Network Technologies

Internet Technologies and Applications

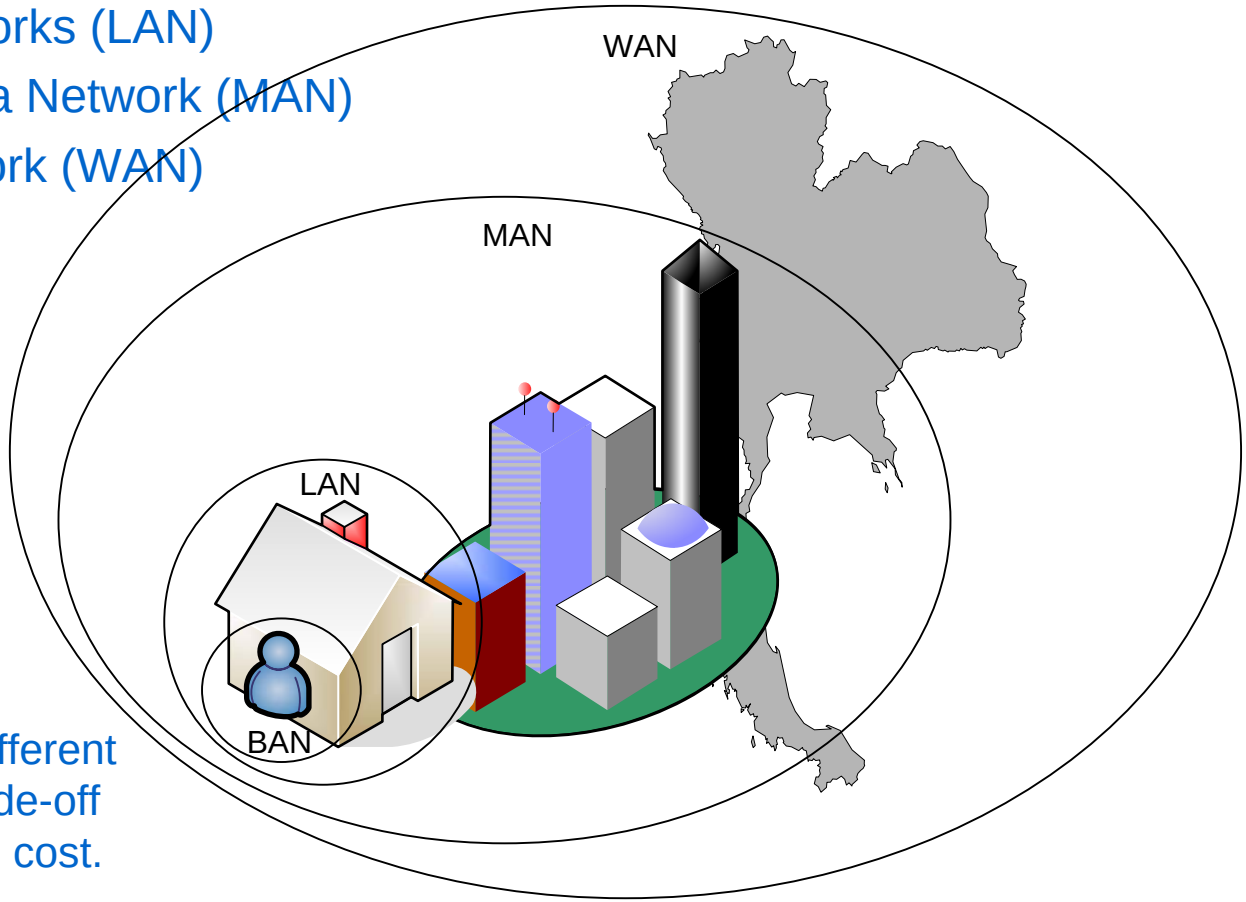
Aim and Contents

- Aim:
  - List and compare popular/future technologies for LANs, WANs; wired and wireless
  - Familiarise students with network technologies in use today

- Contents:
  - Categorizing Networks: geography, users, medium, mobility
  - Wired Networks
  - Wireless Networks

Categorizing Networks

- Based on geographical coverage:
  - Body Area Networks (BAN)
  - Local Area Networks (LAN)
  - Metropolitan Area Network (MAN)
  - Wide Area Network (WAN)

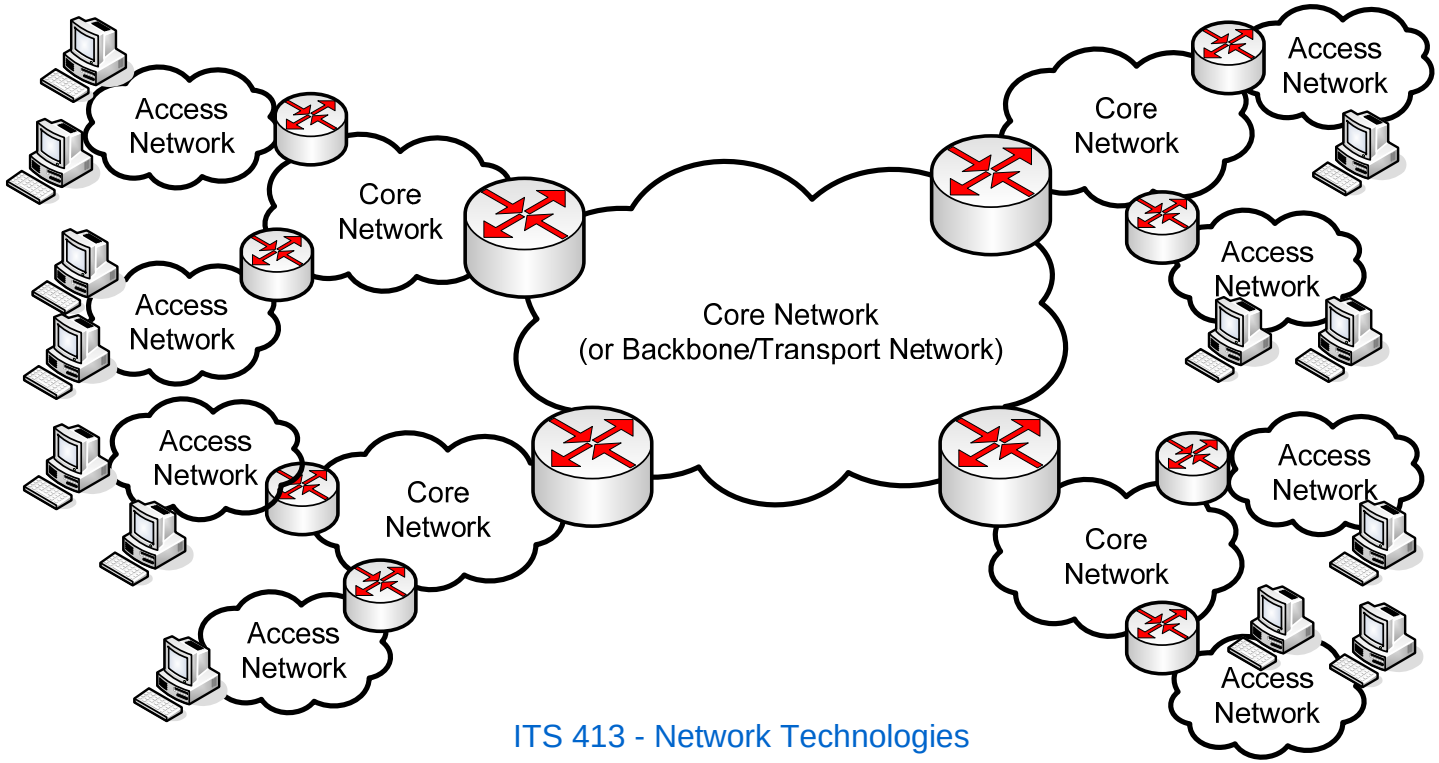


Users of networks have different requirements.

Transmission media have different physical characteristics. Trade-off between data rate, distance, cost.

