Computer Networks and the Internet

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Outline

1. Introduction
2. Network Edge and Network Core
3. Delay, Loss and Throughput
4. Internet Protocol Stack
5. Network Security
6. History

Introduction

What Is the Internet?

- Internet
  - The most popular computer network.
  - Arguably the largest engineered system ever created by mankind.
  - Internet traffic (annual) will be nearly five zettabytes (10^{21} bytes) by 2022 - Cisco.

Note: 1 Zettabyte [ZB] = 1073741824 Terabytes [TB]

What Is the Internet?

What Is the Internet?

- To answer this question, we need to understand
  - Hardware/Software components of the Internet
  - Services the Internet provides to applications

What Is the Internet?

- A computer network that interconnects computing devices throughout the world.
- Internet consists of
  - Hundreds of millions of connected computing devices such as laptops, tablets, smartphones, and smartwatches. Popularly known as hosts or end systems.
  - Communication links
  - Packet Switches
- Hosts are connected with each other by communication links and packet switches.
- A unit to measure the transmission rate of a link is bits/second.

What Is the Internet?

- Hosts exchange the data with each other.
- Data
  - Information that hosts want to exchange
  - Information about data
    - How to merge the fragmented data
    - Which application can read/access the data?
    - Source address
    - Destination address
    - Information to do the error checking

What is a Packet?

- To send the data, a (source) host
  - segments the data
  - adds the header information to each segment
- Packet = Data Segment + Header
- Destination host reassembles the data segments to get the original data.

What is a Packet Switch?

- Packet Switch - Intersection point of two communication links.
- Receives data from one communication link and forwards the same to the other communication link.
- Popular packet switches
  - Routers - Mainly used in the network core
  - Link-layer Switches - Mainly used in access networks

What is a Route or Path?

- Route - A sequence of communication links and packet switches traversed by a packet from the source (host) to the destination (host).

Packet-switched Networks

- Packet-switched networks are analogues to transportation networks of highways, roads, and intersections.

Transportation Networks	Packet-switched networks
Trucks	Packets
Highways and Roads	Communication Links
Intersections	Packet Switches

Internet Service Providers (ISPs)

- To access the Internet, hosts need Internet Service Providers (ISPs).
  - Local telephone or cable companies such as BSNL and Jio work as ISPs.
  - University ISP, corporate ISP, etc. also provide Internet services.
- ISP is also a computer network and consists of hosts, communication links and packet switches.

Internet Service Providers (ISPs)

- ISPs must also be interconnected to facilitate the communication between hosts that are connected to different ISPs.
  - Hosts are interconnected by lower tier ISPs.
  - Lower tier ISPs are interconnected through upper-tier ISPs.
  - Upper-tier ISPs are connected directly to each other.

- All ISPs are managed independently and follow the naming and address conventions and standard IP protocol.

Internet Standards

- Internet Engineering Task Force (IETF) develops Internet standards.
- IETF standards documents are known as Requests For Comments (RFCs).
- Many RFCs define the internet protocols such as TCP, IP, HTTP, and SMTP.
- IEEE 802 LAN Standards Committee develops Ethernet and wireless WiFi standards

What Is the Internet?

What Is the Internet?

- Internet provides services to various applications.
- Distributed applications
  - E-mail
  - Web surfing
  - Internet messaging
  - Real-time road-traffic information
  - Audio and video streaming
  - Social media
  - Video conferencing
  - Multi-person games

How to Facilitate Interactions among Distributed Applications

- Analogy: Postal Service
    - How do individuals communicate using a postal service?
- How does one application running on one host interact with the same/different application running on another host?
    - Applications follow protocols

What Is a Protocol?

- Analogy: Human Interaction Protocol
    - Finding a location in a remote area.
- Internet/Network Protocol
    - Similar to human interaction protocol except the communicating entities are hardware/software.
- To successfully communicate with each other, humans/entities must follow the same protocol.

What Is a Protocol?

- A protocol defines
  - Format of messages exchanged between two or more communicating entities
  - Order of messages exchanged between two or more communicating entities
  - Actions taken on the transmission and/or receipt of a message or other event

Network Edge and Network Core

The Network Edge

- What do we call computing devices that are connected to the Internet?
  - End systems: As these devices are at the edge of the Internet.

    or
  - Hosts: As these devices hosts distributed applications.

Examples: End Systems or Hosts

- Desktop/Laptop
- Servers
- Tablets
- Smartphones
- Smart Watches

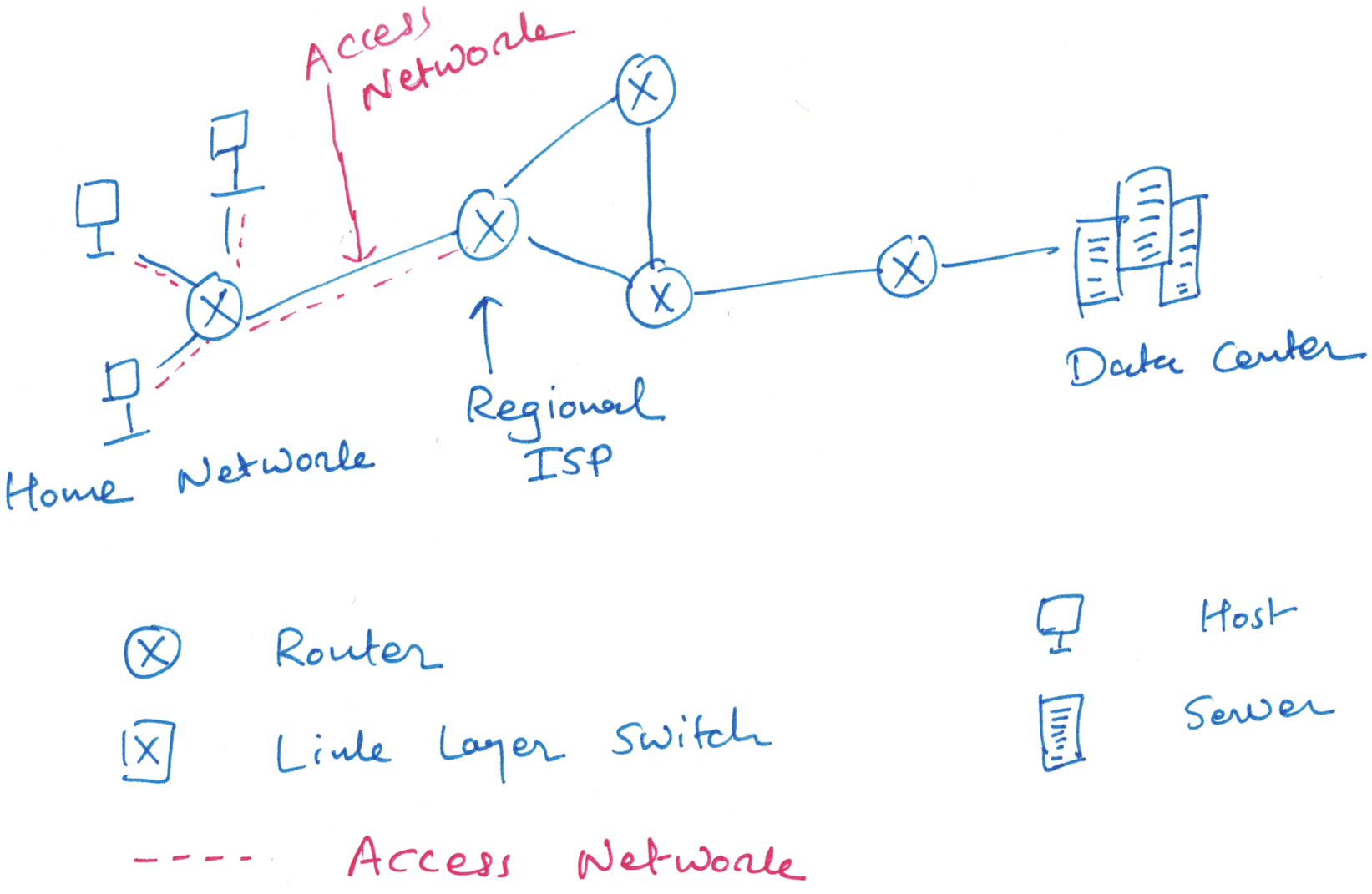
End Systems or Hosts

- Hosts are categorized as:
  - Clients
    - Desktops, Laptops, Smartphones, etc.
  - Servers
    - Computing devices that run specific applications and provide specific services
    - Usually reside in large data centers

Access Network

- Access Network - A network that connects the host to the first router (a.k.a edge router) through which it is connected to the Internet.

Access Network



How do our homes get Internet connectivity?

