Chapter 1: Conceptual Basis

Section 1

V 2.5

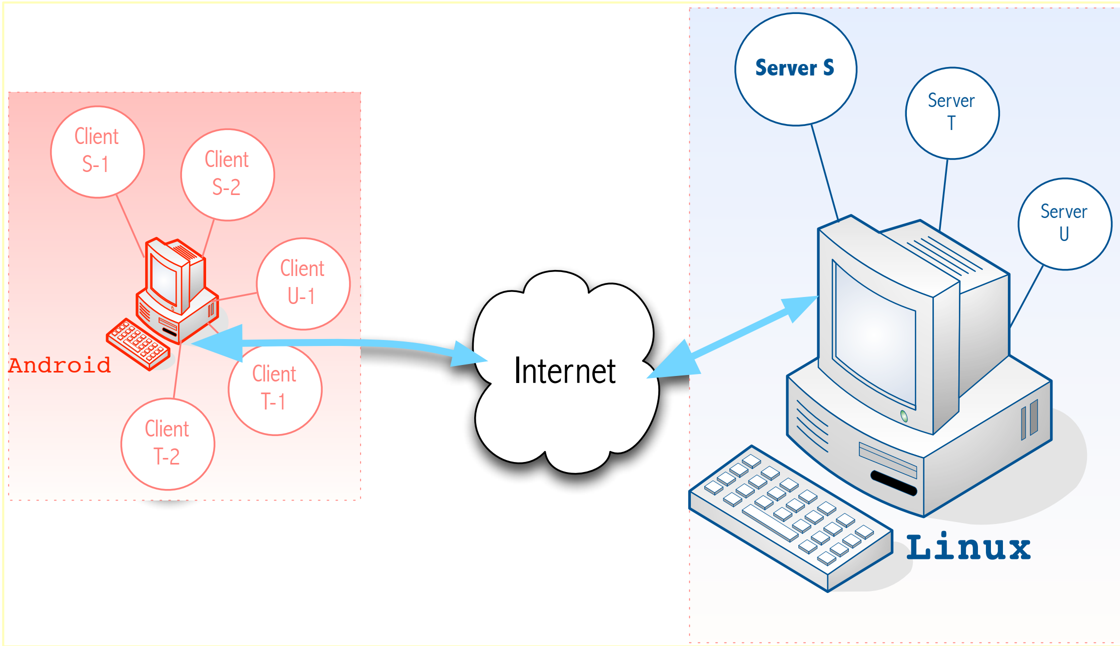
Based on textbook *Conceptual Computer Networks* by:

Leading questions

- What are the principles behind the communication between two parties?
- When can communication be considered fast and efficient?
- What is a network architecture?
- What are the landmarks in the development of Internet?
- Why is networking essential for the progress of humankind?

