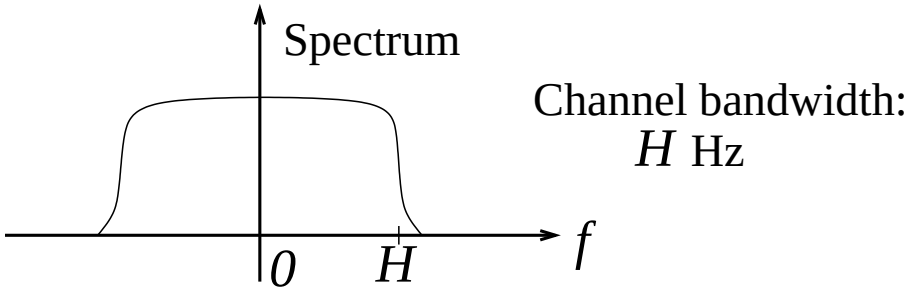
Physical Layer Overview

- **Physical layer** forms the basis of all networks, and we will first revisit some of fundamental limits imposed on communication media by nature

  Recall a medium or physical channel has finite bandwidth and is noisy, and this imposes a limit on information rate over the channel → This is a fundamental consideration when designing network speed or data rate



  Type of medium determines network technology → compare wireless network with optic network

- **Transmission media** can be guided or unguided, and we will have a brief review of a variety of transmission media

- **Communication networks** can be classified as switched and broadcast networks, and we will discuss a few examples

- The term "physical layer protocol" as such is not used, but we will attempt to draw some common design considerations and exams a few "physical layer standards"

Rate Limit

- A medium or channel is defined by its bandwidth H (Hz) and noise level which is specified by the signal-to-noise ratio S/N (dB)
- Capability of a medium is determined by a physical quantity called **channel capacity**, defined as

$$C = H \log_2(1 + S/N) \text{ bps}$$

- Network speed is usually given as data or information rate in bps, and every one wants a higher speed network: for example, with a 10 Mbps network, you may ask yourself why not 10 Gbps?
- Given data rate f_d (bps), the actual transmission or baud rate f_b (Hz) over the medium is often different to f_d
- This is for a more efficient utilisation of bandwidth: by grouping n bits into a symbol, we have

$$V = 2^n \text{ symbols or distinct signal levels}$$

  and transmission or baud rate is then $f_b = \frac{f_d}{n}$ Hz (or baud) $\longrightarrow$ what is the snag here?
- For example, 9600 bps with a 16-QAM scheme (V=16), the baud rate is

$$f_b = \frac{f_d}{n} = \frac{9600}{\log_2(16)} = 2400 \text{ Hz}$$

Rate Limit (continue)

- **Nyquist theorem**: To transmit at a transmission rate of f_b Hz requires a minimum bandwidth of $H_{\min} = \frac{f_b}{2}$ Hz $\longrightarrow$ This specifies the maximum data rate for the noiseless case as:

$$f_{d\max} = 2H \log_2(V) \text{ bps}$$

- This limit is not achievable in practice as, for physically realisable, a communication system need some extra bandwidth specified typically by a roll-off factor
- **Shannon's theorem**: If information rate does not exceed channel capacity, there exists a coding technique such that information can be transmitted over a noisy channel error free
- The channel capacity provides the maximum possible data rate for the general noisy case as:

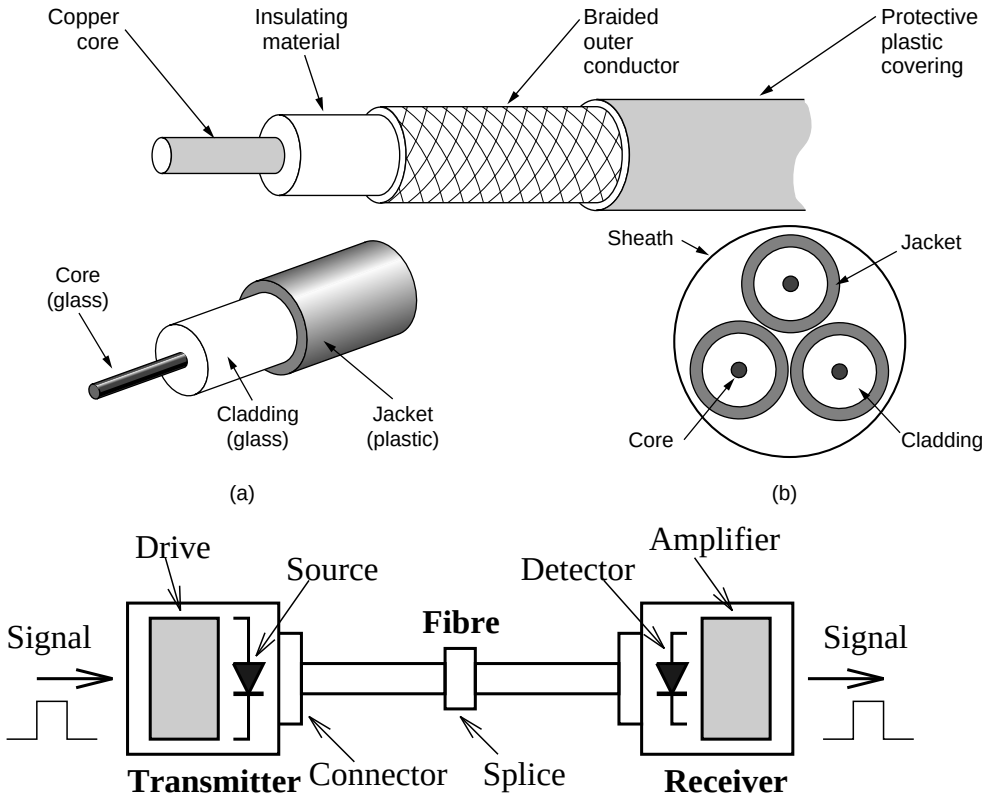
$$H \log_2(1 + S/N) \text{ bps}$$

- This is the ultimate limit, and the best state-of-art communication technology can bring information rate to be very close to channel capacity, but most practical data rates are far smaller
- Network data rate is limited by the choice of medium and communication technology

Transmission Media

- Some key factors in medium choice: bandwidth, cost, mobility, easy of installation and maintenance
- Transmission media can be guided and unguided
- Examples of guided media include copper wires (twisted pair, coax cable) and fiber optics
  - **Twisted pair**: low cost and typically offer a few tens of Mbps bandwidth, but new type can offer a few hundreds of Mbps. Comparable to telephone wiring at home
  - **Coax cable**: higher bandwidth of 1-2 Gbps and good noise immunity, and still used in cable TV and MANs
  - **Fiber optics**: offer huge bandwidth over long distance and immune to electromagnetic interference
  - One-way optical link:

    Fiber types: multimode step-index, multimode graded-index, single mode



Transmission Media (continue)