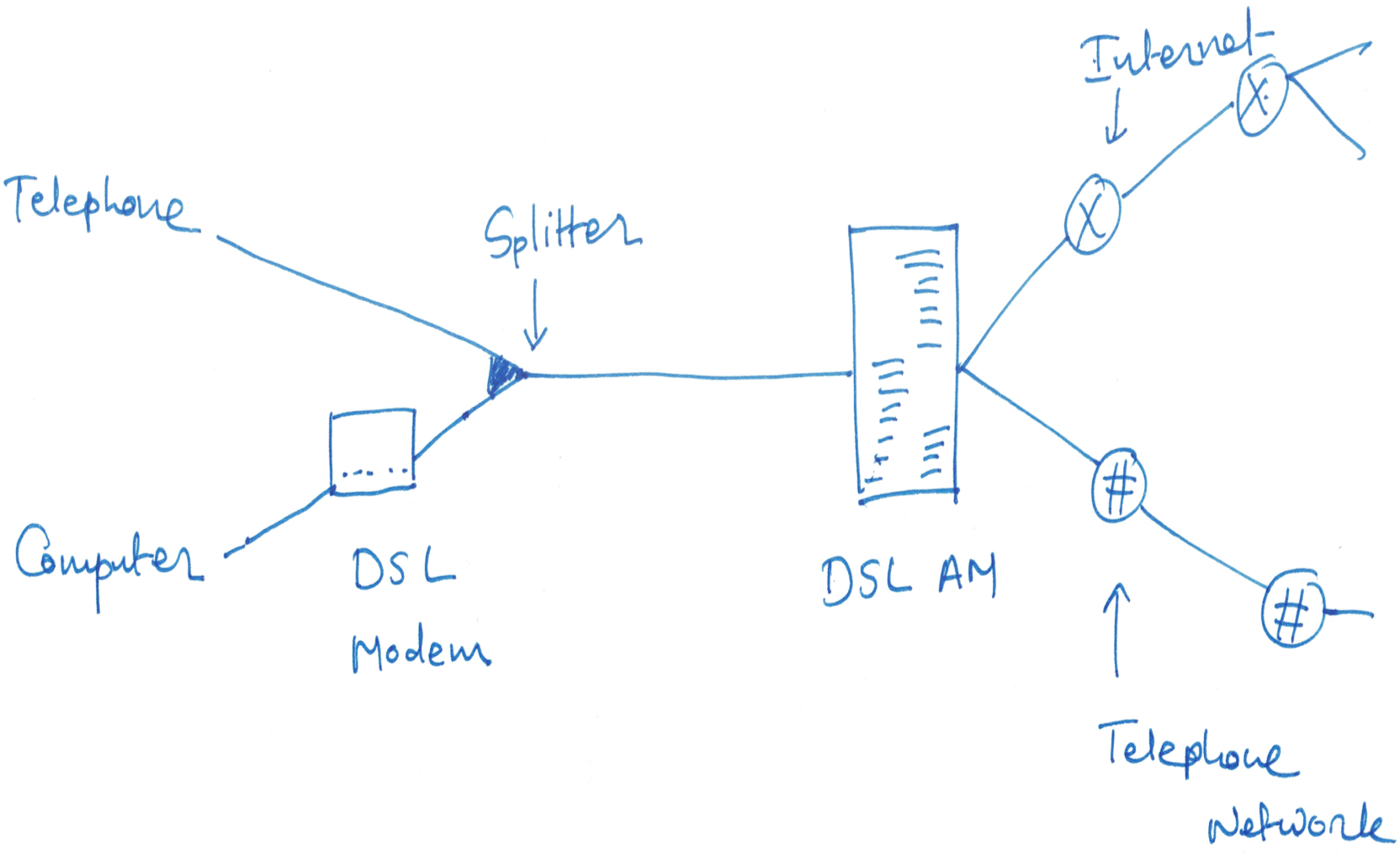
Home Access - Internet

- Home Access
  - Digital Subscriber Line (DSL)
  - Cable
  - Fiber To The Home (FTTH)
  - 5G Fixed Wireless

Home Access - Digital Subscriber Line (DSL)

- Digital Subscriber Line (DSL) - Internet is provided by a local telephone company through the same wires that it uses for telephone networks. In such cases, a telephone company is the ISP.
- DSL uses Twisted-Pair Cables (Insulated and twisted copper wires)

Home Access - Digital Subscriber Line (DSL)



Home Access - Digital Subscriber Line (DSL)

- DSL Modem
  - Translates digital data to high-frequency tones and vice versa.
- Telephone lines use different frequencies to encode data.
  - Downstream channel: (50 kHz to 1 MHz)
  - Upstream channel: (4 kHz to 50 kHz)
  - Telephone (two-way): (0 to 4 kHz)

Home Access - Digital Subscriber Line (DSL)

- Splitter (at customer's location):
  - Splits the data and telephone signals.
  - Forwards the data to the DSL Modem.
- Digital Subscriber Line Access Multiplexer (DSLAM) (at telephone company's location):
  - Splits/Merges the data and telephone signals.
  - Translates the data from analog to digital and forwards the same to the Internet or vice versa.
  - Forwards/Receives telephone signals to/ from the telephone network.

Television Cable

- Internet access is provided using the television cable network.
  - Fiber Optics Cable
  - Coaxial Cable
- As it uses two different cables, it is sometimes called Hybrid Fiber Coax (HFC)
- Cable Modem Termination System (CMTS) – Works similar to DSLAM.

Television Cable

- Cable Internet
  - A shared broadcast medium.
  - Data received by all the hosts on the path (even though it may be destined for a single host).
- As it is a shared broadcast medium, the internet speed is dependent on other hosts. For example, if there are only few active hosts, it will increase the internet speed.

Fiber To The Home (FTTH)

- Optical Fiber Cable directly connects hosts to the ISP.
- Optical Splitter: Splits/merges optical fibers from/to different hosts.

5G Fixed Wireless

- High speed Internet access.
- No need to install costly and failure prone cables.

LAN – Ethernet and WiFi

- Local area network (LAN) - Connects hosts to the edge router.
- Popular LAN Technologies
  - Ethernet: A twisted pair cable is used to connect to an Ethernet switch.
  - Wireless LAN (WiFi)– IEEE 802.11 technology.
    - Connects hosts to the access point and through the access point to the Internet wirelessly.
    - Range: Few meters.

WAN – 3G/4G/5G

- Wide Area Network (WAN)
  - Connects hosts to the Internet wirelessly. For example, mobile devices use 3G/4G/5G technology to connect to the Internet.
  - Range: Few Kilometers

- Physical Media
  - Twisted Pair Copper Wire
  - Coaxial Cable
  - Fiber Optic Cable
  - Radio Spectrum

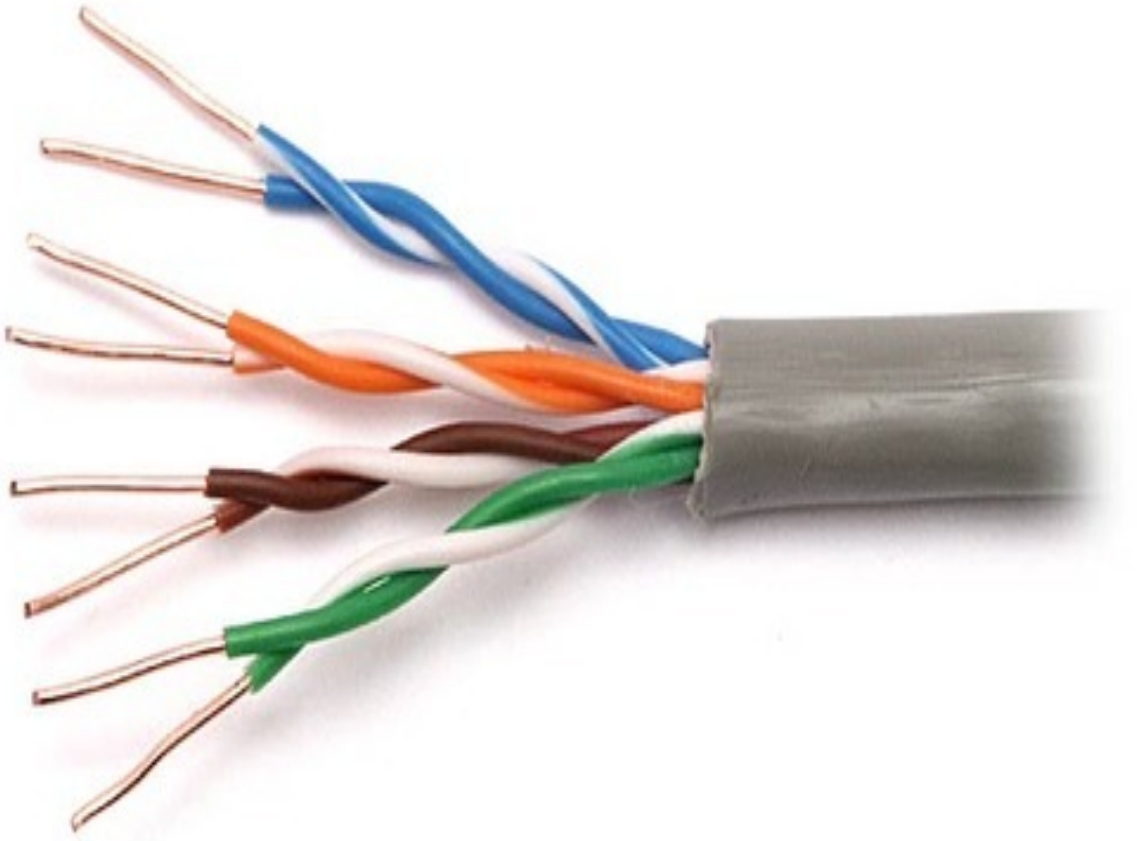
Physical Media

- Physical Media Categories:
  - Guided Media
    - Waves are guided
    - Example: Coaxial Cable, Fiber Optic Cable
  - Unguided Media
    - Waves are not guided
    - Examples: WiFi, Digital Satellite Channel

Twisted-Pair Copper Wire

- Consists of two insulated and twisted copper wires.
- Insulated and twisted to reduce the electrical interference from nearby twisted-pair wires.
- Generally used in telephone networks and LAN.
- Data Rates Range: 10 Mbps to 10 Gbps

Twisted-Pair Copper Wire



Coaxial Cable

- Consists of two concentric copper conductors.
- Used in cable television networks.
- Guided shared medium.

Coaxial Cable

Fiber Optics Cable

- Optical Fiber - Conducts pulses of light where each pulse represents a bit.
- Characteristics:
  - Bit Rates: 51.8 Mbps to 39.8 Gbps
  - Immune to electromagnetic interference
  - Low signal attenuation (reduction in the signal strength) up to 100 kilometers
  - Hard to tap
- Widely used in overseas links.

Fiber Optics Cable

Terrestrial Radio Channels

- Radio channel - Carries signals in the electromagnetic spectrum.
- Characteristics:
  - No wires (No physical installation)
  - Penetrates walls
  - Mobile connectivity
  - Carries signals for long distances
- Environmental interference affect the signal strength.

Classification of Terrestrial Radio Channels

- Short distance (e.g., with one or two meters) – Example: Wireless Keyboard, Wireless Mouse
    - Local areas (ten to a few hundred meters) – Wireless LAN
    - Wide areas (tens of kilometers) – Cellular Access Technologies.