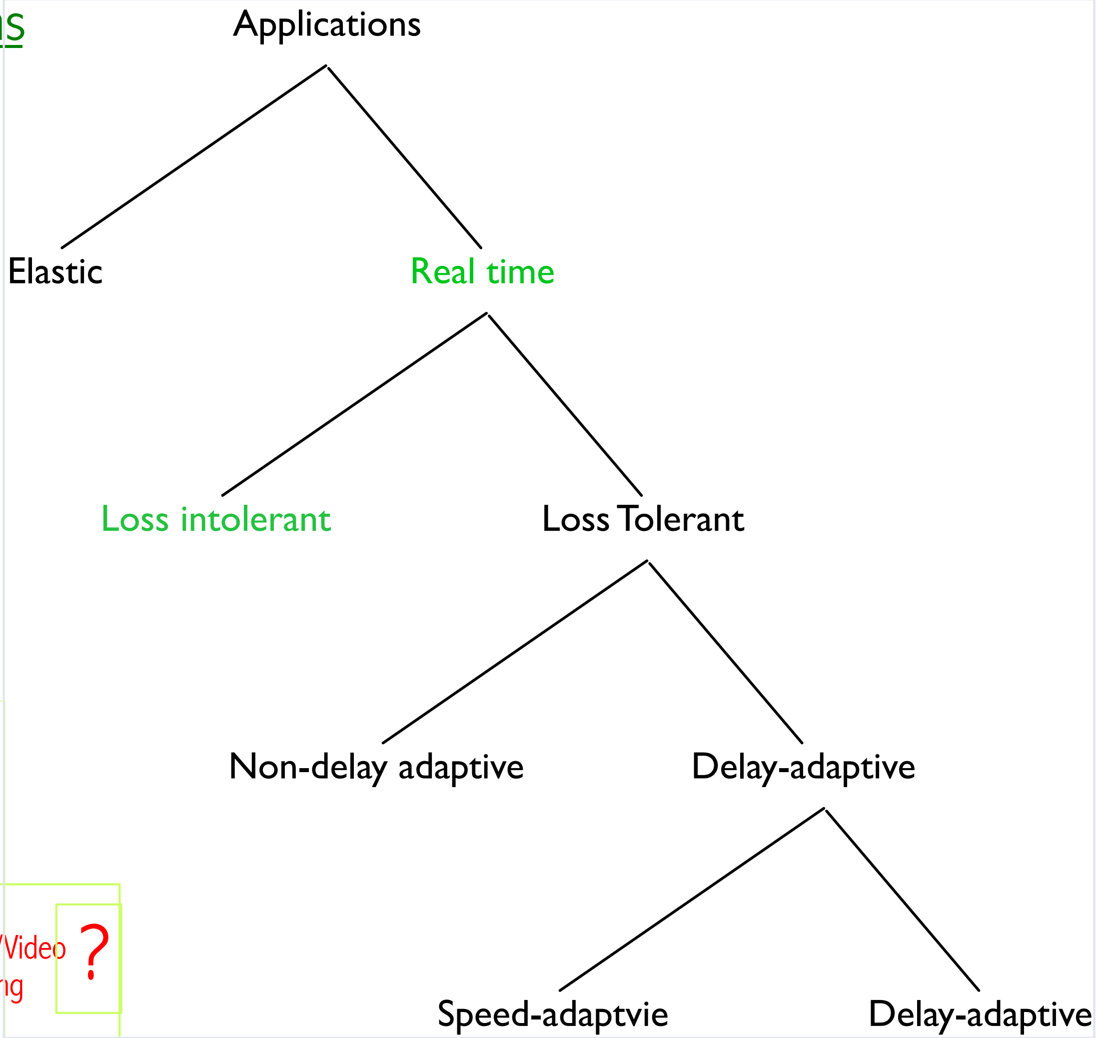
Hosts execute processes that can mutually communicate

- Internet Host
  - Computer System
  - OS
    - PS
    - FS
    - NS (Inet Protocol Stack)
      - TCP, UDP, ICMP, IP, Subnet…
  - NIC
- Collaboration among hosts made possible



Host applications collaborate

- Applications are computer programs
- Communicate over the Internet
- At work, at home and mobile
- Vastly differing **requirements:**
  - Omission faults (Loss of packets)
  - Bandwidth, speed (bps; pps, etc.)
  - Delay (s)
  - Variance of delay (Jitter; s)



- e-mail: smtp, pop3, imap
- File Sharing, file transfer: ftp, rcp, scp
- Printer sharing
- Virtual terminal: telnet, ssh (Secure Shell)
- e-commerce
- Geolocation
- **World Wide Web (www)**
- Social Networks
- Instant Messaging (Whatsup, . . .)

- Network storage
- Streaming Audio/Video
- Video conferencing
- IP Telephony

?

© Summary diagram by Larry Peterson and Bruce Davie (From Clark, Schenker and Zangh)

Example of an Internet application: World Wide Web

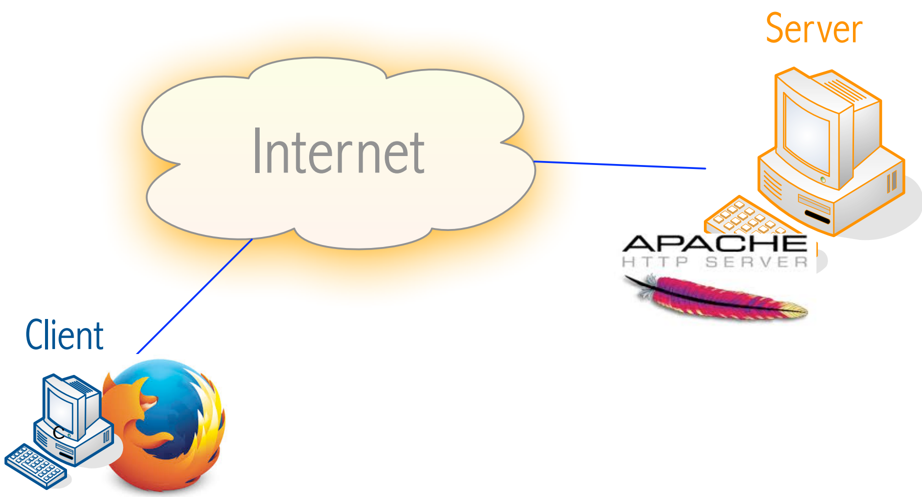
- Web pages are downloaded by the **client** from the **server**
  - Client runs in an Inet host
  - Server also runs in an Inet host
  - Thus, Client and server can collaborate
  - Client and server *speak* the http protocol
  - http = Hyper Text Transfer Protocol

