Networking and Internetworking:
basic issues for distributed computing

Distributed software systems
CdLM Informatica - Università di Bologna

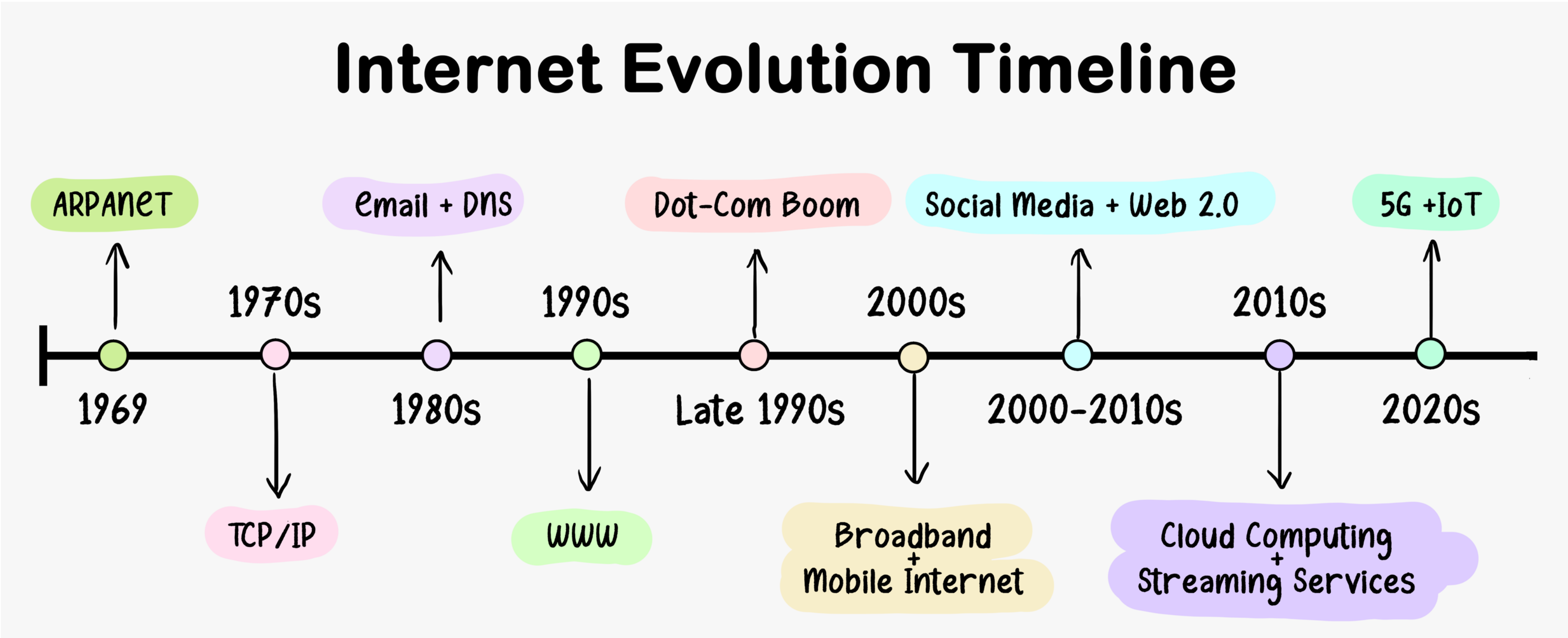
Agenda

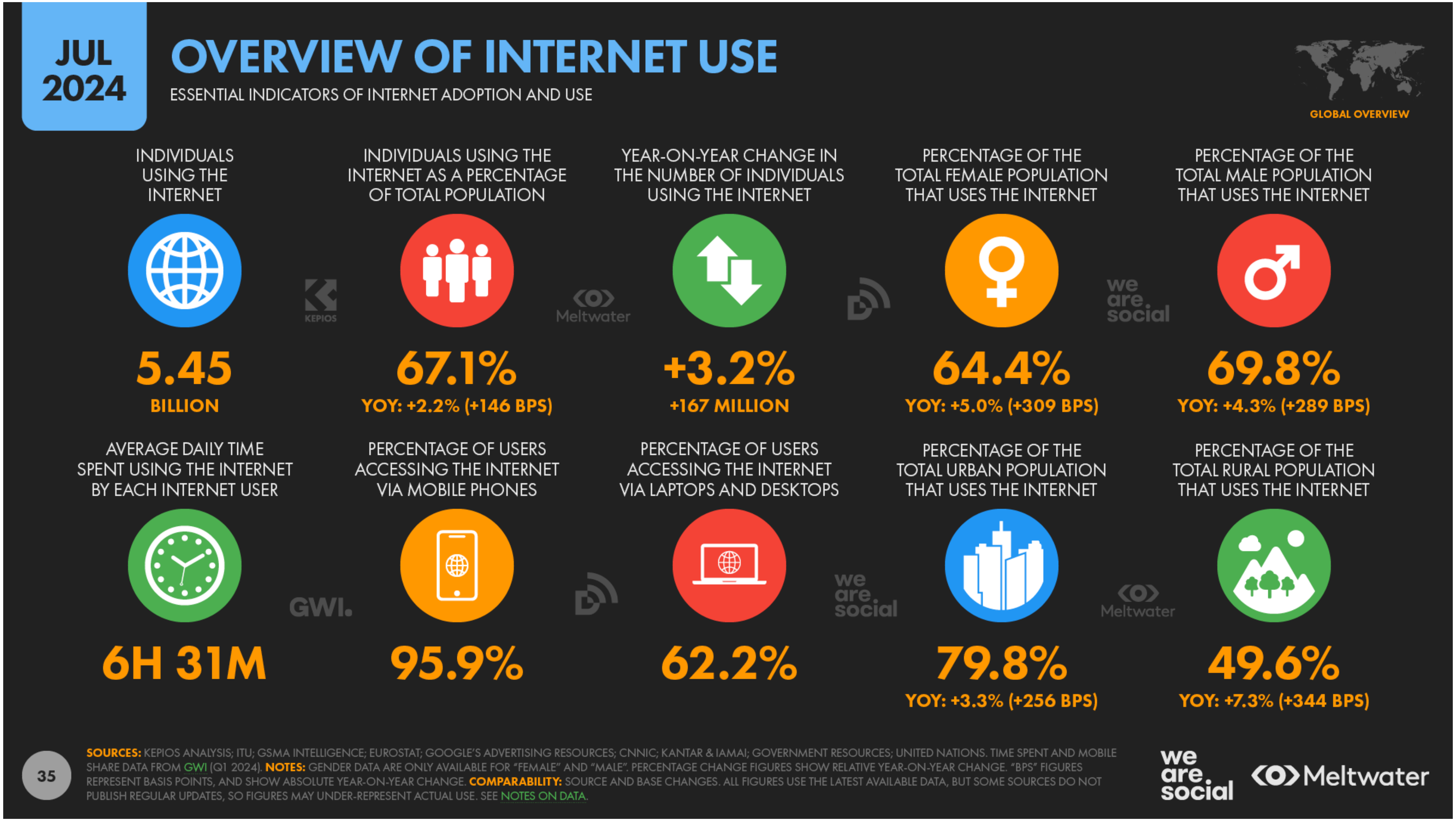
Types of networks

Network principles

Internet protocols

Case studies


Internet Evolution Timeline
ARPANET
1969
TCP/IP
1970s
Email + DNS
1980s
WWW
1990s
Dot-Com Boom
Late 1990s
Broadband
+
Mobile Internet
2000s
Social Media + Web 2.0
2000-2010s
Cloud Computing
+
Streaming Services
2010s
5G +IoT
2020s



https://datareportal.com/global-digital-overview

Internet users (estimates July 2022)

WORLD INTERNET USAGE AND POPULATION STATISTICS 2022 Year Estimates						
World Regions	**Population (2022 Est.)**	**Population % of World**	**Internet Users 30 June 2022**	**Penetration Rate (% Pop.)**	**Growth 2000-2022**	**Internet World %**
Africa	**1,394,588,547**	17.6 %	**652,865,628**	46.8 %	14,362 %	11.9 %
Asia	**4,352,169,960**	54.9 %	**2,934,186,678**	67.4 %	2,467 %	53.6 %
Europe	**837,472,045**	10.6 %	**750,045,495**	89.6 %	614 %	13.7 %
Latin America / Carib.	**664,099,841**	8.4 %	**543,396,621**	81.8 %	2,907 %	9.9 %
North America	**374,226,482**	4.7 %	**349,572,583**	93.4 %	223 %	6.4 %
Middle East	**268,302,801**	3.4 %	**211,796,760**	78.9 %	6,378 %	3.9 %
Oceania / Australia	**43,602,955**	0.5 %	**31,191,971**	71.5 %	309 %	0.6 %
WORLD TOTAL	**7,934,462,631**	**100.0 %**	**5,473,055,736**	**69.0 %**	**1,416 %**	**100.0 %**

NOTES: (1) Internet Usage and World Population Statistics estimates are for July 31, 2022. (2) CLICK on each world region name for detailed regional usage information. (3) Demographic (Population) numbers are based on data from the United Nations Population Division. (4) Internet usage information comes from data published by Nielsen Online, by the International Telecommunications Union, by GfK, by local ICT Regulators and other reliable sources. (5) For definitions, navigation help and disclaimers, please refer to the Website Surfing Guide. (6) The information from this website may be cited, giving the due credit to www.internetworldstats.com.

https://www.internetworldstats.com/stats.htm

Principles of networking

- The principles on which computer networks are based include: protocol layering, packet switching, routing, and data streaming.
- Internetworking techniques enable heterogeneous networks to be integrated.
- The Internet is the major example; its protocols are almost universally used in distributed systems.
- The addressing and routing schemes used in the Internet have withstood the impact of its enormous growth.
- They have been revisionated to accommodate the growth of users and usages and to meet new application requirements for mobility, security and quality of service

