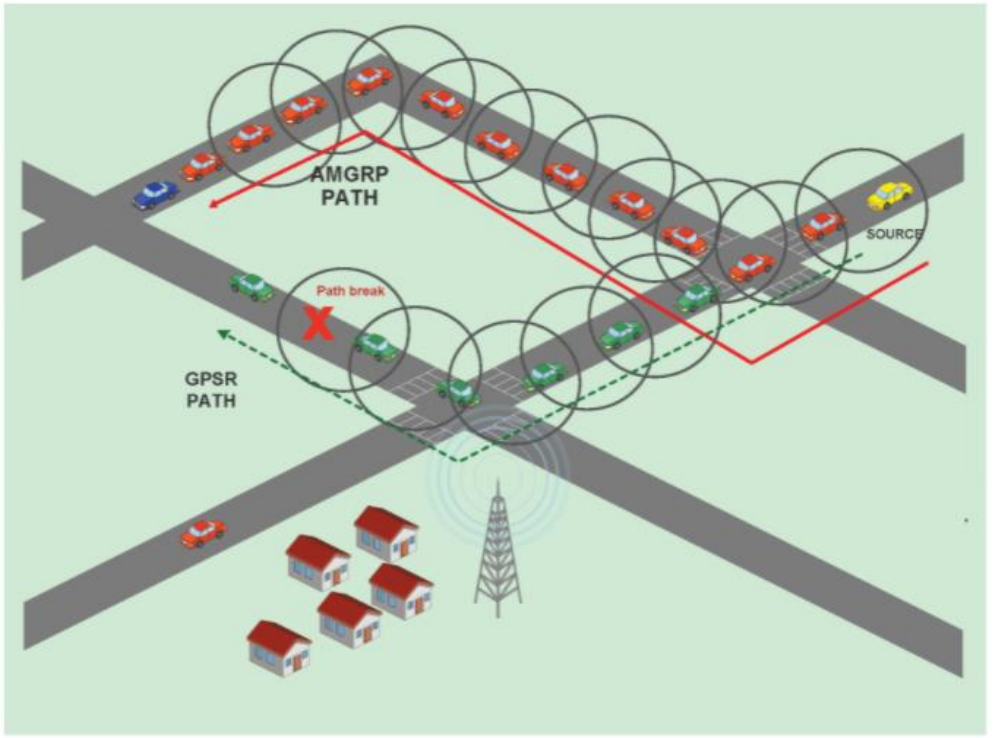
Computer Networks (CN)
EE-353

Huma Ghafoor

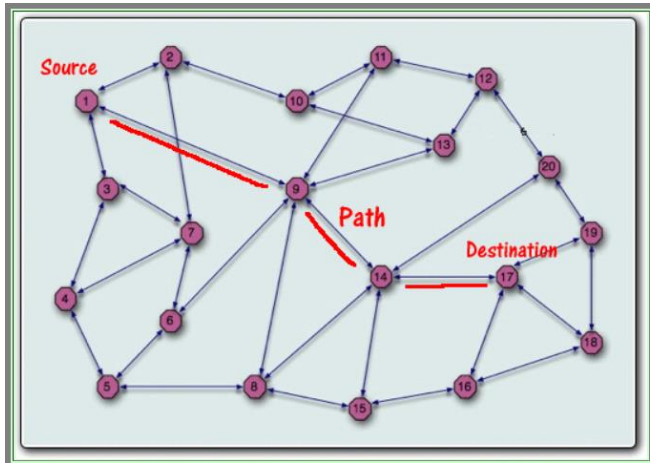
Lectures 4 - 5 (Chapter 1)

1.1.3. Route or Path:

- The sequence of communication links and packet switches traversed by a packet from the sending end system to the receiving end system is known as a **route** or **path** through the network.



- **Example**:
- Packet-switched networks (which transport packets) are in many ways similar to transportation networks of highways, roads, and intersections (which transport vehicles).
- Packets are analogous to? Trucks
- Communication links are analogous to? Highways
- Packet switches are analogous to? Intersections
- End systems are analogous to? Buildings



Source: Internet

1.2. What is the Internet? (A service view):

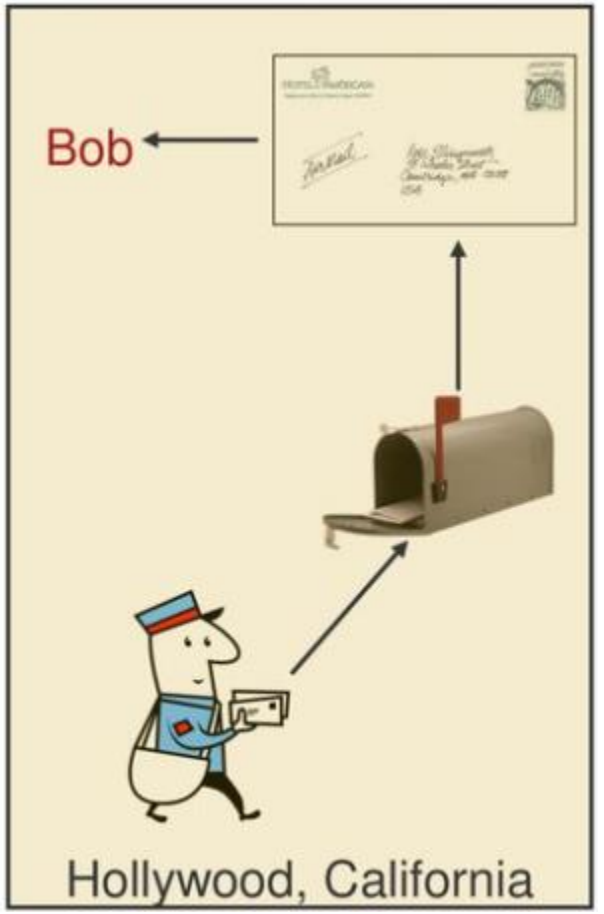
- What is the Internet?

An infrastructure that provides services to applications.

- These applications include
  - electronic mail, Web surfing, internet messaging, mapping with real-time road traffic information, music streaming movie and television streaming, online social media, video conferencing, multi-person games, and much, much more.
- The applications are said to be **distributed applications**, since they involve multiple end systems that exchange data with each other.
- **Where do internet applications run on?**
  - end systems—they do not run in the packet switches in the network core.
- Example:
  - Developing a distributed Internet application
    - How does one program running on one end system instruct the Internet to deliver data to another program running on another end system?
    - **Socket interface—set of rules—API (will study in application layer)**

Example: Alice wants to send a letter to Bob:

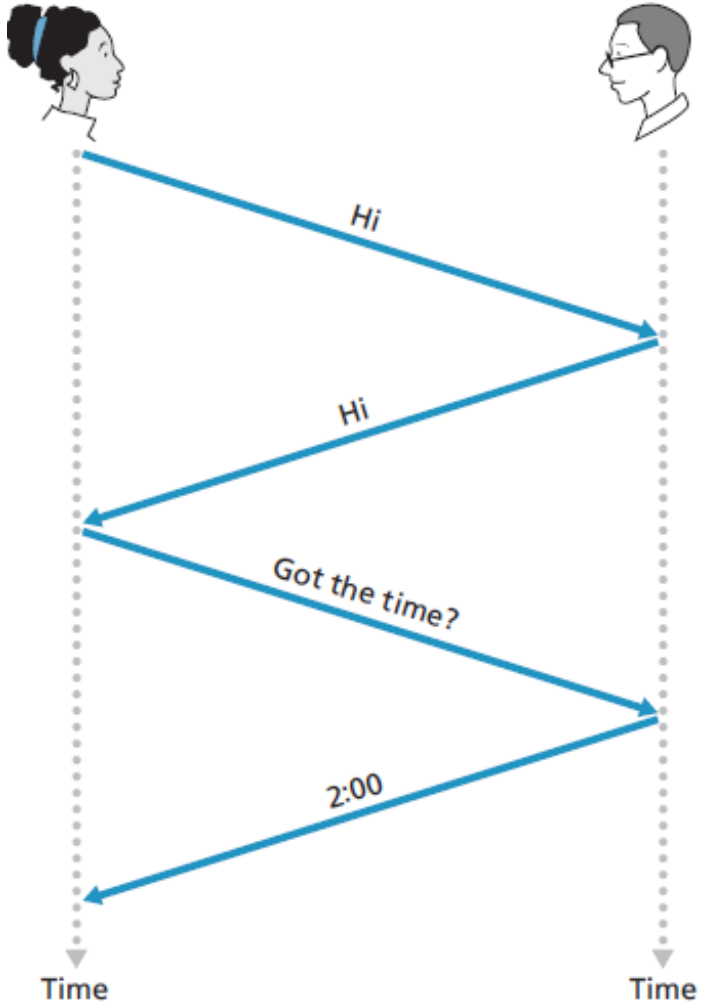
Postal Service API or set of rules:
Alice put the letter in an envelope; write Bob's full name, address, and zip code; seal the envelope; put a stamp in the upper-right-hand corner of the envelope; and finally drop the envelope into an official postal service mailbox.



