Communication Networks

Spring 2017/2018

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By: Mohammad Abu Hashya.

* * *

IP ≡ Internet Protocol.

Comm. Net. :

DEF.#1 : A comm. Network is an arrangement of hardware & software that allows users to exchange information.

DEF.#2: A comm. Network is a set of nodes that are interconnected to permit exchange of information.

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Lecture 1: Introduction to Communication Networks

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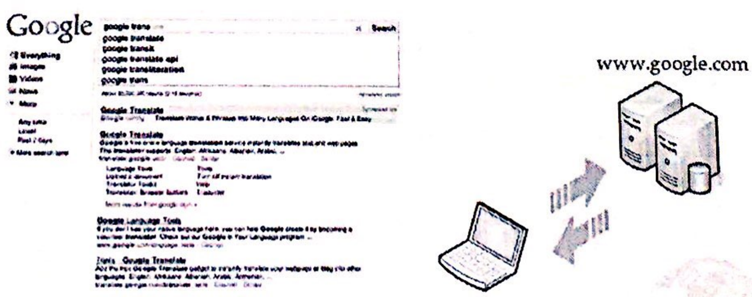
EE426: Communication Networks

What is the Ineternet?



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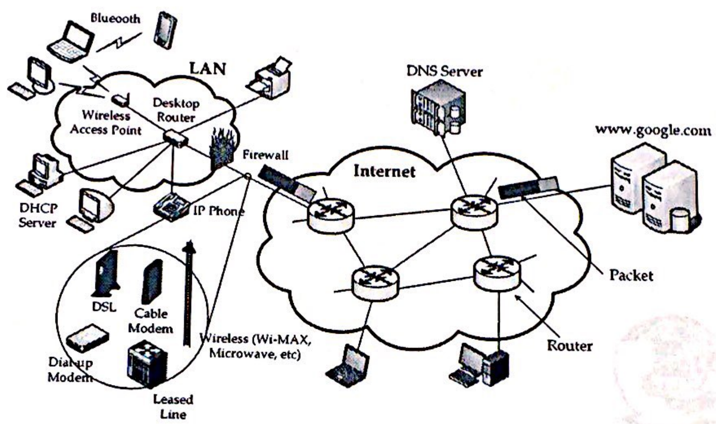
*What is the purpose of comm. Network?

To exchange information.

Behind the Scenes



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Extreme Number of Protocols!

Layer	TCP/IP model (RFC 1122)	Other	SS7	SNA	AppleTalk suite	OSI suite
7. Application	SDP, SOAP, GTP, STUN, IMAP, IRC, POP, POP3, SSH, Telnet, rlogin, Gopher, Whois, BitTorrent, ECHO, RTP, RTSP, ENRP, NFS, RTCP, XMPP, NNTP, SSI, DNS, FTP, TFTP, HTTP, NFS, NTP, NNTP, DHCP, SMPP, SMTP, SNMP, RIP, BGP (both run over UDP or TCP), OSPF (runs over IP)	HL7, Modbus	INAP, MAP, TCAP, ISUP, TUP	APPC	AFP, ZIP, RTMP, NBP	FTAM, X.400, X.500, DAP, ROSE, RTSE, ACSE
6. Presentation	ASN.1, MIME, XDR, SSL, TLS	TDI, ASCII, EBCDIC, MIDI, MPEG, NCP			AFP	ISO/IEC 8823, X.226, ISO/IEC 9576-1, X.236
5. Session	Sockets: Session establishment in TCP, SIP, RPC	Named Pipes, NetBIOS, SAP, ASAP, SDP		DLC	ASP, ADSP, PAP	ISO/IEC 8327, X.225, ISO/IEC 9548-1, X.235
4. Transport	DCCP, RSVP, ECN, TCP, UDP,PPTP, L2TP, SCTP	NBF, nanoTCP, nanoUDP			DDP	ISO/IEC 8073, TP0, TP1, TP2, TP3, TP4 (X.224), ISO/IEC 8602, X.234
3. Network	IP (IPv4 · IPv6), IPsec, ARP, ICMP, ICMPv6, IGMP, IS-IS, IGRP, EIGRP, ARP, RARP	NBF, Q.931	SCCP, MTP		ATP (TokenTalk or EtherTalk)	ISO/IEC 8208, X.25 (PLP), ISO/IEC 8878, X.223, ISO/IEC 8473-1, CLNP X.233.
2. Data Link (LLC/MAC)	NDP, Tunnels, PPTP, PPP, PPPoE, PPPoA, SLIP	802.3 (Ethernet), 802.11a/b/g/n (Wi-Fi), 802.16 (Wi-MAX), 802.15 (Bluetooth), 802.1Q (VLAN), ISDN, ATM, HDP, FDDI, Fibre Channel, Frame Relay, HDLC, ISL, Q.921, Token Ring, CDP	MTP, Q.710	SDLC	LocalTalk,AppleTalk Remote Access, PPP	ISO/IEC 7666, X.25 (LAPB), Token Bus, X.222, ISO/IEC 8802-2 LLC Type 1 and 2
1. Physical		RS-232, V.35, V.34, I.430, I.431, T1, E1, 10BASE-T, 100BASE-TX, POTS, SONET, SDH, DSL, 802.11a/b/g/n PHY, etc	MTP, Q.710	Twinax	RS-232, RS-422, STP, PhoneNet	X.25 (X.21bis, EIA/TIA-232, EIA/TIA-449, EIA-530, G.703)

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• Point to Point Networks:

Disadvantages:

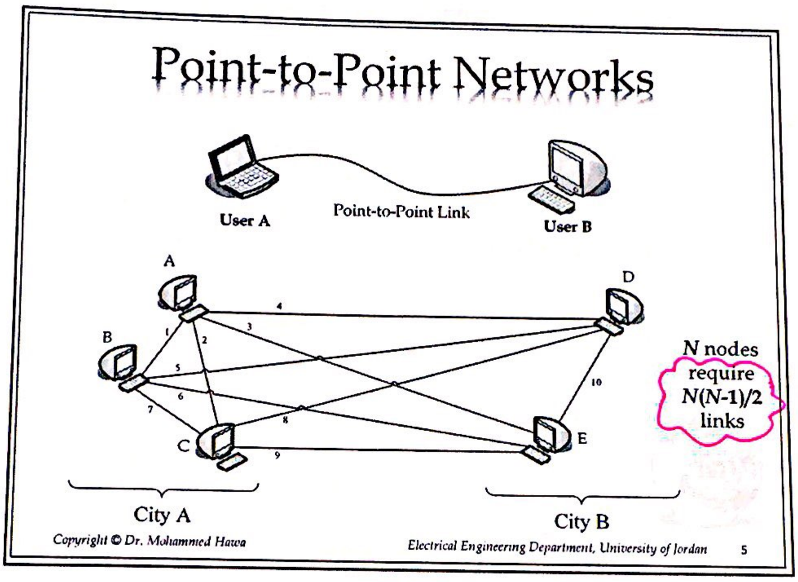
[1] Expensive (cost).

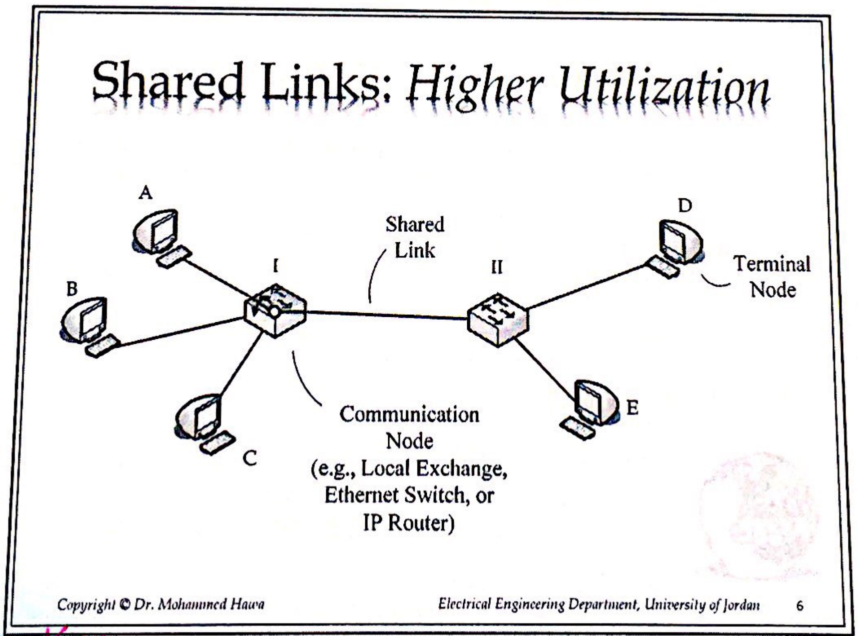
[2] Low Utilization.

Advantages:

[1] Perfect Connectivity.

[2] Reliability.





• shared links:

Disadvantages:

[1] Security.

[2] Reliability.

[3] You have to wait your turn.

[4] Maintain comm. Nodes & Cost.

Advantages:

[1] Lower Cost.

[2] Higher Utilization.

*Example of comm. Networks:
- telephony / cellular.
  - PSTN ≡ Public switched telephone network.
  - POTS ≡ Plain Old Telephony Service.

  } circuit switching.
- Ethernet or Internet.

Methods of Sharing Resources (*Switching at Comm. Nodes*)

- **Circuit Switching:**
  - Used in PSTN (POTS) (Telephony Networks).
- **Message Switching:**
  - Used in a very small number of data networks, and in Email gateways.
- **Packet Switching:**
  - Used in most data networks (and the Internet).
  - *Connection-Oriented* vs. *Connectionless*
- **Virtual Circuit Switching:**
  - Typically built on top of Packet Switching
  - E.g., Asynchronous Transfer Mode (ATM) network.
  - E.g., Multiprotocol Label Switching (MPLS).

Circuit Switching

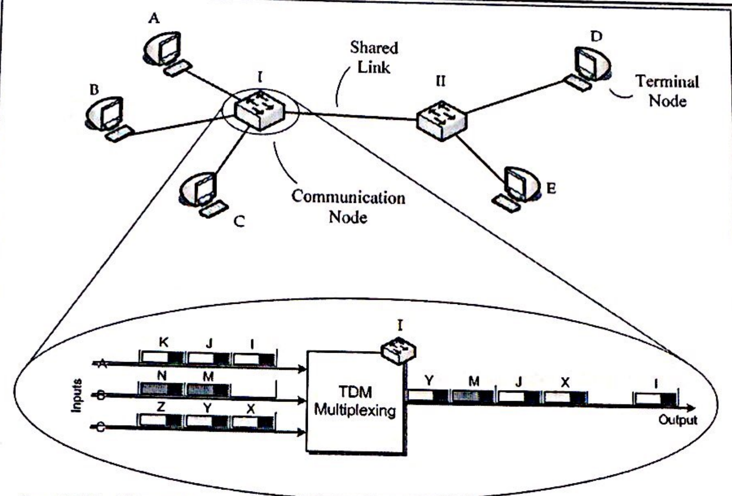
(Circuit switching → only available option for analog; also works for digital.)

- Suitable for time-sensitive (delay-intolerant) traffic, such as voice (voice is interactive by nature).
- Used in PSTN (POTS) (Telephony Networks).
- A *single channel* is reserved between the source and destination *before starting* to send traffic (done by dialing).
- This channel *cannot be used* by any other users *during* the conversation (phone call).
- All traffic of the call must go through the same channel. → doesn't necessarily mean one physical medium.
- One channel can be one *FDM band* or one *TDM slot*, and *not necessarily* one full physical medium.
- The channel can be used for other users only *after* the call has finished. otherwise they are blocked.

- Maximum allowed delay for voice:

standards:
500 msec. round trip.
300 msec " " .

PCM stream ⇒ 64 Kbps.



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Message and Packet Switching

- A **Message** is typically a sizable chunk of information (e.g., one file, one email, etc).
- A message can be divide into *K* smaller chunks, called **Packets**, before being transmitted.
  - Segmentation/Reassembly (Advantages?)
- Both Message switching and Packet switching use the concept of **Statistical Multiplexing**.
- Statistical Multiplexing is different than Channel multiplexing, FDM multiplexing, or TDM multiplexing (*circuit switching*).
- Both Message switching and Packet switching use the concept of **Store and Forward**.

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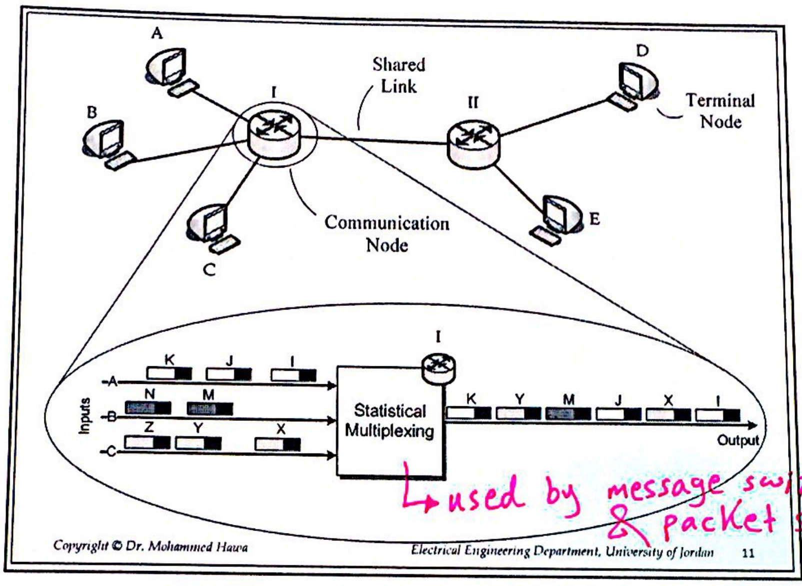
Message
(msg)
packet (PKt)

"Segmentation"
it is the process of dividing the message into smaller pieces.

PKt switching is the most popular type.

statistical Multiplexing is higher utilization than TDM.

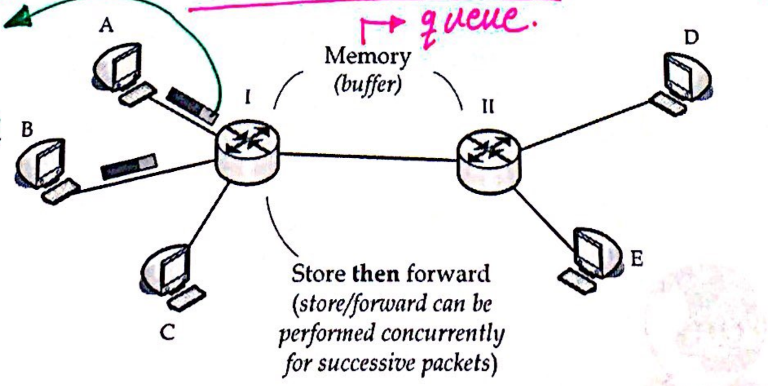


↳ used by message switching & packet switching.

Both Message switching and Packet switching use the concept of **Store and Forward**

→ queue. ⇒ FIFO First in First out.

This called: "Header".
• it will determine where this packet is going.



• Dialing: terminal nodes → comm. nodes → reserve path.

• session (connection) establishment

terminal nodes $\xrightarrow{(T_x \to R_x)}$ terminal nodes → initialization (Reset).

1/28/2018

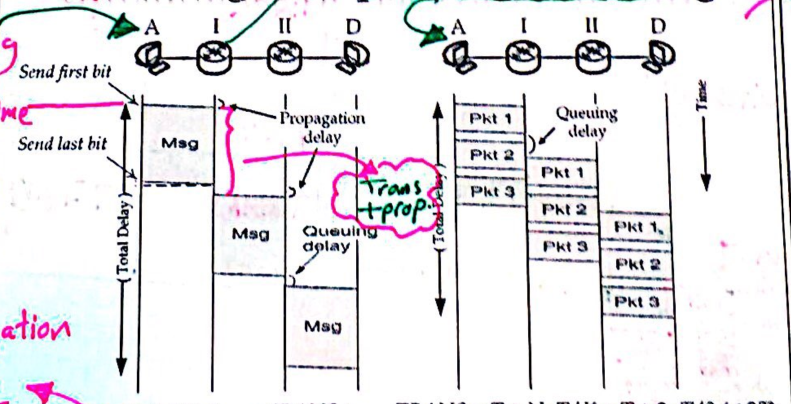
*it has initial phase.

*it doesn't have reserved path.