- Principles of networking are counter-intuitive for software developers with limited experience of networks

Distributed systems are based on networks

- Distributed systems are made of software (processes) which use communication infrastructures:
  local area networks, wide area networks, and internetworks.
- The performance, reliability, scalability, mobility, and Quality of Service properties of the underlying networks impact the design and behaviour of distributed systems.
- Technological innovations have resulted in the emergence of wireless networks and high-performance networks with Quality of Service guarantees

Common **false** assumptions on networks

- The network is reliable
- The network is secure
- The network is homogeneous
- The topology does not change
- Latency is zero
- Bandwidth is infinite
- Transport cost is zero
- There is one global administrator

When developing non-distributed applications, most of these issues will likely not show up

Consequences of the fallacies

Fallacy	Effect
The network is unreliable	App needs error handling/retry lost messages
Latency is greater than zero	App should minimize # of requests
Bandwidth is finite	App should send small payloads
The network is unsecure	App must secure its data/authenticate requests
Topology does change	Changes affect latency, bandwidth and endpoints
There is not one administrator	Changes affect ability to reach destination
Transport cost is more than zero	Costs must be budgeted, someone has to pay
The network is heterogeneous	Affects reliability, latency and bandwidth

Measuring Quality of Service: four main network performance metrics

Bandwidth: The speed of a link: bits per second

Latency (delay): The time it takes for a packet to go from its source to its end destination: measured in milliseconds

Loss: The amount of packet loss, which typically occurs due to network congestion: measured by percentile of data loss

Jitter: The irregular speed of packets as a result of congestion, which can result in packets arriving late and out of sequence; the average of the absolute differences between the expected arrival time of each packet and its actual arrival time: measured in milliseconds

Example: Packet loss should be no more than 1%, and network latency shouldn't exceed 150 ms one-way (300 ms return). Jitter should be below 30ms.

Network performance main parameters

The primary network performance parameters are the **latency** and the **point-to-point data transfer rate**:

- **Latency** is the delay that occurs after a send operation is executed and before data starts to arrive at the destination computer. It can be measured as the time required to transfer an empty message (we are considering only network latency, which forms a part of the process-to-process latency).
- **Data transfer rate** is the speed at which data can be transferred between two computers in the network once transmission has begun, usually quoted in bits per second.

The time required for a network to transfer a message containing *length* bits between two computers is:

Message transmission time = latency + length ⁄ data transfer rate

Network parameters in the Internet

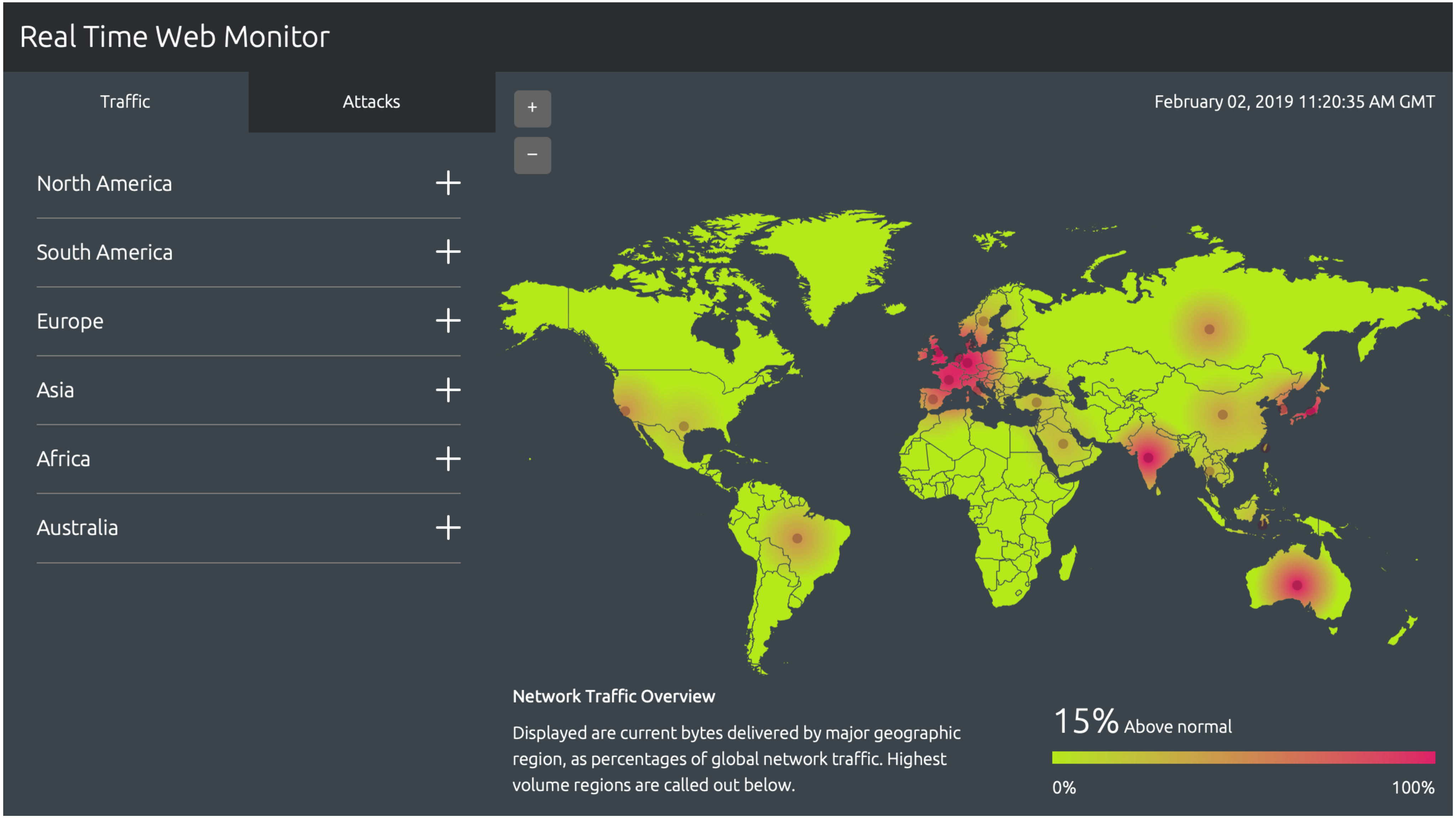
On the Internet, round-trip latencies are in the 5–500 ms range, with means of 20–200 ms depending on distance