Categorizing Networks

- Based on users:
  - Access Network: end-users access network services
  - Core Network: traffic from between access and core networks transported
    - Related terms: Backbone Network, Transport Network



Categorizing Networks

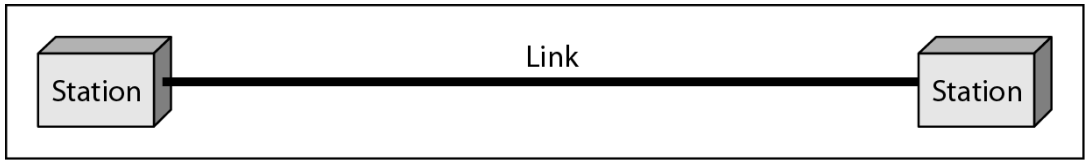
- Based on users:
  - Access networks require capacity to support
    - Traffic between users within the same access network
    - Traffic from users in one access network to another
  - Core networks require capacity to support
    - Traffic between multiple access networks
  - Not all users send the same amount of data at the same time,
    - In access networks, the amount of traffic sent over time varies significantly; hence difficult to take advantage of statistical multiplexing
    - In core networks, the average traffic sent over time is stable; can take advantage of statistical multiplexing
  - Access networks are generally higher speed than core networks (for same cost)

Categorizing Networks

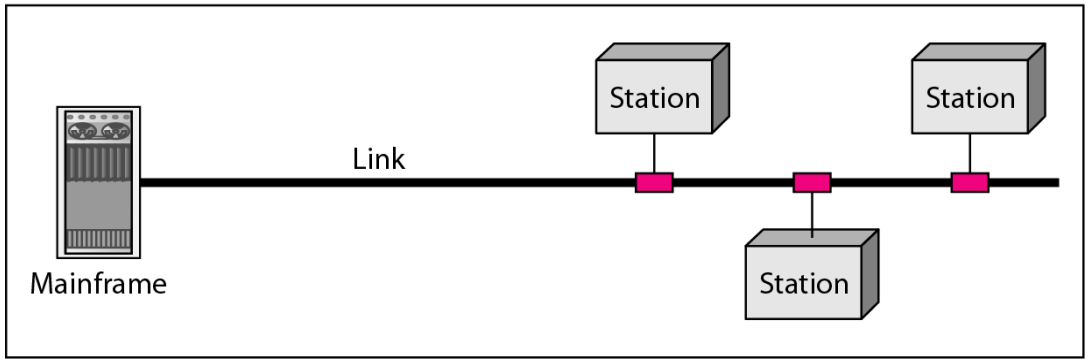
- Based on transmission medium:
  - Wired
    - Easy to control signal transmission
    - Protect from interference from other transmitting sources
    - Higher data rates, less errors, more predictable
  - Wireless
    - Allows mobility
    - Allows convenience

Categorizing Networks

- Based on link configuration:
  - Point-to-point (two devices)
  - Point-to-multipoint (shared among N devices)
    - Easier to allow multiple devices to communicate with each other
    - Harder to control the “sharing” of the medium



a. Point-to-point



b. Multipoint

Categorizing Networks

- Based on user mobility:
  - Fixed
    - Devices in the network are fixed (do not move)
    - Easier to design network; predict traffic requirements
  - Mobile
    - Devices may be move
    - Difficult to know how much capacity is needed in advance

Wired Network Technologies

Access Network Technologies

- IEEE 802.3 Ethernet family
- Copper (Telephone) Access
- Coaxial and Optical Fibre Access
- Wireless
  - IEEE 802.11 Wireless LAN family
  - Bluetooth (and other short range wireless)

IEEE 802.3 Ethernet Family

- Very popular LAN technology
  - Originally point-to-multipoint, but now mainly point-to-point, switched communications
  - Data rates have been increased over time: 10Mb/s, 100Mb/s, 1Gb/s, 10Gb/s, …
  - Very cheap devices, easy to install network

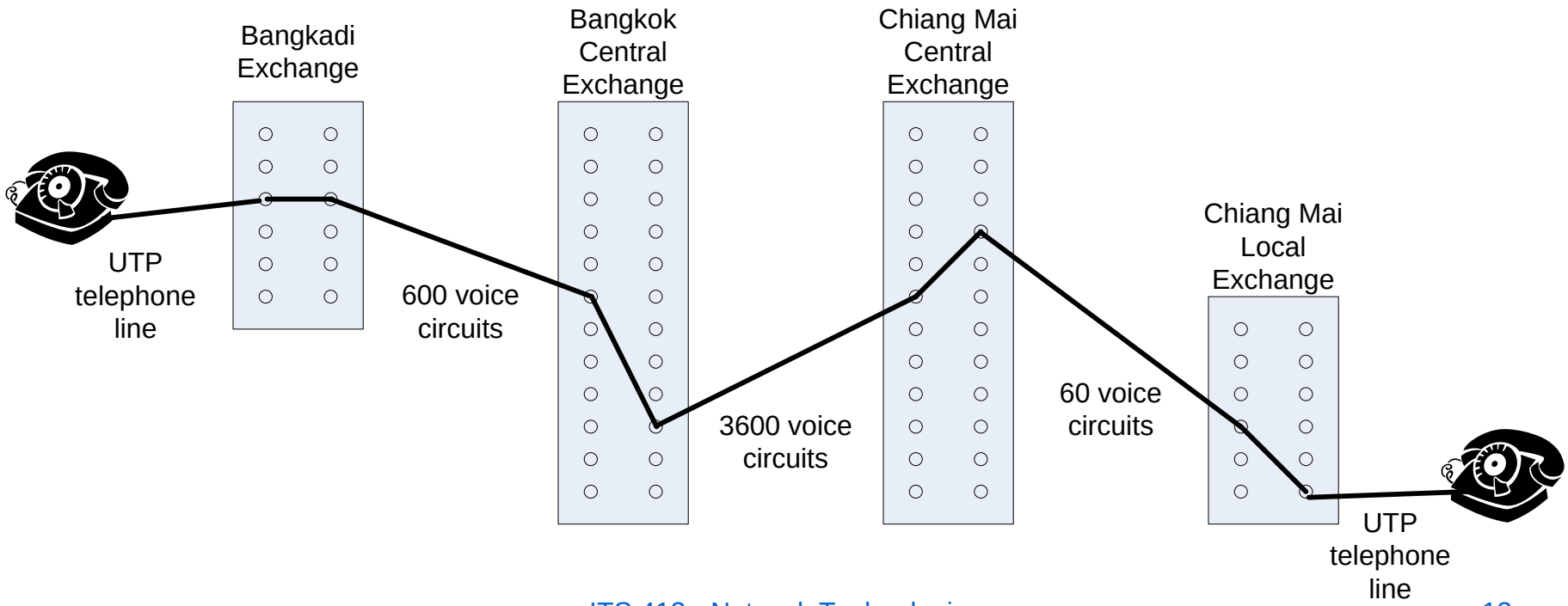
- Because of popularity, has been adapted to non-LAN applications:
  - Long distance links using 10Gb/s (MANs, WANs)
  - Interface between devices (router/switch, Storage Area Networks)