Packet Switching

- Suitable for delay-tolerant traffic (e.g. Web browsing, ftp, etc).
- Used in data networks.
- The *path* taken by packets belonging to one flow ***can be used*** by other information flows (i.e., the path is *shared*).
- This path can change dynamically during the conversation:
  - Thus, two packets of the same message (or flow of messages) can follow two totally different paths through the network.
- Paths are not reserved (no dialing before sending traffic):
  - However, the existence of a session-establishment (connection-setup) phase before starting communications decides whether we have connection-oriented (e.g. TCP) or connectionless (e.g. UDP) packet switching.
  - The session-establishment is used for initializing the source and destination, not for reserving the path.
- Message switching is similar to packet switching but uses larger chunks (messages) not smaller ones (packets).

Advantages of packet-switching



Total Delay = *TRANS* + *PROP* + *QUEUE* + *PROC*

TRANS = (N+1)×T = 3T

TRANS = T + N×T/K = T + 2×T/3 (< 3T)

N: Number of intermediate nodes

K: Number of packets in message

• Bandwidth $\xrightarrow{\text{decides}}$ DATA Rate. ⊓⊔⊓⊔ or ‾‾___/‾ ...

• SNR → Modulation Order.

TRANS ≡ Transmission Time ⇒ $\text{Trans} = \frac{\#\text{bits in msg}}{\text{Data Rate}} \; \frac{\text{bit}}{\text{bit/s}}$ ⟹

$\text{PROP} = \frac{\text{distance}}{c} \; \frac{\text{Km}}{\text{Km/s}}$

Ex. 10,000 bit msg.
datarate 1M bit/s.
distance 100 Km

find Trans + prop?

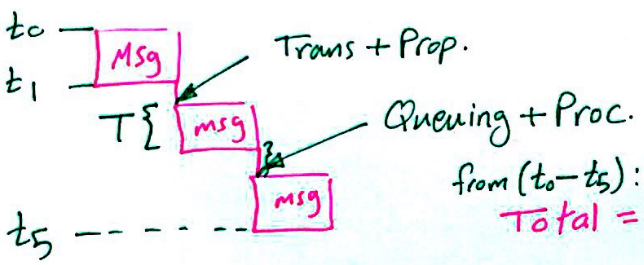
$c = 3 \times 10^8$ m/s = 300,000 Km/s.

Answer: Trans = 10msec
prop = 0.33msec

⇒ Total = 10.33 msec.

- Queueing Delay: waiting in memory for other msgs/packets to use the output channel.

- Processing Delay: checking errors, reading header, deciding on destination.



from $(t_0 - t_1)$:
Total = Trans + Prop.

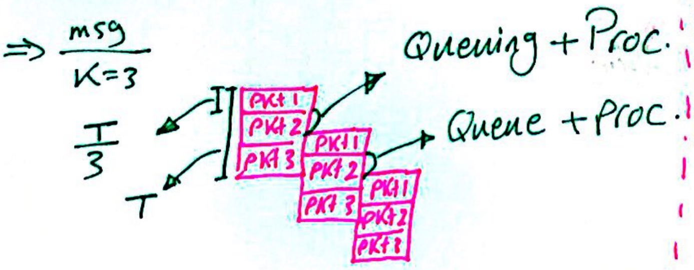
from $(t_0 - t_5)$:
Total = Trans + Prop + Queue + proc.

⇒ Trans = 3T.

* Propagation Time depends on:
⇒ Medium & the Length.

** Packet switching:

⇒ $\frac{msg}{K=3}$



Time \ switching	PKt	msg
PROP.	same ⟷	same.
TRANS	$T + (N)\frac{T}{K}$	$(N+1)T = 3T$

* while receiving PKt 2 we start transmitting PKt 1 & so on.

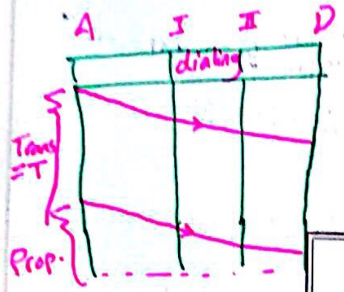
- Smaller packets Give smaller Queuing Delay.

* for Big N:

TRANS PKt << TRANS msg.

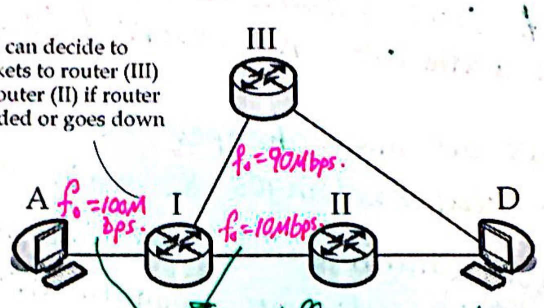
Scanned by CamScanner

• Home work: Draw the time line for circuit switching.



Advantages of packet-switching

Router (I) can decide to forward packets to router (III) rather than router (II) if router (II) is overloaded or goes down



The difference between the DATA rate won't cause a problem since there is another path.

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Virtual Circuit Switching

- A hybrid between circuit switching and packet switching.
- Typically resource reservation (*not* path reservation) is done at intermediate nodes before sending traffic on top of packet switching.
  - Like reserving a seat when you go to the movies.
- *Disadvantage*: Requires storing state information all across the network (similar to circuit switching)
- *Advantage*: Easier to provide Quality-of-Service per flow.
- Defines flows that typically follow a predetermined path (through resource reservations).
- The ATM network uses virtual circuit switching on top of cell (packet) switching, with a well-define dial-up.

Another disadvantage: Expensive!

↳ Q.O.S

guarantee. avg. delay. Min. BW. Max. jitter. → Variation in Delay.

Ex1 (ATM)

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Ex.2 MPLS.

Dialing, Blocking — packet switching — statistical multiplexing

※ Advantages of PKt switching.

- statistical multiplexing is more efficient in utilizing the channel compared to TDM (vs. cKt switching) "for Both pKt & msg"
- There is No need for dialing stage before sending traffic (vs. cKt switching).
- No Blocking of incoming traffic. (vs. cKt switching busy tone after dialing). "for Both msg & PKt"
- No Need to store Network-wide states (difficult & expensive) since actual paths are not reserved (vs. cKt switching).
- Hence, routers are much cheaper & consume less power compared to local exchanges & main exchanges.
- Multiple users sharing link can interleave their pKts & thus maintain continuous communications concurrently (vs. cKt switching).

* for Telephony:

- Circuit switching: we call it L.E & M.E.
- Packet switching: routers switches.

... Continue Advantages of PKt switching:

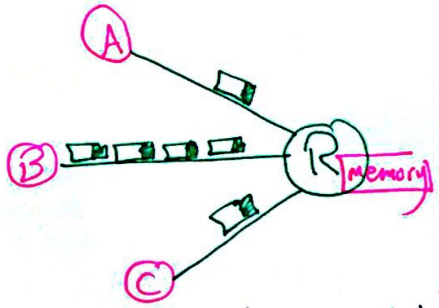
- Packet switching is more efficient than message switching Because intermediate nodes DONOT waste time storing-and-forwarding whole messages in seq., which reduces Total time Delay of sending DATA, especially as the number of intermediate nodes increases (vs. msg switching).
- A bit error during transmission of one pKt or a pKt drop @ an intermediate node means a single pKt needs to be transmitted, not the whole msg (vs. msg switching)
- Probability of a single bit error in a large msg is higher than the probability of a single bit error in a small packet.
- If there are multiple paths between 2-nodes, some pKts of a msg can be sent through one path while other PKts can be sent through another path, reducing congestion & providing redundancy & survivability (vs. msg & cKt switching).

※ Advantages of circuit switching:

- These are also disadvantages of PKt & msg switching.
- CKt switching provides the minimum time delay for sending data after the initial dialing phase, as it does not utilize store-and-forward (No queueing delay), plus there is No need for processing delay (No packet header). Useful for delay intolerant traffic.
- No overhead added to each PKt (header). Unlike PKt & msg switching where intermediate nodes need to Know how to route each PKt or msg individually without having a specific Path reserved.
- NO possibility of congestion since extra traffic is Blocked before it enters the Network.

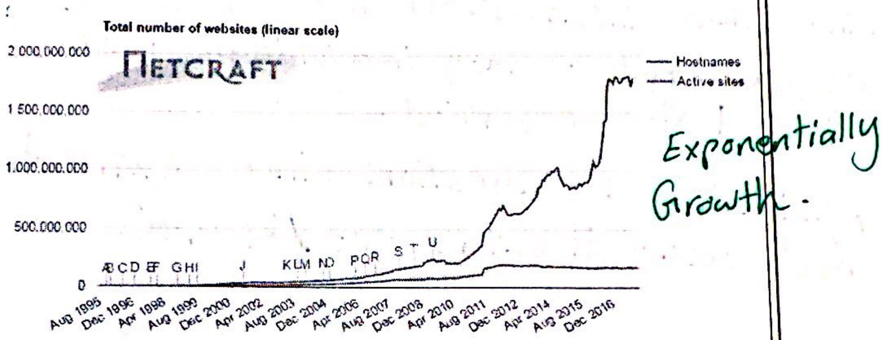
* Congenstion:

Def.: alot of traffic reaching the comm. node causing a loss in the packets.



This memory will be used to store PKts so that circuit switching has No possibility of congestion.

Ineternet growth is *exponential*



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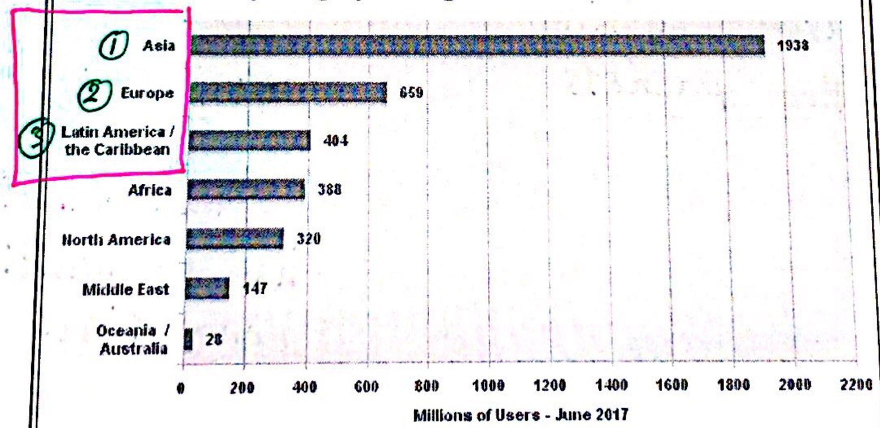
Internet Users in the World by Geographic Regions - June 30, 2017

Memorize the order of these three.



Source: Internet World Stats - www.internetworldstats.com/stats.htm
Basis: 3,885,567,619 Internet users estimated in June 30, 2017
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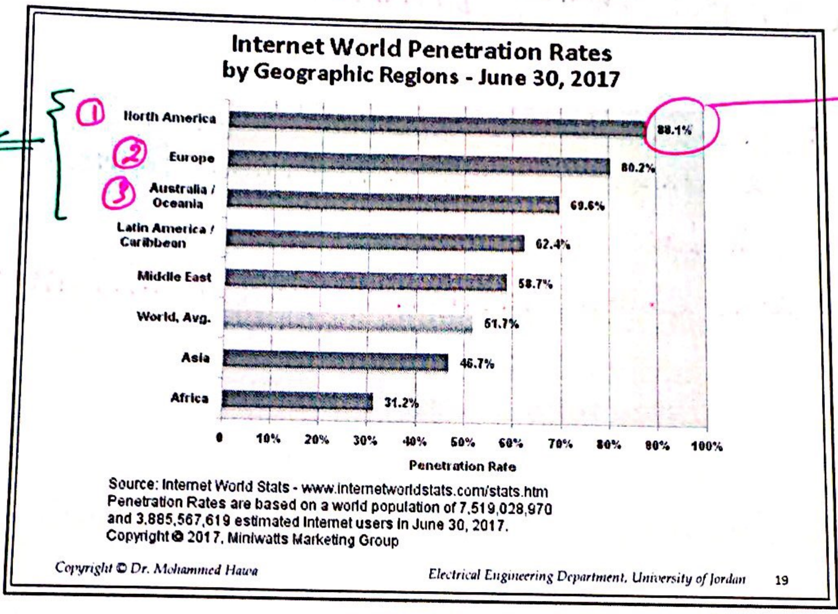
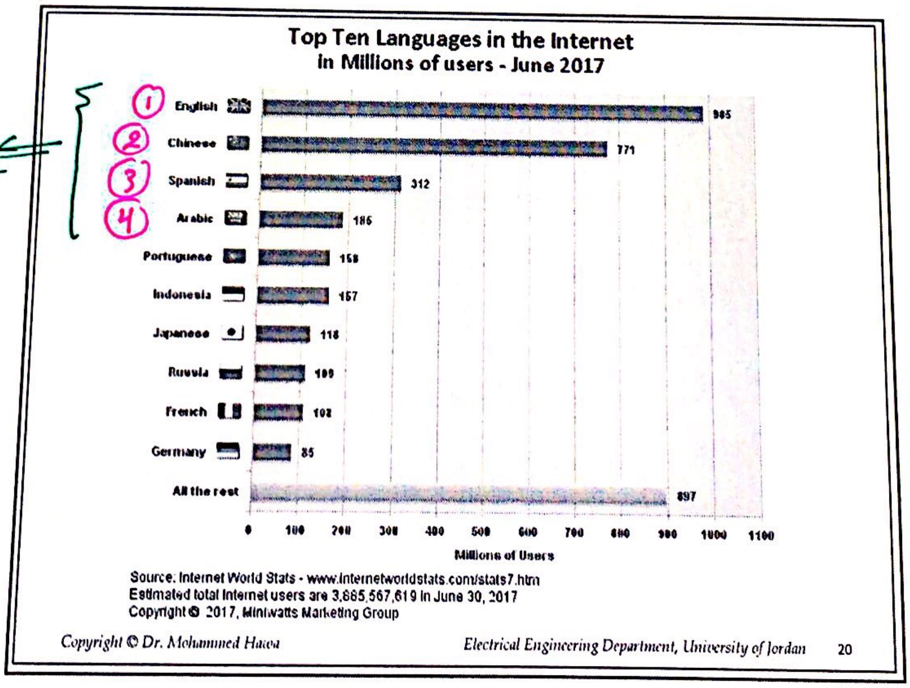
→ memorize the app. number 3.8 billion use internet.

memorize these top 3 countries.



memorize it 88.1% for North America.

Memorize the top 4.



Middle East Internet Users, Population and Facebook Statistics 2017

MIDDLE EAST	Population (2017 Est.)	[illegible]	[illegible]	% Population (Penetration)	Internet [illegible]	[illegible]
Bahrain	1,418,895	40,000	1,390,517	98.0 %	0.9 %	1,000,000
Iran	80,945,718	250,000	56,700,000	70.0 %	38.6 %	17,200,000
Iraq	38,654,287	12,500	14,000,000	36.2 %	9.5 %	14,000,000
Jordan	7,876,703	127,300	6,300,000	80.0 %	4.3 %	4,800,000
Kuwait	4,099,932	150,000	3,214,347	78.4 %	2.2 %	2,300,000
Lebanon	6,039,277	300,000	4,596,494	76.1 %	3.1 %	3,100,000
Oman	4,741,305	90,000	3,310,260	69.8 %	2.3 %	1,500,000
Palestine (State of)	4,928,225	35,000	3,015,088	61.2 %	2.1 %	1,700,000
Qatar	2,338,085	30,000	2,204,580	94.3 %	1.5 %	2,200,000
Saudi Arabia	32,742,664	200,000	24,147,715	73.8 %	16.4 %	18,000,000
Syria	18,906,907	30,000	6,025,631	31.9 %	4.1 %	6,000,000
United Arab Emirates	9,397,599	735,000	8,515,420	90.6 %	5.8 %	8,000,000
Yemen	28,119,546	15,000	6,911,784	24.6 %	4.7 %	2,000,000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.0 %	[illegible]

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Memorize the following:

	population	penetration.
Jordan:	≃ 7.8 million.	80%.
Qatar:	≃ 2.3 million	94.3%.

※ Internet:

- The Internet is a world-wide collection of Networks.

* It started as a research project under taken by a group of U.S Universities & the U.S Department of Defence (DOD) Advanced Research Project Agency (DARPA)

- **Reasons:** ① Building a survivable network.
  ② Connect to expensive main frames.

  in late 1960'S.
  was called (ARPANET) ⟶ Internet.

Communication Networks

Spring 2017/2018

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By: Mohammad Abu Hashya.