1.3. What is a Protocol?

- *A **protocol** defines the format and the order of messages exchanged between two or more communicating entities, as well as the actions taken on the transmission and/or receipt of a message or other event.*

- Mastering the field of computer networking is equivalent to understanding the
  - what,
  - why, and
  - how of networking protocols.



1.3. What is a Protocol? Network Protocol:

- Entities exchanging messages or taking actions are hardware or software components of some device.
  - hardware-implemented protocols in two physically connected computers control the flow of bits on the "wire" between the two network interface cards;
  - congestion-control protocols in end systems control the rate at which packets are transmitted between sender and receiver;
  - protocols in routers determine a packet's path from source to destination.

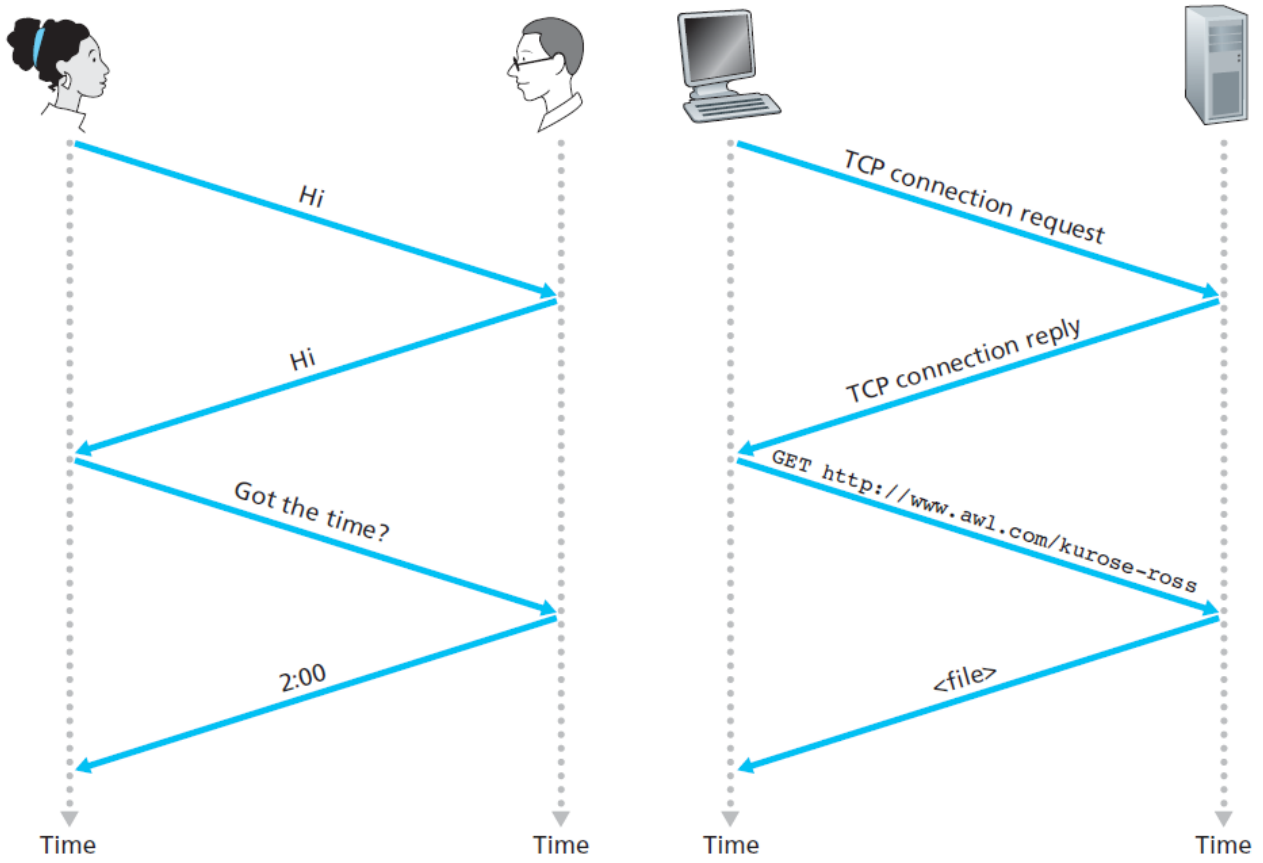
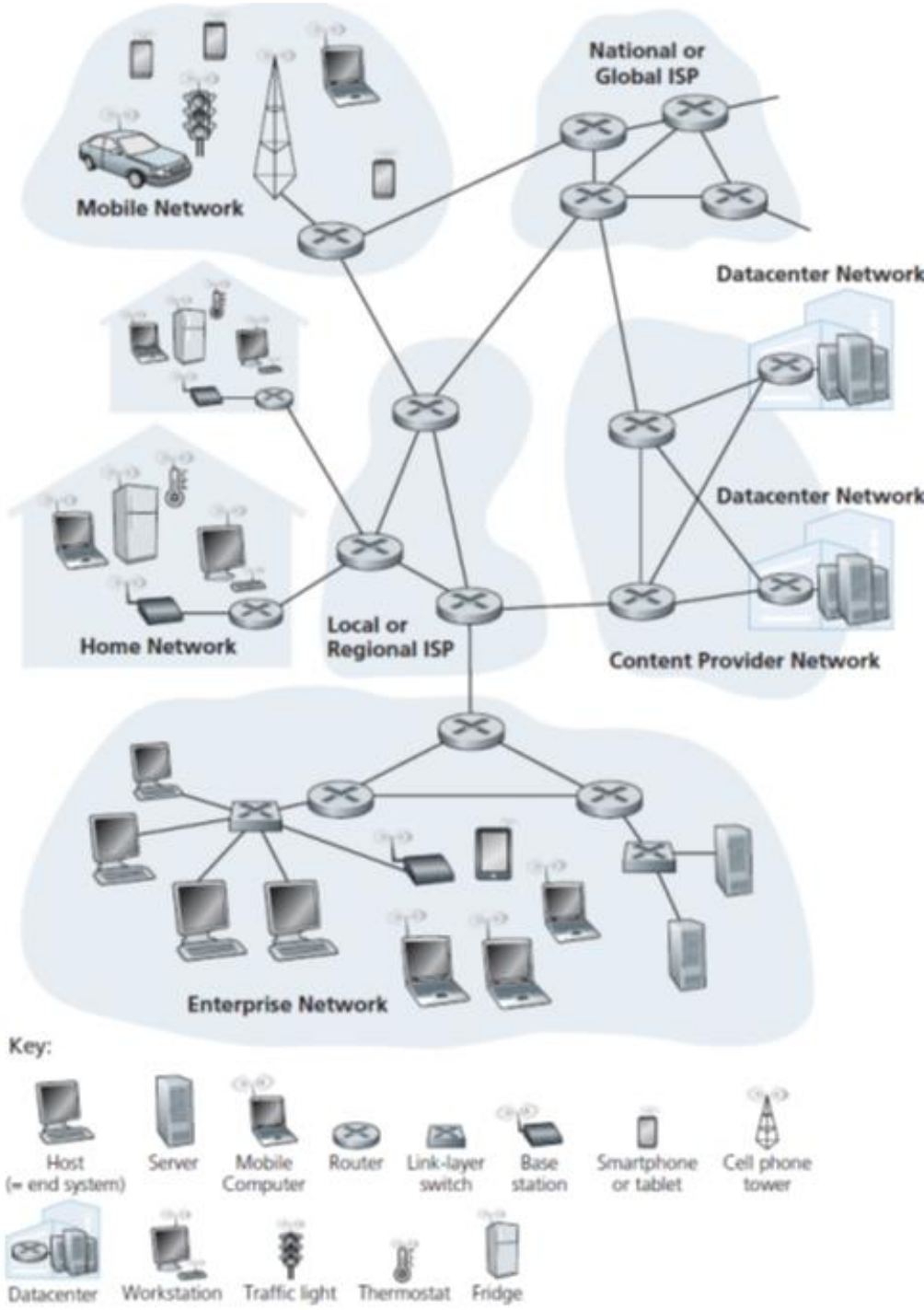