Satellite Radio Channels

- Communication satellite – Connects two or more transmitters/receivers (on earth)

Types of Communication Satellites

- Geostationary Satellites
  - Fix position in orbit at 36,000 kilometers above Earth's surface
  - Introduces signal propagation delay (roughly 280 milliseconds)
  - Used to provide the internet access in remote areas
- Low-earth Orbiting (LEO) Satellites
  - Rotate around Earth (not having a fixed position)
  - For reliable communication, many such satellites need to be placed in orbit.

The Network Core

- The Network Core
  - Consists of packet switches and communication links
  - Interconnect hosts

How to Communicate Data

- Two approaches to communicate data
  - Packet Switching
  - Circuit Switching

Packet Switching

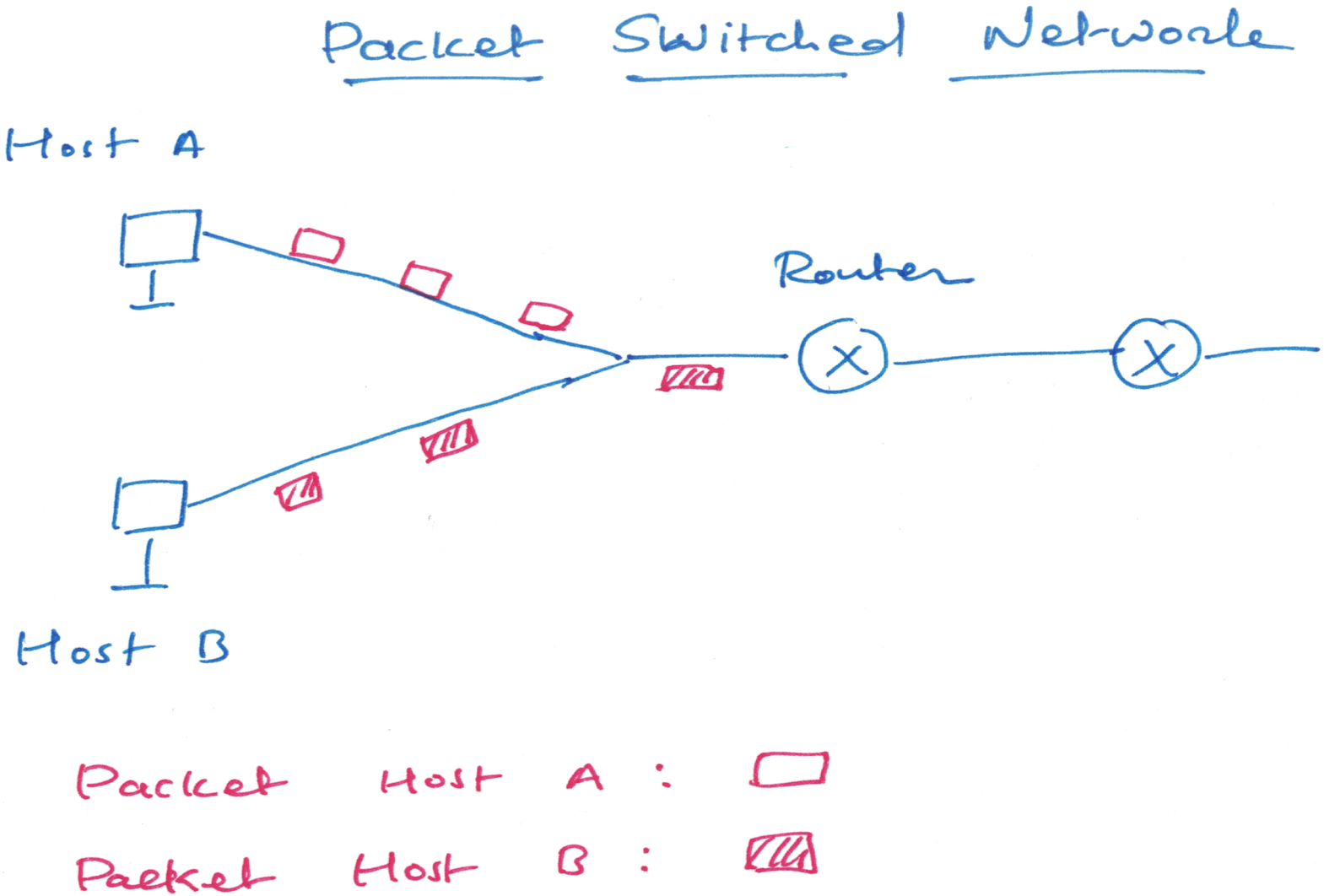
Packet Switching

- To send a message
  - Fragment the message and append headers (i.e., generate packets)
  - Forward packets from the source to the destination.

Packet Switching

- Packets are transmitted at the same rate as of the transmission rate of the link.
- Example
  - Transmission rate of the communication link: R bits/second
  - Packet size: L bits
  - Time to transmit the packet: L/R seconds

Packet Switching - Example



Packet Switching – Store and Forward Transmission

- Packet Switches
    - Follow store and forward transmission

Packet Switching – Store and Forward Transmission

- Store and Forward Transmission
  - Wait for the entire packet
  - Once the complete packet is received, then the packet switch forwards the packet to the outbound communication link.

Example - Store and Forward Transmission

- Source $\rightarrow$ Router $\rightarrow$ Destination
  - Assume that the router has only one incoming communication link and only one outgoing communication link.
  - Source sends 3 packets to the destination.
  - Each packet is of size L bits.
  - Transmission rate of both communication links: R bits/second
- If a packet switch follows store and forward transmission, by what time the destination receives the first packet?
- If a packet switch follows store and forward transmission, by what time the destination receives all three packets?

Packet Switching – Store and Forward Transmission

If a packet switch follows store and forward transmission, by what time the destination receives the first packet?

- At time 0 (seconds)
  - The source begins the transmission of the first packet towards the router.
- At time L/R (seconds)
  - The router receives and stores the first packet, and begins to transmit the first packet towards the destination.
- At time 2L/R (seconds)
  - The destination receives the first packet.

Packet Switching – Store and Forward Transmission

If a packet switch follows store and forward transmission, by what time the destination receives all three packets?

- At time 0 (seconds)
  - The source begins the transmission of the first packet towards the router.
- At time L/R (seconds)
  - The router receives and stores the first packet, and begins to transmit the first packet towards the destination.
  - The source begins the transmission of the second packet.

Packet Switching – Store and Forward Transmission

If a packet switch follows store and forward transmission, by what time the destination receives all three packets?

- At time 2L/R (seconds)
  - The destination receives the first packet.
  - The router receives second packet, and begins the transmission of second packet towards the destination.
  - The source begins the transmission of third packet towards the router.

Packet Switching – Store and Forward Transmission

If a packet switch follows store and forward transmission, by what time the destination receives all three packets?

- At time 3L/R (seconds)
  - The destination receives the second packet.
  - The router receives the third packet, and begins the transmission of third packet towards the destination.

Packet Switching – Store and Forward Transmission

If a packet switch follows store and forward transmission, by what time the destination receives all three packets?

- At time 4L/R (seconds)
    - The destination receives the third packet.

Packet Switching – Store and Forward Transmission

If there are N communication links and $N-1$ routers in the path from the source to the destination, by what time the destination receives all P packets?

- (N+P-1) L/R seconds

- Each host on the Internet has an address, namely, IP address.
- Forwarding Table - Maps the destination address of a packet to one of the outgoing communication links of the router.
- The router uses destination IP address and the forwarding table to forward the packet.
- Analogy: Driving from Ahmadabad to Mumbai without a map.

Who configures/maintains the forwarding tables of routers?

Routing protocols

Packet Switching – Routing protocols

- Routing protocols - Determine the routes and set the forwarding tables.