* * *

Lecture 2: Network Protocols and Layering

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EE426: Communication Networks

protocol: is the set of rules.

What is a *Network Protocol*?

- A protocol is the set of rules that specify:
  - (1) – Format of **messages** exchanged in the network.
  - (2) – Appropriate **actions** required for each message.
- A protocol is executed by running distributed service scripts on remote communicating entities.
- The service scripts within communicating entities are typically **Layered**.
- Protocols are typically written in **standards** and implemented by software and/or hardware.

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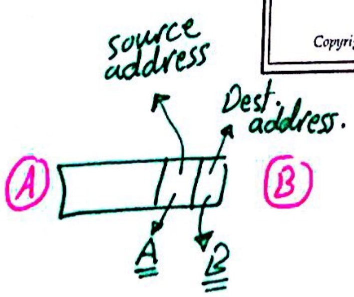
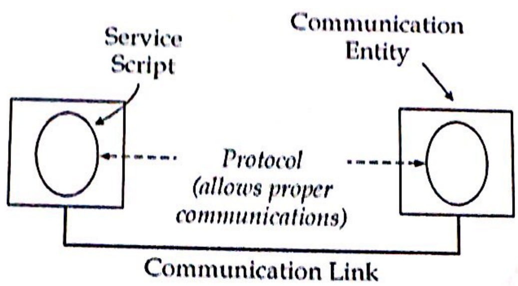


Service script: it is something that runs the protocol. "execute the protocol"

What is a *Network Protocol*?

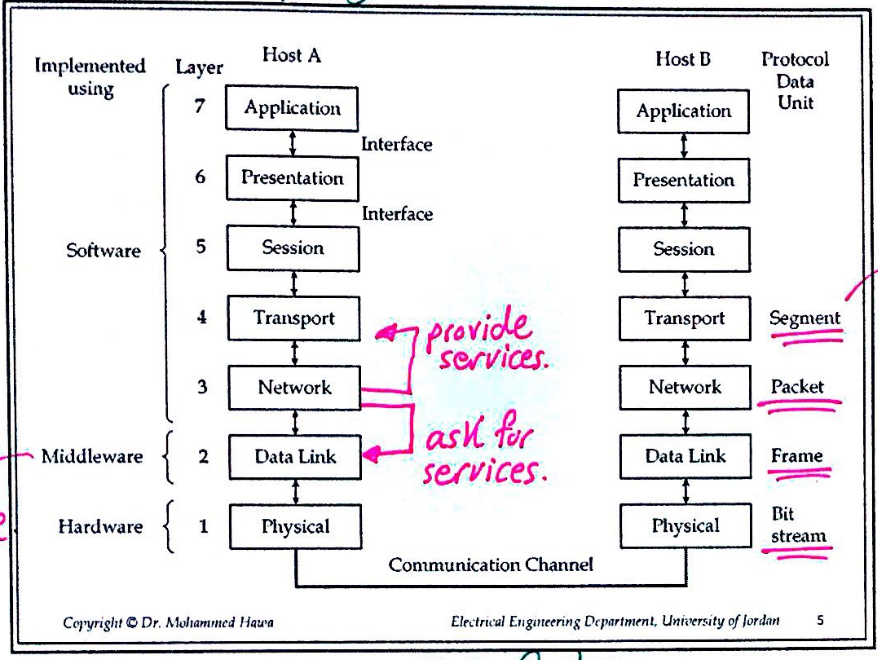


The OSI Model

- One of the main layered models in computer networks is the "Open Systems Interconnection Reference Model" (OSI Model).
- It was developed by the International Organization for Standardization (ISO) in the late 1970s.
- The OSI model contains 7 layers.
- In a layered architecture, layer N uses only the services of layer N – 1 (so communication is valid only between adjacent layers, called *Interface*).

Memorize the 7-layers: (1 → 7).

the seven layers called protocol Entity.



Firmware

provide services.

ask for services.

memorize the names. segment (Transport to Transport).

Full Duplex communication.

Host A → Host B

pimitives "interface"

This for the sending from B to A.

N response

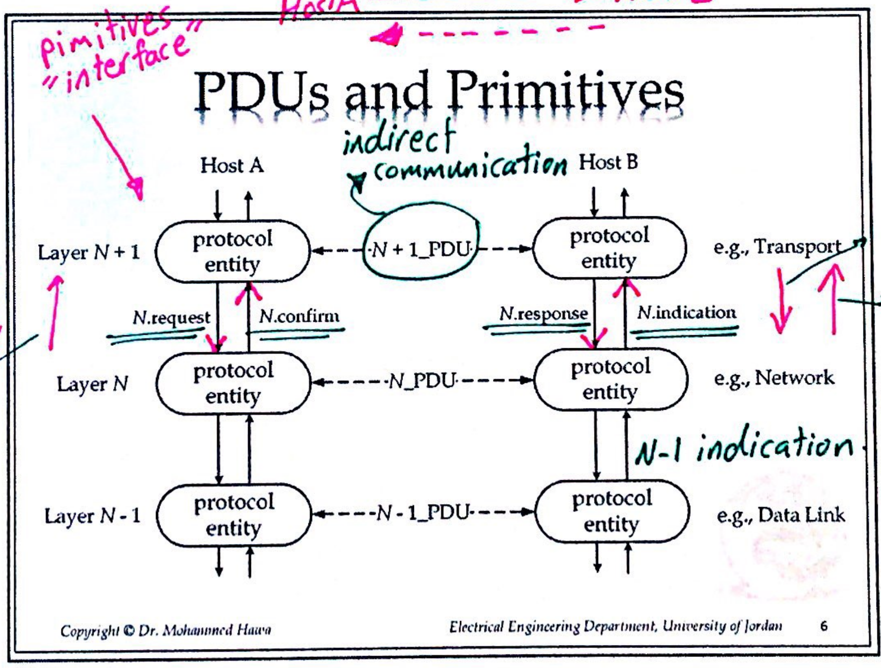
N indication.

indirect communication

N request

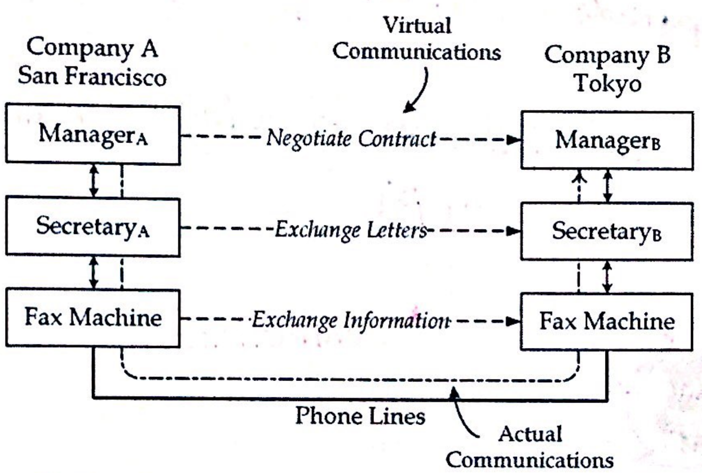
N confirm.

N-1 indication.



- every protocol entity communicates with its peer protocol entity to execute a protocol.
- As they execute the protocol, the exchange Protocol Data Unit (PDU) To send those message, they utilize the services of the Layer beneath them.

Analogy…



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OSI Layers

1. **Physical Layer**: Transmits bits (1's and 0's) as appropriate electrical or optical signals on the transmission medium (physical link) between two adjacent nodes. The functions of this layer include modulation/demodulation, encoding/decoding, clock synchronization, etc. It is usually implemented in hardware.
2. **Data Link Layer**: Handles transmission of frames (sequence of bits) on one given physical link between two adjacent nodes. The data link layer makes sure this sequence of bits arrives correctly (and intact) at the receiving end, and supervises the retransmission of frames that arrive incorrectly (*Old*). Part of the data link layer (called *Medium Access Control* sublayer or MAC) is responsible for controlling access to the shared medium, if one is used.

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Forward Error Correction
FEC → PHY layer1
ask for Retransmission
↳ Layer 4

frame ≡ group of bits.

* which layer responsable on mod/de-mod?
physical layer.

memorize the functions for the layer.

※ Advantages of layered architechure for protocols:

① Different layers can be designed independently which simplifies network to design.

② "Compatibility" because of the independence of the layers.
For Example: VoIP can be designed to run over Ethernet, but then used over WiFi

③ Easier to upgrade software packages.

④ Possibility of multiple instances of a layer running at the same time. (TCP & UDP)

TCP → Connection oriented.

UDP → Connectionless.

* Two main architechures for deliver QoS guarantees in the internet:

① Diff. Serv. : Differential Services — simpler / more popular.

② Int. Serv. : Integrated Services — powerful / complex. → RSVP "Reservation Protocol"

1/28/2018

OSI Layers

3. **Network Layer**: Handles proper *end-to-end* transmission of packets. To do that, this layer collects information about the intermediate nodes in the network to find the *best path* through the network for packets to follow. It also deals with *global address assignment* of different nodes and controls the quality of service (QoS) issues (e.g., delay, jitter, bandwidth reservation, etc).
4. **Transport Layer**: Ensures the *reliable transfer* of messages between end nodes. It handles *dividing* the message into smaller segments, and uses *acknowledgements* (ACKs) to verify that the segments are received correctly by the destination. It supervises the *retransmission* of segments that arrive incorrectly. It also handles *numbering* of the transmitted segments and *rearranges out-of-order* segments at the receiving end. This layer also controls the *rate* at which segments are transmitted. It also allows end nodes to react to ease *congestions* in the network.

→ flow Control.
→ Congestion Control.

→ if it received #1 #2 #3 #4 #6 #5 it will Re-arrange.

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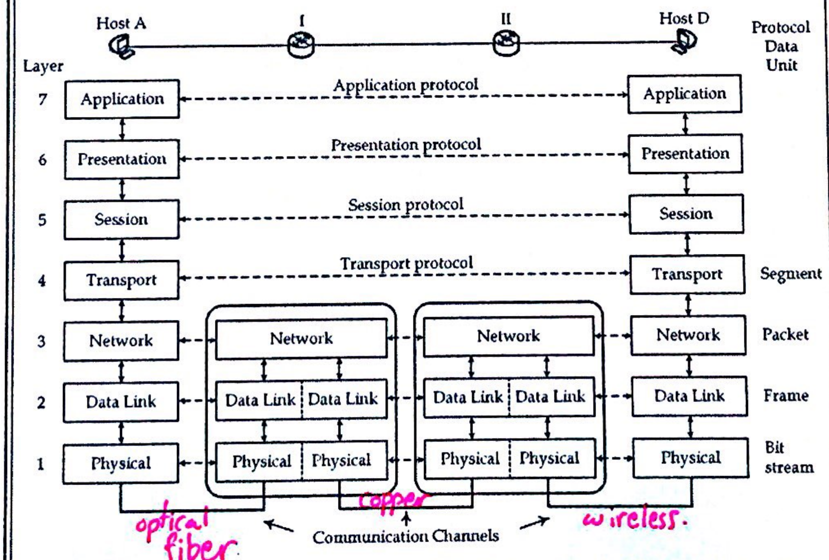

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Example on session layer: (1) SIP ≡ Session Initiation Protocol. ⇒ (for VoIP).
(2) TCAP ≡ Transaction Capabilities Application Part ⇒ TCAP: part of SS7 signalling system #7.

• who handle authentication? Session Layer.

OSI Layers

5. **Session Layer**: Handles the *setup* and *management* of end-to-end sessions (or conversations). It handles *negotiating connection parameters* plus *authentication of users* using passwords.
6. **Presentation Layer**: Handles any necessary *formatting* to translate from the representation on one computer to the representation on another (e.g., ASCII vs. EBCDIC). This layer also handles any necessary *encryption* (for security) and *compression* of data (for faster transfer).
7. **Application Layer**: Those are the applications or services running on top of the network, such as file transfer, web browsing, VoIP and email. Part of the application layer program runs in node A and the other part runs in node B.

EBCDIC ≡ Extended Binary Coded Decimal Interchange Code.

ASCII ≡ American Standard Code for Information Interchange.

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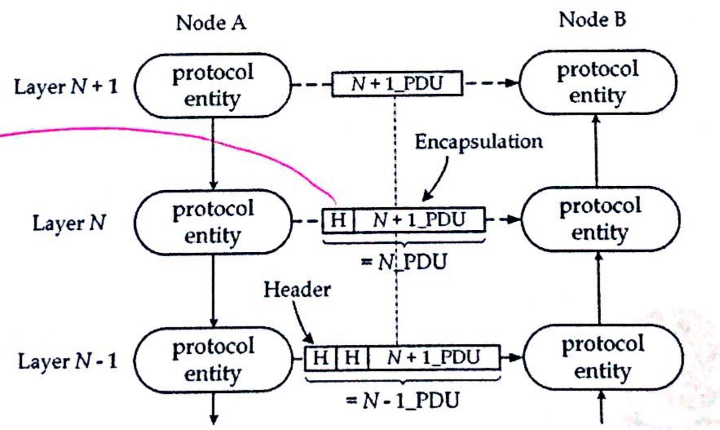
Encapsulation



extra information useful for layer N called: Header.

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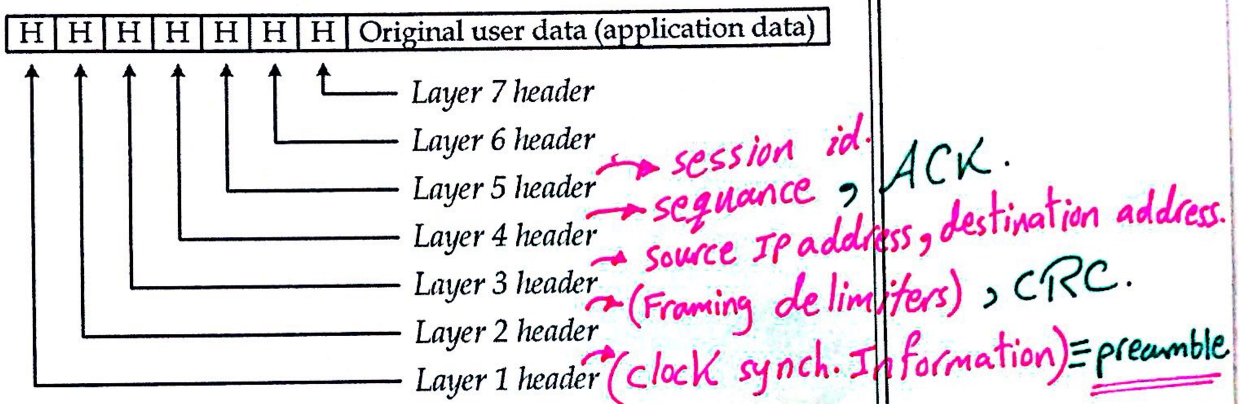
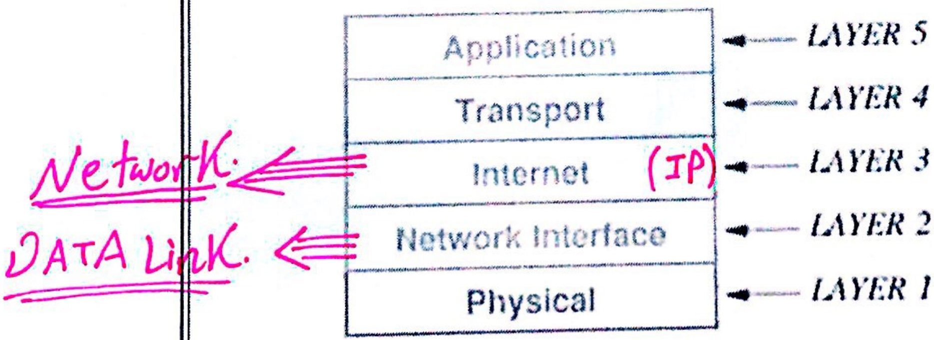
Encapsulation (*Headers*)



group of Layers typically used together.

TCP/IP Stack



Memorize.

Standards & Standardization Bodies

- **ITU-T** (International Telecommunication Union – Telecommunications Sector), formerly CCITT: Mainly physical layer.
- **IEEE** (Institute of Electrical and Electronics Engineers): Mainly layer 2 such as Ethernet (IEEE 802.3) and Wi-Fi (IEEE 802.11).
- **IETF** (Internet Engineering Task Force): Mainly layer 3 and layer 4 such as IPv4 (RFC 791) and TCP (RFC 793).

↳ ≡ Request For Comment.

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Example:

→ Letter.number.

- ITU-T:
  - V.90, V.24 } dial up modem.
  - G.707, G.708 } SDH.