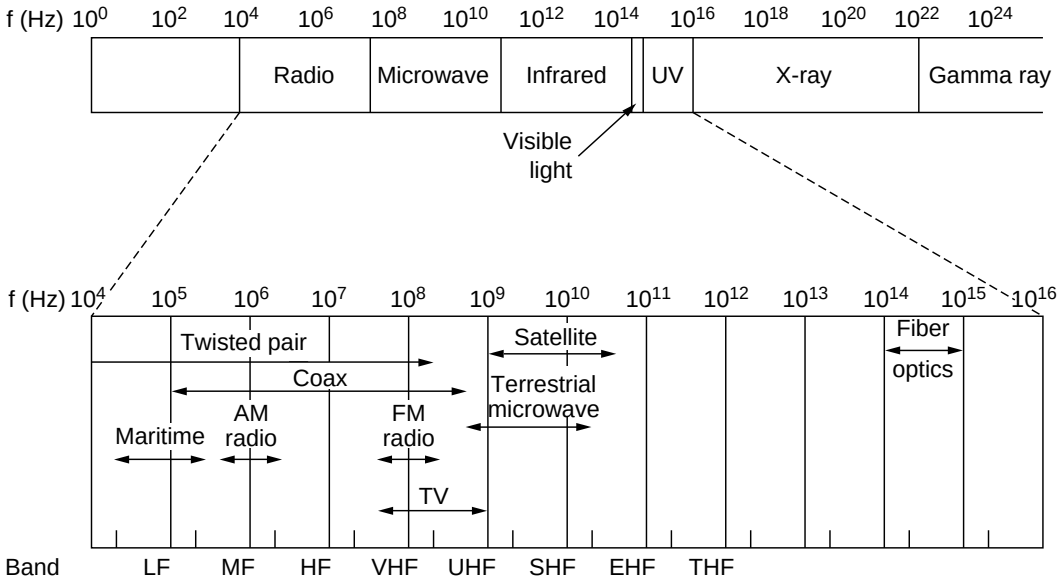
- Examples of unguided media include radio and microwave, infrared

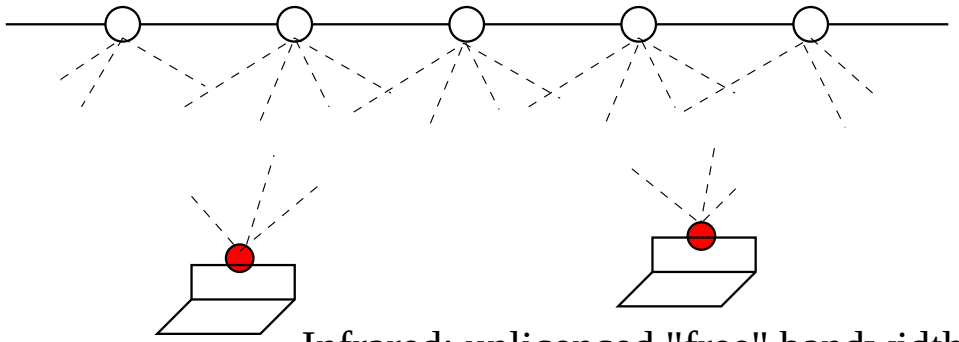
  Electromagnetic spectrum:

  – **Wireless** media are very hostile environments for communication and at present have restricted data rates (The 3G system, UMTS, only offers 2 Mbps for indoor and local area coverage)

  – **Infrared**: short range communications (as your TV remote control), small network for one room (regular reflectors at ceiling form "transmitters" array)