Requests transmitted across the Internet are 10–100 times slower than those sent on fast local networks.

The bulk of this time difference derives from switching delays at routers and contention for network circuits.

www.akamai.com

Try also https://globe.akamai.com



InterProcess Communication (IPC)

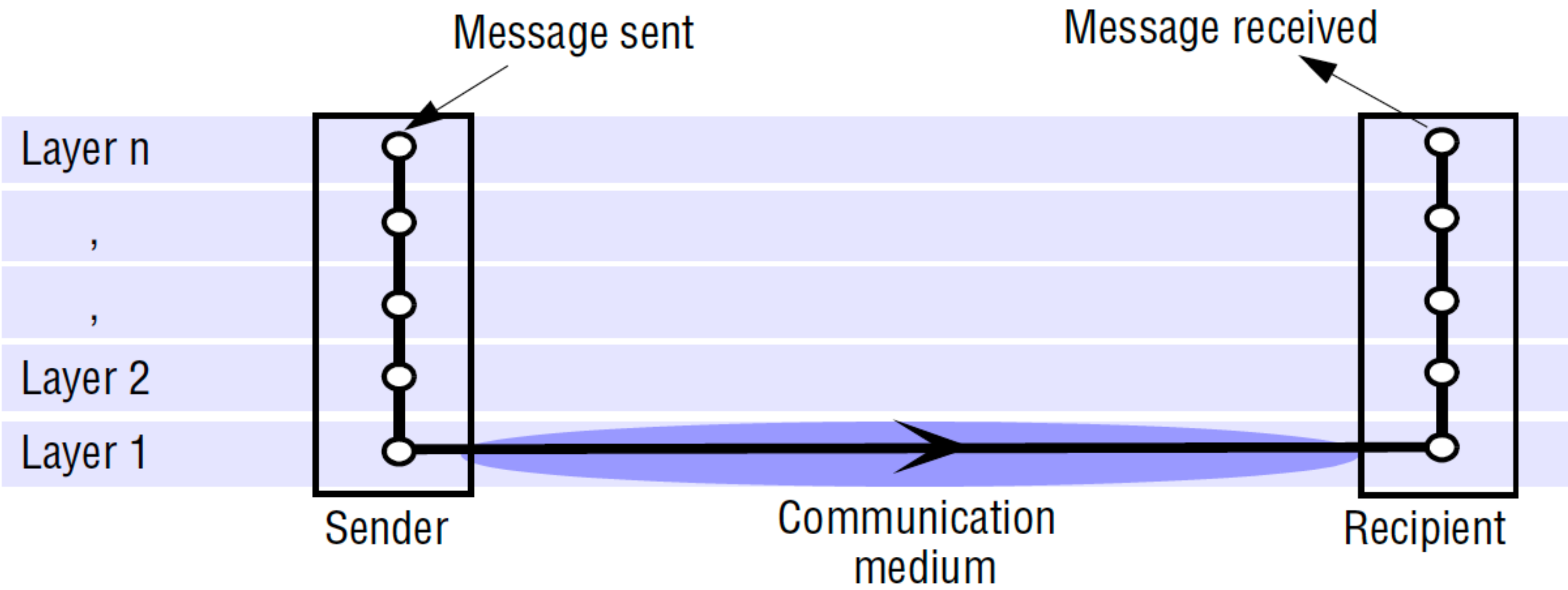
Question: how do processes on different machines exchange information?