Copper (Telephone) Access

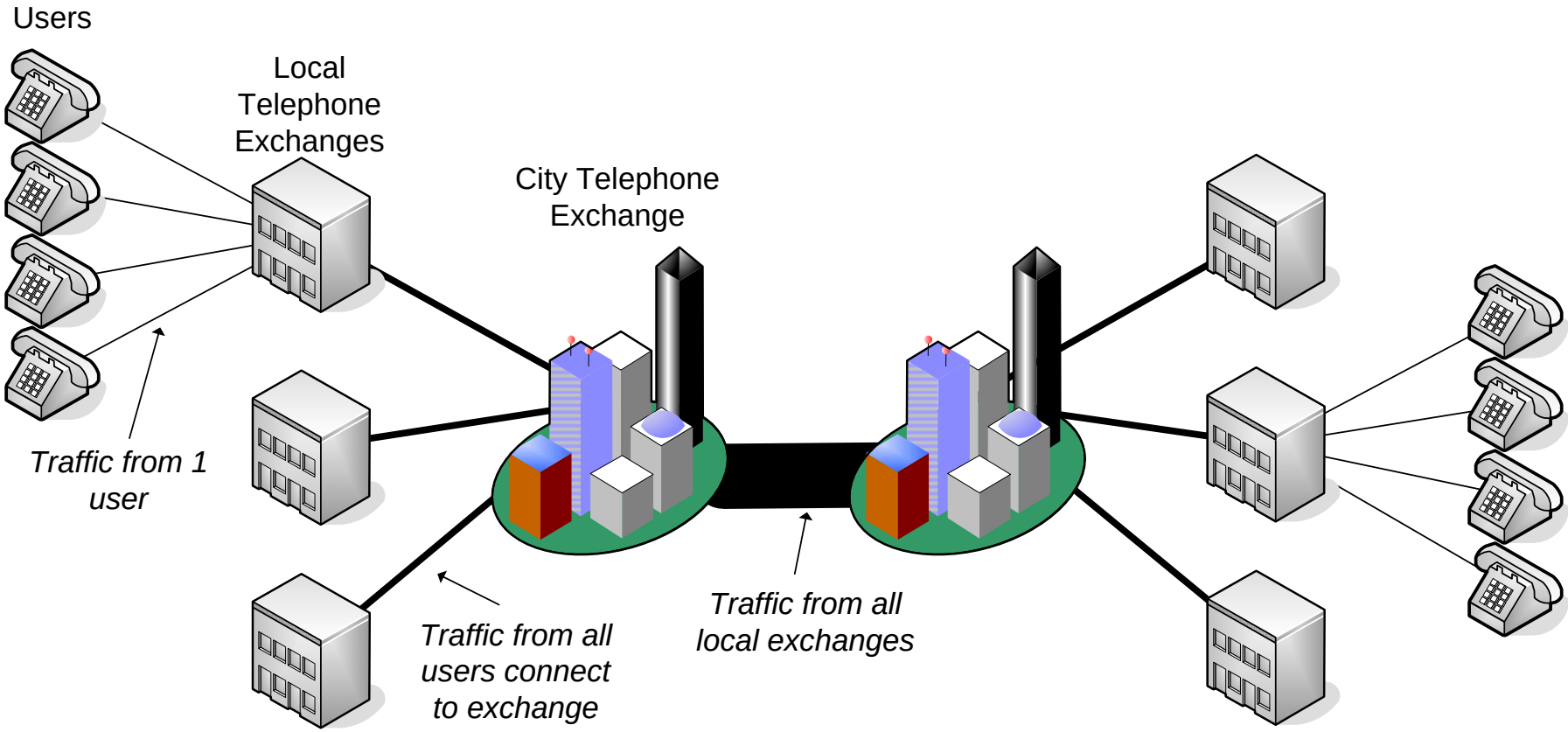
- Telephone networks have provided connectivity to users for decades
  - The network that connects users across countries, and between countries, is called the *Public Switched Telephone Network* (PSTN)
  - The service delivered to the end user is called the *Plain Old Telephone Service* (POTS)
  - The access line in most telephone networks is a twisted pair copper cable between a local telephone exchange and the home (or apartment/office)
  - Wide availability of telephones meant data communications adapted to make use of the network
    - Dial up Internet Access
    - Integrated Services Digital Network (ISDN)
    - Digital Subscriber Line technologies
      - ADSL, HDSL, VDSL, …

PSTN

- Multiple users connect to a local exchange via Unshielded Twister Pair
- Exchanges are connected in a hierarchy across cities, countries and the world
  - Originally using copper, but now using coaxial, satellite and fibre

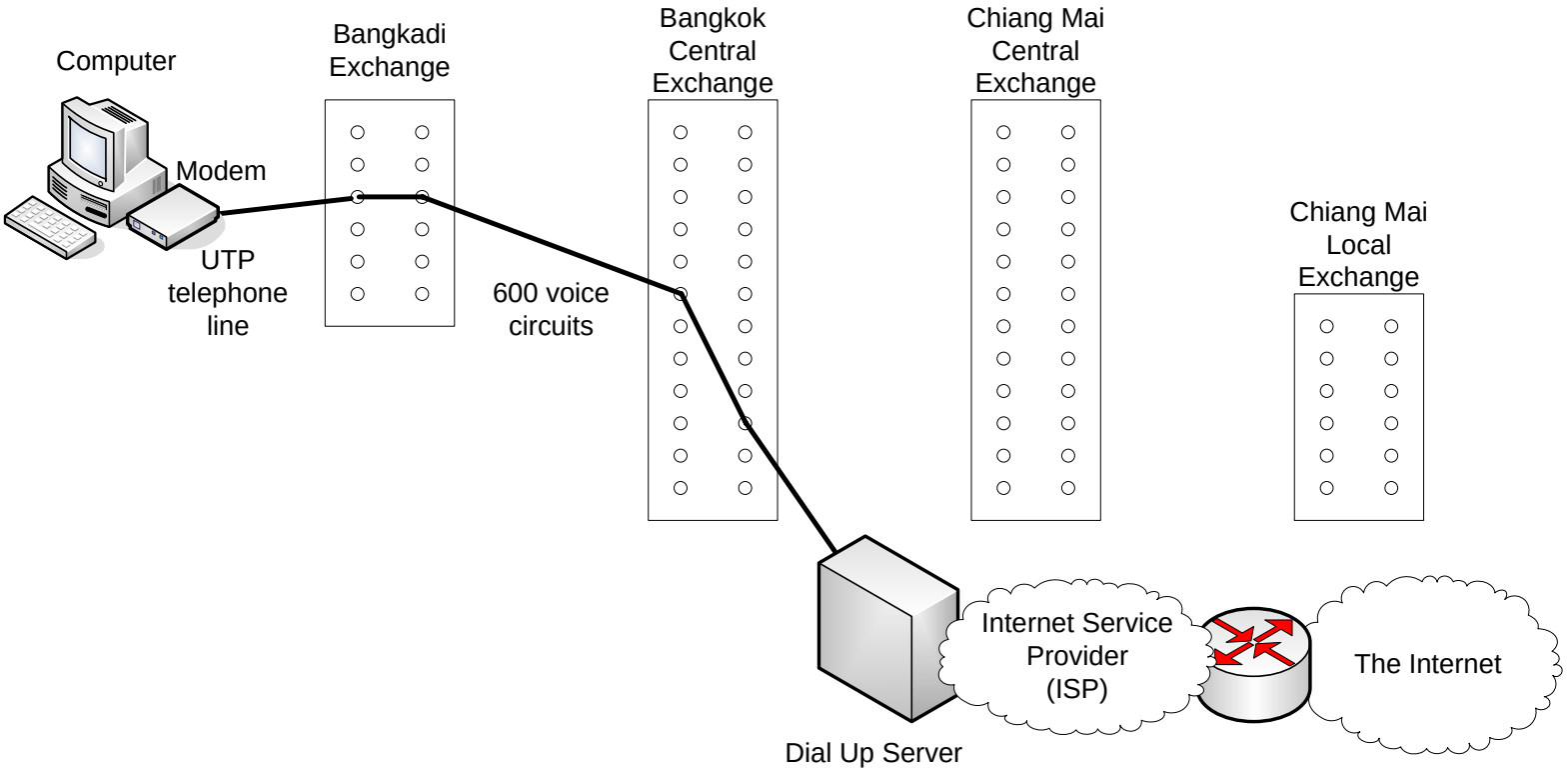


PSTN


Users
Local
Telephone
Exchanges
City Telephone
Exchange
Traffic from 1
user
Traffic from all
users connect
to exchange
Traffic from all
local exchanges

Dial Up Access

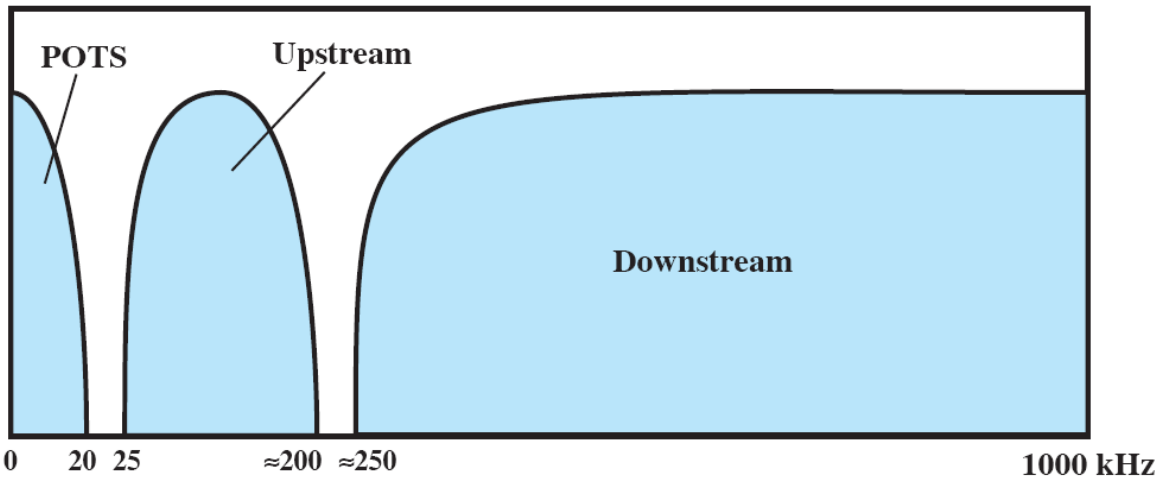
- Dial-up access over telephone lines
  - Modem converts digital data from computer into analog signal to be sent over telephone line (instead of analog voice)
    - Telephone system limits bandwidth to 4kHz (although copper cable can carry more)
    - Maximum data rate 56kb/s