  – **Radio and microwave**: most widely used, various air interface standards



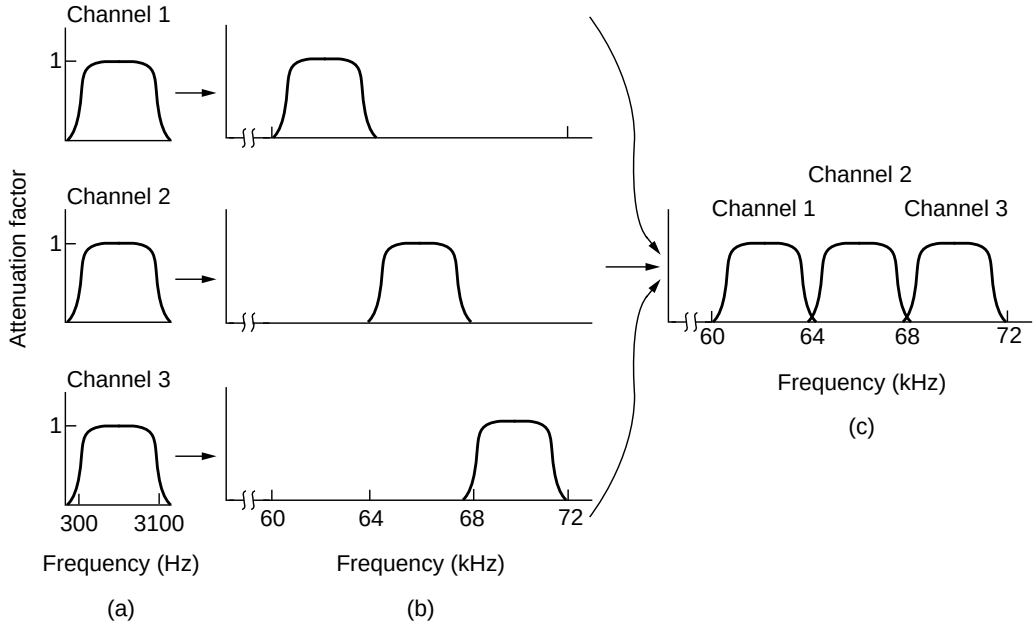


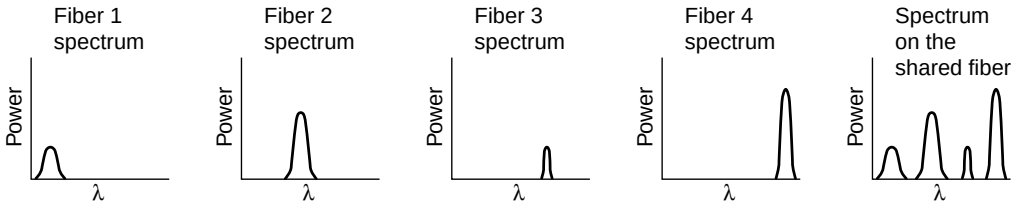
Infrared: unlicenced "free" bandwidth

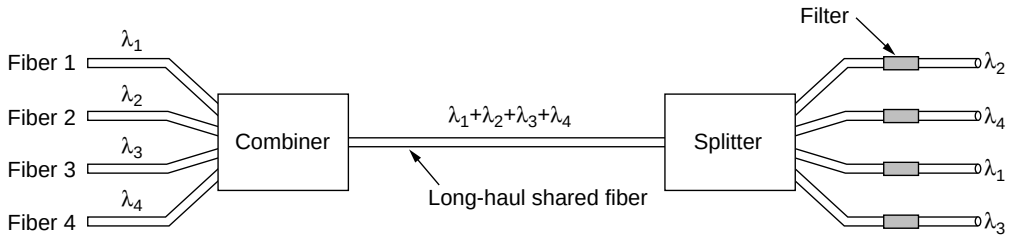
  – Mobile communications is big business, wireless mobile multimedia and internet are coming (MBS of up to 155 Mbps is in development for the future 4G system)

Multiplexing

- Communication facilities, such as telephone trunks, have great capability → To make efficient use of capacity, a communication link is typically shared by many users
- Multiplexing is a technique used to allocate the total capacity of a transmission medium among a number of users
- **Frequency division multiplexing**: divide available bandwidth into channels, an old technique for analogue communications
- **Wavelength division multiplexing**: use same principle as FDM, for fiber optics