Answer: with difficulty … ☹

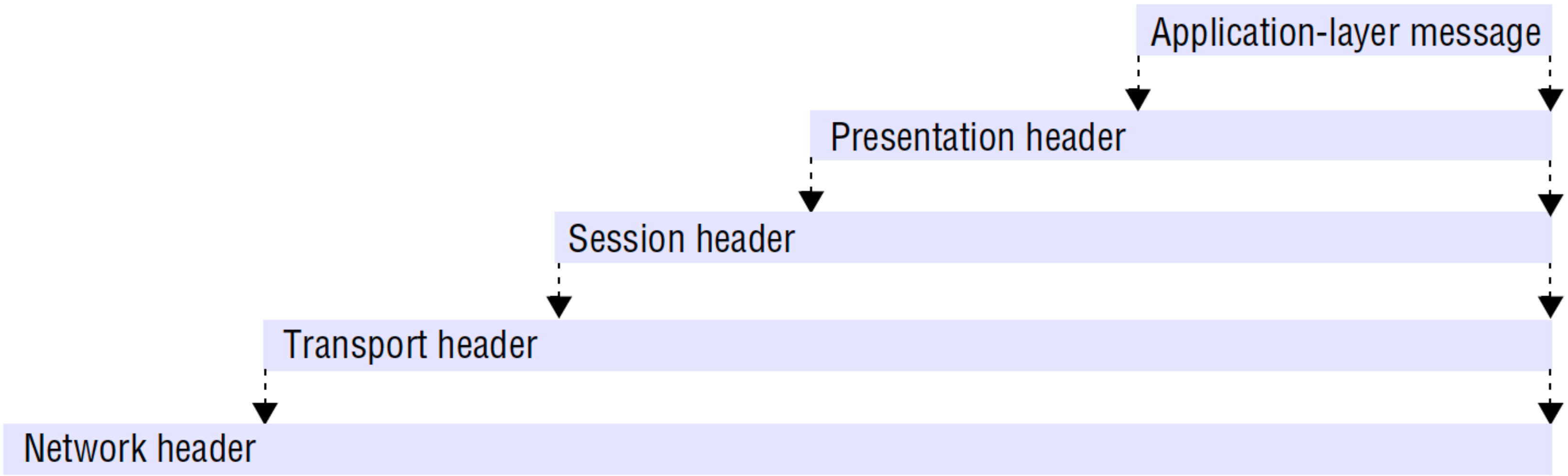
- Established computer network facilities are **too primitive**, resulting in distributed software too difficult to develop – a new model is required
- IPC is the “heart” of every distributed system.
- Four IPC models are popular:

RPC; RMI; Streams; MOM (msg oriented middleware)

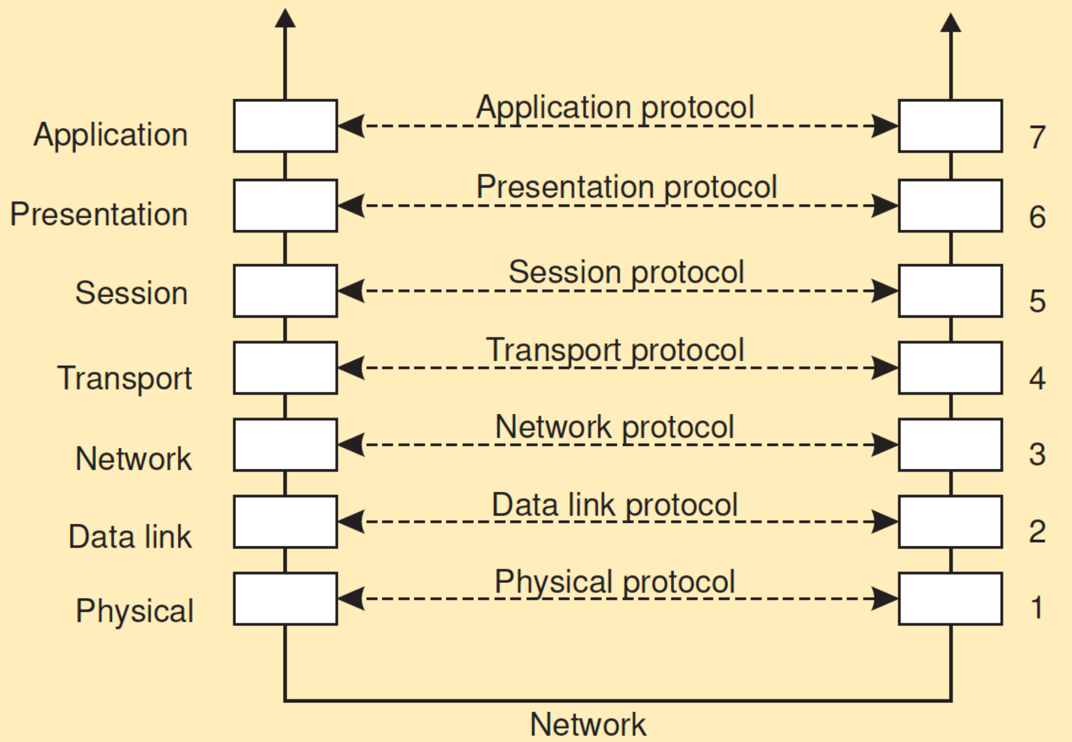
Conceptual layering of protocol software