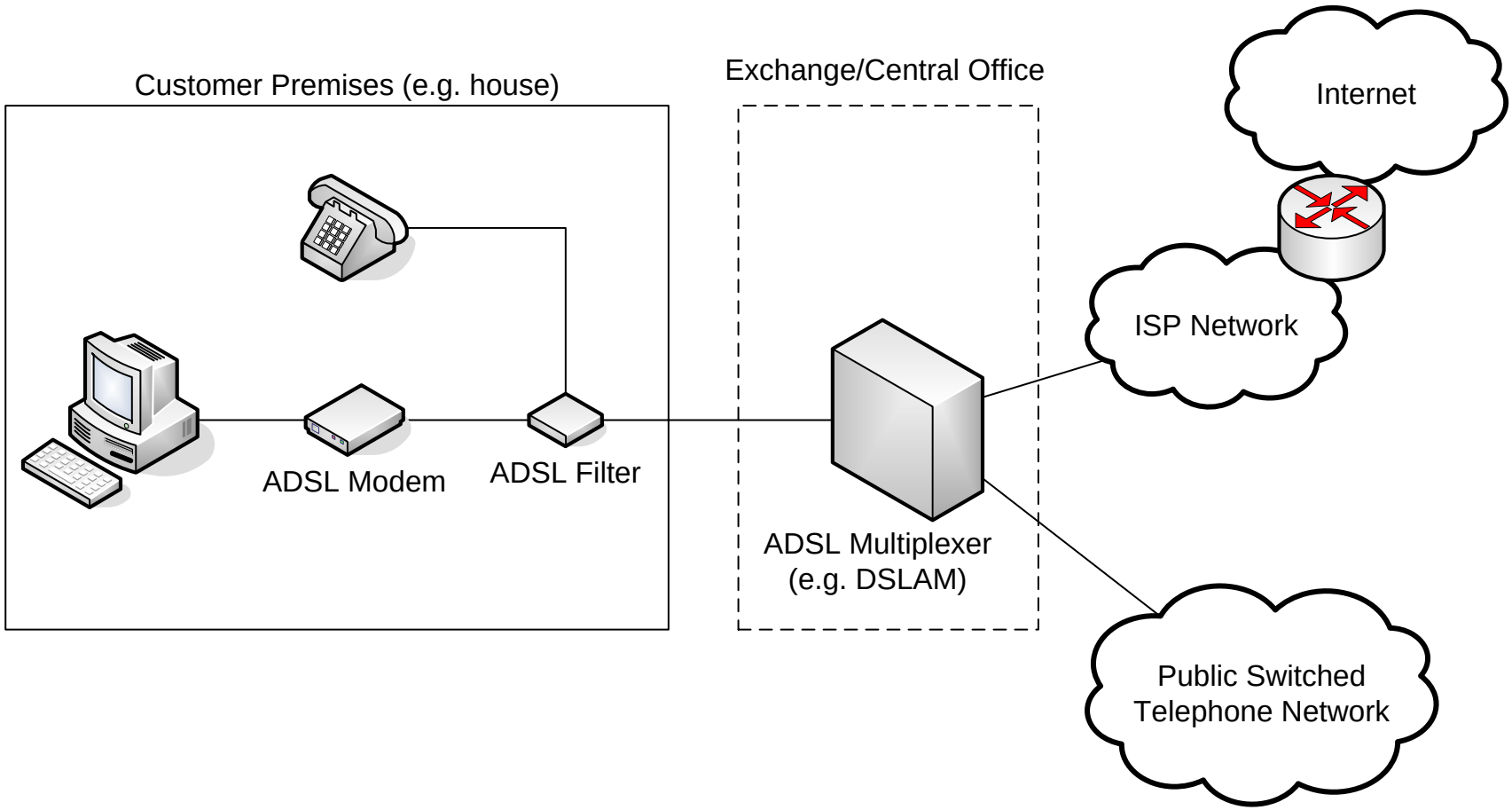
Digital Subscriber Line

- Copper line can actually transmit about 1MHz spectrum
  - DSL technologies make use of most of this 1MHz (except the 4kHz for voice)
  - Digital signals are sent from home (modem) to exchange (multiplexer)
  - Different types of standards

ADSL Example use of copper line spectrum



Digital Subscriber Line



Digital Subscriber Line

- Asymmetric Digital Subscriber Line (ADSL)
  - Larger bandwidth (and hence data rate) for downstream (exchange to you) than upstream (you to exchange) traffic
    - ADSL Multiplexers (in exchange) can support larger bandwidths on transmission
    - Well suited to many Internet applications, e.g. web browsing, email
  - ADSL can adapt data rate depending on amount of noise on line
    - Lower speeds for longer distances and poor quality copper cables
  - Key Features:
    - Makes use of widely installed telephone network
    - Supports basic voice and video applications

Digital Subscriber Line

- Other DSLs:
  - ADSL2, ADSL2+
  - High Data Rate DSL (HDSL)
  - Symmetric (High-Speed) DSL (SDSL, SHDSL)
  - Very High Speed DSL (VDSL, VDSL2)

Technology	*Downlink*	*Uplink*
ADSL	512kb/s	256kb/s
ADSL	1.5Mb/s	512kb/s
ADSL	8Mb/s	820kb/s
ADSL2	12Mb/s	1Mb/s
ADSL2+	24Mb/s	3.5Mb/s

Technology	*Speed*	*Use*
HDSL	1.5Mb/s	Alternative of T1/E1
SHDSL	5.6Mb/s	Home/ business
VDSL	100Mb/s	FTTC

Coaxial Cable Access

- Coaxial cables have been used to deliver cable TV to many homes
  - Cable operator has a separate physical network than telephone network
- Coaxial cable network can be used to deliver data to a home
  - Coaxial cables typically shared medium between homes in neighbourhood
    - Point-to-multipoint topology
    - More people using at the same time, the lower throughput for you
  - DOCSIS is standard for Data over Cable Service Interface Specification
  - Data rates (down/up) :
    - 6Mb/s / 768kb/s
    - 30Mb/s / 1Mb/s

- Key features:
  - Generally faster than ADSL, although shared medium
  - Can avoid paying for telephone line (if use Voice over IP)

Optical Fibre Access

- Optical fibre mostly used in core (not access) networks
- However, delivering fibre to the end user is possible
  - Instead of (or as well as) copper and coaxial cables
  - Referred to as Fibre To The Home (FTTH) or Premise (FTTP) or Building (FTTB)
  - Point-to-multipoint topology
    - Single optical fibre to a building (or multiple buildings) is shared by 10 to 30 users
  - Typical speeds offered are 100Mb/s (but shared between users)

- Key features:
  - Allow much higher data rates than copper and coaxial cable
  - Support data (Internet), voice and video (e.g. digital TV)
  - Requires installation of optical fibre

Summary: Wired Access Networks

- Ethernet is the most common wired access network technology
  - Almost all computing devices have (or can support) Ethernet cards
- From building (home/office) to other core networks, common to make use of existing telecommunication networks:
  - Dial-up, DSL using the telephone network (PSTN)
  - Coaxial used cable TV network
- Optical fibre to the building is becoming more popular
  - Higher speeds, but costly to deploy

Core Network Technologies

- Telephone-based Digital circuits
  - Leased Lines, Digital Hierarchies: PDH, SDH/SONET
  - Point-to-point topology
- Packet Switching WANs
  - X.25, Frame Relay, ATM
- IP Networks
- Wireless Networks
  - Point-to-point microwave, satellite

Telephone Based Digital Circuits

- Telephone networks (PSTN) use circuit switching
- Telephone companies originally designed their core networks to carry digitized voice calls (later extended to carry data)
  - Hence most data rates measured in multiples of 64kb/s (or voice circuits)
    - Using PCM to sample voice at 8000 samples per second, 8 bits per sample
- The circuit switched network of telephone companies can also be used to provide private (dedicated) circuit networks between end-points
  - Typically point-to-point topology, but can be extended to mesh, star and ring topologies

Telephone Based Digital Circuits

- Plesionchronous Digital Hierarchy (PDH)
  - Originally point-to-point links using copper lines
  - Differences between European and US standards

Name	Bit Rate	Voice Circuits	Location
–	0.064 Mbps	1	
T1	1.544 Mbps	24	North America
T2	6.312 Mbps	96	North America
T3	44.736 Mbps	672	North America
T4	274.760 Mbps	4032	North America
E1	2.048 Mbps	30	Europe
E2	8.448 Mbps	120	Europe
E3	34.368 Mbps	480	Europe
E4	139.264 Mbps	1920	Europe

PDH is used to connected between sites and usually leased (rented) from a telecommunications company on a monthly basis. For example, if CAT had a copper cabling between Bangkadi and Rangsit, SIIT could lease a PDH circuit, such as E1 at 2Mb/s.