Circuit Switching

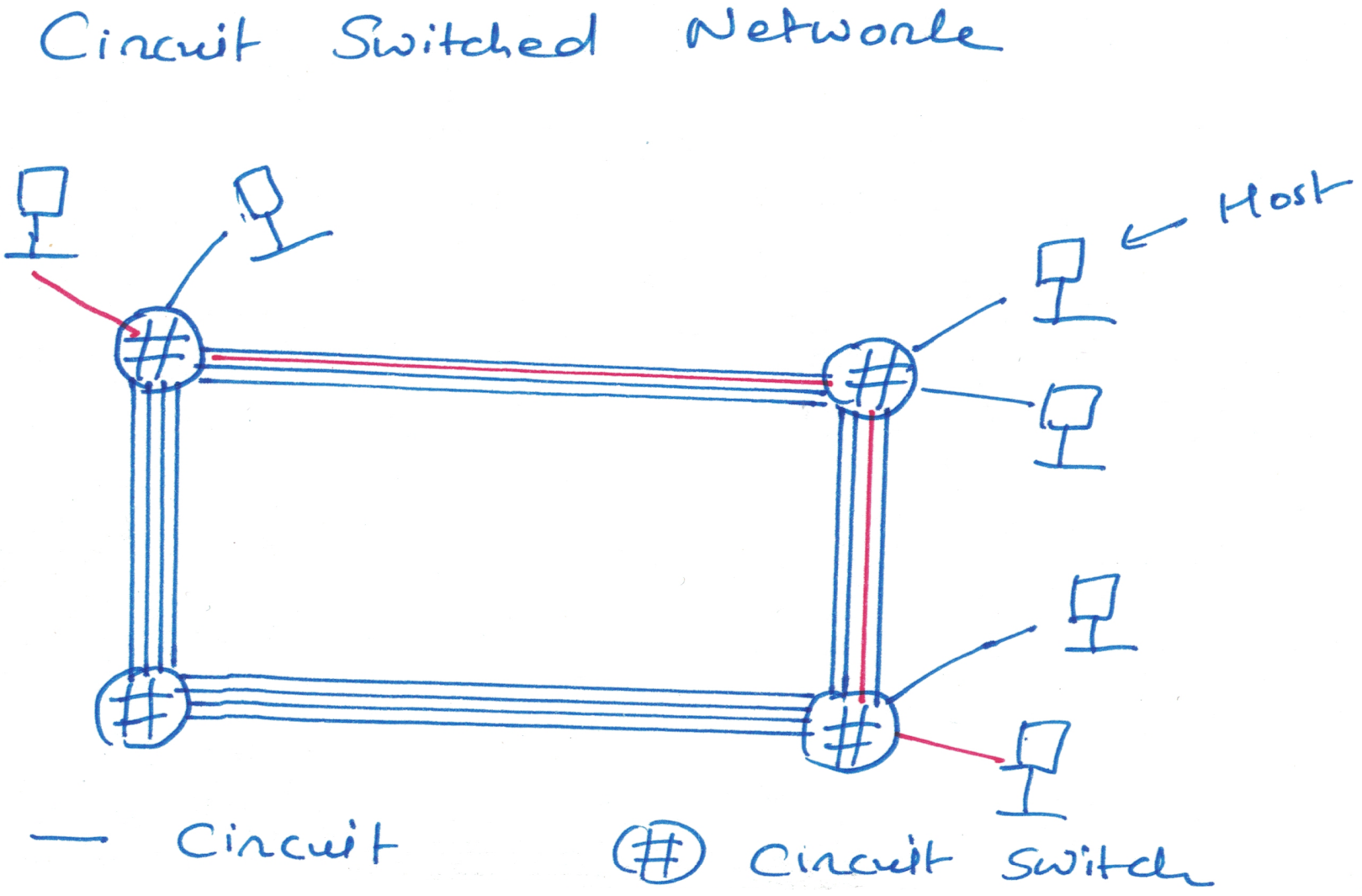
Circuit Switching

- Circuit Switched Networks
  - Facilitate dedicated end-to-end connection between hosts.
  - Reserve the resources required during the communication.
  - Reserve the resources for a specific communication session/duration.
  - Packet switched networks do not reserve the resources.

Circuit Switching - Telephone Networks

- Circuit Switched Networks
  - Source and the destination are connected, and all the switches on the path maintain the connection state.
  - In telephone network, this connection is known as Circuit.

Circuit Switching - Example



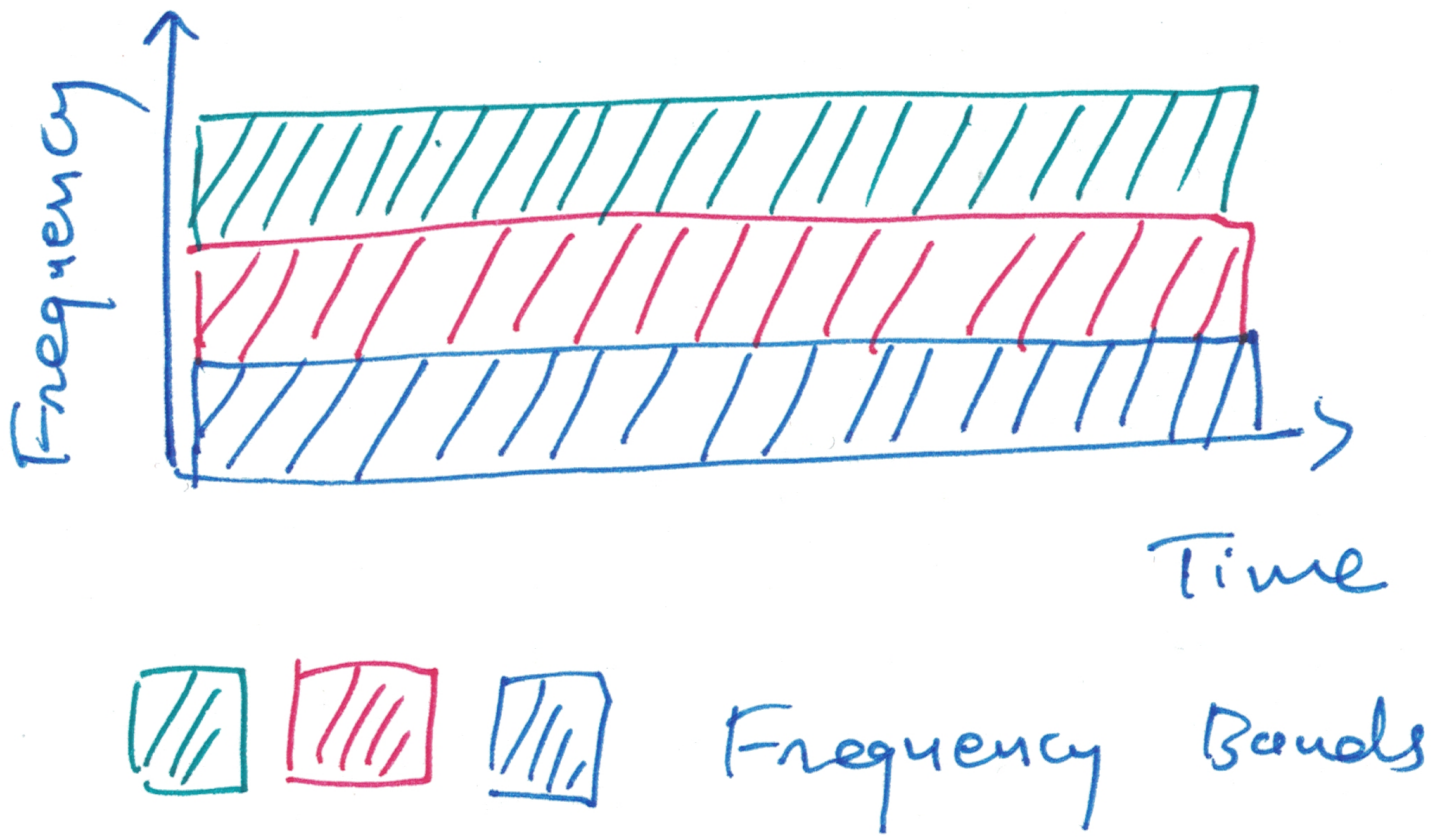
Multiplexing - Circuit Switched Networks

- A communication link can support number of circuits.
- A circuit in a communication link can be implemented as follows.
    - Frequency Division Multiplexing (FDM)
    - Time Division Multiplexing (TDM)

Frequency Division Multiplexing

- A communication link divides the frequency spectrum among number of connections, and each connection will be assigned a frequency band.
- In telephone network, each frequency band has a width of 4 kHz.
- The width of the frequency band is popularly known as Bandwidth.

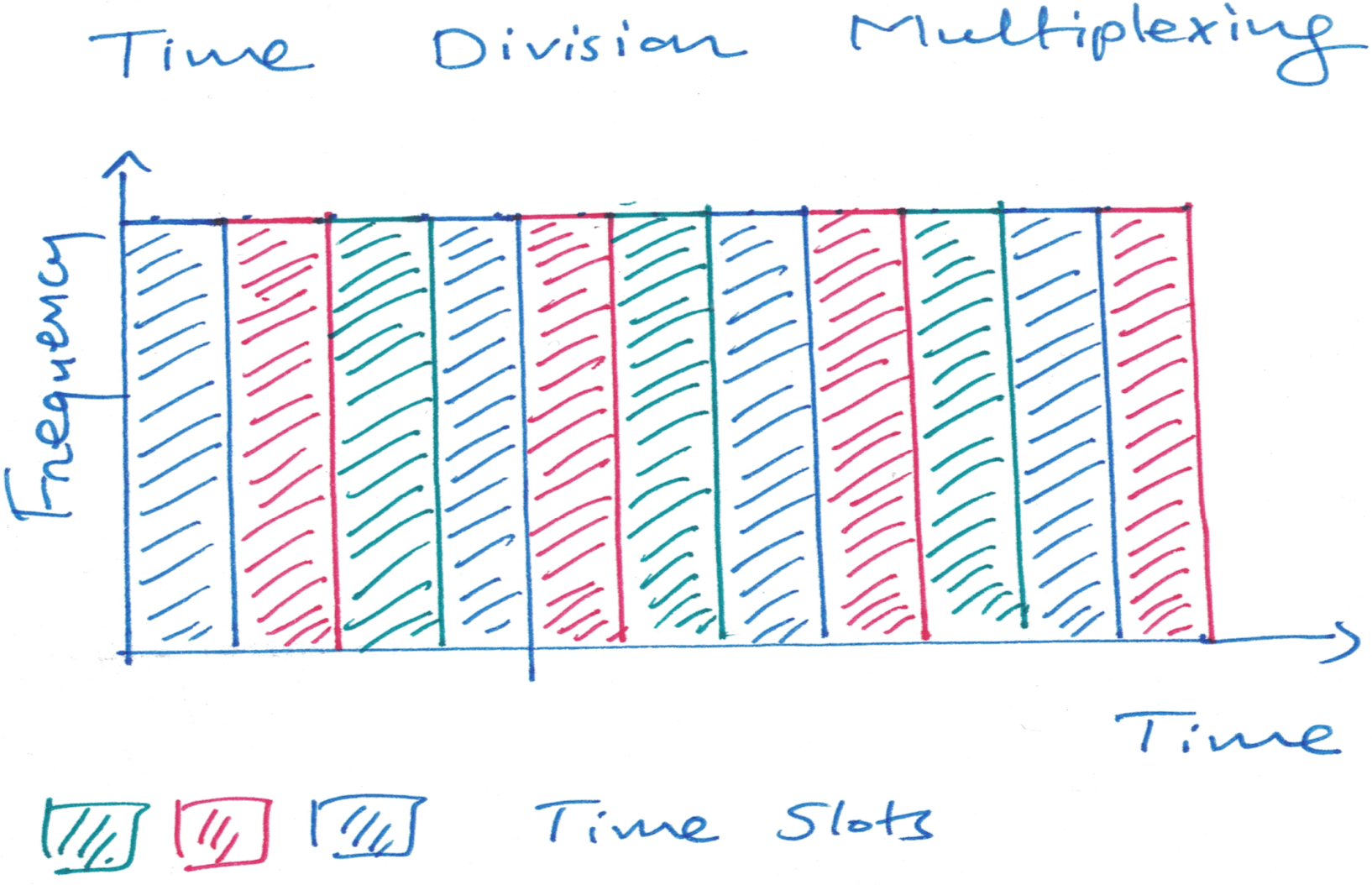
Frequency Division Multiplexing



Time Division Multiplexing

- A communication link divides time into frames, and each frame is divided into fixed time slots. Each connection will be assigned a fixed time slot.
- Transmission rate per second = Number of frames per second $\times$ Number of bits in each time slot of the frame
- For example, if a communication link trasmits 100 frames per second, and each frame is divided into time slots of 8 bits, then the transmission rate is $100 \times 8 = 800$ bits per second.
- In FDM, a bandwidth is shared among number of connections. In TDM, each connection gets the full bandwidth but for a designated time slot.