- WWW
  - Server program (e.g., Apache)
  - Client program (e.g., Firefox)

- URL
  - Uniform Resource Locator
  - Example of a URL:

  http://paloalto.unileon.es/cn/index.html

- HTTP, in turn uses the TCP protocol for reliability
  - TCP = Transmission Control Protocol
  - TCP provides reliability
    - In case of packet loss, duplication, errors, etc



Units and multipliers

- Bandwidth
  - Directly related to the acceptable speed of bit transmission over some medium
  - Number of bits transmitted in one second:
    - Bps (Bits Per Second = Bits/Sec)
  - Since bandwidth is a rate, the multipliers take on the following values:
    - K (Kilo = 10^3)
    - M (Mega = 10^6)
    - G (Giga = 10^9)
    - T (Tera = 10^{12})
- Throughput
  - **Number of packets that can reliably come across some section of an internetwork in every second**
    - **Packets/sec**
    - **Same multipliers as above**
- Delay
  - Seconds
  - How much time it takes to transport one bit from a source to a destination directly connected
  - Propagation delay
- Jitter
  - The variance of the delay

Units and multipliers, standard table

System of Units (SI)			Binary Numeral			
Factor	Name	Symbol	Factor	Name	Symbol	# of Bytes
10^3	kilobyte	KB	2^{10}	kibibyte	KiB	1,024
10^6	megabyte	MB	2^{20}	mebibyte	MiB	1,048,576
10^9	gigabyte	GB	2^{30}	gibibyte	GiB	1,073,741,824
10^{12}	terabyte	TB	2^{40}	tebibyte	TiB	1,099,511,627,776
10^{15}	petabyte	PB	2^{50}	pebibyte	PiB	1,125,899,906,842,624
10^{18}	exabyte	EB	2^{60}	exbibyte	EiB	1,152,921,504,606,846,976
10^{21}	zettabyte	ZB	2^{70}	zebibyte	ZiB	1,180,591,620,717,411,303,424
10^{24}	yottabyte	YB	2^{80}	yobibyte	YiB	1,208,925,819,614,629,174,706,176

Examples

- Transmission speed: bps, SI

- Information: bits, powers of 2

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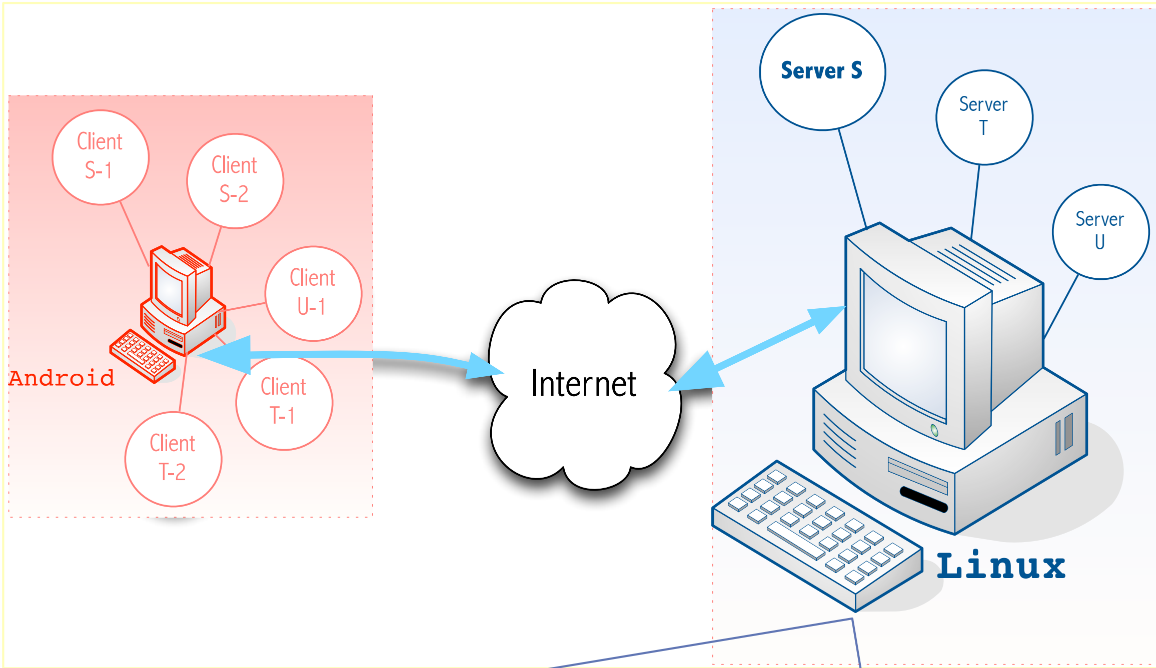
Network Architecture