- IEEE: → Number.Number.
  - WiMAX ⇒ IEEE 802.16
  - Cognitive Radio ⇒ IEEE 802.22
  - WRAN

Homework.

Look-up for Bluetooth IEEE standard name ?

Answer. IEEE 802.15.

Communication Networks

Spring 2017/2018

Dr. Mohammad HAWA

By: Mohammad Abu Hashya.

* * *

Lecture 3: The Physical Layer and Transmission Media

Dr. Mohammed Hawa
Electrical Engineering Department
University of Jordan

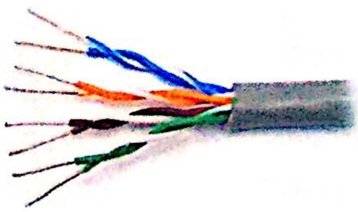
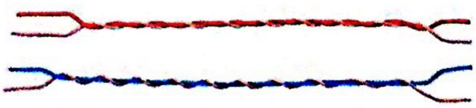
The Physical Layer

- Converts bit streams into electrical or optical (electromagnetic) signals that can transfer information from one part of the network to another over a transmission medium.
- An electromagnetic wave propagates through vacuum at a speed of $c = 3 \times 10^8$ m/s and at smaller speeds in other materials.
- Common transmission media are illustrated in the following slides.

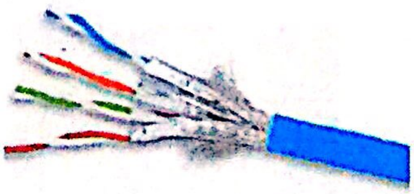
1. Copper Wires

- **Three Types:** Unshielded Twisted Pair (UTP); Shielded Twisted Pair (STP); Coaxial Cable.
- **Advantages:** Inexpensive; Easy to Install.
- **Disadvantages:** High Interference (except for coaxial cable); High Attenuation; Small Bandwidth.
- Very **common** in short-range and medium-range computer networks and telephone networks (i.e., in an office or building).
- Twisting of copper wires reduces outside interference.

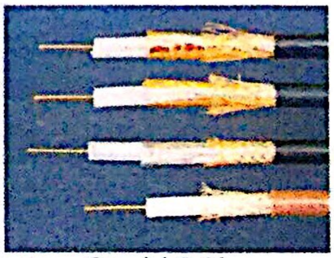
Copper Wires

UTP



STP



Coaxial Cables

2. Optical Fibers

- Flexible fibers made of glass/plastic.
- **Advantages:** Minimal Interference; Small Attenuation (a repeater is needed every 100 km instead of every 5 km in copper wires); Wider Bandwidth; Need only a single fiber not a pair of wires to transmit a signal.
- **Disadvantages:** Expensive (specially lasers); Special equipment to install; If fiber breaks inside the plastic jacket finding the break point is difficult and requires special equipment to fix (create the splice).
- Very **common** in long-range computer networks (i.e., on the level of a city or a country).

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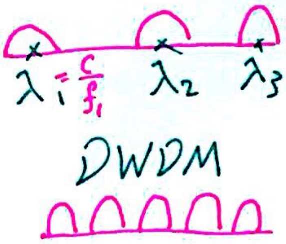
$\lambda = \frac{c}{f}$

WDM

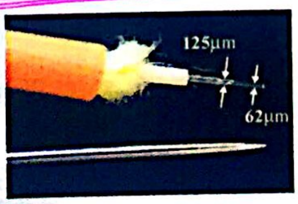


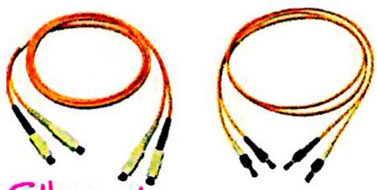
→ Freq. Division Multiplexing ⇒ Modulation at different frequancies.

same FDM

Optical Fibers (Cont.)

- Can use Dense Wavelength Division Multiplexing (**DWDM**) to multiplex multiple carries on one fiber thus efficiently utilizing its huge bandwidth.
- The **main** transmission technology used on fiber is **SDH/SONET**.





Ethernet Cables.

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RF ← | → μwave
1GH

RF. μwave.

3. Radio Frequency/Microwave (Wireless Channel)

- Use the signal to modulate a radio frequency carrier.
- Low frequency is RF transmission. Higher frequency is **Microwave** transmission.
- **Advantages:** Easy to setup. Lower cost (no cables).
- **Disadvantages:** High attenuation; High Interference; Radio transmission can harm humans if power is high; Microwave requires line-of-sight.

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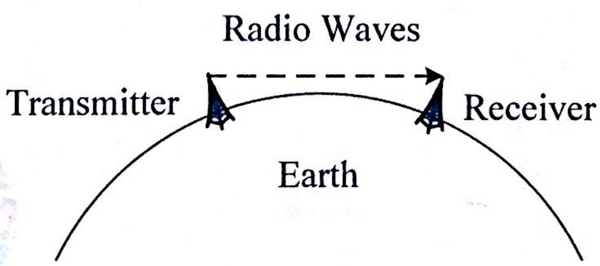
Wireless Channel (*Cont.*)

Examples:

- Wi-Fi, Wi-MAX and Bluetooth are examples of networks that use wireless links. TV and AM/FM Radio are older systems that use RF.



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4. Satellite

- Satellites contain **transponders** that receive signals from an earth station, amplify these signals and retransmit them to another earth station.
- **Advantages:** Larger coverage area compared to Radio/Microwave (suitable for broadcasting); Mobility is possible.
- **Disadvantages:** Expensive (Satellite/Earth Station cost); High attenuation; High Interference; Long delay (for GEO satellites).

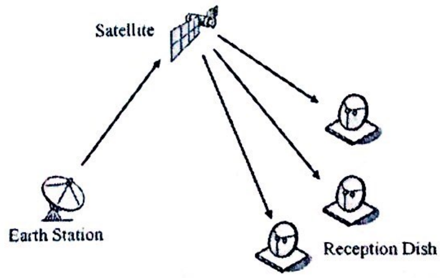
when sending for many people.

* propagation delay depends on distance.

→ for GEO Long Delay since it is very far.

Satellite (Cont.)

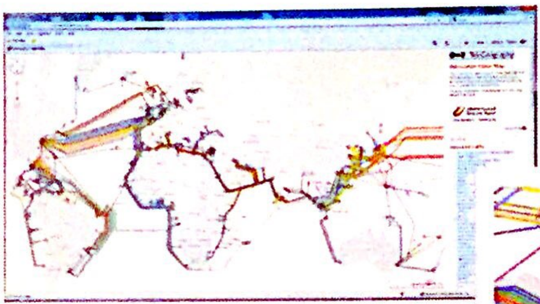
- Three orbits for satellite systems:
- Geostationary (Geosynchronous) Earth Orbit (**GEO**) [Examples: Thuraya, Inmarsat and TV broadcasting].
- Medium Earth Orbit (**MEO**) [Examples: GPS
- (Global Positioning System), Glonass, Galileo, and Satellites that cover North and South Poles].
- Low Earth Orbit (**LEO**) [Examples: Iridium, Globalstar and Teledesic].



Distances:
GEO: 36,000 Km.
LEO: 1000 Km.

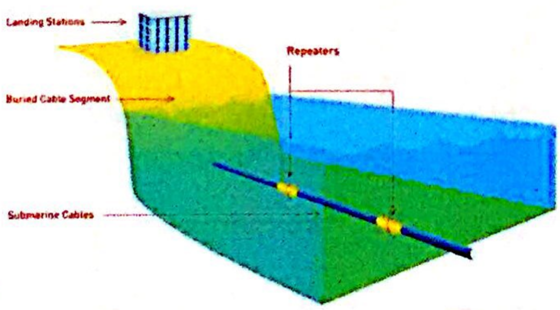
Advantages for LEO:
Low Noise & Low Attenuation.
Disadvantage for LEO:
# of satellites needed to cover the earth.

Interactive map @ http://www.submarinecablemap.com



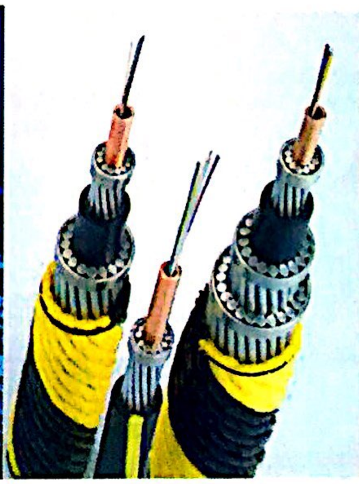
Submarine Cable Laying

Submarine Cable System Components



Cable Laying (*Cont.*)

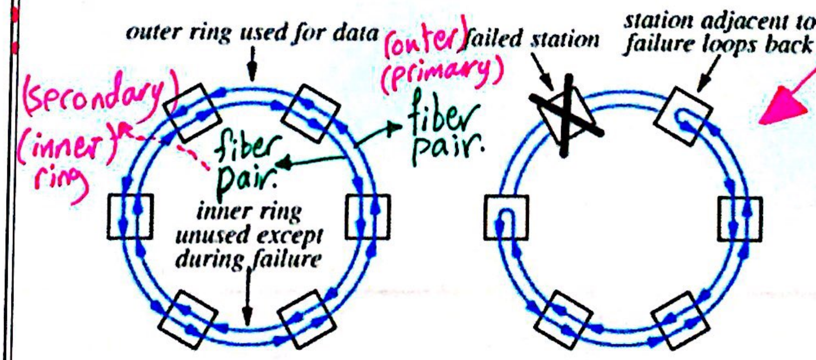
Cable Laying (*Cont.*)



Cable Cuts: Ship Anchors

Network Protection using SDH/SONET rings

Network Protection → or Protection Ring or Self-healing Ring or protection loop.



SDH ≡ Synchronous Digital Hierarchy. "European".

SONET ≡ Synchronous optical Network. "U.S".

in 1950 :

FLAG: Fiber Link Across the Globe

- **FLAG** (Fiber Link Across the Globe) is one of the main operators of an optical fiber cable system that connects major cities around the world.
- FLAG is now part of Global Cloud Xchange.
- FLAG was built on multiple stages. The parts that cross the middle east are:
  - FLAG Europe-Asia (FEA)
  - FALCON (FLAG Alcatel …)

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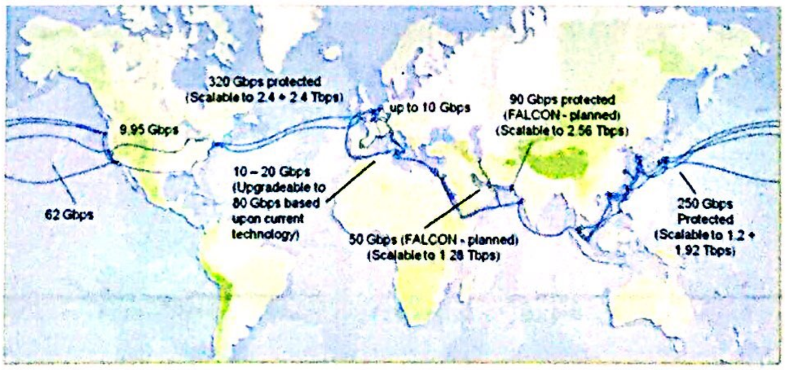
Homework:
FALCON ≡ Flag Alcatel-Lucent Optical Network.

FLAG Submarine Cables



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FLAG Europe-Asia (FEA)

- Links Western Europe and Japan through the Middle East, India and China. The cable comes ashore at 16 landing points in 13 countries (China, Egypt, Hong Kong, India, Italy, Japan, Jordan, Korea, Malaysia, Saudi Arabia, Spain, Thailand, UAE and UK). It is a two fiber pair, multi-sectioned point-to-point system with a capacity of 20 Gbps on many segments. Went live on November 1997 and is 28,000 km in length. Allowed services include bandwidth purchase and lease of E1, DS-3, STM-1 and STM-4.

DS-3 → T-3 "U.S"
E1 → "Europe"

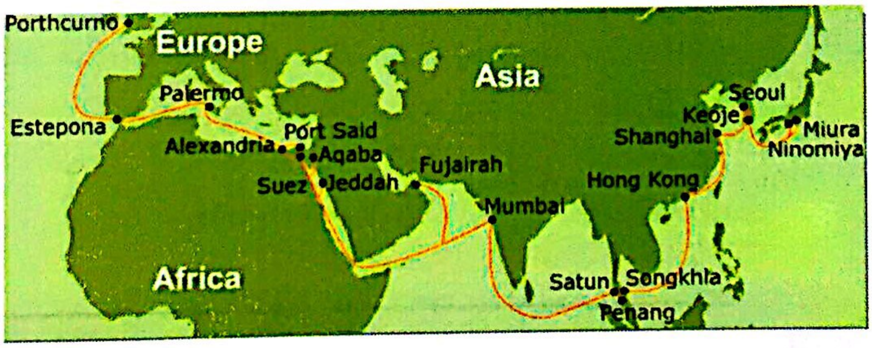
DONOT memorize the countries.

Initial Capacity (Gbps)	20	Capacity fully upgraded (Gbps)	80+
Fiber Pairs	2	Fiber Pairs	2
Wavelengths per Fiber Pair	1 - 2	Wavelengths per Fiber Pair	4
Gbps per Wavelength	5 - 10	Gbps per Wavelength	10

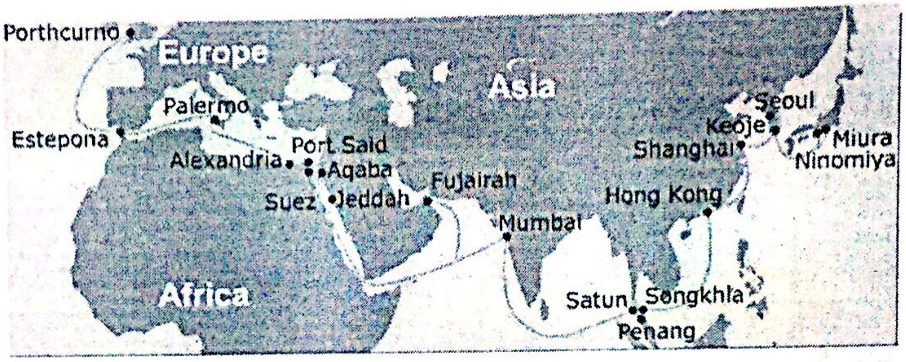
For FEA:
How many fiber pairs we have: = 2
" " fiber we have: = 4

→ 80Gbps.
40Gbps 40Gbps
2 pairs (4 fibers)
WDM ≡ FDM
x4 wave length. each one can carry 10 Gbps.

FLAG Europe-Asia (FEA)



FLAG Europe-Asia (FEA)



memorize the underlined Text below:

FALCON

- FALCON delivers a high-capacity, self-healing submarine network ring (loop) with multiple landings throughout the Gulf region (Initial launch capacity 50 Gbps, Maximum design capacity of 1.28 Tbps) in addition to four fiber pair route linking the Gulf to Egypt and India (Initial launch at 90 Gbps, Design capacity of 2.56 Tbps). Announced on February 2004. Full service launch in September 2006. Cable length is 10,300 km.

memorize:

AEConnect	January 2016	5,522 km	4 × 10 Tbit/s (four strand 100 × 100 Gbit/s) = 40Tbps.	54 ms	Shirley, US-NY; Killala, IE-C	Aqua Comms
MAREA	Q1 2018 (planned)	6,600 km	160 Tbit/s		Virginia Beach, US-VA; Bilbao, ES-PV	Facebook, Microsoft, Telefónica

40Tbps.

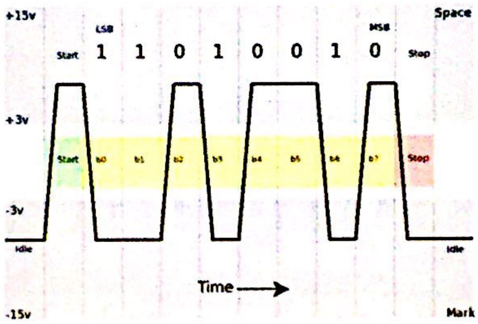
160Tbps.

※ Clock Synch. : → Asynchronous. → Plesiochronous. → Synchronous.