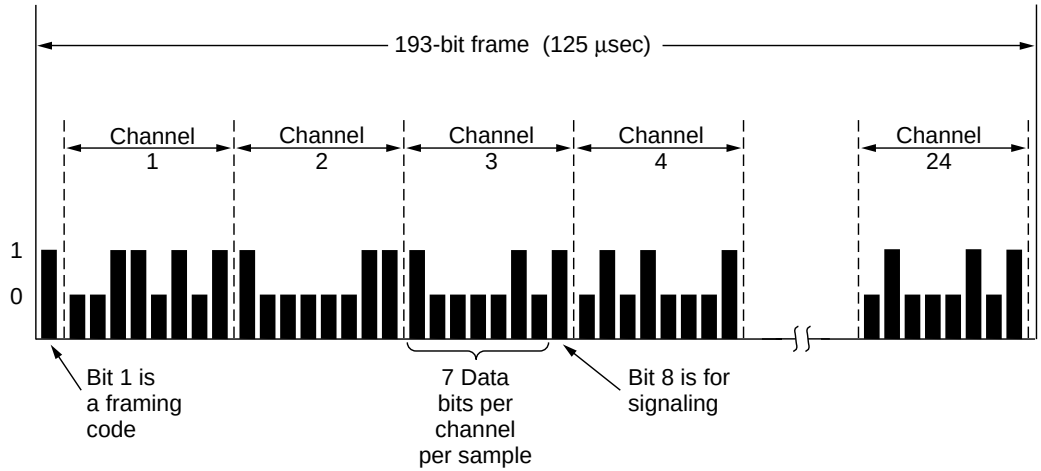


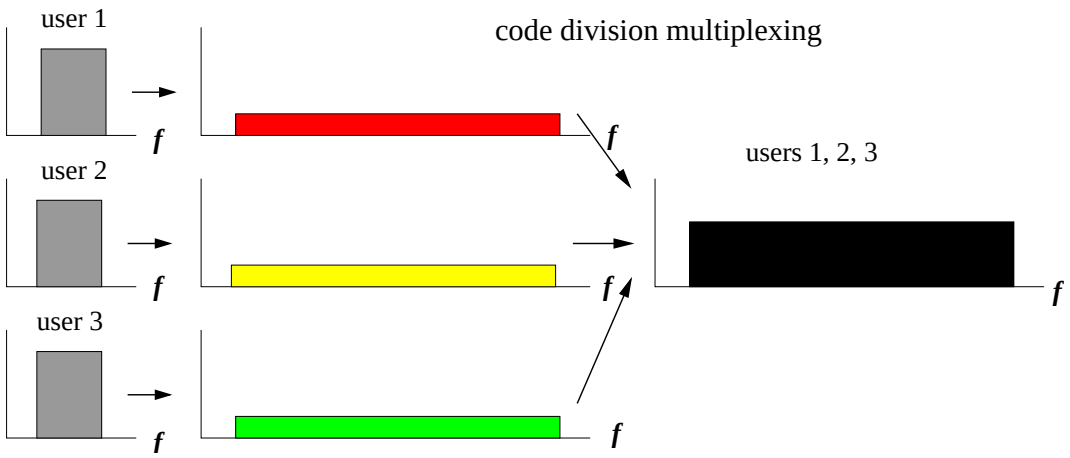




Multiplexing (continue)

- **Time division multiplexing**: combine low-bit-rates into high-bit-rate in frames, e.g. in telephone digital TDM hierarchy and 2G mobile system called GSM
- **Code division multiplexing**: user data is multiplied by a high-rate code sequence so its spectrum spread over total system bandwidth, e.g. in 3G mobile system
- **Space division multiplexing**: users with same carrier frequency, time slot in frame structure and spreading code can still be mixed up together, if they can be separated spatially (multi-antenna system)
- Users must be **separable** in some way, either in frequency or wavelength, or time, or code, or spatial domain

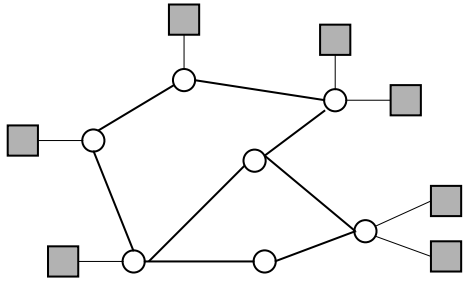




- Use multiplexing techniques for shared medium access leads to **multiple access** schemes FDMA or equivalently WDMA, TDMA, CDMA and SDMA

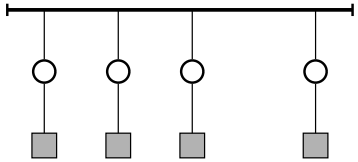
Communication Networks

- **Switched networks**: based on point-to-point transmission → as it is impossible to make point-to-point links for every pairs of users, switching is necessary
- In a switched network, data are transferred from source to destination via a series of intermediate switching nodes
  Switching nodes (routers) are not concerned with the content of the data

