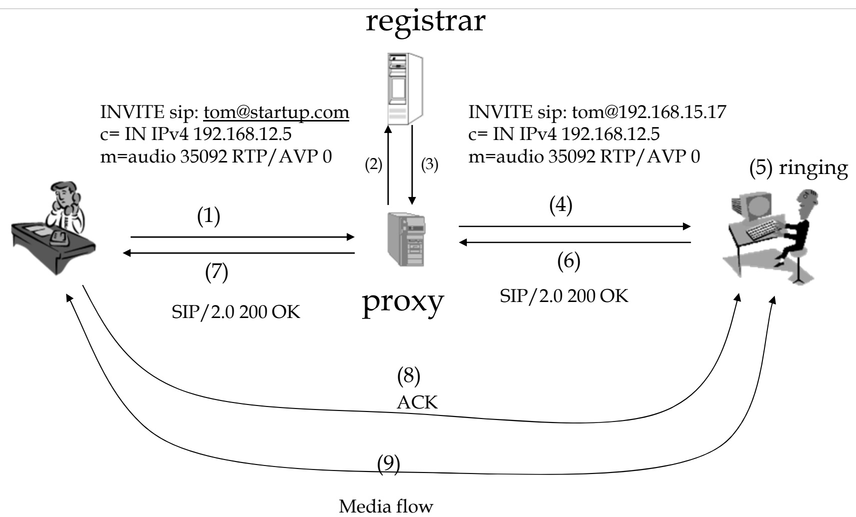
Signaling Example



Why are lines sloping?

Example of Signaling

Session Initiation Protocol (SIP) for Voice over IP (VoIP)



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

How are packets treated in the network

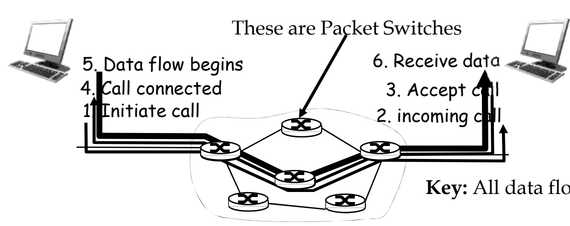
- Packets treated independently, analogous to US mail.
  - Datagram Packet Switching
    - Network does its best to deliver the packets: Best-effort service
    - The Internet provides **Best-effort service**
    - No reserved resources
    - Packets with same destination may take different routes through the network
    - Each Network Element (NE), e.g., router, makes independent forwarding decisions
    - Packets can arrive out-of-order
- A flow of related packets use the same path with possible reserved resources
  - Virtual Circuit packet switching

Network Switching Technologies: Virtual Circuit Packet Switching

- Virtual circuit packet switch provides a **connection oriented service**
- A *"logical connection"* is established between the source and destination using all the NEs along the set-up path
- All packets flow over the same route through the network
- Packets still *"statistically share"* link
- Connection oriented does not imply virtual circuits

Virtual circuits: signaling protocols

- Used to setup, maintain teardown VC
- Used in
  - DWDM networks
  - Multiprotocol Label Switching → MPLS
  - Used in legacy technologies, ATM, frame-relay, X.25



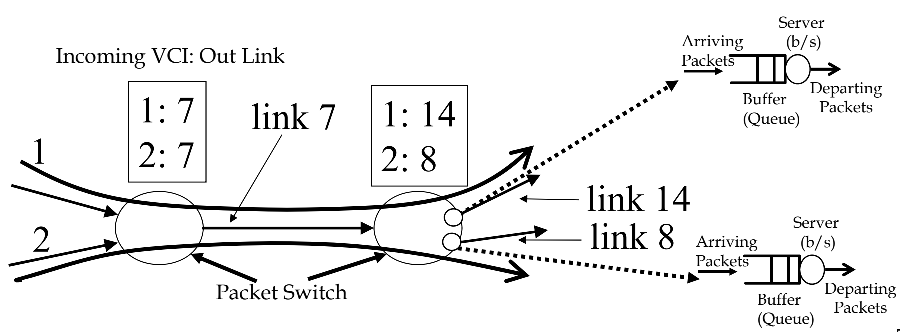
Key: All data flow packets through same NEs

Network Switching Technologies: Virtual Circuit Packet Switching

- Forwarding decisions are made based on a *"virtual circuit identifier" (VCI)* not on the full address
- Packet statistically share transmission facilities
- Uses statistical multiplexing
- Switches save state/connection
- State is saved for duration of the connection along the path
- QoS can be guaranteed because
  - Know prior allocation of resources
  - Know requested resources, learn this during call set-up phase
  - If (prior allocation of resources)+(requested resources)> total available resources then fail the call set-up phase, i.e., block connection (busy signal).