Encapsulation as it is applied in layered protocols



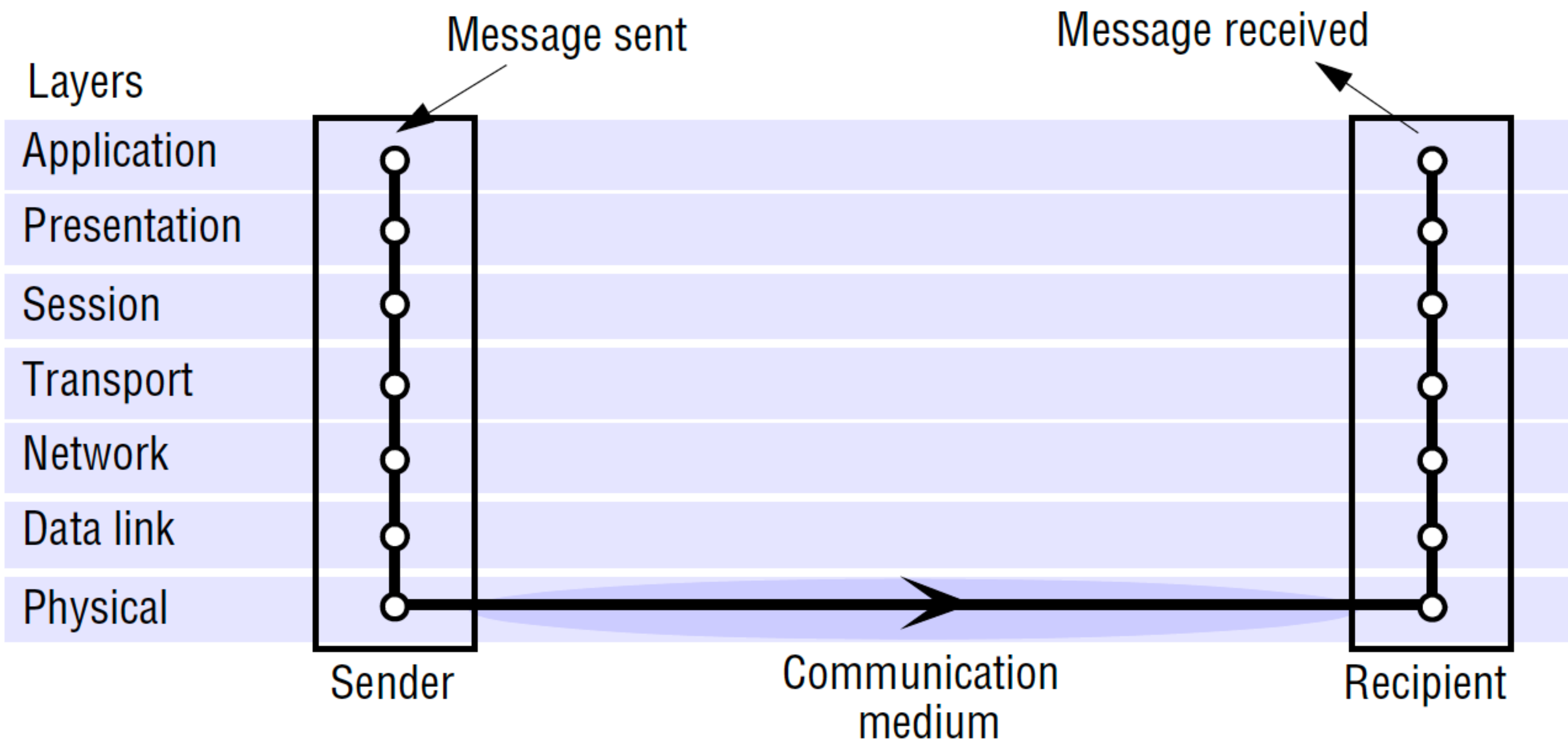
Basic networking model



Drawbacks

- Focus on message-passing only
- Often unneeded or unwanted functionality
- Violates access transparency