Telephone Based Digital Circuits

- Synchronous Digital Hierarchy (SDH)
  - Developed for increased data rates and overcome limitations of PDH
  - Uses optical fibre
  - SDH is “International” standard; SONET is the US version

Standard Name	Optical Name	Bit Rate	Voice Circuits
STS-1	OC-1	51.840 Mbps	810
STS-3	OC-3	155.520 Mbps	2430
STS-12	OC-12	622.080 Mbps	9720
STS-24	OC-24	1,244.160 Mbps	19440
STS-48	OC-48	2.488 Gbps	38880
STS-96	OC-96	4.976 Gbps	64512
STS-192	OC-192	9.952 Gbps	129024
STS-256	OC-256	13.271 Gbps	172032

Packet Switching WANs

- Several packet switching network technologies have been developed and used over past 30 years
  - A telecommunications company (or large organisation) deploy their own transmission media (copper cables or optical fibre) and run a packet switching service
- Virtual Circuit Packet Switching
  - X.25
  - Frame Relay
  - ATM
- Datagram Packet Switching
  - IP

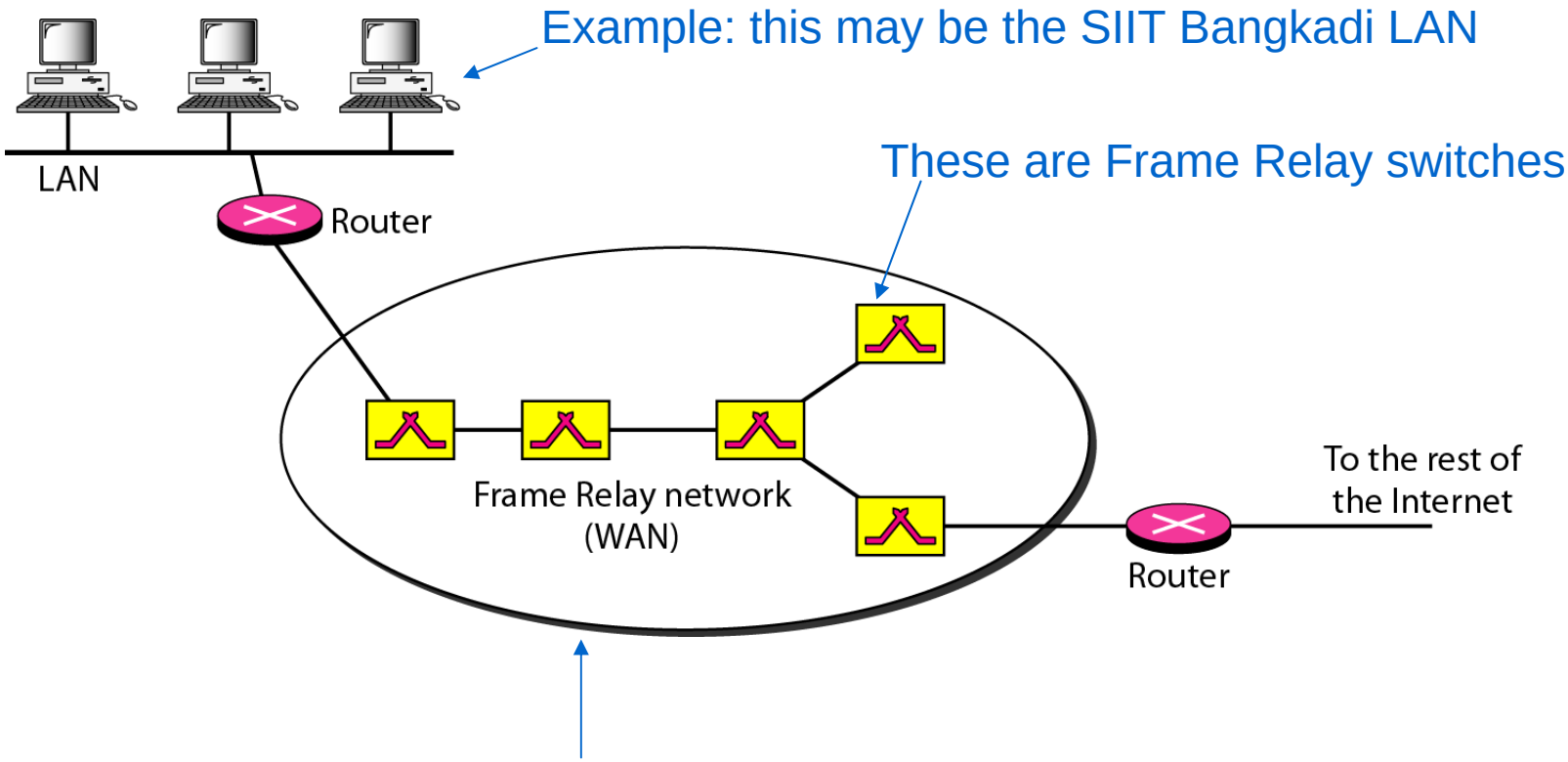
X.25

- ITU-T standard for interface between host and packet switched network
  - Developed in 1970's; initiated by telephone carriers – there was a need to provide WAN connectivity over public data networks
  - Designed to transmit over error-prone analog links
  - Today, largely replaced by other technologies (frame relay, IP over SONET, …)
    - Legacy networks mainly support transaction-oriented application (e.g. financial)
    - Still used in developing countries
- Defines three layers
  - Physical
  - Link
  - Packet (like Network layer)
- Typical speed is 64kb/s; up to 2Mb/s

Frame Relay

- Developed in late 1980's, early 1990's
- Designed to eliminate most X.25 overhead
- A single user data frame is sent from source to destination
  - There are no Acknowledgements for hop-by-hop (Layer 2) flow control or error control
    - But since many communication links are very reliable now, this is not a big issue
  - Fewer overheads than X.25. **Frame Relay is more efficient**
- Provides data rate of 1.5Mb/s, extended to 44Mb/s