Figure 1.2 ♦ A human protocol and a computer network protocol

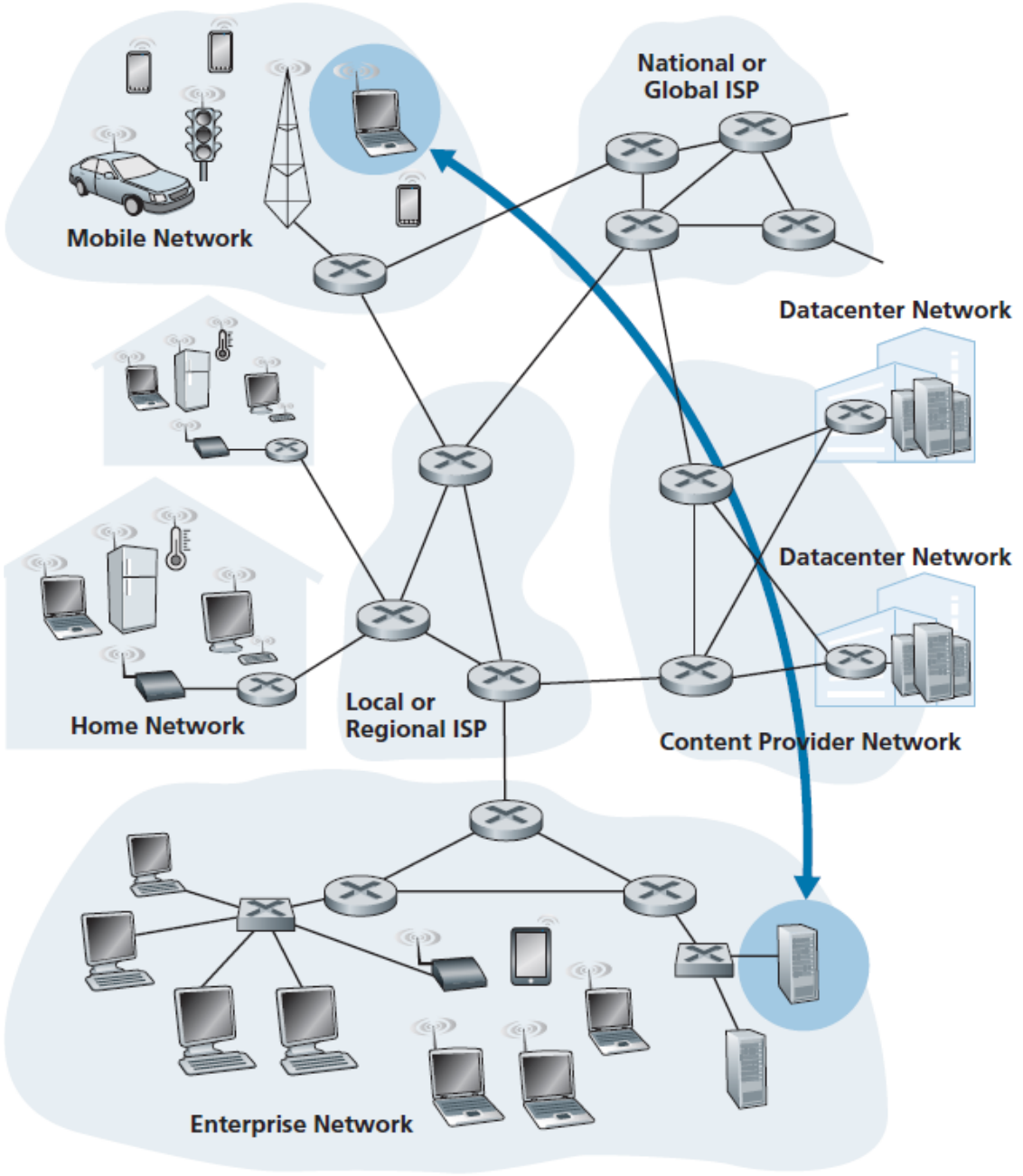
Overview:

- What is the Internet?
- **The Network Edge**
- The Network Core
- Delay, loss, and throughput in Packet-Switched Networks
- Protocol Layers and their Service Models
- Networks under attacks (Security)



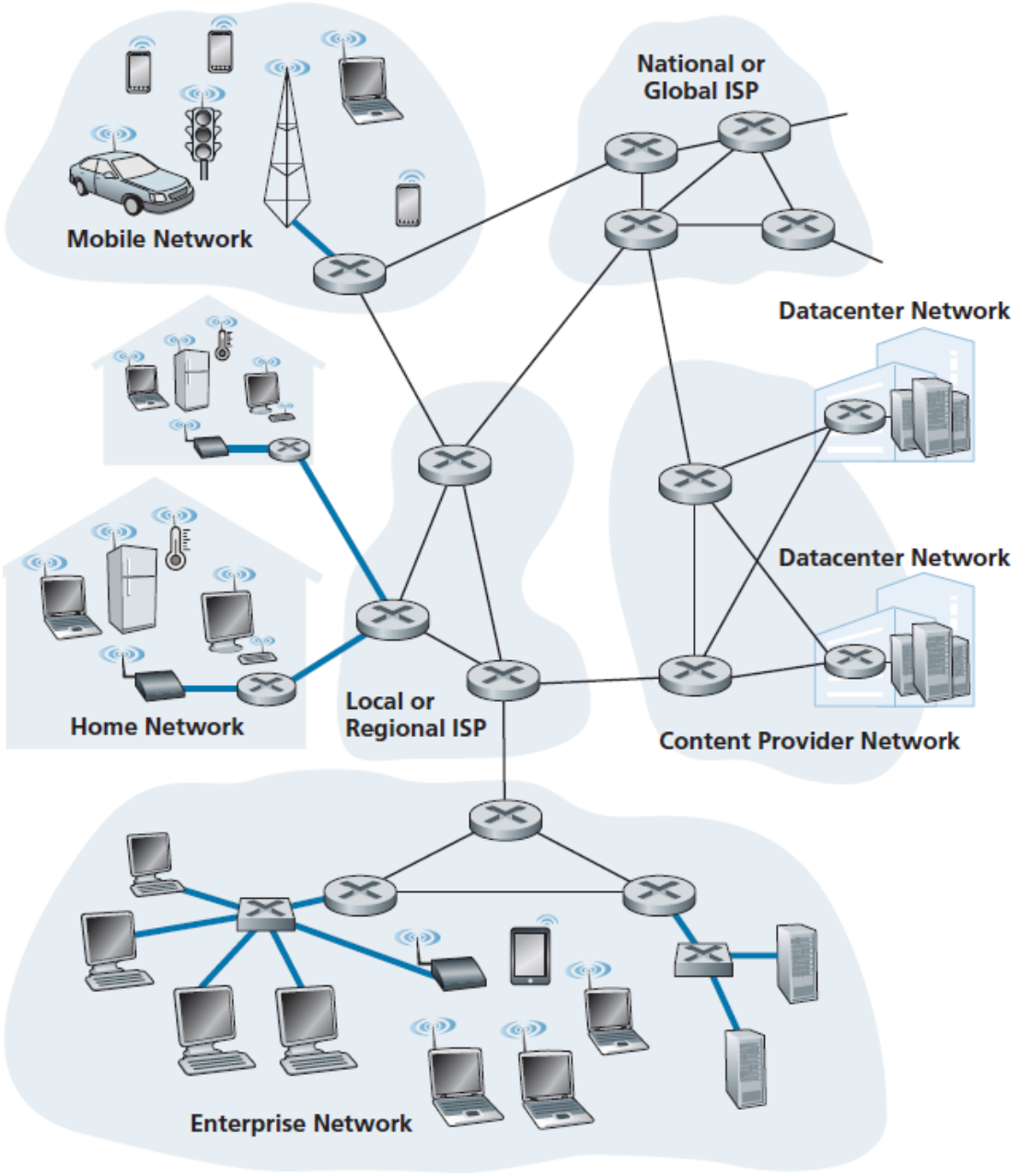
2. The Network Edge:

- Why are they called as end systems or hosts?
  - Because they sit at the edge of the internet and they host (i.e.,) run application program.
- Hosts are sometimes further divided into two categories:
  - **clients**
  - **servers**
- Informally, **clients** tend to be desktop and mobile PCs, smartphones, and so on, whereas **servers** tend to be more powerful machines that store and distribute Web pages, stream video, relay e-mail, and so on.
- Today, most of the servers from which we receive search results, e-mail, Web pages, and videos reside in large **data centers**.
  - For example, as of 2020, Google has 19 data centers on four continents, collectively containing several million servers.