Asynchronous Transmission

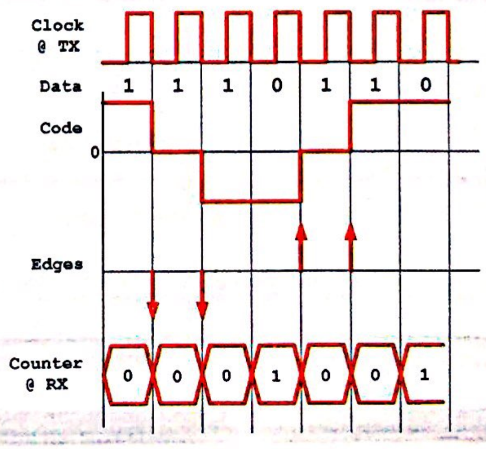
RS-232 serial port.

- This is an extreme case in which the transmitter and receiver clocks do not coordinate with each other except to set their circuitry to run at the same frequency.



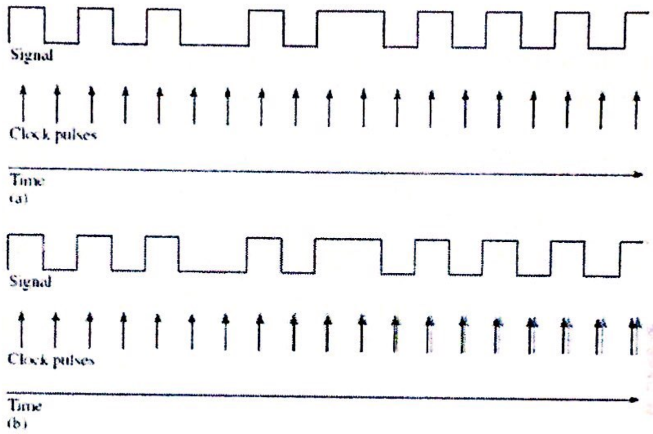
Plesiochronous Transmission

- To allow larger chunks of bits to be transmitted in higher data rate networks, the clocks of the transmitter and receiver must be continuously synchronized.
- This is done in plesiochronous transmission using special bit-encoding schemes that carry clock information along with bit information (called self-synchronizing codes).



100MHZ (L) Tx —bits→ Rx. 100.1MHZ 100MHZ (L) "clock" drift.

Clock Drift between TX and RX



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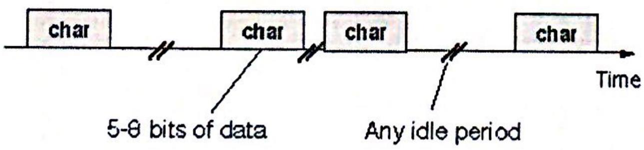
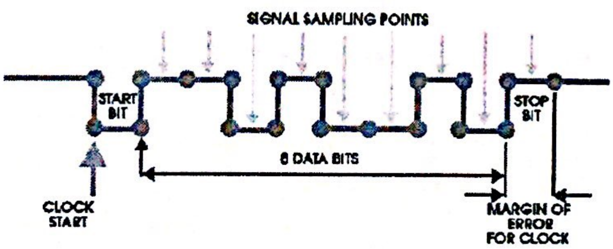
Reset RX Clock After Idle





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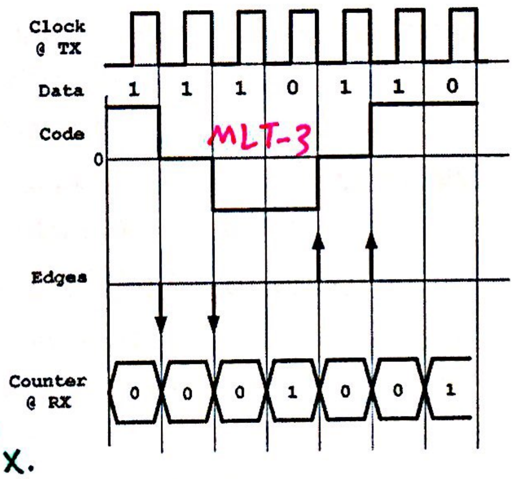
Asynchronous Transmission

- Disadvantages:
  - Works only for short distance communication systems, as different temperature/humidity/etc increase clock drift significantly.
  - Only low data rate is possible (wider bits are more resilient to clock drifts).
  - Can send only in short bursts (8-10 bits) to minimize the possible effects of drift before the next clock reset.
  - Low utilization of the link.
- Advantages:
  - Simple to build.
  - Inexpensive.

Plesiochronous Transmission

- To allow larger chunks of bits to be transmitted in higher data rate networks, the clocks of the transmitter and receiver must be continuously synchronized.
- This is done in plesiochronous transmission using special bit-encoding schemes that carry clock information along with bit information (called self-synchronizing codes). & PLL @ Rx.



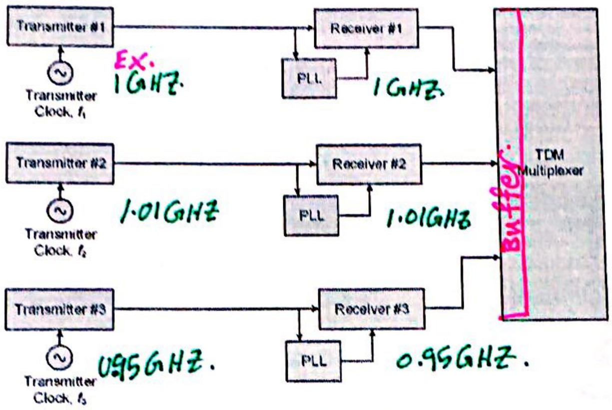
PLL → phase locked loop.

Advantages & Disadvantages ⇒ opposite to the Asynch Transmission.

use PLL.

Buffering At High Data Rate

300 - 400 Mbps.



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Synchronous Transmission

- In this case, the clocks of the transmitter and receiver (and all other devices in the network) are controlled by a main clock.
- A special Distributed Clock Synchronization Protocol is used by the network. ← GPS.
- An example is SDH/SONET systems.
- High data rate possible, minimum buffering, flexible multiplexing, but expensive.

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SDH vs. PDH:

- SDH is more expensive.
- SDH is Higher Data Rate.
- SDH is Synchronous.

Communication Networks

Spring 2017/2018

Dr. Mohammad HAWA

By: Mohammad Abu Hashya.

* * *

Lecture 4: Local Loop Technologies, Internet Access and Leased Lines

Dr. Mohammed Hawa
Electrical Engineering Department
University of Jordan

EE426: Communication Networks

Internet Access Technologies

- Digital Subscriber Line (xDSL) ← memorize.
- Fiber (FTTx)
- Cable TV (CATV) Networks
- WiMAX and Cellular
- Power line communication (PLC)
- Leased Lines

These with cellular are the most popular.

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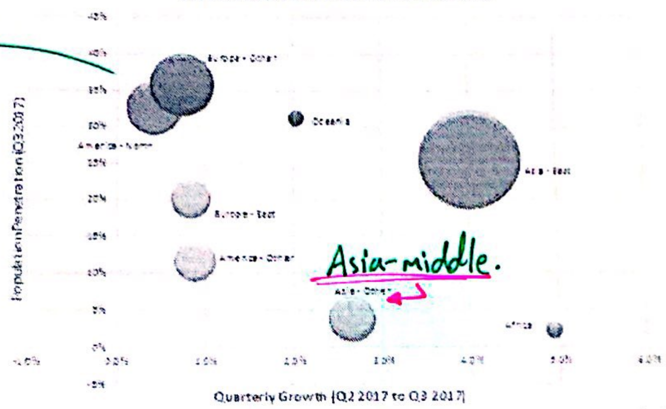
Higher Data Rate.

Broadband in Different Regions

• memorize:
North America & Europe.
Highest population penetration.

• Memorize:
East Asia.
Highest Growth.

Regional Growth and Population Penetration
Bubble size represents subscriber number volumes



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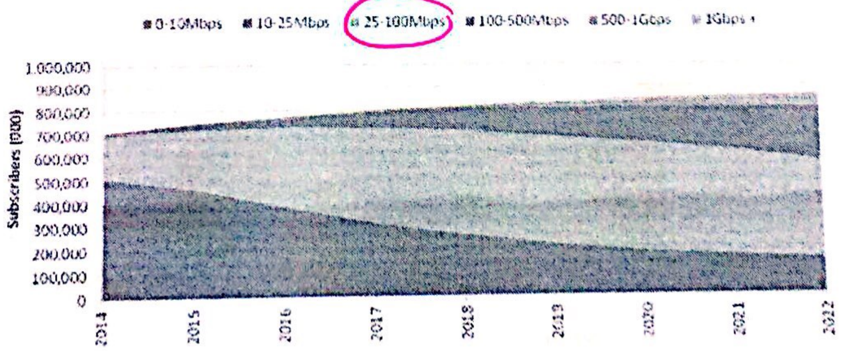
memorize: Broadband (25-100) Mbps.

Global Fixed Broadband Subscribers by Speed



Source: Broadbandtrends

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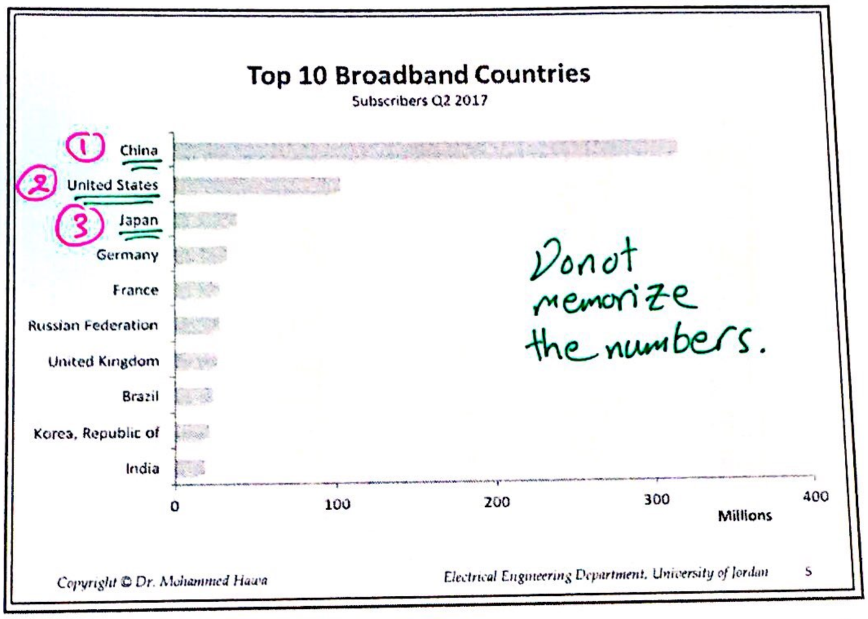
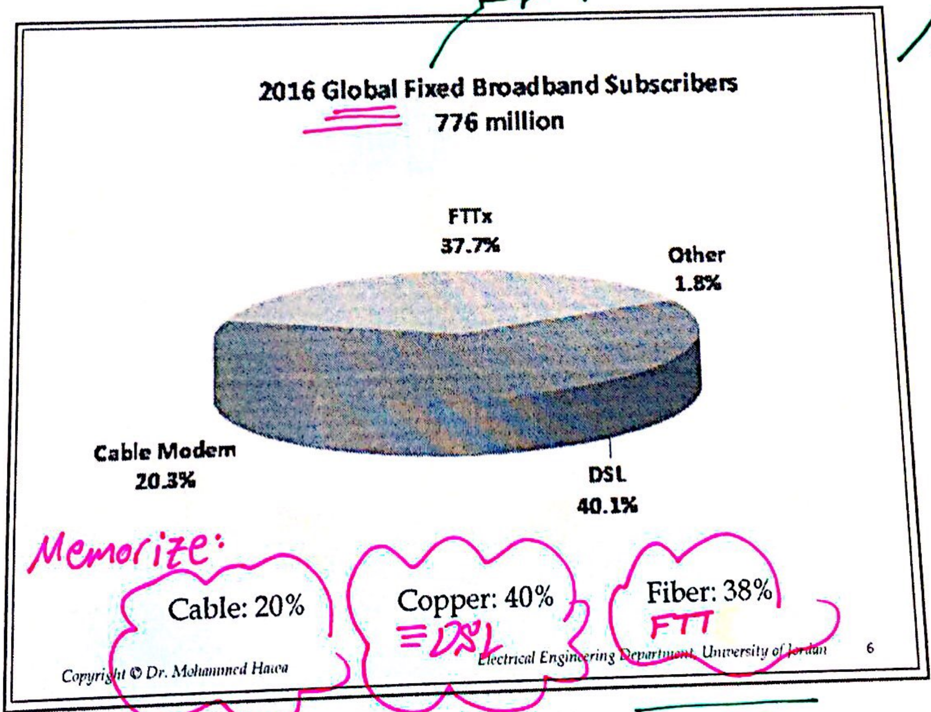
Memorize Top three.



Do not memorize the numbers.

Not mobile / Not cellular / Not wireless.



Memorize:

≡ DSL

FTT

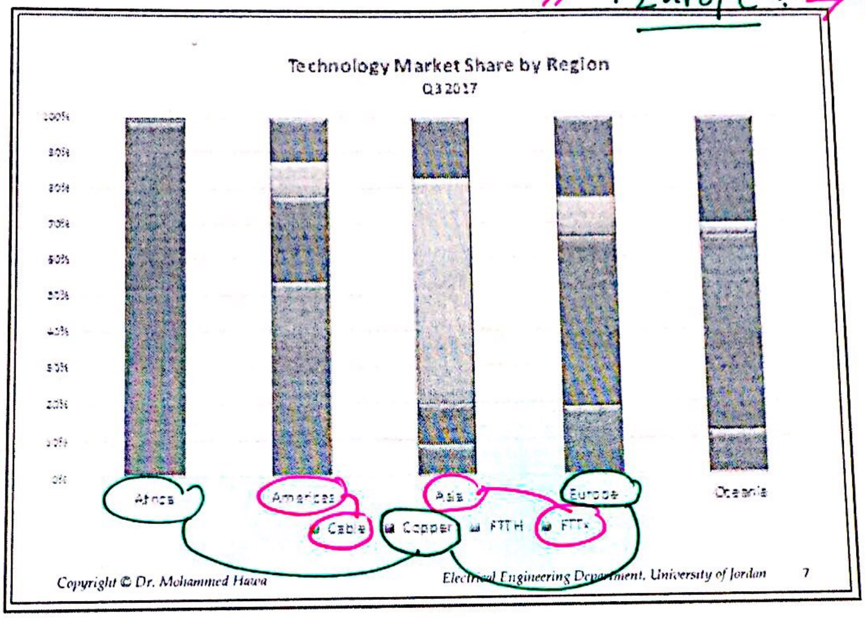
* What is the most popular fixed broadband Internet Access technology in: Africa ? → copper (DSL).

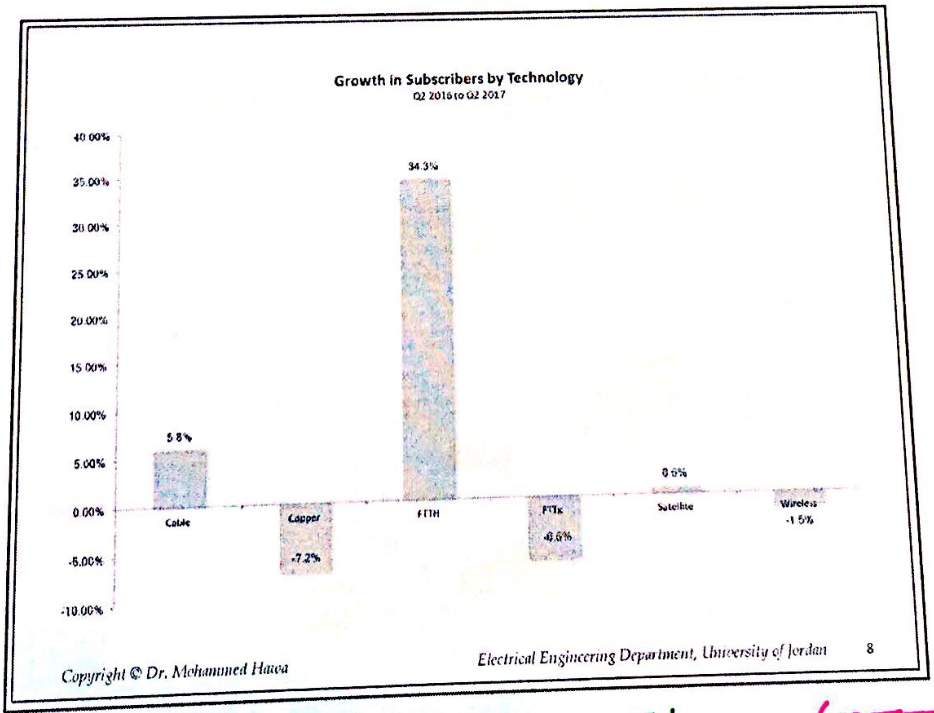
" : America? ⇒ Cable.