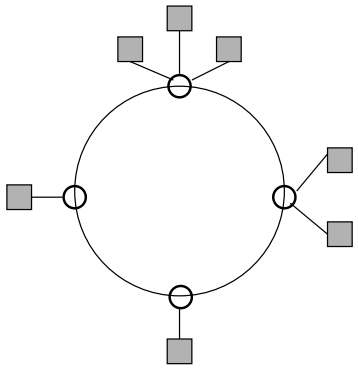


- Switched networks include circuit-switched and packet-switched networks
  - Circuit switching: a fixed connection through the network is established between two users, the dedicated connection exists for the duration of the call and is not shared by other users
  - Packet switching: a packet switched connection defines a logical pathway between two users through the network but does not dedicate any physical facilities to that connection
- **Broadcast networks**: based on broadcast transmission
- They do not have intermediate switching nodes, and communicate over a medium shared by many users

  A transmission from any one user is broadcast to and received by all others, e.g. packet radio, satellite and local area networks



Bus local network



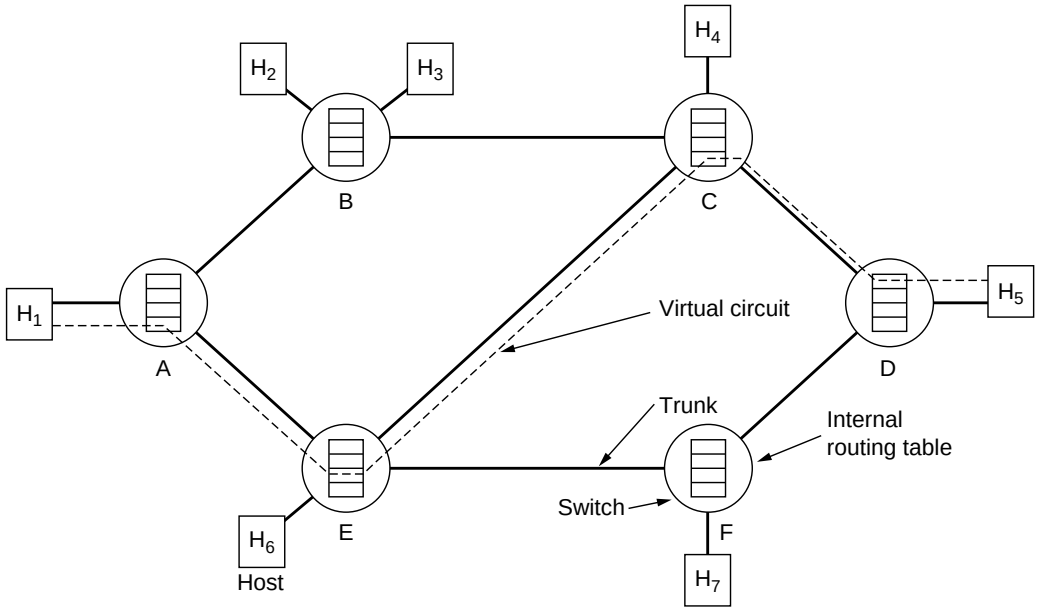
Ring local network

Broadband ISDN

- The ISDN is a fully digital network into home and supports integrated voice and data services but, with the basic rate interface of 2 B channels at 128 kbps for domestic use, it is clear inadequate
- Broadband ISDN, with two standard interfaces at 155.52 Mbps and 622.08 Mbps, supports the same ISDN services and offers enhanced services, such as video-on-demand and multimedia
- The basic B-ISDN services are built around the concept of virtual circuits

Virtual circuits: a full connection is set up between sender and receiver, but is implemented by packet switching, i.e. the route through the network is established prior to data exchange and is fixed for the duration of the logical connection but the connection is shared not dedicated

ATM Technology: use small fixed-length packets called cells to enable routing by hardware routing table for high speed