2.1. Access Networks:

- The network that physically **connects an end system to the first router** (also known as the "**edge router**") on a path from the end system to any other distant end system.
  - **Home Access: DSL, Cable, FTTH, and 5G Fixed wireless**
  - **Access in the Enterprise (and the Home): Ethernet and WiFi (will study in Chap. 6 and 7)**
  - **Wide-Area Wireless Access: 3G and LTE 4G and 5G (Chap. 7)**



2.1.1. Home Access: **DSL**, Cable, FTTH, and 5G Fixed Wireless:

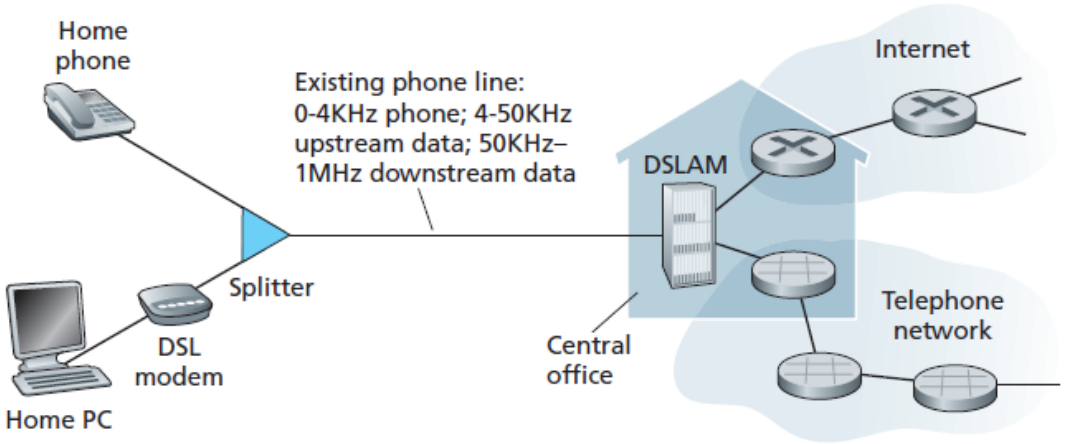


Figure 1.5 ♦ DSL Internet access

- The two most prevalent types of broadband residential access are
  - **Digital subscriber line (DSL)** and Cable Internet Access
    - residence typically obtains DSL Internet access from the same **local telephone company** (telco) that provides its wired local phone access.
    - when DSL is used, **a customer's telco is also its ISP**
    - The home's DSL modem takes digital data and translates it to high frequency tones for transmission over telephone wires to the local **CO** (Central Office);
    - the analog signals from many such houses are translated back into digital format at the **DSLAM** (Digital subscriber line access multiplexer).
- The residential telephone line **carries both data and traditional telephone signals simultaneously**, which are encoded at different frequencies:
  - A high-speed downstream channel, in the 50 kHz to 1 MHz band
  - A medium-speed upstream channel, in the 4 kHz to 50 kHz band
  - An ordinary two-way telephone channel, in the 0 to 4 kHz band

2.1.1. Home Access: **DSL**, Cable, FTTH, and 5G Fixed Wireless:

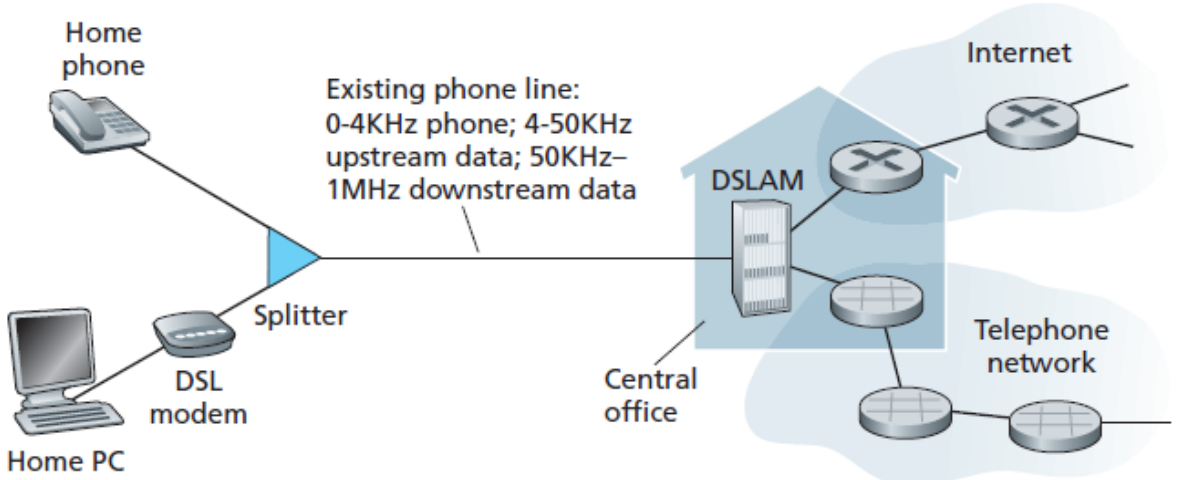


Figure 1.5 ♦ DSL Internet access

- On the customer side, **a splitter separates the data and telephone signals** arriving to the home and forwards the data signal to the DSL modem.
- On the telco side, in the CO, **the DSLAM separates the data and phone signals** and sends the data into the Internet.
- The DSL standards define multiple transmission rates of
  - downstream transmission rates of 24 Mbps and 52 Mbps, and
  - Upstream transmission rates of 3.5 Mbps and 16 Mbps;
  - the newest standard provides for aggregate upstream plus downstream rates of 1 Gbps [ITU 2014].
- Because the downstream and upstream rates are different, the access is said to be **asymmetric**.
- Engineers have expressly designed DSL **for short distances** between the home and the CO; generally, if the **residence is not located within 5 to 10 miles of the CO**, the residence must resort to an alternative form of Internet access.

2.1.1. Home Access: DSL, **Cable**, FTTH, and 5G Fixed Wireless:

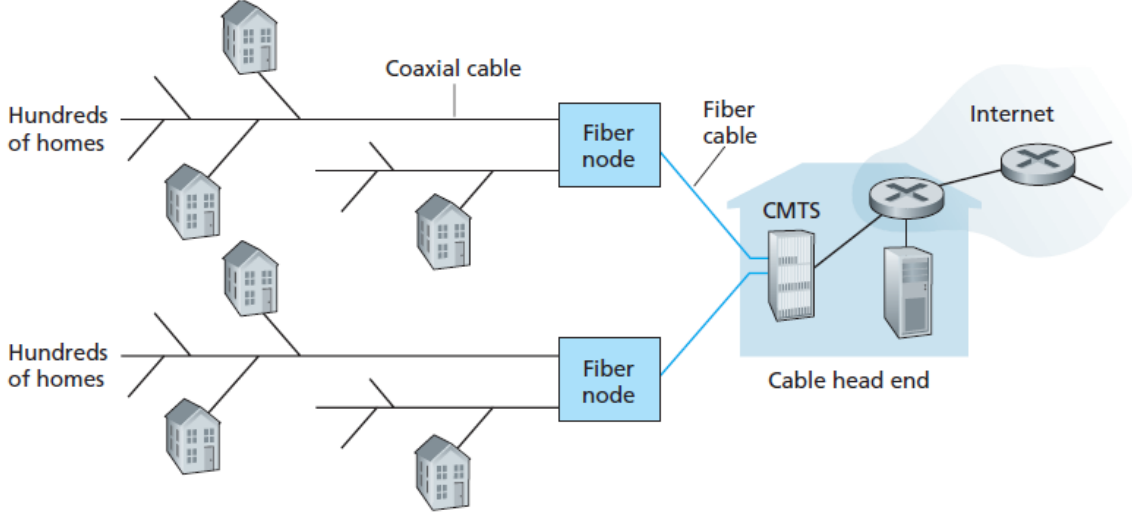


Figure 1.6 ♦ A hybrid fiber-coaxial access network

- It makes use of the **cable television company**'s existing cable television infrastructure.
- Fiber optics connect the **cable head end** to neighborhood-level junctions, from which **traditional coaxial cable** is then used to reach individual houses and apartments.
- Each **neighborhood junction** typically **supports 500 to 5,000 homes**.
- Because both fiber and coaxial cable are employed in this system, it is often referred to as **hybrid fiber coax (HFC)**.
- Cable internet access requires **special modems**, called **cable modems**. As with a DSL modem, the cable modem is typically an external device and **connects to the home PC through an Ethernet port** (will discuss in Chap. 6).
- At the cable head end, the **cable modem termination system** (CMTS) serves a similar function as the DSL network's DSLAM.
- Cable modems divide the HFC network into two channels, a downstream and an upstream channel .
- The DOCSIS 2.0 and 3.0 standard defines **downstream bitrates of 40 Mbps & 1.2 Gbps** and **upstream rates of 30 Mbps & 100 Mbps, respectively.**

2.1.1. Home Access: DSL, **Cable**, FTTH, and 5G Fixed Wireless :

- One important characteristic of cable Internet access is that it is **a shared broadcast medium**.
  - In particular, every packet sent by the head end travels downstream on every link to every home and every packet sent by a home travels on the upstream channel to the head end.
  - For this reason, if several users are simultaneously downloading a video file on the downstream channel, **the actual rate at which each user receives its video file will be significantly lower than the aggregate cable downstream rate**.
  - On the other hand, if there are only a few active users and they are all Web surfing, then each of the users may actually receive Web pages at the full cable downstream rate, because the users will rarely request a Web page at exactly the same time.
- Because the upstream channel is also shared, **a distributed multiple access protocol is needed** to coordinate transmissions and avoid collisions.