Virtual Circuit Identifier (VC ID)

- Virtual Circuit Identifier (VC ID)
  - Source set-up: establish path for the VC
  - Switch: mapping VC ID to an outgoing link
  - Packet: fixed length label in the header

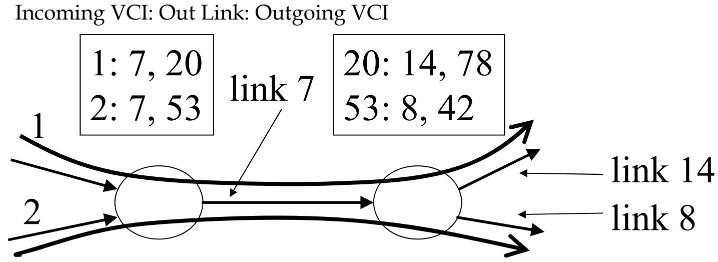


Modified from: http://www.cs.princeton.edu/courses/archive/spring07/cos461/

Swapping the Label at Each Hop

- Problem: using VC ID along the whole path
  - Each virtual circuit consumes a unique ID
  - Starts to use up all of the ID space in the network
- Label swapping
  - Map the VC ID to a new value at each hop
  - Table has old ID, and next link and new ID

Incoming VCI: Out Link: Outgoing VCI



Modified from: http://www.cs.princeton.edu/courses/archive/spring07/cos461/

Network Switching Technologies:
Virtual Circuit/Datagram Trade-offs

What is the Datagram vs VC performance trade-off considering propagation time, and holding time=service time=L(bits)/R(b/s)?

Example:

Find the time to transmit a 1 Kbyte message
coast-to-coast is the USA (3000Km)
on a 600 Mb/s link. Propagation time = 3000km/c=10ms

a) Using Datagrams:

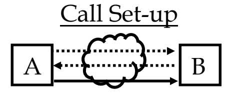
1*8000/(600Mb/s) + 10 ms ~ 10ms

Clocking time =(13 µs)

b) Using Virtual Circuits

30ms

Call Set-up



Data Transmission

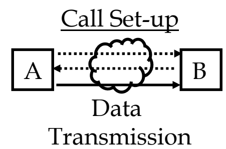
Network Switching Technologies:
Virtual Circuit/Datagram Trade-offs

Example:

Find the time to transmit a 37.5 Mbyte message coast-to-coast is the USA (3000Km) on a 600 Mb/s link

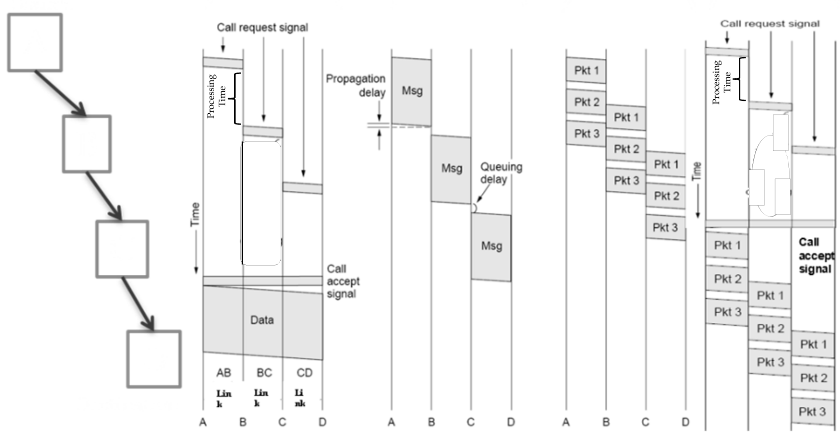
a) Using Datagrams:
510ms

b) Using Virtual Circuits
530ms



Key issue is holding time relative to call set-up time

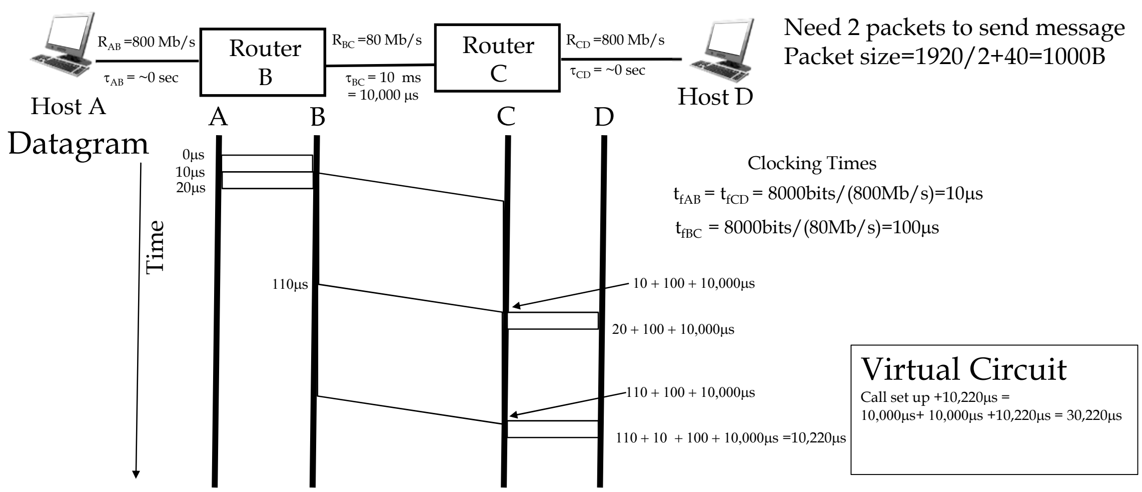
Comparison



Modified from: Computer Networks, A. S. Tannenbaum, 4th Ed, Prentice Hall, 2003

Example: Compare datagram to VC Packet Switching

Message=1920B, Header=40B, Packet size=1000B



Summary

- Transmission media
- Sharing transmission resources
- Data Plane
  - Circuit switching
  - Datagram packet switching – **Best Effort**
  - Virtual circuit packet switching
- Control Plane
  - Routing
  - Signaling (call set-up/teardown)