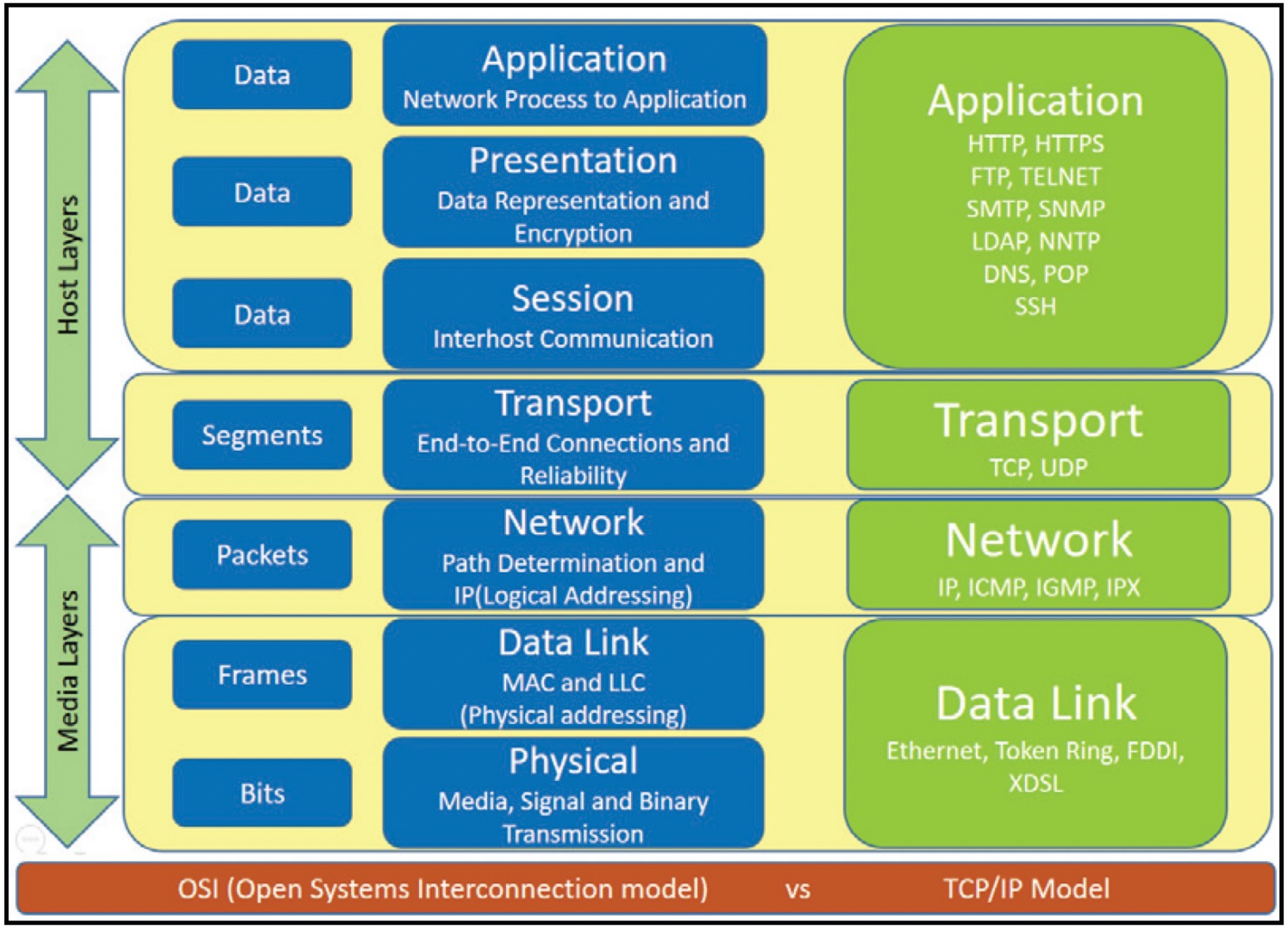
Protocol layers in the ISO Open Systems Interconnection (OSI) model