Frame Relay Network

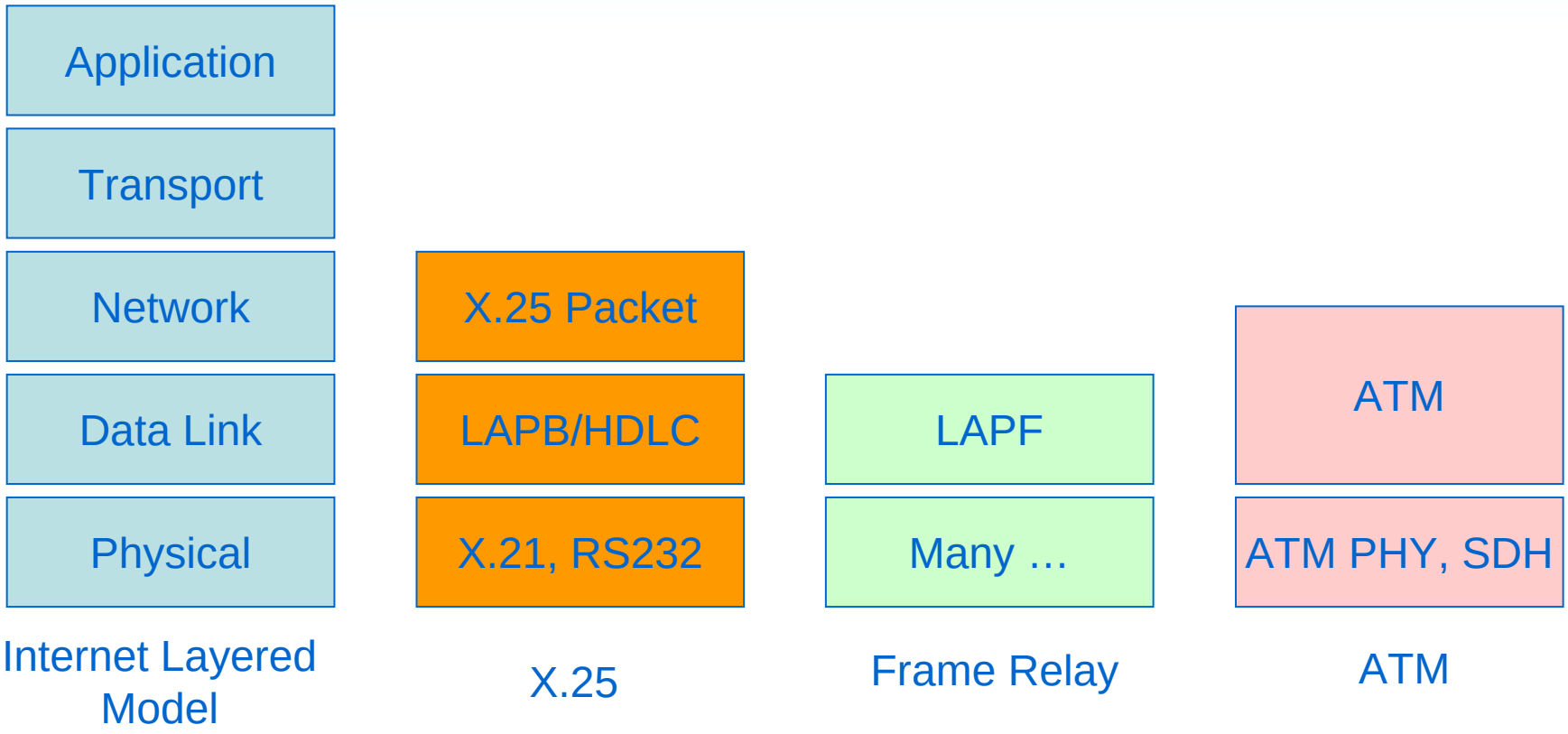


Example: this may be a network owned and operated by an ISP. SIIT pays the ISP to carry traffic to other networks (e.g. Rangsit, other Uni's, the Internet)

Asynchronous Transfer Mode

- In 1980's, as Internet grew, people wanted faster methods than IP datagram switching (and routing)
  - Routers performing forwarding/routing in software were slow for large networks
- Developed ATM, with the intention that it could be used as a fast WAN and LAN technology
  - Virtual circuit based packet switching
    - Use fixed size (53 byte) packets, or ATM cells: 48 bytes of data and 5 bytes of header
  - Better support for voice, video and data: Quality of Service control (wasn't available in IP at the time)
  - Support data rates from 25Mbs up to 622Mb/s (now even faster)
- Current status:
  - ATM WANs are today used by telecommunication companies to connect their networks (e.g. within ISPs, across cities, between cities)
    - In the future, may be replaced with IP over optical networks (SDH/SONET)
  - ATM LANs were not successful: Ethernet is the dominant LAN standard

Layers in Packet Switching Technologies



Circuit switching (PDH, SDH) can be considered to be at the Physical layer

Summary: Wired Core Networks

- Circuit Switching technologies
  - Make use of existing telecommunication networks
- Packet Switching technologies
  - More efficient than circuit switching for data traffic

- Many of the technologies are used together
  - ATM can use SDH as a physical layer

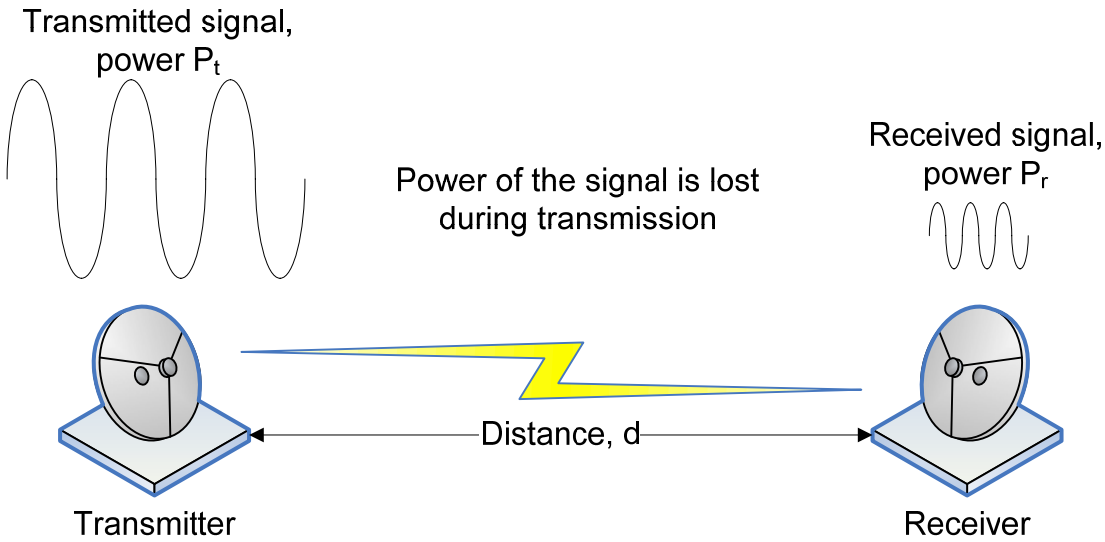
Wireless Network Technologies

Wireless Communications

- Benefits
  - Untethered communications (no wires)
    - In some cases, can enable quick installation
    - Deploying and maintaining cables is expensive
  - Mobility of users and devices
- Challenges
  - Wireless channel is not as robust as wired
    - More errors, therefore more losses and retransmissions, less throughput
    - Higher delays, therefore must wait long time for retransmissions, less throughput
    - Varying conditions due to mobility and environment
      - Example: timeout based retransmissions can lead to poor performance
  - Radio spectrum is limited (cannot just add more wires)
    - Therefore must efficiently “share” the spectrum amongst all users
  - Many Internet protocols designed assuming a “perfect link”
    - For examples, sometimes TCP may perform poorly over wireless link
  - Physical security is difficult (e.g. cannot easily limit the transmissions to a building)
    - Hence, extra network security is needed

Wireless Transmission

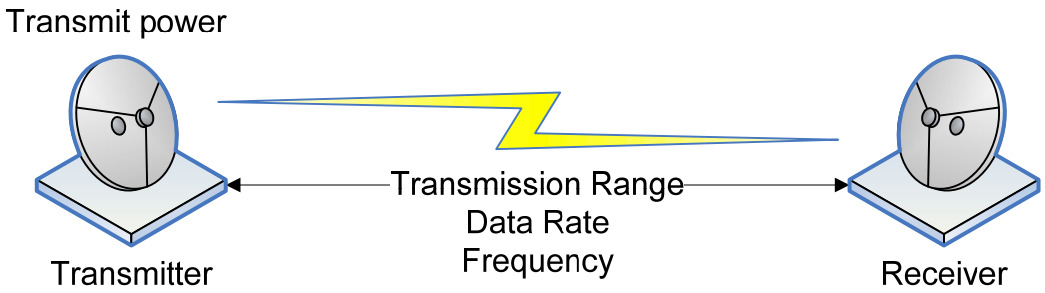
- A simple model of wireless transmission:



  - The amount of power lost between transmitter and receiver depends on:
    - Distance, frequency, size of antenna, directionality of antenna, obstructions
  - The encoding of bits (0's and 1's) into an analog signal, and decoding at receiver, determines the data rate that can be used it particular environment
  - A receiver can only successfully decode ("understand") a signal received above a certain power level

Wireless Transmission

- An even simpler model of wireless transmission:



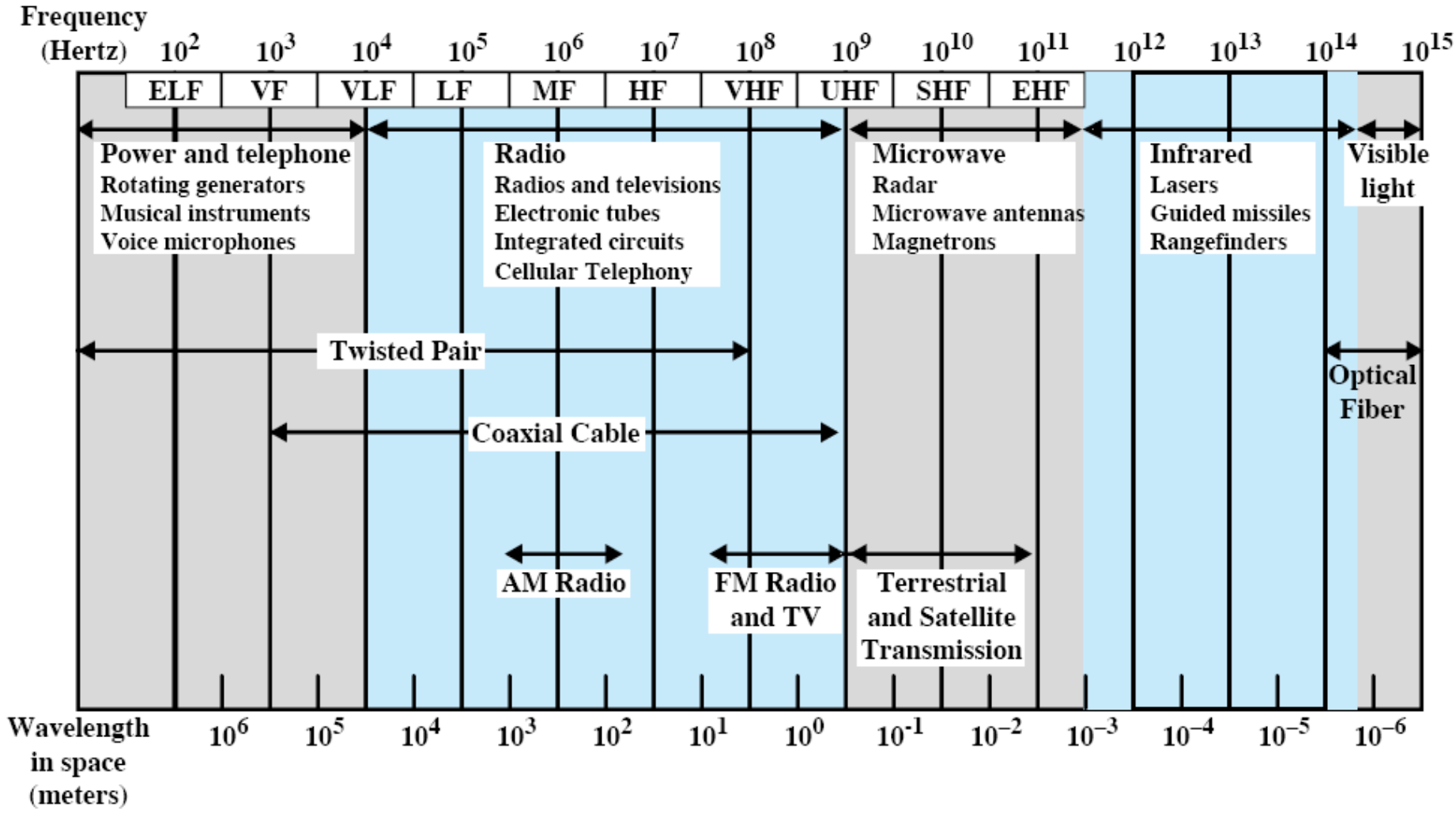
- As IT professionals, we are interested in:
  - Data Rate: how fast can we send the data? [bits per second]
  - Transmission Range: how far can we send the data? [metres]
  - Frequency: is it free or licensed? Who else may interfere? [Hertz]
  - Transmit power: how much battery of our wireless device will it use? [Watts]

  - (and of course, cost: different technologies will have different costs) [Baht]

Spectrum, Frequency and Bandwidth

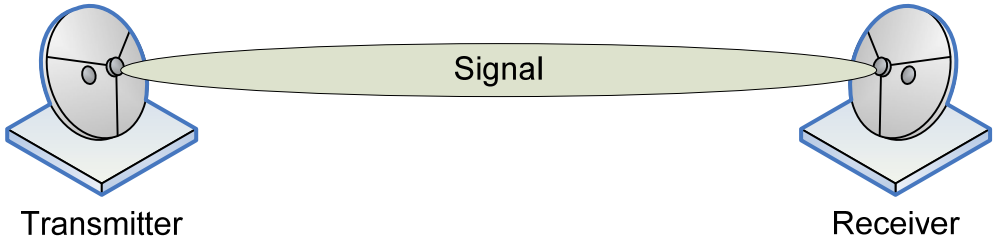
- A signal is sent at some frequency f with bandwidth b
  - The set of all frequencies available is called the spectrum
- Why is the frequency (and bandwidth) important?
  - Data rate
    - A higher bandwidth (and frequency) generally leads to higher data rate
  - Transmission range
    - Higher frequency leads to shorter range
    - Different frequency signals are affected by obstacles in different ways
      - E.g. some frequencies are affected by rain, some frequencies will pass through walls, others wont, …
  - Interference
    - If other people/technologies use the same frequency, they may interfere, causing lower data rates
      - E.g. some cordless home phones may interfere with wireless LAN
  - Cost
    - The spectrum is limited and managed by national/international organisations
    - Some frequencies are free to use by anybody (within some rules)
      - E.g. most wireless LANs operate at the free Industrial Scientific Medical (ISM) frequency
    - Other frequencies you need a license to use
      - The license may be expensive, e.g. companies in Germany spent 2 trillion Baht (2,000,000,000,000) on licenses to use spectrum for 3G mobile networks

Spectrum, Frequency and Bandwidth

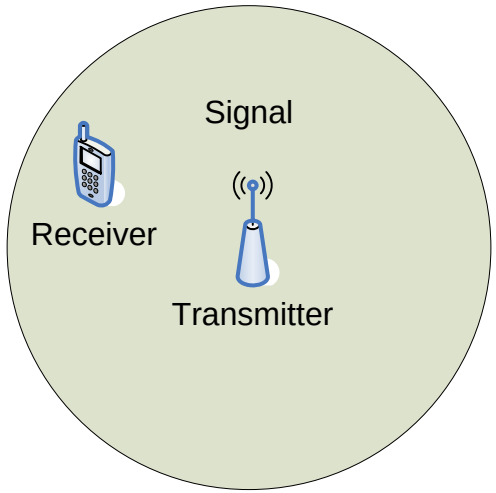


Transmission Topology

- Point-to-point
  - Transmit antenna points at receive antenna: directional
  - Signal power is concentrated between transmitter and receiver



- Broadcast Radio (point-to-multipoint)
  - Transmitter sends signal in every direction: omni-directional
  - Anyone “within range” can receive the signal



Short Range Wireless Communications

- Range: up to about 10 metres
- Examples: Bluetooth, IrDA (infrared), ZigBee and IEEE 802.15.4, Ultra Wide Band (UWB)
- Applications: connect electronic devices together
  - Wireless desktop: keyboard, mouse, PC, monitor connected *without* cables
  - Personal or Body Area Networks: devices carried with you (mobile phone, PDA, camera, watch, headset) connected
  - Automation: control and monitoring of devices (lights, machinery, A/C, entertainment) in homes, offices, factories, hospitals, …

Technology	*Frequency*	*Data Rate*	*Power*	*Range*
Bluetooth	2.4GHz	<3Mb/s	1-3mW	1-10m
ZigBee	915MHz/ 2.4GHz	<250kb/s	1mW	10's m
UWB	3-10GHz	>100Mb/s	~1mW	<10 m
IrDA	350THz	115kb/s to < 4Mb/s	~1mW	<1 m

Wireless LANs

- Range: metres to 100's of metres
- Examples: IEEE 802.11 series (11b, 11a, 11g, 11n)
- Applications: home/office LAN connectivity; city/public hot spots; …
- Topology: point-to-multipoint (shared medium)

Technology	*Frequency*	*Data Rate*	*Range*
11b	2.4GHz	11Mb/s	20-300m
11a	5GHz	54Mb/s	15-30m
11g	2.4GHz	54Mb/s	25-75m
11n	5GHz	300Mb/s	20-60m

Point-to-Point Fixed Wireless

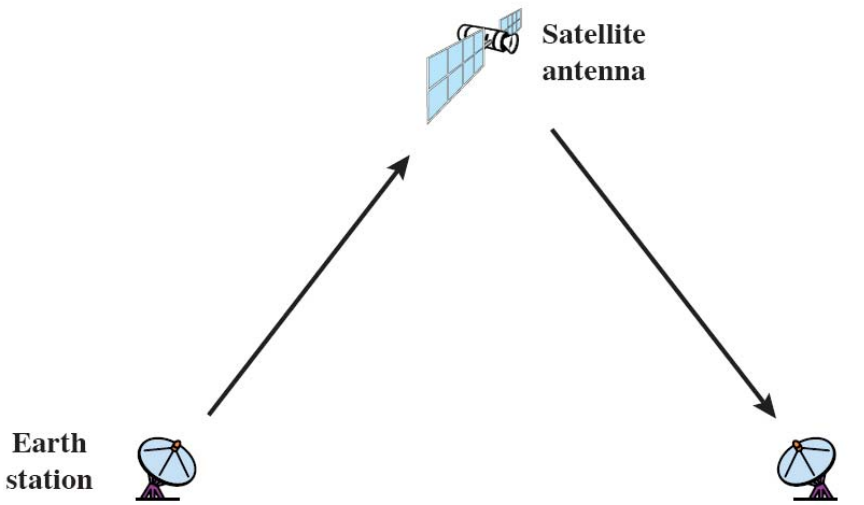
- Range: up to 10's of kms
- Examples: proprietary microwave products, IEEE 802.16 (WiMax), IEEE 802.11
- Applications: replacement for point-to-point WAN (core) links (e.g. alternative for PDH, SDH)
- Typically fixed devices (e.g. antennas on towers), using highly directional antennas
- WiMax (802.16) theoretically provides speeds up to 70Mb/s (or a range of 50km)
  - Symmetrical speeds, licensed spectrum