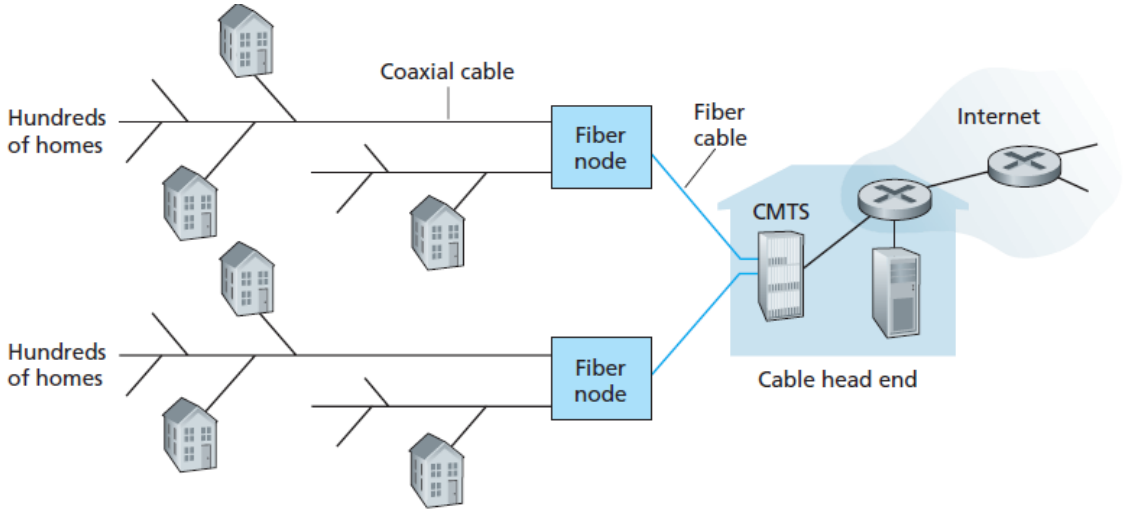
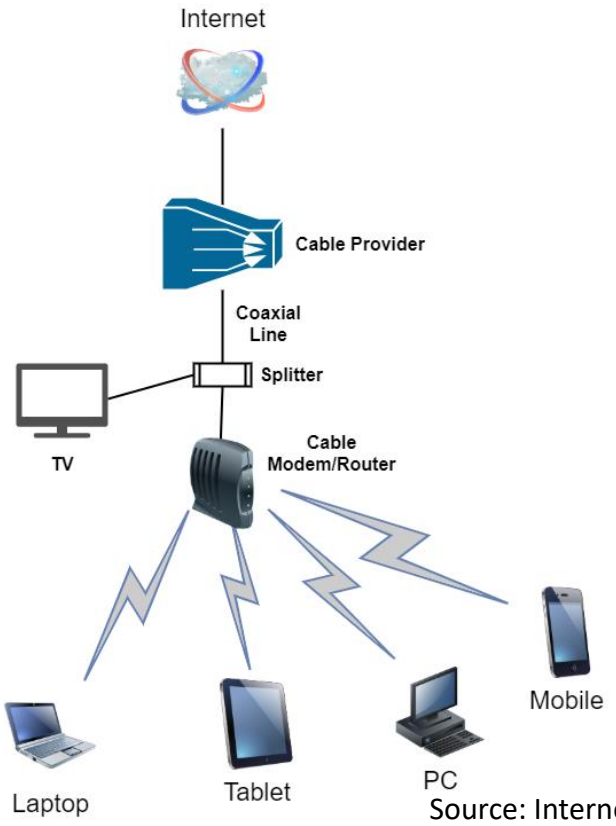


Figure 1.6 ♦ A hybrid fiber-coaxial access network



Source: Internet

2.1.1. Home Access: DSL, Cable, **FTTH**, and 5G Fixed Wireless:

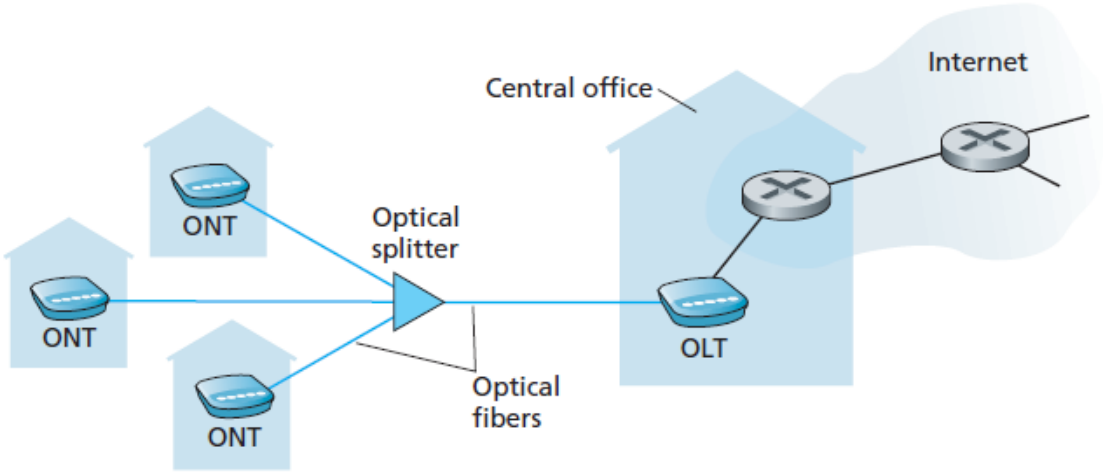
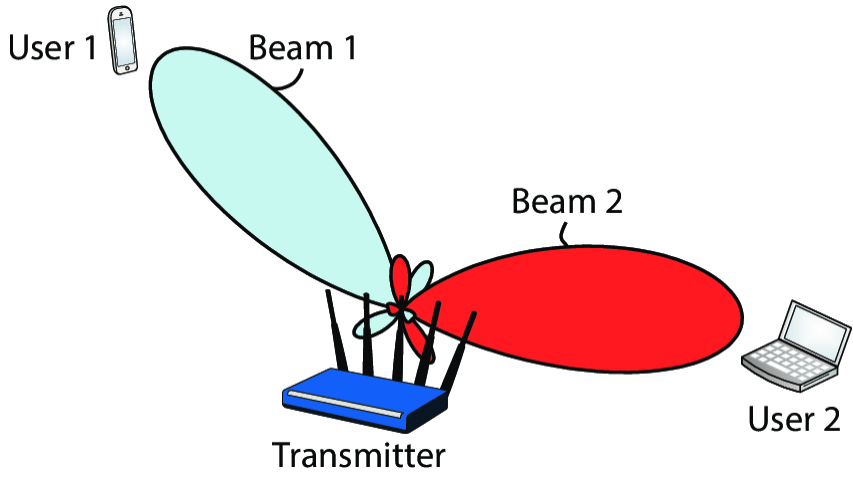


Figure 1.7 ♦ FTTH Internet access

- An up-and-coming technology that promises even higher speeds is the deployment of **fiber to the home (FTTH)** [Fiber broadband 2020].
- FTTH concept is simple— **provide an optical fiber path from the CO directly to the home** (provides Internet access rates in Gbps range)**.**
- There are two competing optical-distribution network architectures that perform this splitting:
  - **active optical networks (AONs)**
    - essentially switched Ethernet (Chap. 6)
  - **passive optical networks (PONs)**
    - Each home has an **optical network terminator** (ONT), which is connected by dedicated optical fiber to a neighborhood splitter.
    - The **splitter combines a number of homes** (typically less than 100) onto a single, shared optical fiber, which connects to an optical line terminator (OLT) in the telco's CO.
    - The OLT, providing conversion between optical and electrical signals, connects to the Internet via a telco router.
    - In the home, users connect a home router (typically a wireless router) to the ONT and access the Internet via this home router.
    - In the PON architecture, all packets sent from OLT to the splitter are replicated at the splitter (similar to a cable head end).

2.1.1. Home Access: DSL, Cable, FTTH, **5G Fixed Wireless**:

- **5G fixed wireless** not only promises **high-speed residential access**, but will do so without installing costly and failure-prone cabling from the telco's CO to the home.
- With 5G fixed wireless, using **beam-forming technology**, data is sent wirelessly from a provider's base station to a modem in the home.
- A WiFi wireless router is connected to the modem (possibly bundled together), similar to how a WiFi wireless router is connected to a cable or DSL modem.