2/18/2018

" : Asia ? ⇒ Fiber.

" : Europe ? ⇒ Copper.





* The Fastest in Growth: Fiber. (FTTH) "fiber to the Home"

* Baud Rate is Decided By Bandwidth.

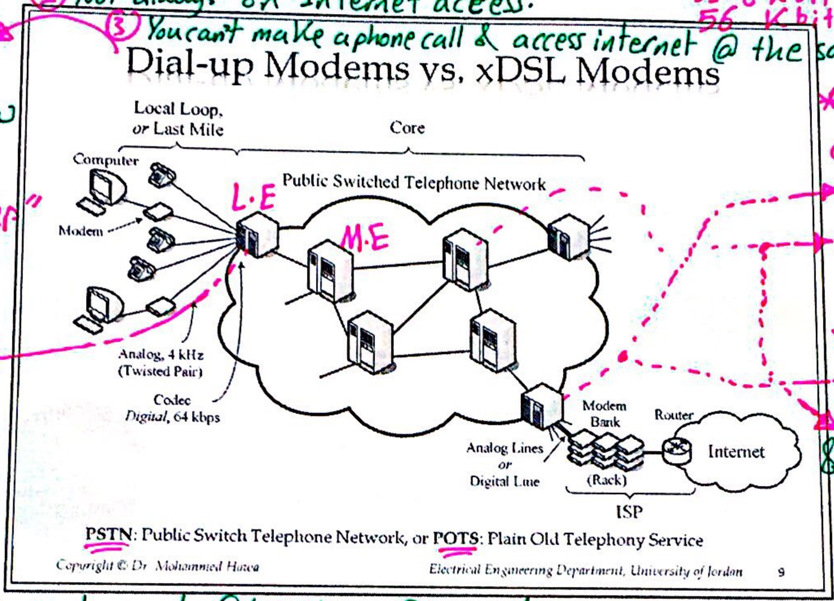
* 1Km → copper → BW = 1-2 MHZ.
* bits/symbol → Decided By SNR.

Modem ≡ Modulator - Demodulator.

2/18/2018

* Disadvantages: (1) lower data rate because of lower BW — 9.6 Kbit/s, 33.6 Kbit/s, 56 Kbit/s → down stream.
(2) Not always on Internet access.
(3) You can't make a phone call & access internet @ the same time.

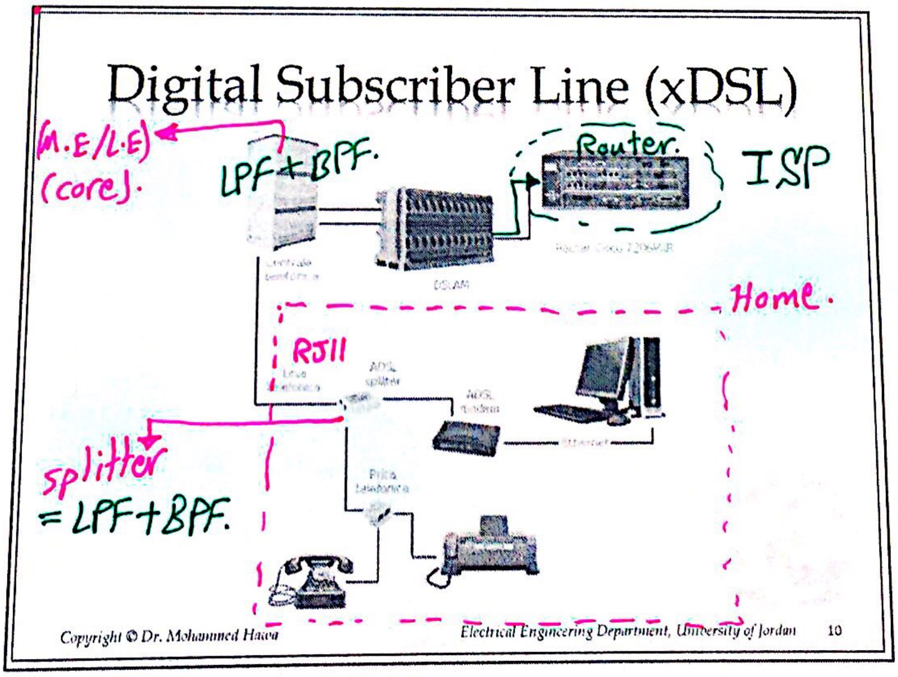
* Advantage: No need for new infrastructure "very low cost to ISP"



Anti-Aliasing LPF
$f_s = 8KHZ$.
$B_{LPF} = 4KHZ$.

* in Europe: called: Local exchange & {Main Exchange "Tandem Exchange"}
* in U.S: end office. & {Central office "toll office"}

ISP ≡ Internet Service Provider.



L.E → DSLAM → ISP.

* DSLAM ≡ DSL Access Multiplexer.

Memorize it:

xDSL Standards

- Different variants of DSL technologies exist: ADSL/ADSL2/ADSL2+ (Asymmetric DSL), SDSL (Symmetric DSL), HDSL (High-bit-rate DSL), VDSL/VDSL2 (Very High Rate DSL), RADSL (Rate-Adaptive DSL), GDSL (Gigabit DSL).

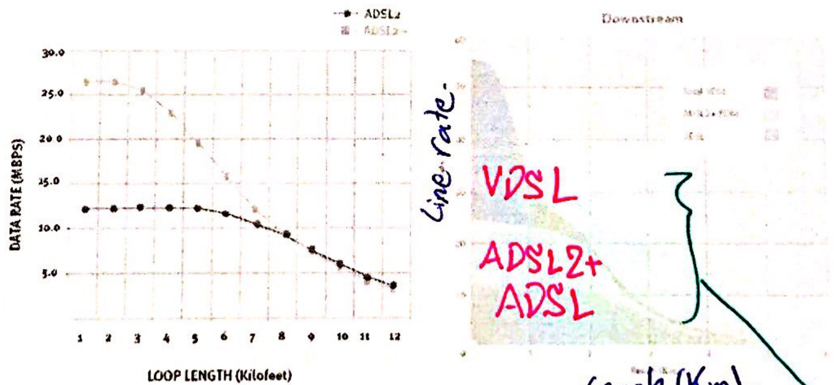
Name	Standard Name	Downstream rate	Upstream rate
ADSL	ANSI T1.413-1998 Issue 2	8 Mbit/s	1.0 Mbit/s
ADSL2	ITU-T G.992.3 Annex J	12 Mbit/s	3.5 Mbit/s
ADSL2+M	ITU-T G.992.5 Annex M	24 Mbit/s	3.3 Mbit/s
VDSL	ITU-T G.993.1	55 Mbit/s	3 Mbit/s
VDSL2-Vplus	ITU-T G.993.2 Amendment 1	300 Mbit/s	100 Mbit/s
G.fast	ITU-T G.9700 & G.9701	1 Gbit/s	100 Mbit/s

Memorize.

These are the Maximum values. NOT necessary to have this number.

Down stream ≡ from ISP to Home.
Up stream ≡ from Home to ISP.

Above Data Rates are *Maximum*



There are Limitations e.g. Type of the Line.

memorize the order of them.

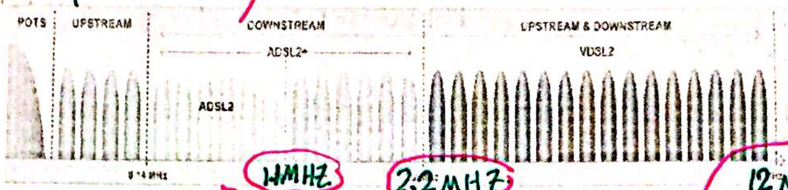
*when distance is increased:

Attenuation ↑
Noise ↑
SNR ↓

home → internet.

internet → home.

Use bandwidth *above* 4 kHz



1.1MHZ 2.2MHZ (memorize.)

12MHZ. also 30MHZ. → BW of ADSL2

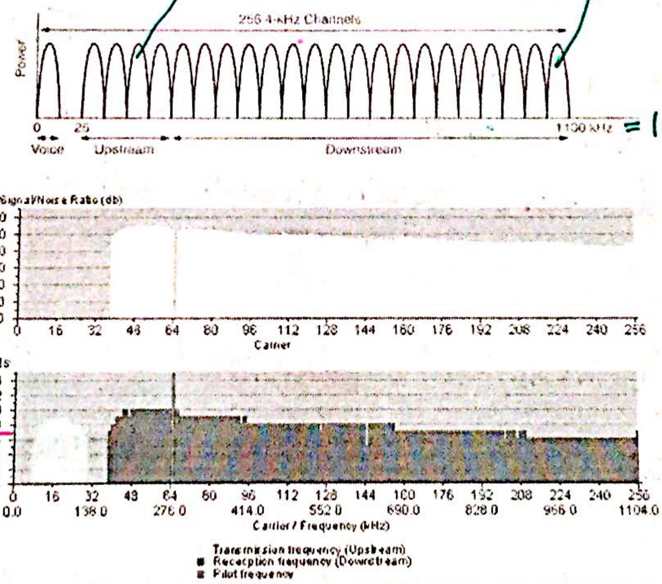
G. fast Service rate performance targets over 0.5 mm straight loops

Distance	Performance target
<100 m, FTTB	500–1000 Mbit/s
100 m	500 Mbit/s
200 m	200 Mbit/s
250 m	150 Mbit/s
500 m	100 Mbit/s

Behind the page. ⟹

Better SNR

Bad SNR.



= 1.1MHZ.

10bits/symbol. 1024QAM.

7bits/symbol. 128QAM.

⇒ upstream ⇒ lower freq (lower attenuation).

* Why we use OFDM?

Because we have different levels of SNR & different levels of Att. which leads to linear distortion this avoided by using OFDM.

* ADSL (Annex A)

uses Discrete Multi-Tone (DMT) modulation
(But it is Not Modulation)

DMT: ↓

ⓐ OFDM ≡ orthogonal Freq. Division Multiplexing.

ⓑ QAM ≡ Modulation.

ⓒ Adaptive.

ⓓ DSP.

* ADSL divides the local loop Bandwidth (~1.1MHZ)
into independent channels of 4312.5HZ ≃ 4KHZ

- channel 0 is used for voice calls (POTS)
- channel 1-5 guardband.
- some of the remain 250 channels (Typically 32) are used for upstream data, while the rest are used for down stream data.

* Baud rate (symbols/sec) decided by Bandwidth.

- Baud rate for each channel ≡ 4000 symbols/sec.

* Modulation order decided by SNR
↳ (bits/symbol).

64 QAM → 128 QAM → 256 QAM
6 7 8 bits/symbol.

*QAM modulation : is used in each channel with a baudrate of 4000 sym/sec. for a max of 15 bits/sym. depending on the SNR. measured for that channel.

*ADSL uses very powerful DSP (Digital Signal Processing) to create OFDM & to perform error correction, echo cancellation & Equalization.

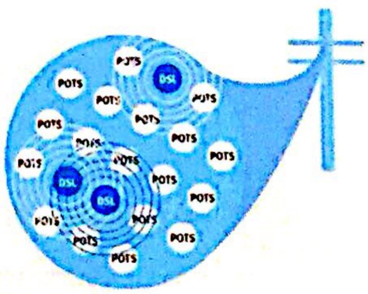
G.fast and Vectoring

FDD ≡ Freq. Division Duplex.

- G.fast provides up to 1 Gbit/s aggregate uplink and downlink data rate at 100m distance.
- Approved in December 2014, deployments in 2016.
- G.fast uses DMT. It modulates up to 12 bit per DMT frequency carrier, reduced from 15 in VDSL2 to reduce complexity.
- G.fast uses 106 MHz bandwidth, with 212 MHz profiles planned for future amendments.
- (memorize.) Compared to 8.5, 17.664, or 30 MHz profiles in VDSL2.
- G.fast uses TDD as opposed to ADSL2 and VDSL2, which use FDD, with symmetry ratios of 90/10 (U D) up to 10/90 (U D), including 50/50.
- Performance in G.fast systems is limited by crosstalk between multiple wire pairs in a single cable (called Self-FEXT: far-end crosstalk).

Vectoring

- Vectoring coordinates line signals to reduce crosstalk (noise cancellation).
- Vectoring was previously specified for VDSL2 by the ITU-T in G.993.5, called G.vector.
- The first version of G.fast will support an improved version of the linear precoding scheme found in G.vector.
- Non-linear precoding planned for a future amendment.



L.E VDSL → modem ~~ADSL2+~~ → Lower speed
L.E VDSL → VDSL → This get the high speed.
} due to Backward Compatibility.

2/11/2016

G.fast Deployment

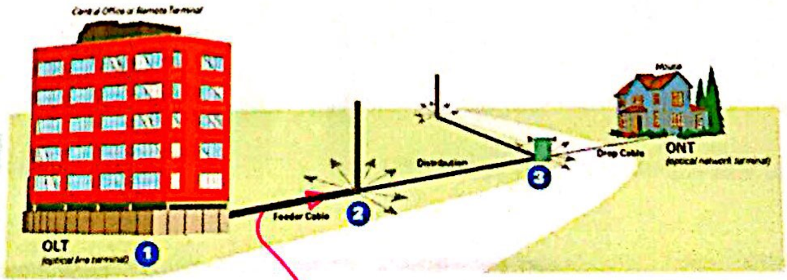
- **FTTdp** (fiber to the distribution point) is commonly associated with G.fast, similar to how FTTN is associated with VDSL2. ↳ Fiber to the Neighborhood.
- FTTdp is in between FTTN and FTTH.
- In FTTdp, a limited number of subscribers at a distance of up to 200–300 m are attached to one fiber node (can be mounted on a pole or underground), which acts as a DSLAM.
- Compared to ADSL2 where the DSLAM is located in the Local Exchange at a distance of up to 5 km from the subscriber, while in some VDSL2 the DSLAM is located in a street cabinet and serves hundreds of subscribers at distances up to 1 km.

different distance with 100m since different data rate But 100m could give the 1 G bits/sec.

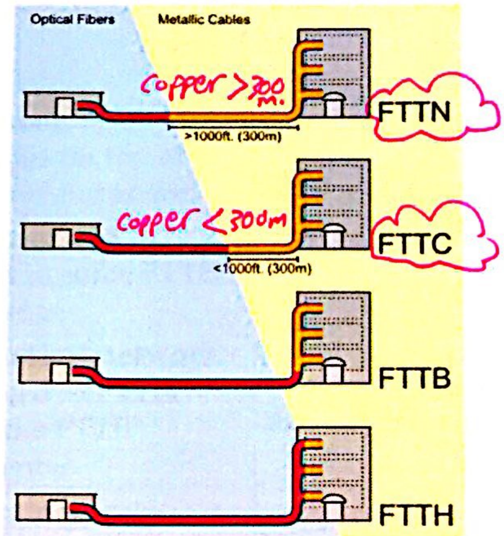
VDSL2 distance ⟹ 1 Km.

Fiber to the x (FTTx)

- Telephony networks consist of a large distribution network of copper wires.
- Fiber to the node / Fiber to the neighborhood (FTTN)
- Fiber to the curb (FTTC) / Fiber to the kerb (FTTK)
- Fiber to the distribution point (FTTdp)
- Fiber to the building (FTTB)
- Fiber to the home (FTTH)



MDF ≡ Main Distribution Frame.