Time Division Multiplexing



Packet Switching vs Circuit Switching

- Packet Switching
    - Variable and unpredictable end-to-end delays.
- Circuit Switching
    - Waste of unused time slots/frequency bands when fewer active users.

A Network of Networks - Terminology

- Points of Presence (PoP) - A group of routers (from higher-tier ISP network) that connects a lower-tier ISP to a higher-tier ISP.
- Multi-homing - An ISP is connected to two or more ISPs.
- Peering - Two ISPs at the same level in the hierarchy connect with each other to facilitate the communication.
- Internet Exchange Point (IXP) - Facilitates connection among ISPs.

Delay, Loss and Throughput

Types of Delay

- A packet encounters different types of delays between the source and the destination.
  - Processing Delay
  - Queuing Delay
  - Transmission Delay
  - Propagation Delay
- Nodal delay - Sum of all above delays.

Processing Delay

- Time required to analyze the packet's header and identify where to direct the packet.
- Time to analyze packets for error checking etc.

Queuing Delay

- If the communication link is occupied,
  - packet is kept in a buffer before it is transmitted.
  - Time for which a packet remains in the buffer, waiting to be transmitted, is known as the queuing delay.

Transmission Delay

- Transmission Delay - Time required to transmit all the bits of the packet over a communication link.
- Example
  - Packet size - L bits
  - Transmission rate of the communication link - R bits/second
  - Transmission delay = packet size/transmission rate of the communication link

Propagation Delay

- Time required for a bit to propagate through the communication link (from a node to the next node)
- Propagation speed of the communication link depends on the type of the link. For example, twisted pair copper wire, fiber optics, etc.
- Propagation speed ranges from 2×10^8 to 3×10^8 meters/second (nearly equal to the speed of the light).
- Propagation delay (d/s) = Distance between two consecutive nodes (d)/ Propagation speed (m/s).

Nodal Delay

- Processing Delay - d_{proc}
- Queuing Delay - d_{queue}
- Transmission Delay - d_{trans}
- Propagation Delay - d_{prop}
- Total Nodal Delay

$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

Traffic Intensity

- Arrival rate of packets at the queue - a (packets/second)
- Packet size - L (bits)
- Transmission rate of communication link - R (bits/second)
- Traffic Intensity - La/R

Queuing Delay

- If $La/R > 1$, then the arrival rate of bits at the queue is more than the transmission rate of the link. It will introduce queuing delay, and it will increase infinitely.
- If $La/R < 1$, then the queuing delay depends on whether packets are arriving at a regular interval or arriving in bursts. If the arrival rate is L/R and transmission rate is L/R, then there is no queuing delay.
- If the arrival rate is La/R where $a > 1$ and transmission rate is L/R, then there is a queuing delay.

Packet Loss

- If the queue is full and the new packet will arrive at the router, then the router will drop the packet.
- The dropped packets need to be re-transmitted by the source.
- Animation: Queuing Delay

Traceroute

- Trace the route from the source to the destination.
- The Source forwards n special packets, numbered as 1 to n, toward the destination where $n - 1$ is the number of routers.
- When a router receives the special packet from source, it sends the name and address as a response (to source).
- The source records the round trip delay, name and address of the router.
- The source repeats the same procedure thrice.

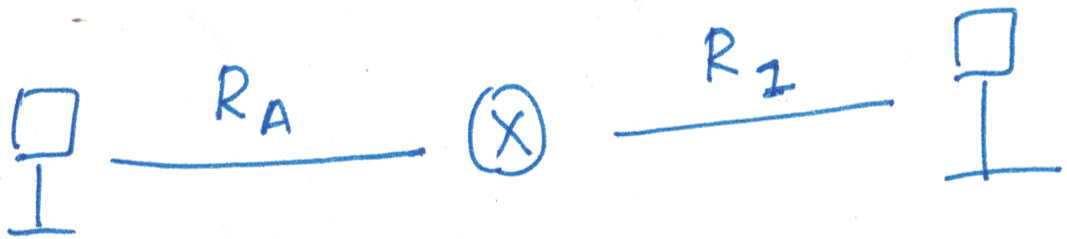
Traceroute

- Output: Router number - Name of the router - IP address of the router - Round trip delay (experiment 1) - Round trip delay (experiment 2) - Round trip delay (experiment 3)
- Router name - If the router name shows *, it means there is a packet loss in one or more of the experiments.
- Graphical Interface to Traceroute: PingPlotter

Throughput

- If we send a file form Host A to Host B, the rate at which the Host B receives the file is known as instantaneous throughput.
- Instantaneous throughput depends on the transmission rate of bottleneck link.
- If we send L-bits file form Host A to Host B, and if it takes T seconds to reach the Host B, then the average throughput is L/T bits/seconds.

Instantaneous Throughput - Example



Throughput: $\text{Min}\{R_A, R_1\}$

Instantaneous Throughput - Example

- What will be the throughput if we transfer a file from Host A to Host B? $min\{R_A, R_1\}$. Here, R_A and R_1- Transmission rate of communication links.
- If the communication link is shared by multiple hosts, throughput not only depends on the transmission rate of the communication link, but also depends on the network traffic.

Internet Protocol Stack

How would you describe an airline system?

How would you describe the Internet?

The Internet Protocol Stack

- Application Layer
- Transport Layer
- Network Layer
- Link Layer
- Physical Layer

The Internet Protocol Stack

- Each protocol is at a specific layer and provides a specific service to the next layer.
- Protocols are implemented by hardware, software, or both.

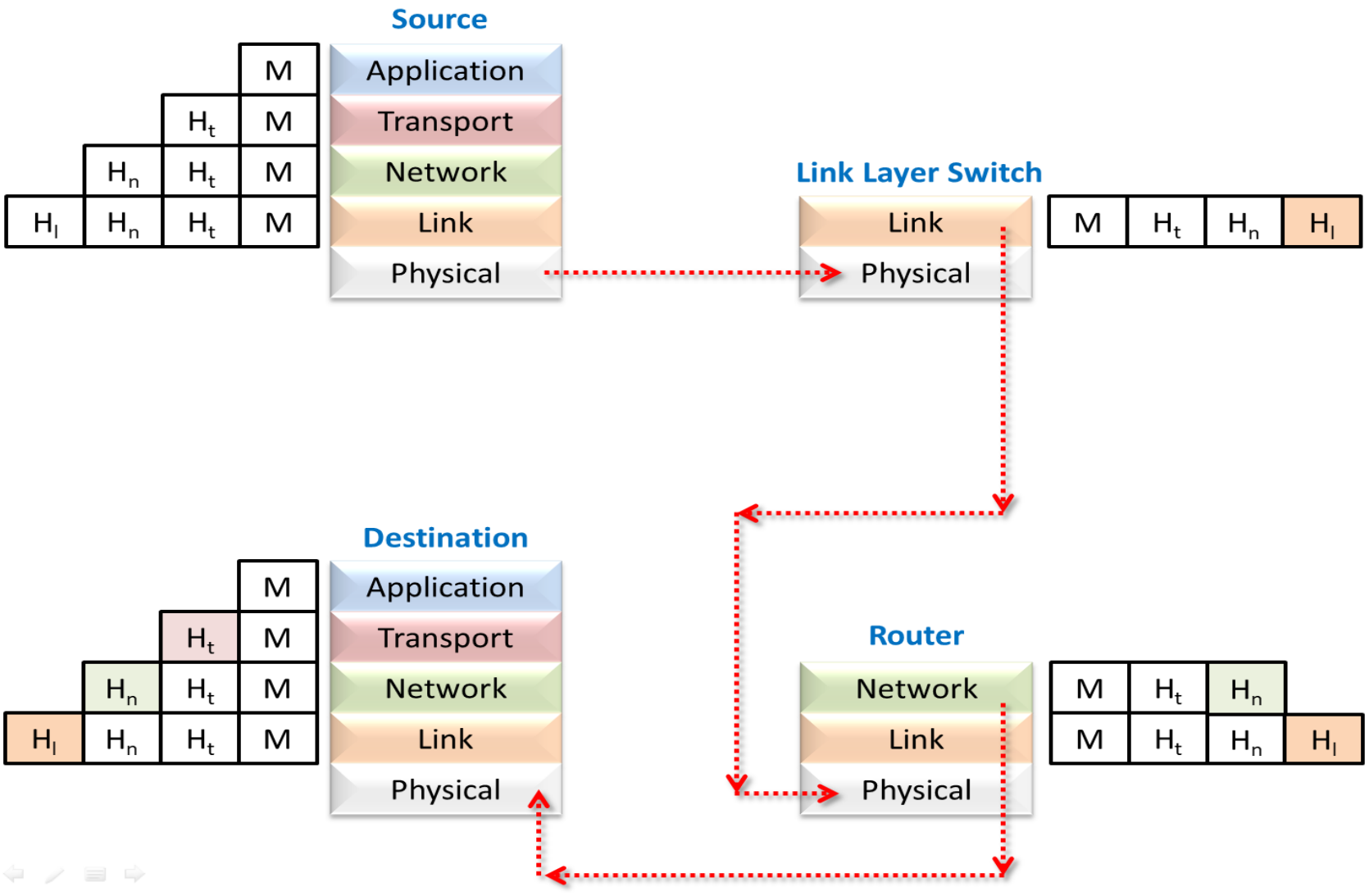
The Internet Protocol Stack

- Application layer and transport layer protocols, such as HTTP, FTP, and TCP, are implemented as software.
- Network layer protocols are implemented by combination of hardware and software.
- Physical layer and data link layer protocols interact with the hardware and have been implemented by network interface card (i.e., Ethernet or WiFi Interface cards).