Source: Internet

2.2. Physical Media:

- Physical media falls into two categories:
  - Guided media
    - The waves are guided along a solid medium, such as
      - a fiber-optic cable,
      - a twisted-pair copper wire, or
      - a coaxial cable.
  - Unguided media
    - The waves propagate in the atmosphere and in outer space, as in
      - a wireless LAN or
      - a digital satellite channel

2.2.1. Physical Media: Twisted-Pair Copper Wire

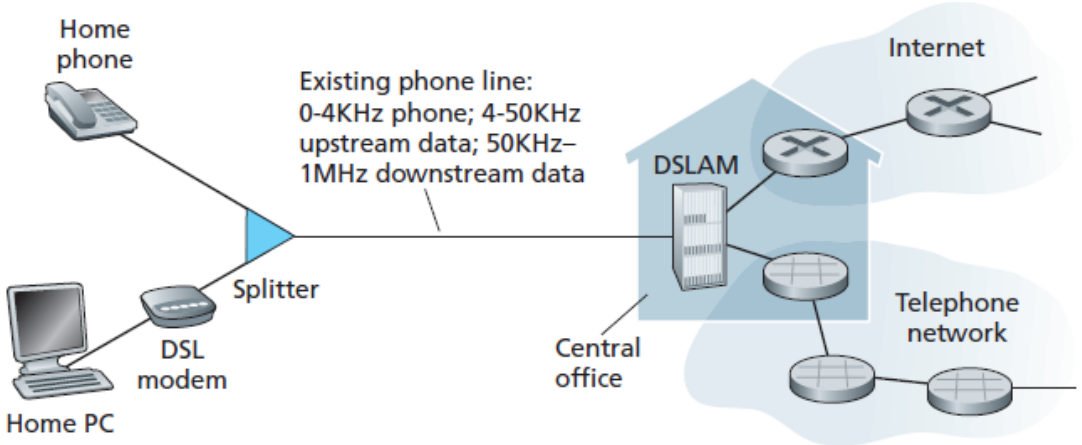
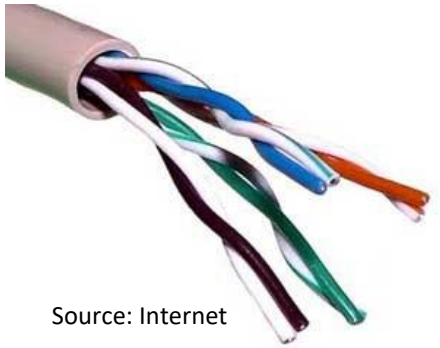


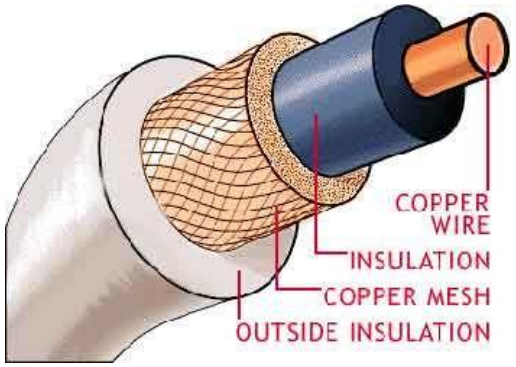
Figure 1.5 ♦ DSL Internet access



Source: Internet

- made up of **two insulated copper wires** that are twisted together.
- least expensive and most commonly used guided transmission medium
- used by telephone networks,
- used by residential internet access,
  - **dial-up modem** technology enables access at rates of up to **56 kbps** over twisted pair
  - **DSL** (digital subscriber line) technology has enabled residential users to access the Internet at **tens of Mbps** over twisted pair
- emerged as the dominant solution for high-speed LAN networking.
  - **Unshielded twisted pair** (UTP) is commonly used for computer networks within a building, that is, for LANs
  - Data rates for LANs using twisted pair today range from **10 Mbps to 10 Gbps**.
  - **Modern twisted-pair technology**, such as **category 6a cable**, can achieve data rates of **10 Gbps for distances up to a hundred meters**

2.2.2. Physical Media: Coaxial Cable



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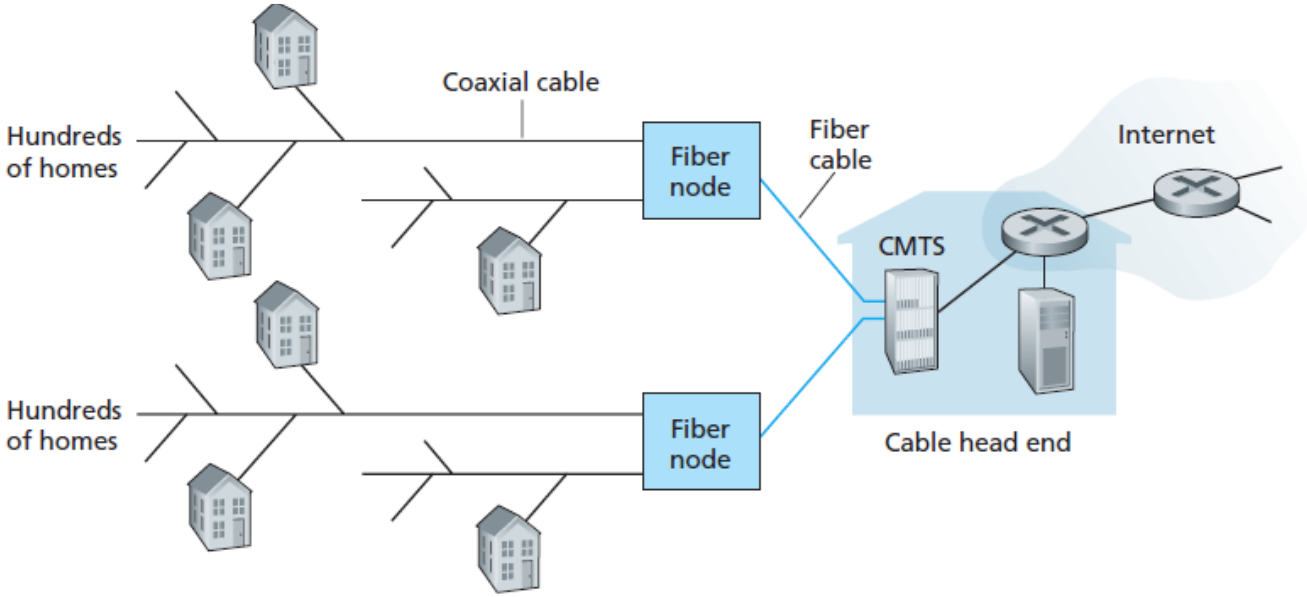
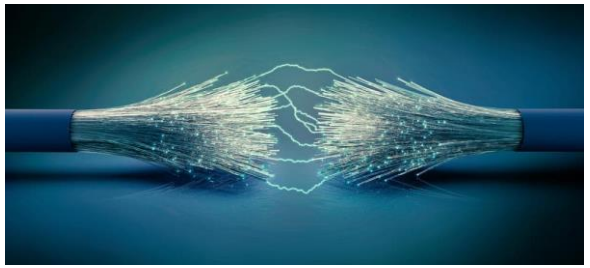


Figure 1.6 ♦ A hybrid fiber-coaxial access network

- consists of two copper conductors
- can achieve **high data transmission rates**
- quite common in cable television systems
- Can be used as a guided **shared medium**
  - a number of end systems can be connected directly to the cable, with each of the end systems receiving whatever is sent by the other end systems