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Equipment

FTTC

FTTH

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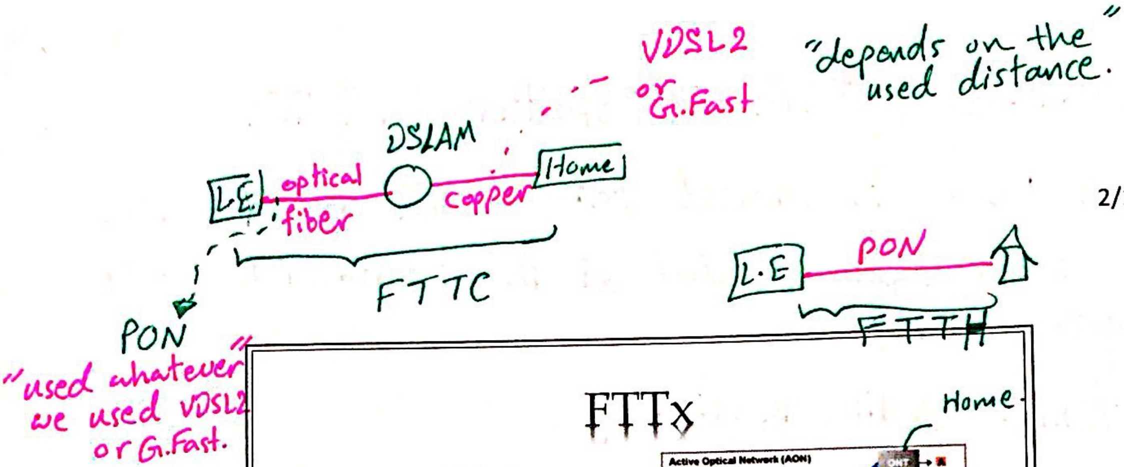
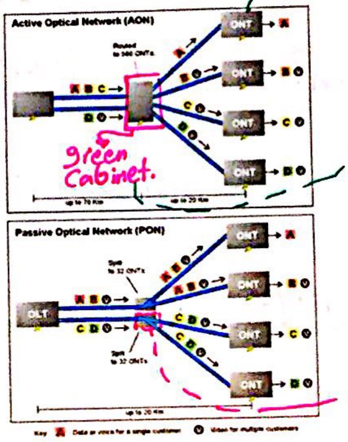


FTTx

- The two main technologies on top of FTTx architectures are:
- **VDSL2:** used in FTTN, FTTC and in some FTTB deployments. (or G.fast.)
- **Passive optical network (PON):** used in FTTH and in some FTTB deployments.



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Memorize.

Main standards for PON

Name	Standard	Maximum Split ratio	Downstream Capacity*	Upstream Capacity*	Layer 2 encapsulation
BPON (Broadband PON)	ITU-T G.983	1:32	1.25 Gbps	622 Mbps	ATM
GPON (Gigabit PON)	ITU-T G.984	1:64	2.5 Gbps	1.25 Gbps	ATM & Ethernet
10G-PON (10 Gigabit PON)	ITU-T G.987	1:128	10 Gbps	2.5 Gbps	Ethernet
EPON (Ethernet PON)	IEEE 802.3ah	1:32	1.25 Gbps	1.25 Gbps	Ethernet
10G-EPON (10 Gigabit Ethernet PON)	IEEE 802.3av	1:64	10 Gbps	1.25 Gbps	Ethernet

(*) before being divided by the number of splits

$\frac{1.25\text{G BPS}}{32} \simeq 40$ Mbps for each user.

Behind the page

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※ Advantages of Passive Splitters in PON:

① One Laser is shared between 32 or 64 users.

② No Power supply Needed at the intermediate node (green cabine).

③ Flexible Splite Ratio.

※ Disadvantages of passive Splitters in PON:

① Security → solved by encryption.

② Bandwidth is shared.

- As a summary for the advantages: "Lower Cost"

* Standards:

- OLT ≡ Optical Line Terminal → located in the L.E.
- ONT ≡ Optical Network Terminal → located in the green cabinet.

Bandwidth of:

Coax ⇒ 1-2 GHZ

copper ⇒ 1-2 MHZ.

NTSC & ATSC ⇒ 6MHZ

PAL ⇒ 8MHZ.

Cable Network:

HBO

show time

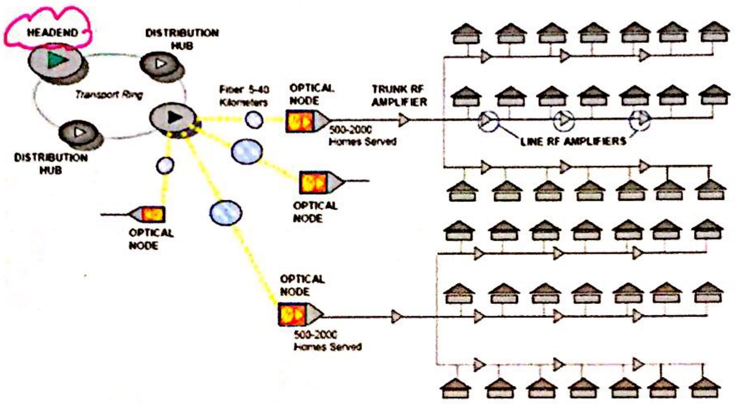
OSN.

"less att. than wireless".

2/11/2016

HFC ≡ Hybrid Fiber Coax.

Cable TV (CATV) Networks



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one-way Amplifier

two-way Amplifier

Cable Modems

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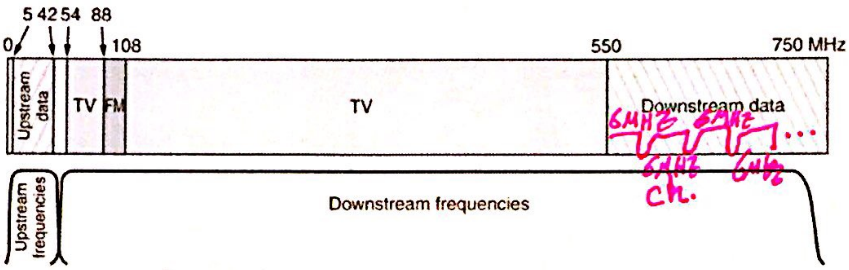
⇒ Head end or optical node: CMTS ≡ Cable Modem Termination System.

⇒ Home: CM ≡ Cable Modem.

Coaxial Cable Bandwidth



do-not memorize the exact Number.

Memorize the Approximate Numbers:

DOCSIS (Data Over Cable Service Interface Specifications)

related to it by *8/6

CableModem Standard Name	Ratified as ITU-T Standard	DOCSIS (6 MHz channels)		EuroDOCSIS (8 MHz channels)	
		Downstream rate	Upstream rate	Downstream rate	Upstream rate
DOCSIS 1.1	J.112 Annex B	42.88 Mbit/s	10.24 Mbit/s	55.62 Mbit/s	10.24 Mbit/s
DOCSIS 2.0	J.122	42.88 Mbit/s	30.72 Mbit/s	55.62 Mbit/s	30.72 Mbit/s
DOCSIS 3.0 4 channel	J.222	171.52 Mbit/s	122.88 Mbit/s	222.48 Mbit/s	122.88 Mbit/s
DOCSIS 3.0 8 channel	J.222	343.04 Mbit/s	122.88 Mbit/s	444.96 Mbit/s	122.88 Mbit/s
DOCSIS 3.1 OFDM	2017	10 Gbit/s	10 Gbit/s		

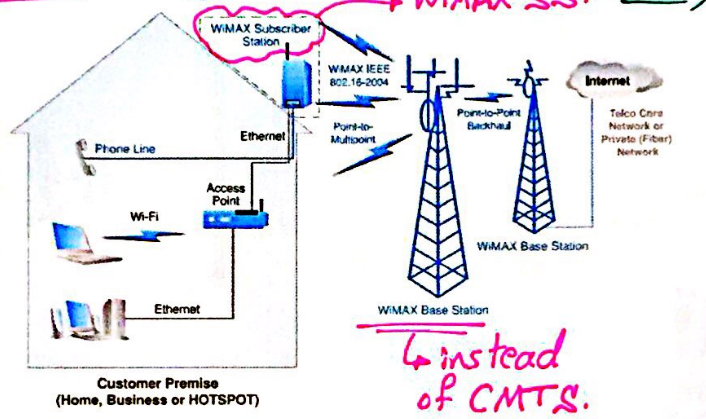
OFDM → Full Duplex.

most popular standard for fixed BWA.

Fixed Broadband Wireless Access (BWA) (Wi-MAX or IEEE802.16)

Compete with xDSL & Cable Modem.

WiMAX SS. ⟹ insted of CM.



↳ instead of CMTS.

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Base Station (BS)

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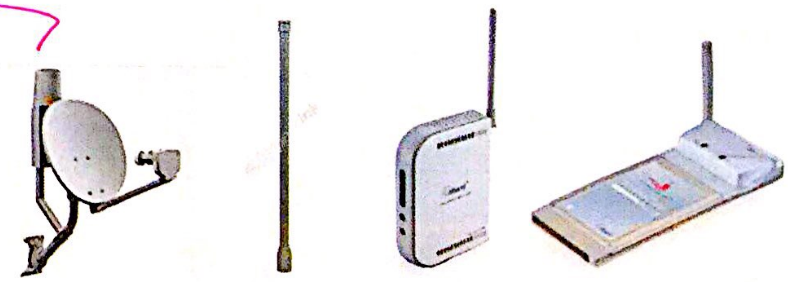
μwave (6-10)GHz. ⇒ "Line of sight"..

Subscriber Stations (SS)
(LOS and Non-LOS antennas)



IEEE 802.16 Standards (Wi-MAX)

- IEEE 802.16a-2003 ⇒ → 10 GHz – 60 GHz.
  - Maximum range of 50 km
  - 6 MHz channels
  - 42 Mbps downstream and 10 Mbps upstream in each channel
- IEEE 802.16e-2005
  - At 3.5 GHz and lower, does not require line-of-sight.
  - Adds mobility features.
  - Narrower bandwidth (a max of 5 MHz for each channel).
  - Uplink/Downlink data rate per channel is 70 Mbps/70 Mbps.
- IEEE 802.16m-2011
  - Advanced Air Interface
  - Data rates of 100 Mbit/s mobile and 1 Gbit/s fixed.
  - Also known as Mobile WiMAX Release 2 or WirelessMAN-Advanced.
  - Aiming at fulfilling the ITU-R IMT-Advanced requirements on 4G.
- IEEE 802.16-2012
  - Rollup of 802.16h, 802.16j and 802.16m (excluding WirelessMAN-Advanced radio interface, which was moved to IEEE Std 802.16.1)
  - Supports cognitive radio operation.

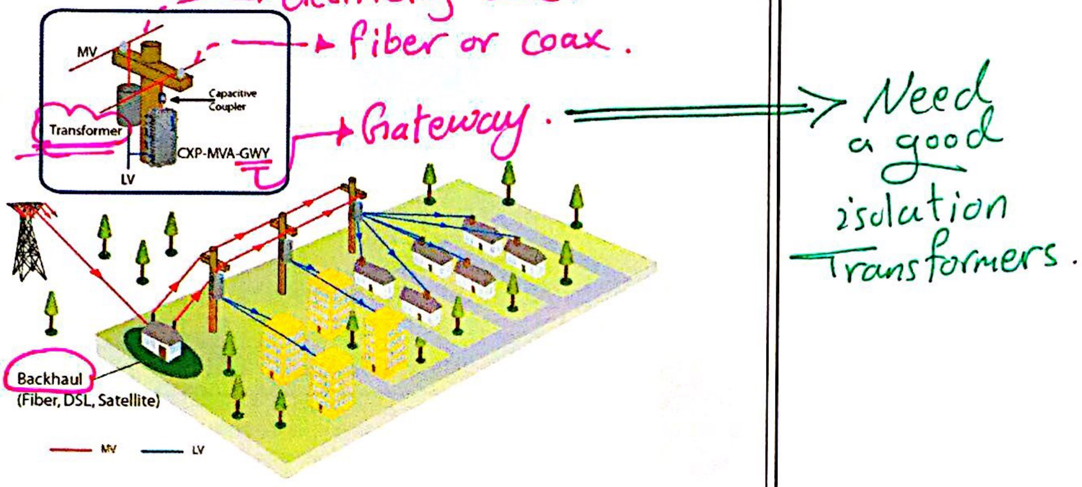
WiFi ⇒ LAN: Local Area Network.

WiMAX ⇒ MAN: Metropolitan Area Network.

Disadvantage of WiMAX vs. Fiber:
- Need High power.
- Under bad weather conditions (very high Att.)

Advantage of WiMAX vs. Fiber:
- No Need to dig the ground.

Power line communication (PLC)



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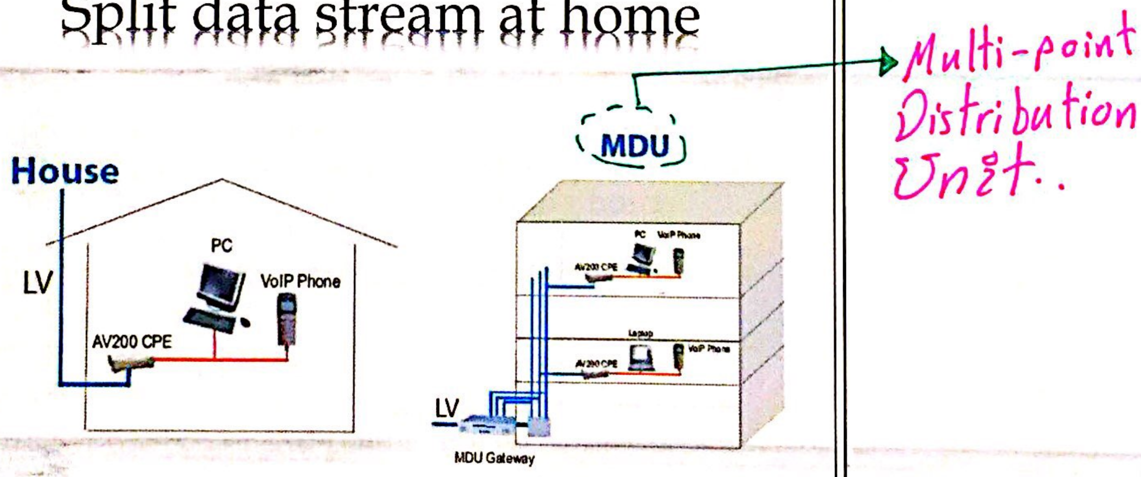
Split data stream at home



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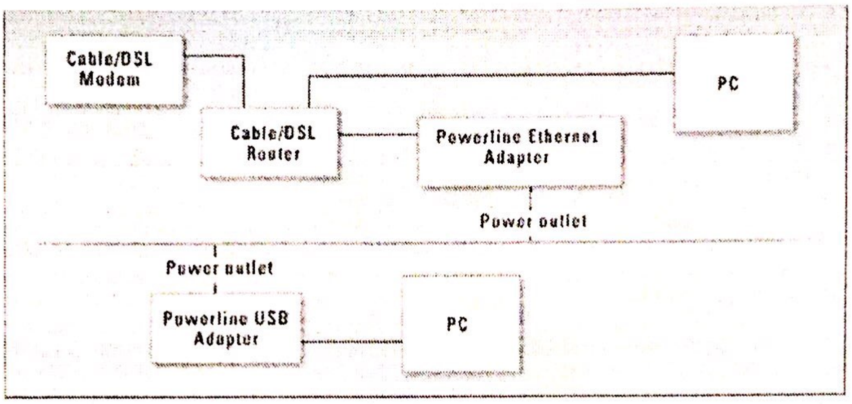
Also for Home Networking



Memorize:

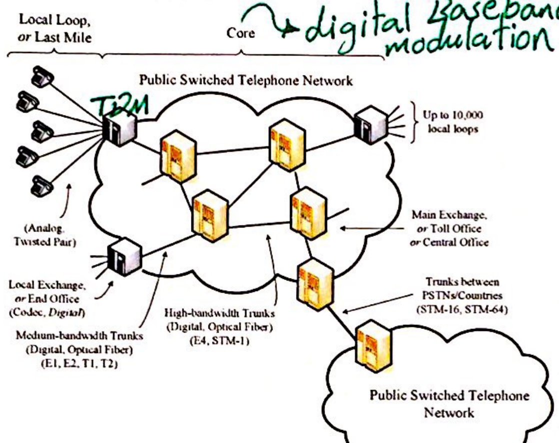
PLC Standards Groups

- High Definition PLC (HD-PLC), led by Panasonic;
- HomePlug Powerline Alliance (HomePlug); various power line communications specifications that support networking over existing home electrical wiring (HomePlug 1.0 (14 Mbit/s), HomePlug AV (200 Mbs) and HomePlug AV2 (1 Gbps and 1.3 Gbps).
- IEEE 1901 supports both HomePlug and HD-PLC.
- ITU-T G.hn/G.9960 as a standard for high-speed power line, coax and phone line communications (1 Gbps).

Leased Lines from Telephony

→ symmetric, Reliable, Expensive. → 99.999%

Core → digital Baseband modulation.