- The actual switching is implemented by the ATM (asynchronous transfer mode) Technology

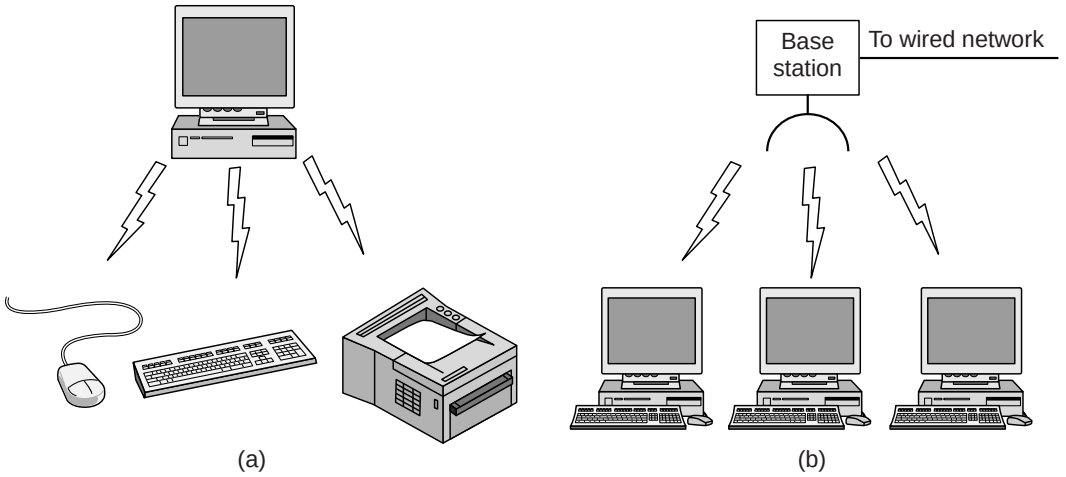
Wireless and Mobile Networks

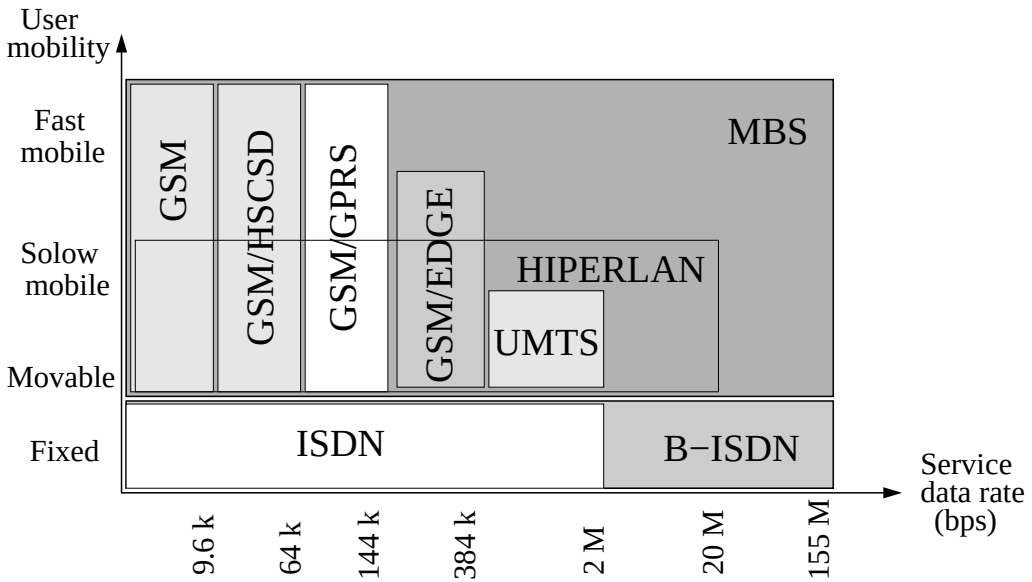
- System interconnection: interconnecting components of a computer using short-range radio (Fig.(a))