2.2.3. Physical Media: Fiber Optics

Source: Internet



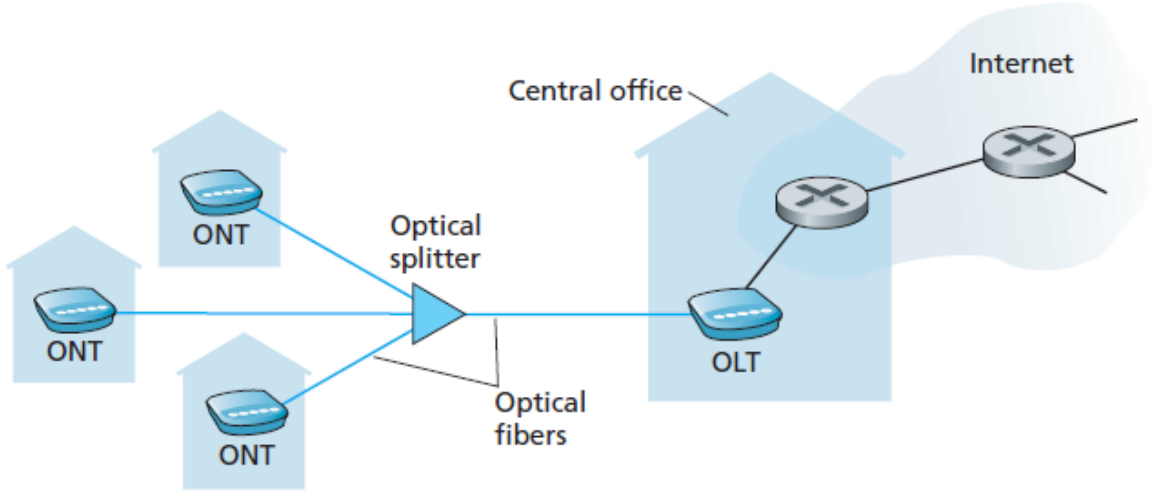
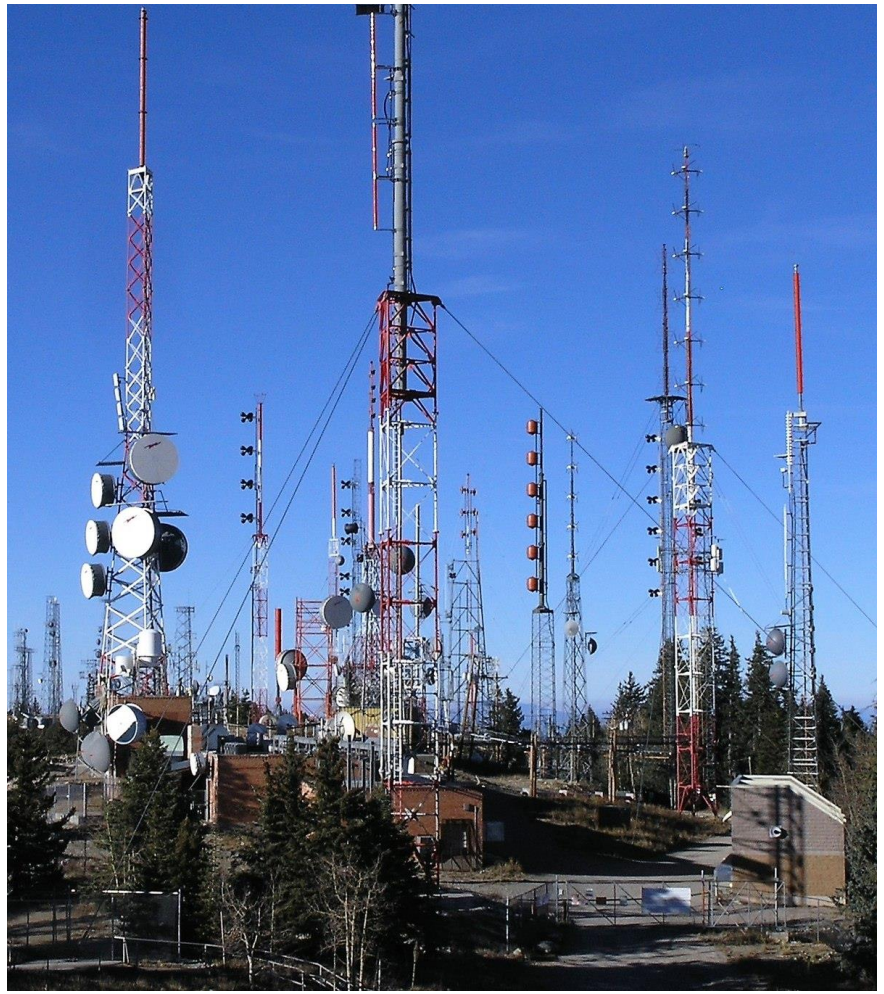


Figure 1.7 ♦ FTTH Internet access

- A thin, flexible medium that **conducts pulses of light** with each pulse representing a **bit**.
- Preferred for **long-haul guided transmission media**, particularly for overseas links.
- Also prevalent in the backbone of the Internet.
- A single OF can support **tremendous bit rates**, up to **tens or even hundreds of gigabits per second**,
  - are immune to **electromagnetic interference**,
  - have very **low signal attenuation up to 100 kilometers**, and
  - are **very hard to tap**
- The high cost of optical devices—such as transmitters, receivers, and switches—has hindered their deployment for short-haul transport, such as in a LAN or into the home in a residential access network.
- The Optical Carrier (OC) standard link speeds range from **51.8 Mbps to 39.8 Gbps**.

2.2.4. Physical Media: Terrestrial Radio Channels

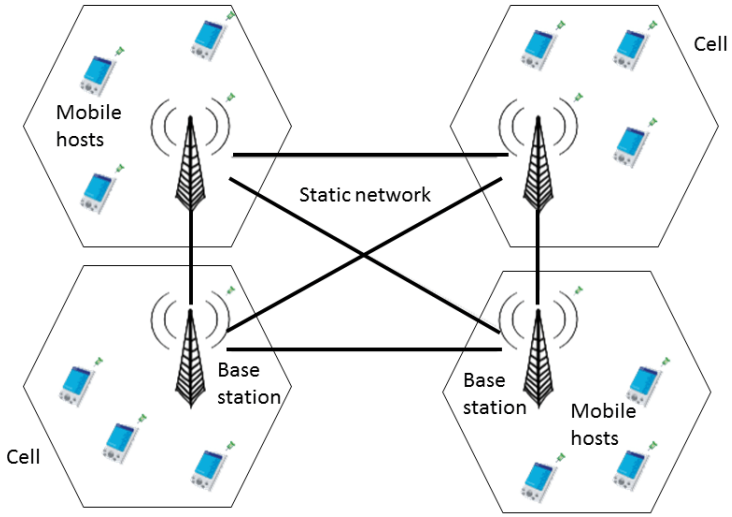
- An **attractive medium** because
  - they require **no physical wire** to be installed,
  - can **penetrate walls**,
  - provide **connectivity to a mobile user**, and
  - can potentially carry a **signal for long distances**.
- The characteristics of a radio channel depend significantly on
  - the **propagation environment** and
  - the **distance** over which a signal is to be carried
- Environmental considerations determine
  - **path loss and shadow fading** (which decrease the signal strength as the signal travels over a distance and around/through obstructing objects),
  - **Multipath fading** (due to signal reflection off of interfering objects), and
  - **interference** (due to other transmissions and electromagnetic signals).



Source: Internet

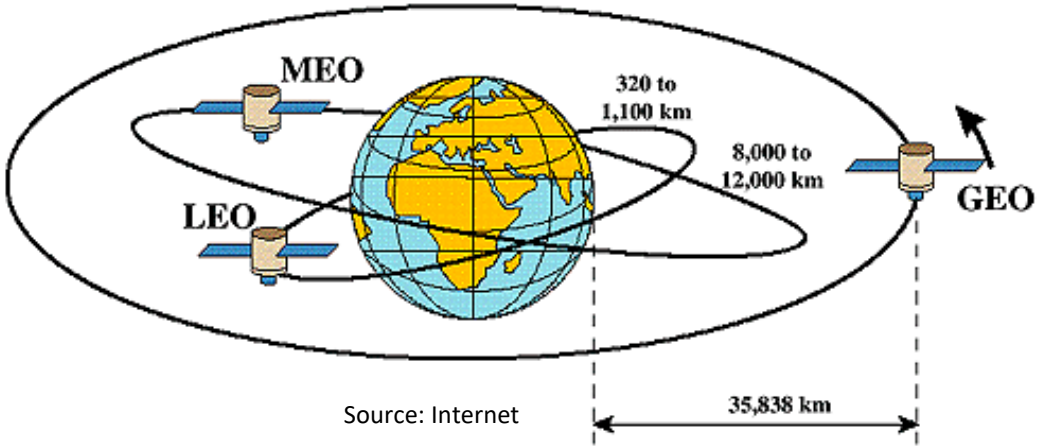
2.2.4. Physical Media: Terrestrial Radio Channels

- broadly classified into three groups:
  - those that operate over **very short distance** (e.g., **with one or two meters**);
    - **Personal devices** such as wireless headsets, keyboards, and medical devices operate over short distances.
  - those that operate in **local areas**, typically **spanning from ten to a few hundred meters**;
    - the **wireless LAN technologies** use local-area radio channels.
  - those that operate in the **wide area**, spanning **tens of kilometers**
    - the **cellular access technologies** use wide-area radio channels.



Source: Internet

2.2.5. Physical Media: Satellite Radio Channels



Source: Internet

- Two types of satellites are used in communications:
- **geostationary satellites** (used for TV and radio transmissions)
  - Geostationary satellites **permanently remain above the same spot on Earth**.
  - This stationary presence is achieved by **placing the satellite in orbit at 36,000 kilometers** above Earth's surface.
  - This huge distance from ground station through satellite back to ground station introduces a substantial signal **propagation delay of 280 milliseconds**.
  - Nevertheless, satellite links, which can operate at **speeds of hundreds of Mbps**, are often used in areas without access to DSL or cable-based Internet access.
- **low-earth orbiting (LEO) satellites** (for point to point communications)
  - LEO satellites are **placed much closer to Earth** and do not remain permanently above one spot on Earth.
  - They **rotate around Earth** (just as the Moon does) and may communicate with each other, as well as with ground stations.
  - LEO satellite technology may be used for Internet access sometime in the future.
- The satellite receives transmissions on one frequency band, regenerates the signal using a repeater, and transmits the signal on another frequency.