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Plesiochronous Digital Hierarchy (PDH)

European Standard: A-low

Carrier	Multiplex …	Data Rate	MUX Level
E0	1 channel (voice or signaling)	64 kbps	
E1	30 speech + 1 framing + 1 signaling channels	2.048 Mbps	1st Level
E2	Four E1 carriers + framing	8.448 Mbps	2nd Level
E3	Four E2 carriers + framing	34.368 Mbps	3rd Level
E4	Four E3 carriers + framing	139.264 Mbps	4th Level
E5	Four E4 carriers + framing	565.148 Mbps	5th Level

U.S. Standard: μ-low

Carrier	Multiplex …	Data Rate	MUX Level
T0	1 channel (voice and signaling combined)	64 kbps	
T1	24 PCM channels + framing	1.544 Mbps	1st Level
T2	Four T1 carriers + framing	6.312 Mbps	2nd Level
T3	Seven T2 carriers + framing	44.736 Mbps	3rd Level
T4	Six T3 carriers + framing	274.176 Mbps	4th Level

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for one phone call (E0):

$B_{voice} = 4KHZ$

$f_s = 8KHZ$

$L = 2^8 = 256$, 8 bits/symbol.

$\Rightarrow f_o = 64Kbps$.

T0: DS-0

for E1:

32 { 64 Kbps, 64 Kbps, ⋮ } → f_o output $= 32 \times 64K = 2.048Mbps \simeq$ 2Mbps.

* How many phone calls in E4?

$30 \times 4 \times 4 \times 4$

→ data rate $= 64Kbps \times 32 \times 4 \times 4 \times 4$

* How many calls we have in T3?

T_1 · Max. phon calls: 24

T_2 " " : 24×4

T_3 " " : $24 \times 4 \times 7$.

Eч set inside → STM-1

SDH (Synchronous Digital Hierarchy) / SONET (Synchronous Optical NETwork)

European Standard:

Optical Carrier	Multiplex ...	Data Rate
STM-1	Basic	155.52 Mbps
STM-4	Four STM-1 carriers using TDM Mux	622.08 Mbps
STM-16	Four STM-4 carriers	2.48832 Gbps
STM-64	Four STM-16 carriers	9.95328 Gbps
STM-256	Four STM-64 carriers	39.813 Gbps
STM-1024	Four STM-256 carriers	159.252 Gbps

U.S. Standard:

Optical Carrier	Electrical Carrier	Multiplex ...	Data Rate
OC-1	STS-1	Basic	51.84 Mbps
OC-3	STS-3	Three OC-1 carriers	155.52 Mbps
OC-12	STS-12	Four OC-3 carriers	622.08 Mbps
OC-48	STS-48	Four OC-12 carriers	2.48832 Gbps
OC-192	STS-192	Four OC-48 carriers	9.95328 Gbps
OC-768	STS-768	Four OC-192 carriers	39.813 Gbps
OC-3072	STS-3072	Four OC-768 carriers	159.252 Gbps

Memorize.

Remember...

- SDH is an ITU-T standard (G.707, G.708, G.709)
- STM-n stands for: Synchronous Transport Module – Level n
- STS-n stands for: Synchronous Transport Signal – Level n
- OC-n stands for: Optical Carrier – Level n
- Benefits of SDH/SONET over PDH: simpler and a more flexible multiplexing at high data rates. Huge capacity of extra bits dedicated for network management and maintenance functions to allow protection rings.

Cellular Telephony

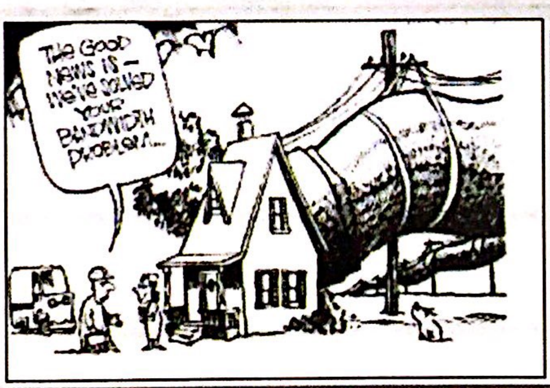
	Standard	Name (Technology)	Downstream Rate	Upstream Rate
2.5G	GPRS	General Packet Radio Service (TDMA)	54 kbps	27 kbps
3G	UMTS	Universal Mobile Telecommunications System (CDMA)	384 kbps	128 kbps
	HSPA	High Speed Packet Access (OFDMA)	7.2 Mbps	3.6 Mbps
3.75G or 3.5G	HSPA+ Rel. 6	Evolved High Speed Packet Access Release 6 (OFDMA + MIMO)	14.4 Mbps	5.76 Mbps
	HSPA+ Rel. 9	Evolved High Speed Packet Access Release 9 (OFDMA + MIMO)	84.4 Mbps	11.5 Mbps
	LTE	Long Term Evolution (OFDMA + MIMO)	100 Mbps	50 Mbps
4G	LTE Advanced	Long Term Evolution Advanced (OFDMA + MIMO)	1 Gbps	500 Mbps

compete dial-up modem.

2G | GSM

4G+ 5G

↳ if there is a movement you will get Lower than 1Gbps due to: doppler shift & Fading.



Communication Networks

Spring 2017/2018

Dr. Mohammad HAWA

By: Mohammad Abu Hashya.

* * *

Lecture 5: Data Link Layer Basics

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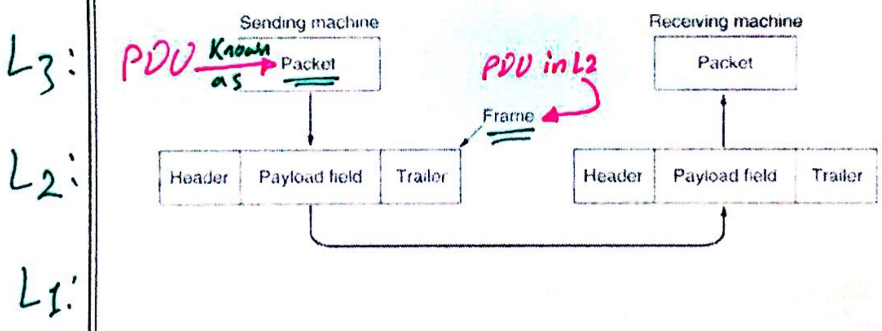
Layer 2 PDU: Frame



one of the main jobs of Layer 2:

- Framing: identifying the start & the end of each frame (L2 PDU).
- Error checking (& sometimes correction).
- Coordinate access to shared medium (MAC).

we can send: 50 bits, 51 bits, 1505 bits ...

we can send: 128 bits, 256 bits, ... ~~129 bits~~

Bit-oriented vs. Byte-oriented

- Layer 2 protocols can be either: byte-oriented or bit-oriented.
- In bit-oriented, frames can contain an arbitrary number of bits.
  - Example: HDLC (High-Level Data Link Control) protocol.
- In byte-oriented (character-oriented), frames consist of an integral number of bytes (8 bits).
  - Example: PPP (Point-to-Point Protocol).
- In both, the data link layer has the job of dividing a continuous bit stream into identifiable frames.

* HDLC for what Layer? Layer 2. "Bit-oriented".

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There are 3- Techniques to do Framing:

※ Job1: Framing

1. Insert time gaps of no transmission periods between frames.

- *Example*: Asynchronous transmission in RS-232 standard.
- *Example*: Ethernet.
- Easiest method.
- Inefficient because bandwidth is wasted while not transmitting useful data.
- Unreliable except for short distances (*noise*).

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→ Disadvantage for this Technique: Low Utilization.

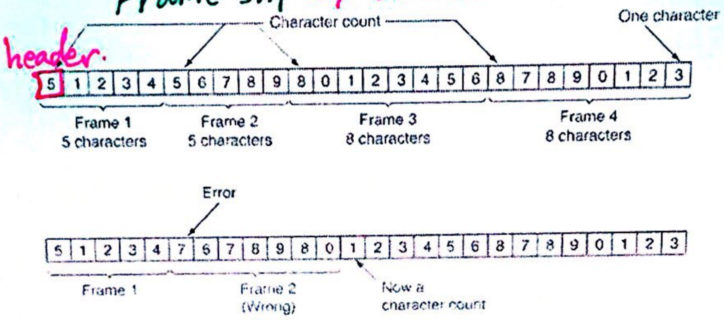
other names: Frame Length / Byte Count.

Framing

2. Character Count (used mainly in byte-oriented protocols) (High Utilization).

Frame slip ⇒ difficult to recover After frame slip.

This Technique is high utilization BUT suffers from Frame slip.



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→ we put FLAG @ the start & the end of the frame

Framing

3. **Frame Delimiters** (used in bit-oriented and byte-oriented).

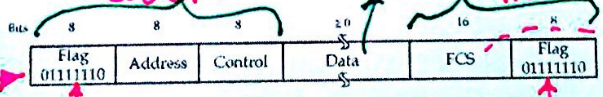
Example: Ethernet.

FLAG → special Bit Pattern.

Preamble	FLAG	Header	Payload field	Trailer	FLAG

This Technique: Difficult bo have frame slip & easy to recover after frame slip.

For example, the HDLC data link protocol (a *bit-oriented* protocol) uses the 8-bit sequence **01111110** as a flag sequence (see figure).



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01111110 ----- 01111110 01111110 ------ 01111110 01111110 ----

- 01111110 → start of the 1st frame.
- 01111110 → end of the 1st frame
- 01111110 → start of the 2nd frame
- 01111110 → end of the 2nd frame
- . . .

if an error ocure it is easy to recover.

Framing

- PPP (a *byte-oriented* protocol) uses the FLAG = 0x7E = 01111110

Bytes	1	1	1	1 or 2	Variable	2 or 4	1
	Flag 01111110	Address 11111111	Control 00000011	Protocol	Payload	FCS	Flag 01111110

in Bit-oriented the flag could be any size.

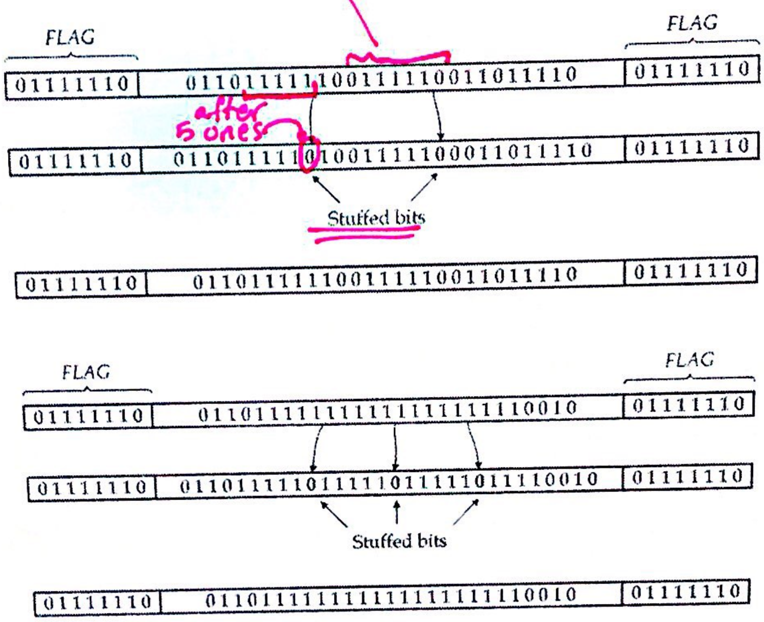
in Byte-oriented the flag must be a multiple of 8 bits.

used in Bit-oriented.

Bit Stuffing

- Prevents flags occurring in the middle of a frame, which would lead the receiver to have a frame slip.
- **TX**: add an extra 0 after a group of five ones that appears in the middle of the frame. This way whatever bit precedes or follows the 11111, there is no chance the flag will appear in the middle of the frame. The start and end flags are not stuffed.
- **RX**: performs *destuffing* by replacing every pattern 111110 by 11111 before the data is handed to the network layer.

flag contain 6 ones so this is Not a flag BUT it will stuff any way since the Rx will destuff for any 111110 & replace it By 11111



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Byte Stuffing

- Byte stuffing (character stuffing) consists of using a special *data link escape* character DLE to prevent the occurrence of the FLAG (and DLE) bytes in the middle of the frame.
- The stuffed bytes are removed by the receiving end.
- For example, PPP uses the FLAG = 0x7E = 01111110, and the DLE = 0x7D = 01111101.

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• Advantage: for any slip frame it recover very fast.
↳ "difficult to have slip frame" & easy to recover.

• Disadvantage:
↳ using a lot of DLE
⇒ Lower utilization ⇒ lower efficincy.

3/3/2018

stuff DLE Before Flag.

* Rule: whenever R_x sees DLE it remove the first one & keep the one after it directly.

Byte Stuffing

| FLAG | A S FLAG B Z D DLE K V M Z DLE FLAG R U | FLAG |

| FLAG | A S DLE FLAG B Z D DLE DLE K V M Z DLE DLE DLE FLAG R U | FLAG |

70h 7Eh.

Stuffed bytes

× ✓ × ✓

↳ DLE FLAG

| FLAG | A S B Z D DLE DLE FLAG K V M Z R U | FLAG |

| FLAG | A S B Z D DLE DLE DLE DLE DLE FLAG K V M Z R U | FLAG |

※ Job2: Error Detection and Correction

- (1) **Parity**: A parity bit is added to the sent message *M*. The parity bit is set to 1 or 0 to force the transmitted message to contain **even** or **odd** number of 1's.
- 7 bit data: $M = 1010001$
- 8 bits transmitted (including parity):
  - 10100011 (*even* parity)
  - 10100010 (*odd* parity)

Disadvantage: → weak detection especially for a burst of errors.
10100011 ⇒ also detect that is even parity.

Advantage: Simple.

Example on using Parity: RS-232.

more powerful than parity.

② Checksums

- Checksum is the sum (plus carry) of the 16-bit words making up the message *M*. The receiver checks that the sum of the received message *M'* matches the checksum sent by the transmitter. If both sums match, no errors have occurred during the transmission of the message.
- Examples: Checksums are used in TCP (L4) and IP (L3) headers.

H	e	l	l	o		w	o	r	l	d	.
48	65	6C	6C	6F	20	77	6F	72	6C	64	2E

4865h + 6C6C + 6F20 + 776F + 726C + 642E + carry = 71FC

4865 = 16 bits.

48h or 0x48 → 0100 1000

4865h
6C6Ch +
6F20h +
776Fh +
726Ch +
642Eh +
carry ← 2 71FA h
add it → 71FC h.

③ Cyclic Redundancy Check (CRC)

the most popular because its advantages

- Message bits *M* are divided by a bit sequence called a *generating polynomial G*, and the remainder of the division *R* (called a CRC) is sent along with the message.
- The receiver divides the received message bits along with the CRC code (*M'* : *R'*) by the generating polynomial G.
- If the remainder is zero, no errors have occurred. If the remainder is not zero, an error occurred.
- CRC can be implement in hardware using a shift register and X-OR gates (inexpensive and fast).
- CRC can detect burst errors. "very powerful".
- CRC is used in HDLC, PPP, Ethernet, and many others. It is the most common error detection code nowadays.

4-bit → CRC
5-bit → generating polynomial.
16-bit → CRC ⇒ 17G
32-bit → CRC ⇒ 33G

Some times G = 10011 could be written as: $G = x^4 + x^1 + 1$ (→ x^0)
same as G = 10011

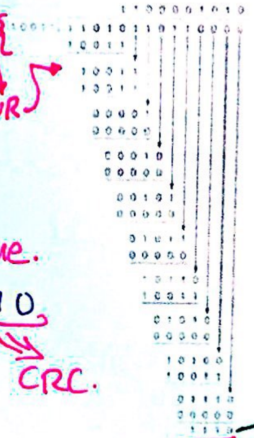
3/3/2018

Frame: 1101011011 = M
Generator: 10011 = G

*Division is required in the exam.

Frame: 1101011011
Generator: 10011
Message after 4 zero bits are appended: 11010110110000

M after 4 zero bits:
11010110110000



Reminder. ≡ CRC.
smaller than 10011

Transmitted frame.
1101011011 1110
msg (data). CRC.

Transmitted frame: 11010110111110

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HW#1: repeat slide 15

HW#2: Rx 10011 ⟌ 1101011011 1110
0000 (No error).

HW#3: error in data.
10011 ⟌ 1100011011 1110
!??!

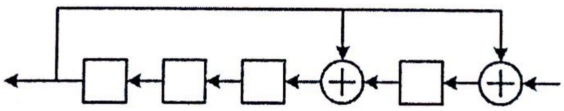
Bitwise Arithmetic (X-OR)

XOR gate.

- 0 + 0 = 0
- 0 + 1 = 1
- 1 + 0 = 1
- 1 + 1 = 0, carry neglected

XOR.

- 0 - 0 = 0
- 0 - 1 = 1, borrow neglected
- 1 - 0 = 1
- 1 - 1 = 0



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HW#4: error in CRC
10011 ⟌ 1101011011 1100
!??!

G = 10011
→ feedback.

10111 need 3 XOR's
10001 need 1 XOR
since this is for feedback.