The Internet Protocol Stack - Layered Architecture

- Advantage
    - Easy to update/upgrade
- Disadvantage
    - Duplication of functionality

The Internet Protocol Stack - Example



Application Layer

- Different application layer protocols provide different services. For example, HTTP facilitates web browsing.
- Examples: HTTP, FTP, SMTP, DNS
- Message: Data that the application layer communicates with other layers.

Transport Layer

- Transport layer protocols are used to transport application layer messages between application end-points.
- Examples: TCP and UDP
- Segments: Data that the transport layer communicates with other layers.

Network Layer

- Network layer facilitates communication between hosts through packet switches. Network layer includes routing protocols to determine the routes.
- Examples: IP
- Datagrams: Data that the network layer communicates with other layers.

Link Layer

- Link layer facilitates the communication from one node to the other node.
- The network layer depends on the services provided by the link layer to move a packet from the source to the destination.
- Examples: Ethernet, WiFi
- Frames: Data that the link layer communicates with other layers.

Physical Layer

- Physical layer facilitates the actual communication of bits from one node to the next.
- The protocols of physical layer vary with the physical communication medium, e.g., a twisted pair cable or a fibre optic cable.
- Bits: Data that the physical layer communicates with other layers.

Encapsulation

- Internet Protocol Stack: Each layer encapsulates the data of the layer above it.
- Hosts: Implement the entire protocol stack.
- Packet Switches: Do not implement entire protocol stack.
    - Link layer switches implement physical layer and link layer protocols.
    - Routers implement network layer, link Layer, and physical layer protocols.

Encapsulation

- At each layer of the protocol stack, a packet consists of two fields.
  - Payload: Data transported by the layer above a specific layer.
  - Header: Data communicated with the specific layer in the next node/destination.

Network Security

Do we need to secure the Internet? Why?

What are the vulnerabilities that make the Internet insecure?

Security Attacks

- Eavesdropping
- Traffic Analysis
- Masquerade
- Modifications of Messages
- Replay Attack
- Denial of Service Attack

History

History

- Packet Switching [Leonard Kleinrock, 1961]
- Advanced Research Project Agency (ARPA)net - A computer network that uses packet switching. [Lawrence Roberts, 1967]
- Host-to-Host Network Control Protocol (NCP)
- E-mail Program [Ray Tomlinson , 1972]

History

- Internetting - A network of networks [Vinton Cerf and Robert Kahn 1974]
- TCP/IP Protocol (Replacing NCP) [1983]
- Emergence of the world wide web application - Developed HTML, HTTP, a web server, and a web browser [Berners-Lee 1989]

Conclusions

Conclusions

- Internet Components
- Packet switching and circuit switching
- Delay (transmission, processing, queuing, propagation), loss, throughput
- A protocol stack
- Network security
- History

Interesting Statistics

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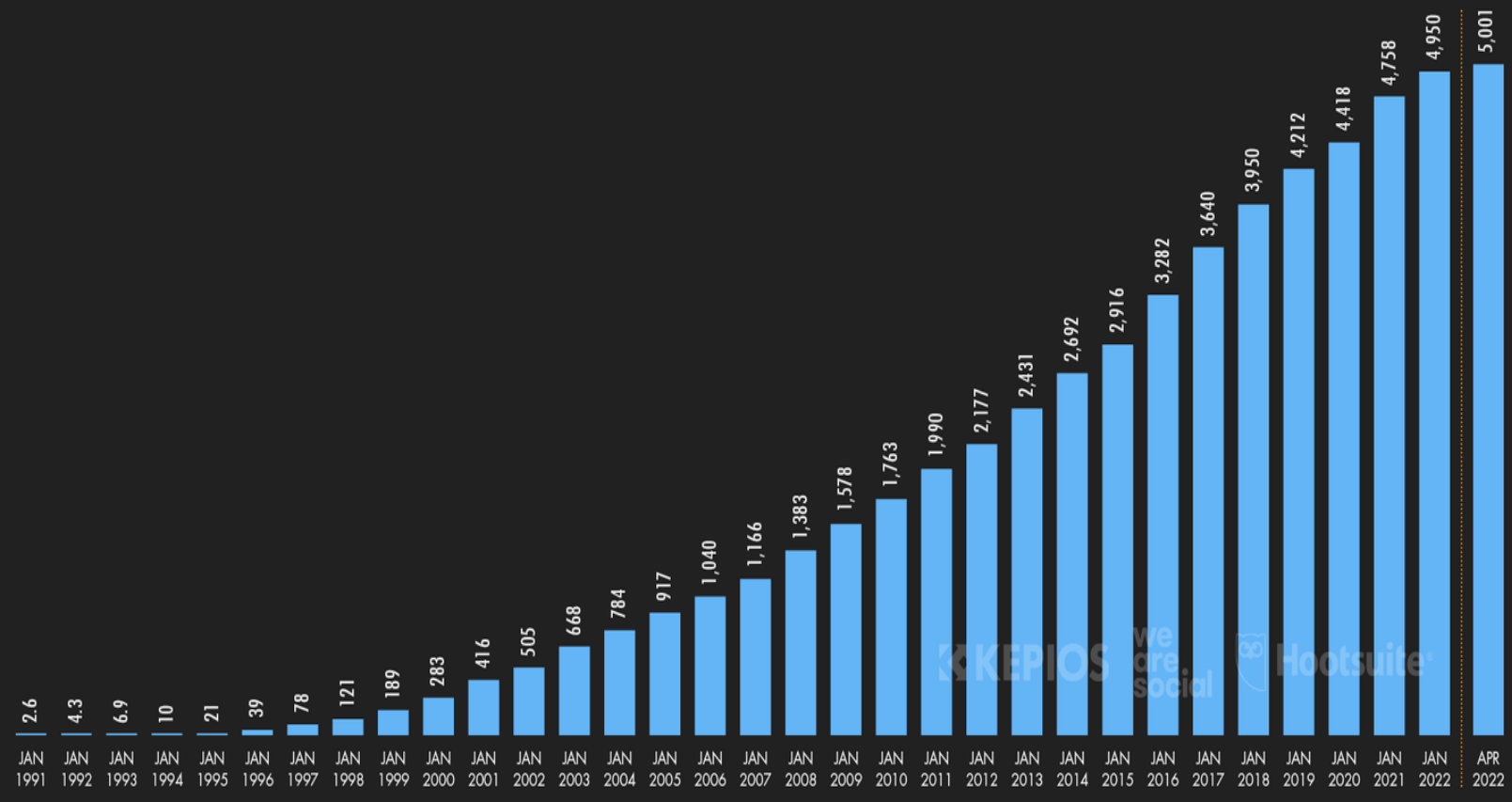
INTERNET USERS OVER TIME

NUMBER OF INTERNET USERS (IN MILLIONS)

GLOBAL OVERVIEW



SOURCES: KEPIOS ANALYSIS; ITU; GSMA INTELLIGENCE; EUROSTAT; GWI; CIA WORLD FACTBOOK; CNNIC; APJII; LOCAL GOVERNMENT AUTHORITIES. **NOTE:** INTERNET USER NUMBERS FOR YEARS PRIOR TO 2011 ARE BASED ON THE ITU'S PUBLISHED FIGURES FOR THE **PREVIOUS YEAR**, BECAUSE THESE FIGURES WOULD HAVE BEEN THE LATEST AVAILABLE IN JANUARY OF EACH REPORTING YEAR. **ADVISORY:** DUE TO COVID-19-RELATED DELAYS IN RESEARCH AND REPORTING, FIGURES FOR PERIODS AFTER 2020 MAY UNDER-REPRESENT ACTUAL USER NUMBERS AND ASSOCIATED GROWTH TRENDS. SEE NOTES ON DATA FOR MORE DETAILS. **COMPARABILITY:** SOURCE AND BASE CHANGES. FIGURES MAY NOT MATCH OR CORRELATE WITH DATA PUBLISHED IN PREVIOUS REPORTS.

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UNCONNECTED POPULATIONS

COUNTRIES AND TERRITORIES WITH THE LARGEST UNCONNECTED POPULATIONS AND THE LOWEST LEVELS OF INTERNET ADOPTION

GLOBAL OVERVIEW

ABSOLUTE: LARGEST UNCONNECTED POPULATIONS

#	LOCATION	UNCONNECTED POPULATION	% OF POP. OFFLINE
01	INDIA	743,757,000	53.0%
02	CHINA	415,456,000	28.7%
03	PAKISTAN	145,509,000	63.7%
04	BANGLADESH	113,700,000	67.9%
05	NIGERIA	105,545,000	49.0%
06	ETHIOPIA	90,054,000	75.0%
07	DEM. REP. OF THE CONGO	77,628,000	82.1%
08	INDONESIA	64,598,000	23.2%
09	TANZANIA	47,133,000	75.0%
10	BRAZIL	40,116,000	18.7%

RELATIVE: LOWEST LEVELS OF INTERNET ADOPTION

#	LOCATION	% OF POP. OFFLINE	UNCONNECTED
01	NORTH KOREA[1]	>99.9%	[BLOCKED]
02	ERITREA	92.0%	3,355,000
03	COMOROS	91.5%	826,000
04	CENTRAL AFRICAN REPUBLIC	89.6%	4,473,000
05	SOUTH SUDAN	88.6%	10,241,000
06	SOMALIA	85.9%	14,368,000
07	NIGER	85.2%	22,008,000
08	BURUNDI	84.9%	10,641,000
09	DEM. REP. OF THE CONGO	82.1%	77,628,000
10	MALAWI	80.2%	16,077,000