  Bluetooth: IEEE 802.15 specifies physical and data link layers

- Wireless LAN: in which every computer has a radio modem and antenna to communicate with other, and often there is an antenna on ceiling as base station (Fig.(b)) – **WIFI**
- Wireless MANs: **WMAX**
- Wireless WANs: 2G GSM, 3G UMTS (universal mobile telecommunication system) and MBS (mobile broadband system) for 4G mobile system

HSCSD: high-speed circuit switched data, GPRS: general packet radio service, EDGE: enhanced data rates for GSM evolution, HIPERLAN: high performance radio local area network





The Internet

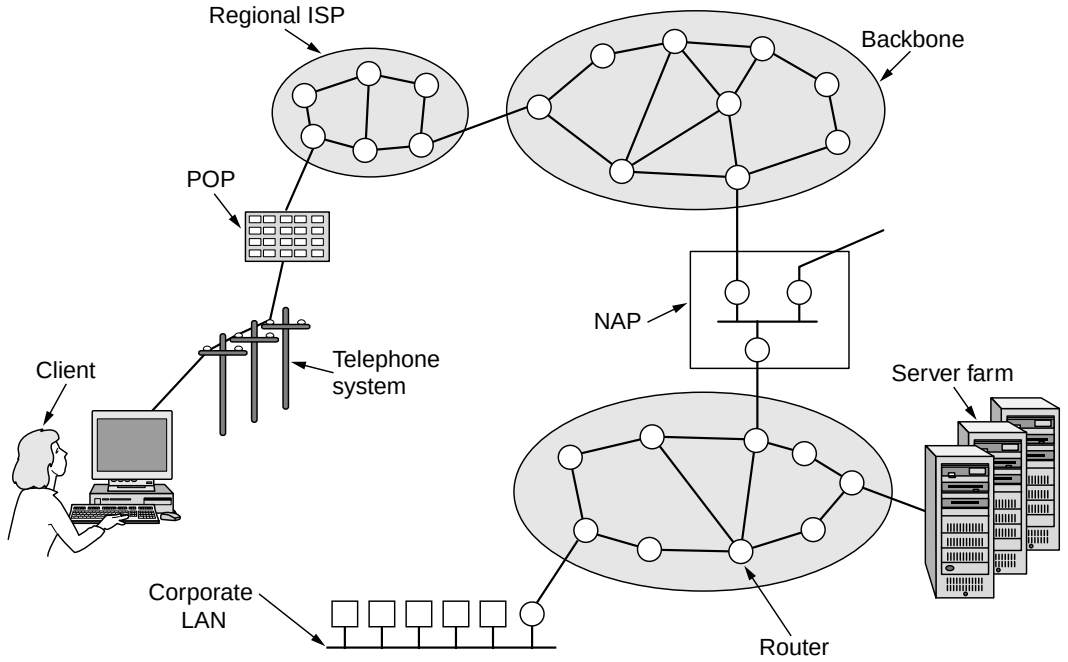
- The **Internet** is not a network at all, rather is a vast collection of different networks that use certain **common** protocols and certain common services

- A now **classical view** of the Internet:

  ISP: Internet service provider

  POP: point of presence (Connecting via telephone modem is circuit switched and signals in telephone system may be analogue. At POP, these signals are removed from telephone system and injected into ISP's regional network → From this point, the system is fully digital and packet switched)

  NAP: network access point



- What are missing in this picture are **wireless** mobile network components: Various air interfaces are being developed for mobile users to connect to the Internet

Summary

- Rate limit: bandwidth, channel capacity, data rate or information rate and baud rate or transmission rate, Nyquist theorem and Shannon theorem
- Transmission media: guided media (copper wires and fiber), unguided media (radio wireless), multiplexing concept
- Communication networks: switched networks (circuit-switched and packet-switched), broadcast networks
- B-ISDN: virtual circuits and ATM
- Wireless and mobile networks: system interconnection (Bluetooth), wireless LANs, and wireless WANs
- The Internet