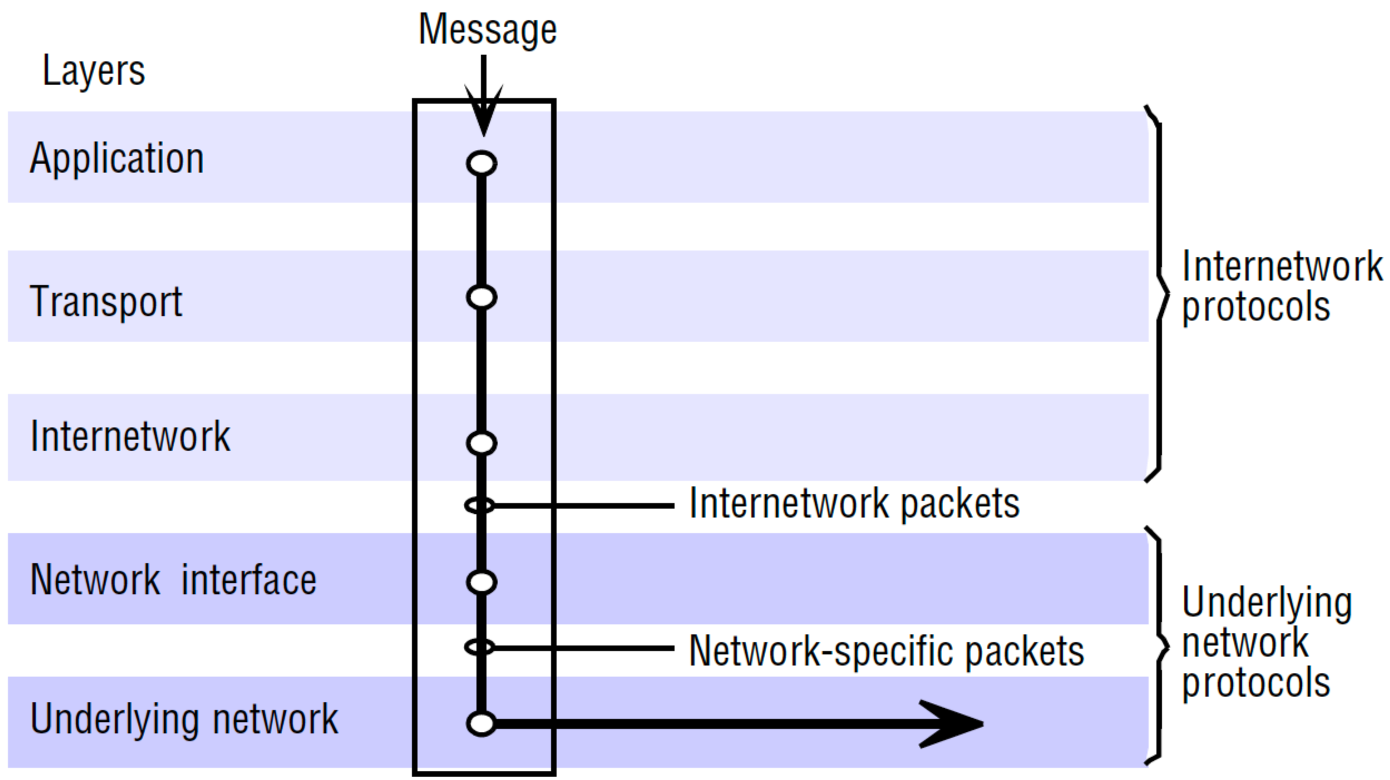
OSI protocol summary

Layer	*Description*	*Examples*
Application	Protocols that are designed to meet the communication requirements of specific applications, often defining the interface to a service.	HTTP, FTP , SMTP, CORBA IIOP
Presentation	Protocols at this level transmit data in a network representation that is independent of the representations used in individual computers, which may differ. Encryption is also performed in this layer, if required.	Secure Sockets (SSL),CORBA Data Rep.
Session	At this level reliability and adaptation are performed, such as detection of failures and automatic recovery.	
Transport	This is the lowest level at which messages (rather than packets) are handled. Messages are addressed to communication ports attached to processes, Protocols in this layer may be connection-oriented or connectionless.	TCP, UDP
Network	Transfers data packets between computers in a specific network. In a WAN or an internetwork this involves the generation of a route passing through routers. In a single LAN no routing is required.	IP, ATM virtual circuits
Data link	Responsible for transmission of packets between nodes that are directly connected by a physical link. In a WAN transmission is between pairs of routers or between routers and hosts. In a LAN it is between any pair of hosts.	Ethernet MAC, ATM cell transfer, PPP
Physical	The circuits and hardware that drive the network. It transmits sequences of binary data by analogue signalling, using amplitude or frequency modulation of electrical signals (on cable circuits), light signals (on fibre optic circuits) or other electromagnetic signals (on radio and microwave circuits).	Ethernet base- band signalling, ISDN

Clustering the stack: the TCP/IP model



Internetwork layers



For many distributed systems, the lowest-level interface is that of the network layer

Conclusions

- We have summarized the networking principles that are needed as a basis for programming distributed systems (approaching them from the point of view of a distributed system programmer).
- Packet networks and layered protocols provide the basis for communication in distributed systems.
- Local area networks are based on packet broadcasting on a shared medium; Ethernet is the dominant technology
- Wide area networks are based on packet switching to route packets to their destinations through a connected network
- Routing is a key mechanism and a variety of routing algorithms are used, of which the distance-vector method is the most basic but effective.
- Congestion control is needed to prevent overflow of buffers at the receiver and at intermediate nodes.

Networks vs distributed systems

- A computer network is an interconnected collection of independent computers able to exchange messages
- A computer network usually requires users to login to a machine, explicitly submit jobs remotely, explicitly move files/data around the network

- In a distributed system the existence of multiple computers is transparent to the user
- The (distributed) operating system automatically allocates jobs to processors & moves files without explicit user intervention

Exercise

Compare connectionless (UDP) and connection-oriented (TCP) communication for the implementation of each of the following application-level or presentation-level protocols:

i. virtual terminal access (for example: Telnet);
ii. file transfer (for example: FTP);
iii. user location (for example: rwho or finger);
iv. information browsing (for example: HTTP);
v. remote procedure call.

Answer

i. The long duration of sessions, the need for reliability and the unstructured sequences of characters transmitted make connection-oriented communication most suitable for this application. Performance is not critical in this application, so the overheads are of little consequence.

ii. File calls for the transmission of large volumes of data. Connectionless would be ok if error rates are low and the messages can be large, but in the Internet, these requirements aren't met, so TCP is used.

iii. Connectionless is preferable, since messages are short, and a single message is sufficient for each transaction.

iv. Either mode could be used. The volume of data transferred on each transaction can be quite large, so TCP is used in practice.

v. RPC achieves reliability by means of timeouts and re-trys. So connectionless (UDP) communication is often preferred.