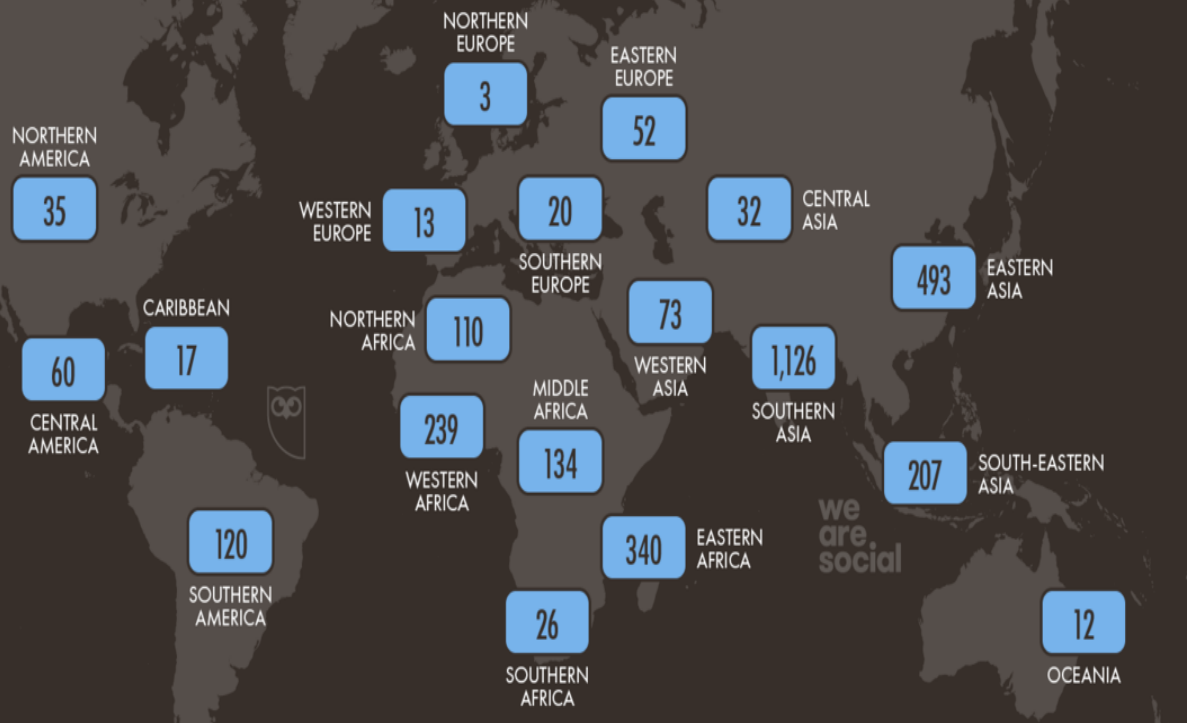
SOURCES: ITU; GSMA INTELLIGENCE; EUROSTAT; GWI; CIA WORLD FACTBOOK; CNNIC; APJII; LOCAL GOVERNMENT AUTHORITIES; UNITED NATIONS. **NOTES:** FIGURES IN THE "% OF POP. OFFLINE" COLUMN REPRESENT THE PERCENTAGE OF THE POPULATION THAT DOES NOT YET USE THE INTERNET. ABSOLUTE VALUES HAVE BEEN ROUNDED TO THE NEAREST THOUSAND. (1) THE INTERNET (AT LEAST AS THE REST OF THE WORLD KNOWS IT) REMAINS BLOCKED FOR EVERYDAY CITIZENS IN NORTH KOREA. **COMPARABILITY:** SOURCE AND BASE CHANGES.

APR 2021

THE 'NEXT 3 BILLION': UNCONNECTED POPULATIONS

THE NUMBER OF PEOPLE (IN MILLIONS) IN EACH REGION WHO ARE NOT CONNECTED TO THE INTERNET

⚠ *INTERNET USER NUMBERS NO LONGER INCLUDE DATA SOURCED FROM SOCIAL MEDIA PLATFORMS, SO VALUES ARE NOT COMPARABLE WITH PREVIOUS REPORTS*



SOURCES: KEPIOS (APR 2021) BASED ON EXTRAPOLATIONS OF DATA PUBLISHED BY: THE ITU; LOCAL GOVERNMENT BODIES; GWI; GSMA INTELLIGENCE; EUROSTAT; APJII; CNNIC; THE U.N. **ADVISORIES:** INTERNET USER NUMBERS NO LONGER INCLUDE DATA SOURCED FROM SOCIAL MEDIA PLATFORMS. FIGURES ARE NOT COMPARABLE WITH DATA PUBLISHED IN PREVIOUS REPORTS. **NOTES:** REGIONS BASED ON THE U.N. GEOSCHEME. ◈ **COMPARABILITY ADVISORY:** SOURCE AND BASE CHANGES.

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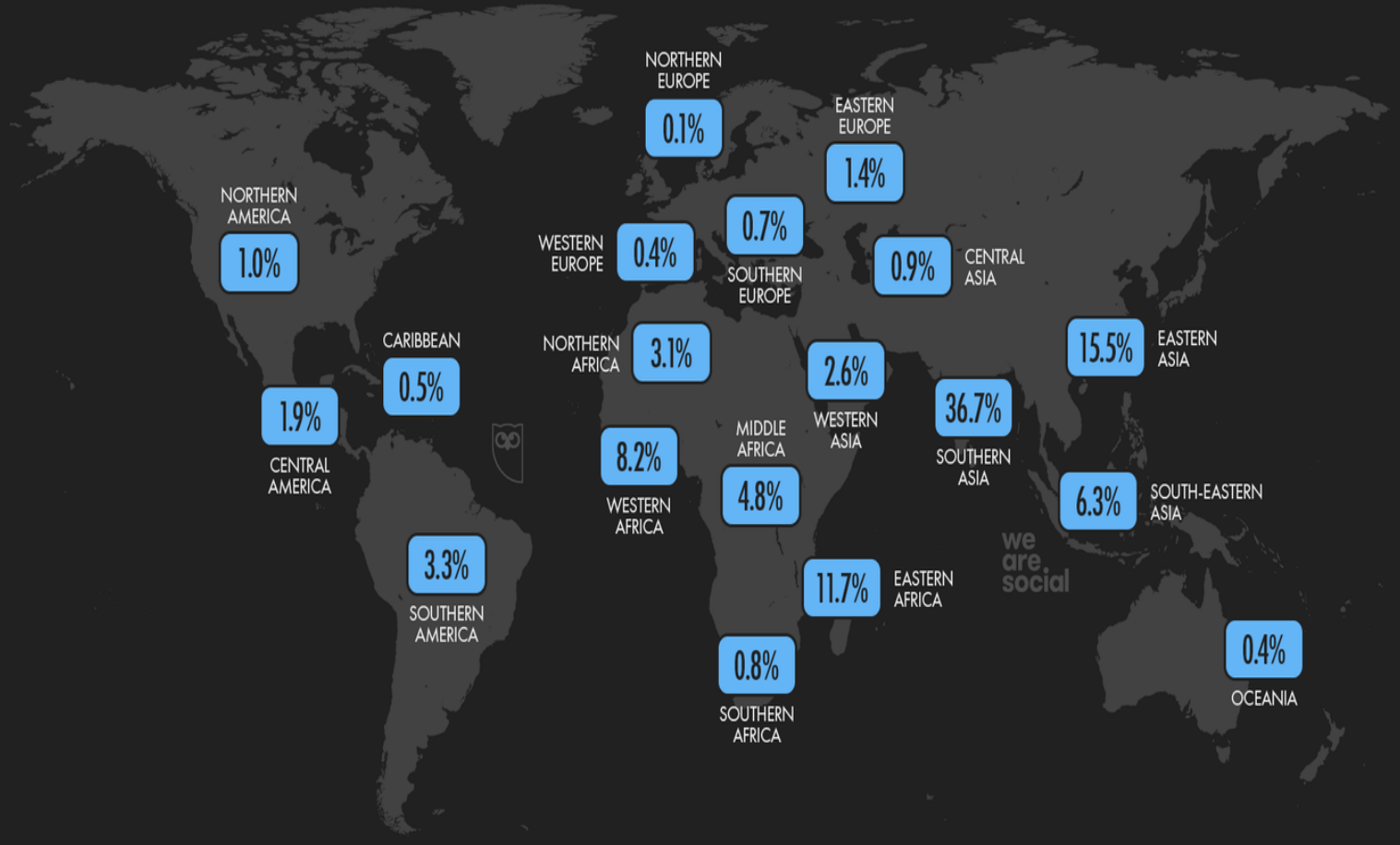
SHARE OF THE WORLD'S OFFLINE POPULATION

PERCENTAGE SHARE OF THE WORLD'S TOTAL OFFLINE POPULATION

GLOBAL OVERVIEW



SOURCES: KEPIOS ANALYSIS; ITU; GSMA INTELLIGENCE; EUROSTAT; GWI; CIA WORLD FACTBOOK; CNNIC; APJII; LOCAL GOVERNMENT AUTHORITIES; UNITED NATIONS. **NOTE:** REGIONS BASED ON THE UNITED NATIONS GEOSCHEME. **COMPARABILITY:** SOURCE AND BASE CHANGES.

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ESSENTIAL DIGITAL HEADLINES

OVERVIEW OF THE ADOPTION AND USE OF CONNECTED DEVICES AND SERVICES

GLOBAL OVERVIEW

TOTAL POPULATION	UNIQUE MOBILE PHONE USERS	INTERNET USERS	ACTIVE SOCIAL MEDIA USERS
7.98 BILLION	5.34 BILLION	5.03 BILLION	4.70 BILLION
URBANISATION	vs. POPULATION	vs. POPULATION	vs. POPULATION
57.0%	66.9%	63.1%	59.0%

SOURCES: UNITED NATIONS; U.S. CENSUS BUREAU; GOVERNMENT BODIES; GSMA INTELLIGENCE; ITU; GWI; EUROSTAT; CNNIC; APJII; CIA WORLD FACTBOOK; COMPANY ADVERTISING RESOURCES AND EARNINGS REPORTS; OCDH; TECHRASA; KEPIOS ANALYSIS. **ADVISORY:** SOCIAL MEDIA USERS MAY NOT REPRESENT UNIQUE INDIVIDUALS. **COMPARABILITY:** SOURCE AND BASE CHANGES. THE U.N. REVISED ITS POPULATION DATA SINCE OUR PREVIOUS REPORT, WHICH MAY AFFECT ALL VALUES THAT COMPARE DIGITAL ACTIVITY TO POPULATION, AND MAY RESULT IN APPARENT DECREASES IN DIGITAL ADOPTION. HOWEVER, WE ADVISE CAUTION WHEN INTERPRETING ANY CHANGES IN THESE COMPARATIVE FIGURES, BECAUSE ANY SUCH CHANGE MAY BE SOLELY THE RESULT OF REVISIONS TO POPULATION DATA.