Overview:

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- **The Network Core**
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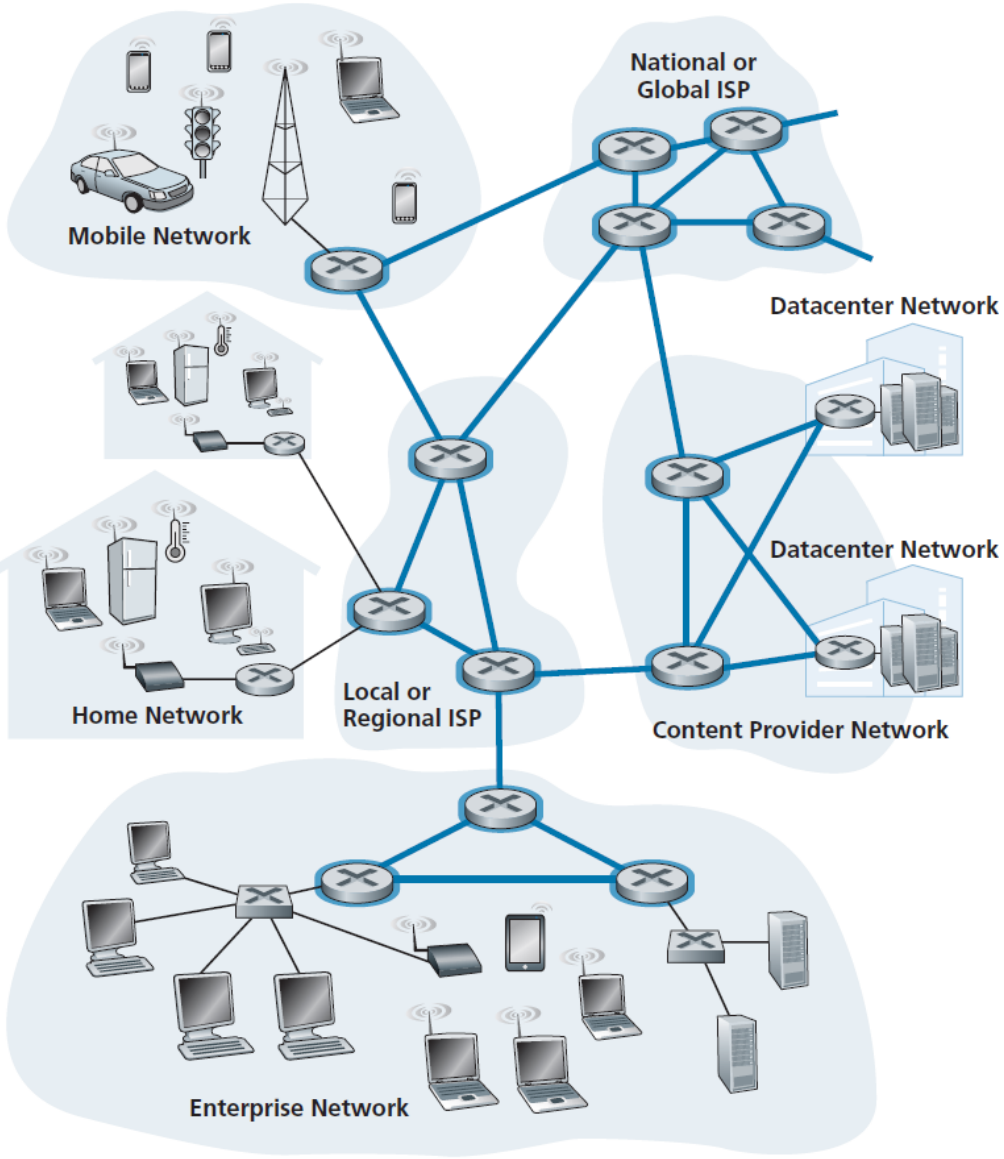
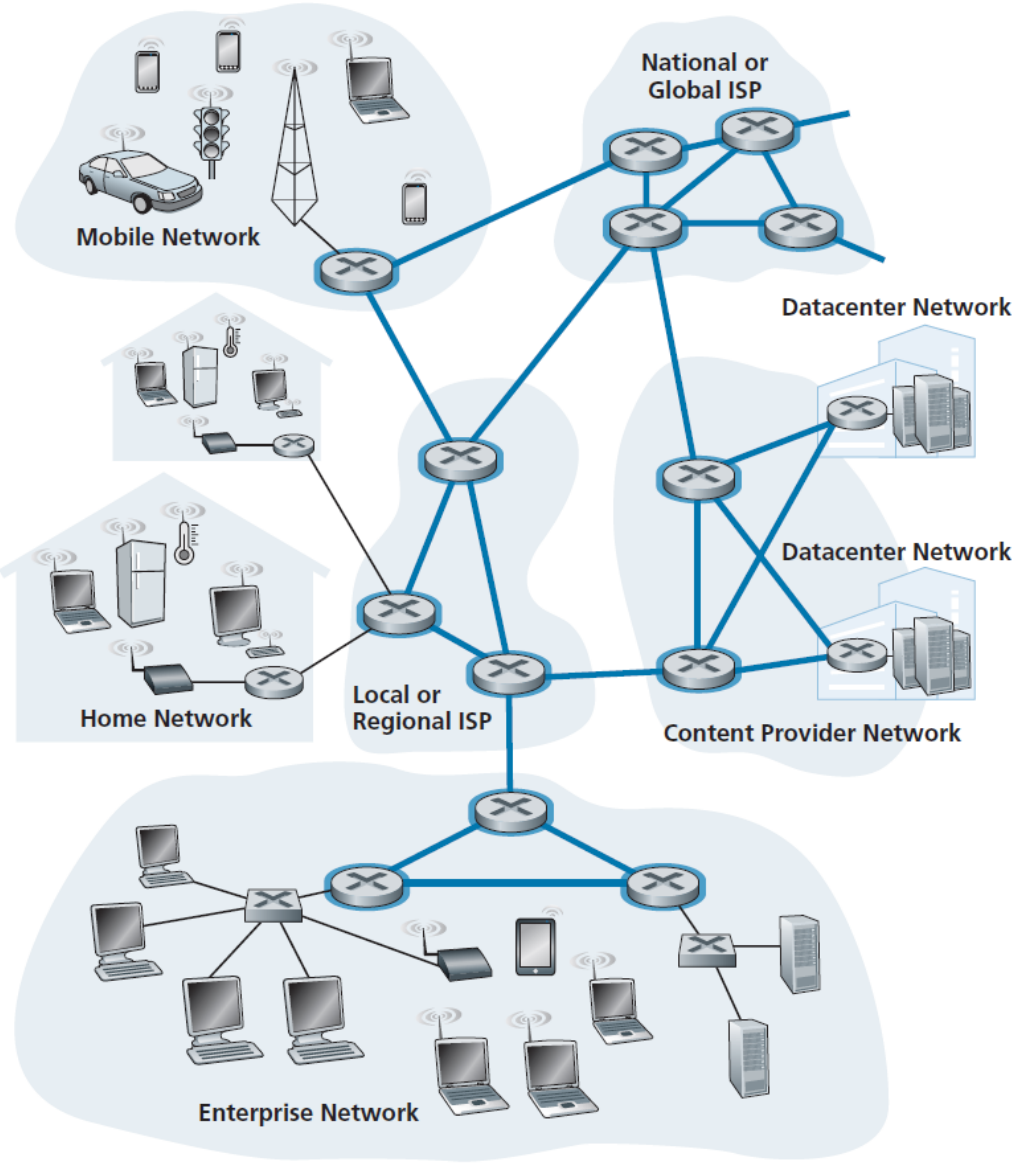
- Networks under attacks (Security)



3. The Network Core:

- Mesh of packet switches and links that interconnects the Internet's end systems.
- Two fundamental approaches to moving data through a network of links and switches are:
- **Packet Switching**
- **Circuit Switching**
- **Network of Networks**



3. The Network Core:

- Packet Switching
  - resources not reserved
  - need to wait
- Circuit Switching
  - reserved
  - serve immediately

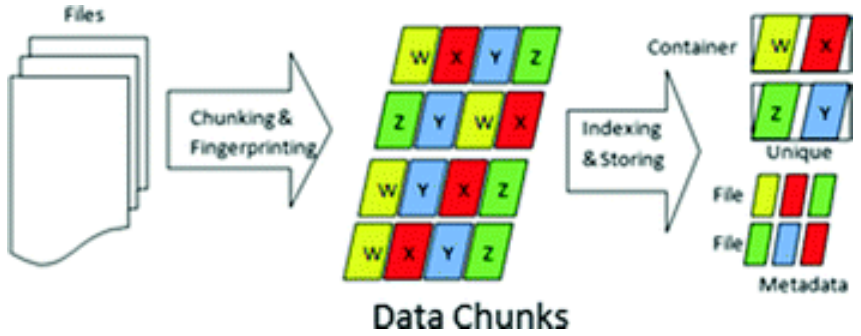
- restaurant example

Source: Internet

3.1. The Packet Switching:

- In a network application, end systems exchange **messages** with each other.
  - Control message
    - Hi, hello packets
  - Data message
    - email message,
    - a JPEG image, or
    - an MP3 audio file.

Source: Internet



- Source breaks long messages into smaller chunks of data known as **packets.**
- Each packet travels through **communication links** and **packet switches** (routers and link-layer switches).
- Packets are transmitted over each communication link at a **rate** equal to the ***full*** transmission rate of the link.
  - If a source end system or a packet switch is sending a packet of *L* bits over a link with transmission rate *R* bits/sec, then the time to transmit the packet is *L/R* seconds.