Technology	*Frequency*	*Data Rate*	*Range*	*Direction*
802.11b	2.4GHz	11Mb/s	10-20km	LOS
802.16	~11GHz	10-20Mb/s	10-20km	LOS
802.16	2.3/2.5/ 3.5GHz	2Mb/s	10km	NLOS

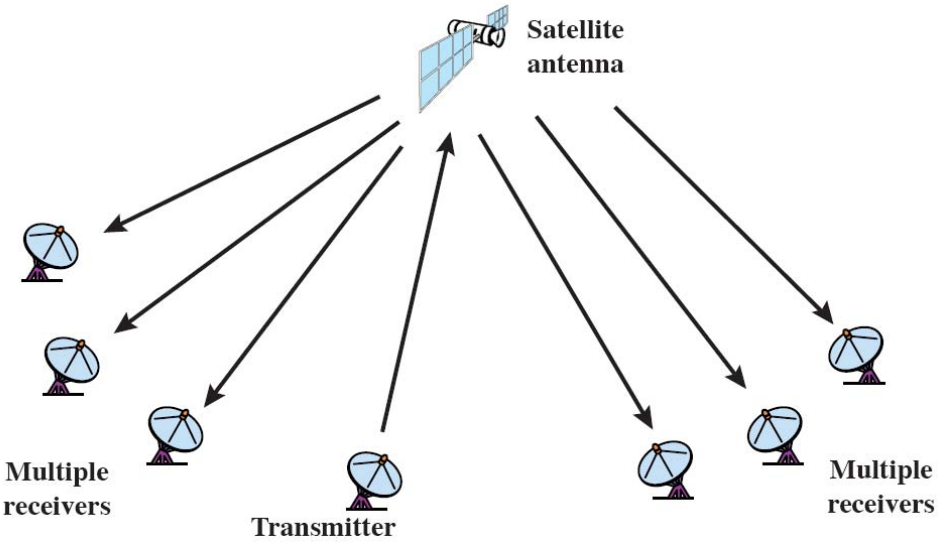
Satellite

- Range: 1000's of kms
- Examples: IPStar; CCSDS, SCPS, proprietary protocols
- Applications: Internet access; TV/radio broadcasting; remote telephony
- Satellite links range from Mb/s to 10's of Gb/s (often shared amongst many users)

Point-to-point topology



Point-to-multipoint topology

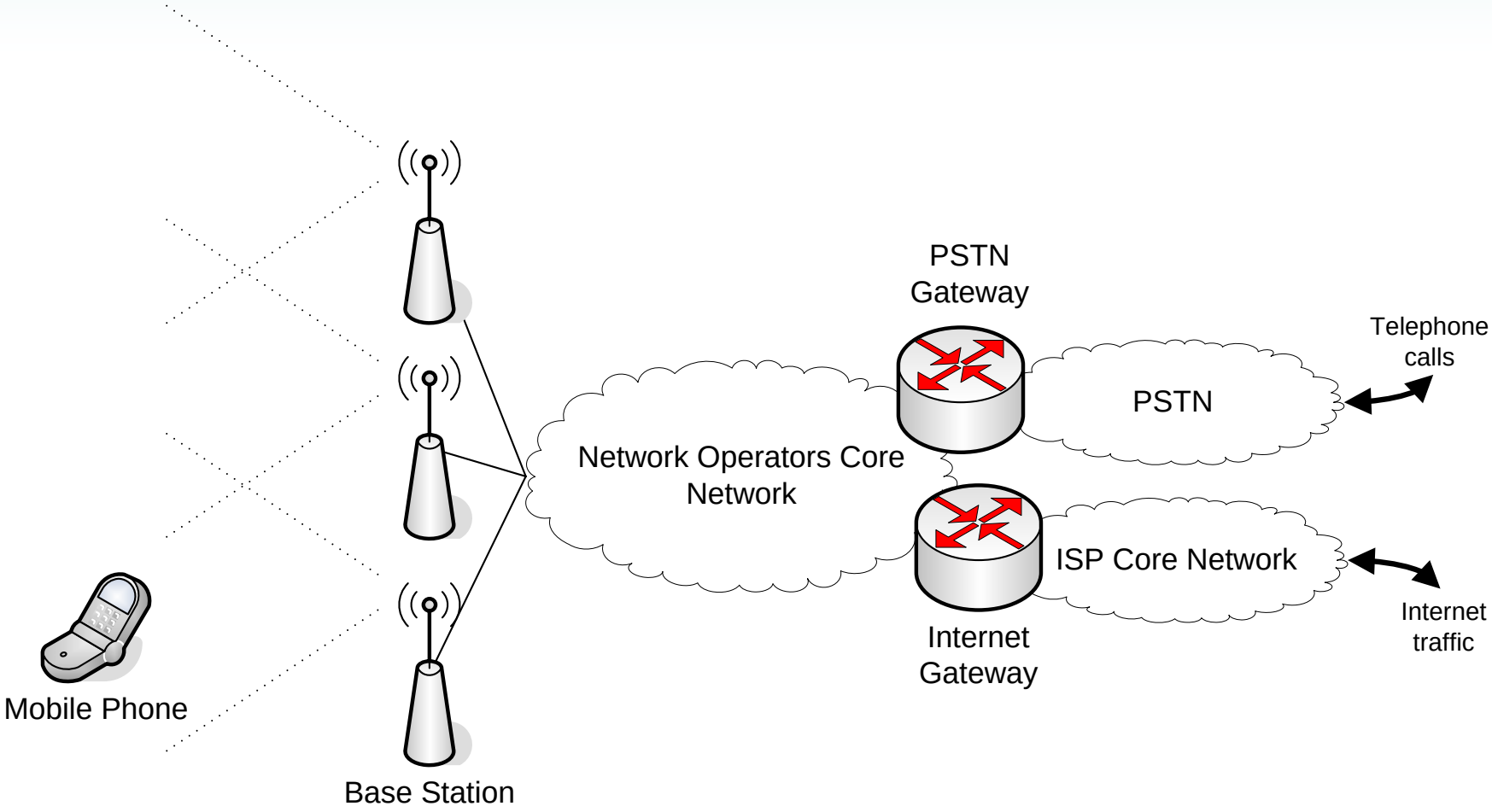


Mobile Telephony

- Range: km’s
- Examples:
  - GSM derived: CSD, GPRS, EDGE, UMTS, HSPA, LTE
  - CDMAone derived: 1xRTT, EV-DO, UMB
- Applications: mobile Internet access; voice/video over IP; data collection and monitoring

- Mobile phone networks have progressively been updated to support both voice calls and data

Mobile Telephony



GSM Derived Data Technologies

- Circuit Switched Data (CSD) 14 kb/s
  - Create a circuit-switched connection over original GSM voice call connection
- General Packet Radio Service (GPRS) 60/40 kb/s
- Enhanced Data Rates for GSM Evolution (EDGE) 240/120 kb/s
  - GPRS and EDGE are extensions to GSM; most networks support them with minor upgrades
- Universal Mobile Telecommunication System (UMTS) 384 kb/s
  - A new system compared to GSM; most widely used 3G system
- High Speed Packet Access
  - Extensions of UMTS to increase data rates
  - HSDPA (D = downlink) 14.4Mb/s
  - HSUPA (U = uplink) 5.7Mb/s
  - HSPA+ 42/22 Mb/s
- Long Term Evolution (LTE) 326/86 Mb/s
  - A new system compared to UMTS

Summary: Wireless Networks

- Wireless technologies can be used for both access and core networks
  - Access: WLAN, Bluetooth, Mobile Telephony, WiMax, Satellite
    - Mainly provide mobility to users or access in remote areas
  - Core: WiMax, Satellite, WLAN
    - Act as cable replacement where hard to deploy cables; typically fixed devices

- Wireless technologies are typically lower data rates than similar cost wired technologies
  - WLAN (54Mb/s) vs Ethernet (100/1000Mb/s)
  - EDGE (240kb/s) vs ADSL (1.5Mb/s)
  - HSPA (~10Mb/s) vs Optical (100Mb/s)
  - WiMax (35Mb/s) vs Optical (1000Mb/s)