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INTERNET CONNECTION SPEEDS

MEDIAN SPEEDS AND LATENCY FOR MOBILE AND FIXED INTERNET CONNECTIONS

GLOBAL OVERVIEW

MEDIAN SPEED OF MOBILE INTERNET CONNECTIONS

DOWNLOAD (MBPS)

30.37

UPLOAD (MBPS)

8.60

LATENCY (MS)

29

YEAR-ON-YEAR CHANGE IN MEDIAN SPEED OF MOBILE INTERNET CONNECTIONS

DOWNLOAD

+25.2%

UPLOAD

+13.2%

LATENCY

-3.3%

MEDIAN SPEED OF FIXED INTERNET CONNECTIONS

DOWNLOAD (MBPS)

64.70

UPLOAD (MBPS)

27.74

LATENCY (MS)

10

YEAR-ON-YEAR CHANGE IN MEDIAN SPEED OF FIXED INTERNET CONNECTIONS

DOWNLOAD

+28.9%

UPLOAD

+36.0%

LATENCY

-9.1%

SOURCE: OOKLA. **NOTE:** FIGURES REPRESENT MEDIAN DOWNLOAD AND UPLOAD SPEEDS IN MEGABITS PER SECOND, AND MEDIAN CONNECTION LATENCY IN MILLISECONDS IN MAY 2022. **TIP:** A NEGATIVE VALUE FOR YEAR-ON-YEAR CHANGE IN LATENCY REPRESENTS AN IMPROVEMENT, BECAUSE LOWER LATENCY SHOULD RESULT IN FASTER CONTENT DELIVERY. **COMPARABILITY:** FIGURES PUBLISHED IN PREVIOUS REPORTS IN THIS SERIES FEATURED MEAN CONNECTION SPEED VALUES, WHEREAS WE NOW FEATURE MEDIAN VALUES. CONSEQUENTLY, VALUES SHOWN HERE ARE NOT COMPARABLE WITH VALUES SHOWN IN PREVIOUS REPORTS.

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MOBILE CONNECTIVITY

ADOPTION AND USE OF MOBILE PHONES AND DEVICES THAT CONNECT TO CELLULAR NETWORKS

GLOBAL OVERVIEW

NUMBER OF UNIQUE MOBILE USERS (ANY TYPE OF HANDSET)	UNIQUE MOBILE USERS AS A PERCENTAGE OF TOTAL POPULATION	ANNUAL CHANGE IN THE NUMBER OF UNIQUE MOBILE SUBSCRIBERS	CELLULAR MOBILE CONNECTIONS (EXCLUDING IOT)	ANNUAL CHANGE IN THE NUMBER OF CELLULAR CONNECTIONS (EX. IOT)
GSMA	we are social	GSMA	we are social	
5.34 BILLION	**66.9%**	**+1.8%** +93 MILLION	**8.40** BILLION	**+2.5%** +203 MILLION

SOURCE: GSMA INTELLIGENCE. **NOTES:** TOTAL CELLULAR CONNECTIONS INCLUDE DEVICES OTHER THAN MOBILE PHONES, BUT EXCLUDE CELLULAR IOT CONNECTIONS. FIGURES MAY SIGNIFICANTLY EXCEED FIGURES FOR POPULATION DUE TO MULTIPLE CONNECTIONS AND CONNECTED DEVICES PER PERSON. **COMPARABILITY:** BASE CHANGES. VERSIONS OF THIS CHART PUBLISHED IN SOME OF OUR PREVIOUS REPORTS FEATURED CELLULAR CONNECTION FIGURES THAT INCLUDED CELLULAR IOT CONNECTIONS. FIGURES SHOWN HERE DO **NOT** INCLUDE CELLULAR IOT CONNECTIONS.

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OVERVIEW OF SOCIAL MEDIA USE

HEADLINES FOR SOCIAL MEDIA ADOPTION AND USE (NOTE: USERS MAY NOT REPRESENT UNIQUE INDIVIDUALS)

GLOBAL OVERVIEW

NUMBER OF SOCIAL MEDIA USERS

4.70

BILLION

QUARTER-ON-QUARTER CHANGE IN SOCIAL MEDIA USERS

+1.0%

+47 MILLION

YEAR-ON-YEAR CHANGE IN SOCIAL MEDIA USERS

+5.1%

+227 MILLION

AVERAGE DAILY TIME SPENT USING SOCIAL MEDIA

2H 29M

YOY: +3.5% (+5 MINS)

AVERAGE NUMBER OF SOCIAL PLATFORMS USED EACH MONTH

7.4

SOCIAL MEDIA USERS vs. TOTAL POPULATION

59.0%

SOCIAL MEDIA USERS vs. POPULATION AGE 13+

75.5%

SOCIAL MEDIA USERS vs. TOTAL INTERNET USERS

93.6%

FEMALE SOCIAL MEDIA USERS vs. TOTAL SOCIAL MEDIA USERS

45.7%

MALE SOCIAL MEDIA USERS vs. TOTAL SOCIAL MEDIA USERS

54.3%

SOURCES: KEPIOS ANALYSIS; COMPANY ADVERTISING RESOURCES AND ANNOUNCEMENTS; CNNIC; TECHRASA; OCDH; U.N.; U.S. CENSUS BUREAU. DATA FOR TIME SPENT AND AVERAGE NUMBER OF PLATFORMS: GWI (Q1 2022). SEE GWI.COM FOR MORE DETAILS. NOTE: FIGURE FOR "AVERAGE NUMBER OF SOCIAL PLATFORMS USED EACH MONTH" INCLUDES DATA FOR YOUTUBE. ADVISORY: SOCIAL MEDIA USERS MAY NOT REPRESENT UNIQUE INDIVIDUALS. FIGURES FOR REACH vs. POPULATION AND REACH vs. INTERNET USERS MAY EXCEED 100% DUE TO DUPLICATE AND FAKE ACCOUNTS, DELAYS IN DATA REPORTING, AND DIFFERENCES BETWEEN CENSUS COUNTS AND RESIDENT POPULATIONS. SEE NOTES ON DATA FOR FURTHER DETAILS.

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WEEKLY ONLINE SHOPPING ACTIVITIES

PERCENTAGE OF INTERNET USERS AGED 16 TO 64 WHO ENGAGE IN SELECTED ECOMMERCE ACTIVITIES EACH WEEK

GLOBAL OVERVIEW

SOURCE: GWI (Q1 2022). FIGURES REPRESENT THE FINDINGS OF A BROAD GLOBAL SURVEY OF INTERNET USERS AGED 16 TO 64. SEE GWI.COM FOR FULL DETAILS.

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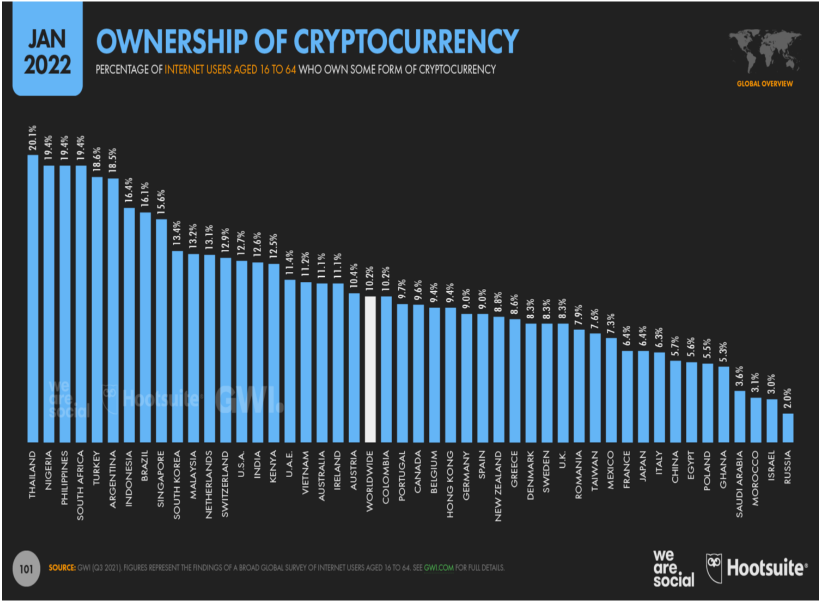
JAN 2022
OWNERSHIP OF CRYPTOCURRENCY
PERCENTAGE OF INTERNET USERS AGED 16 TO 64 WHO OWN SOME FORM OF CRYPTOCURRENCY
GLOBAL OVERVIEW
20.1%
19.4%
19.4%
19.4%
18.6%
18.5%
16.4%
16.1%
15.6%
13.4%
13.2%
13.1%
12.9%
12.7%
12.6%
12.5%
11.4%
11.2%
11.1%
11.1%
10.4%
10.2%
10.2%
9.7%
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5.5%
5.3%
3.6%
3.1%
3.0%
2.0%
THAILAND
NIGERIA
PHILIPPINES
SOUTH AFRICA
TURKEY
ARGENTINA
INDONESIA
BRAZIL
SINGAPORE
SOUTH KOREA
MALAYSIA
NETHERLANDS
SWITZERLAND
U.S.A.
INDIA
KENYA
U.A.E.
VIETNAM
AUSTRALIA
IRELAND
AUSTRIA
WORLDWIDE
COLOMBIA
PORTUGAL
CANADA
BELGIUM
HONG KONG
GERMANY
SPAIN
NEW ZEALAND
GREECE
DENMARK
SWEDEN
U.K.
ROMANIA
TAIWAN
MEXICO
FRANCE
JAPAN
ITALY
CHINA
EGYPT
POLAND
GHANA
SAUDI ARABIA
MOROCCO
ISRAEL
RUSSIA
101
SOURCE: GWI (Q3 2021). FIGURES REPRESENT THE FINDINGS OF A BROAD GLOBAL SURVEY OF INTERNET USERS AGED 16 TO 64. SEE GWI.COM FOR FULL DETAILS.
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- Textbook Resources
- Internet Engineering Task Force

Thank You.