Manage the complexity of networks

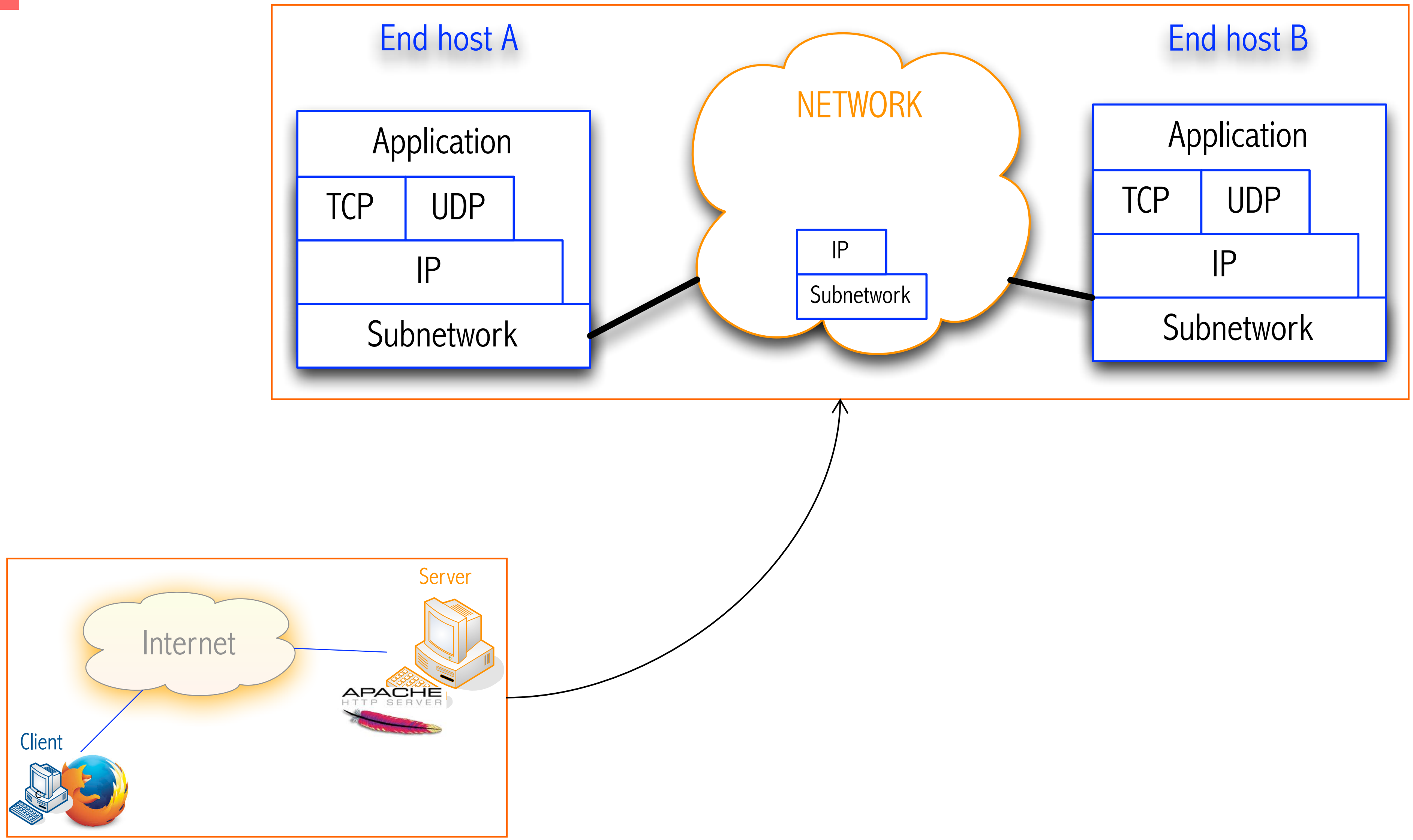
Logical channels

- Applications communicate over the Internet
- The channel between two communicating applications is logical
- Each channel:
  - *Connects* two applications
  - Hosts must be identified:
    - IP address
  - Applications must be identified:
    - Port numbers



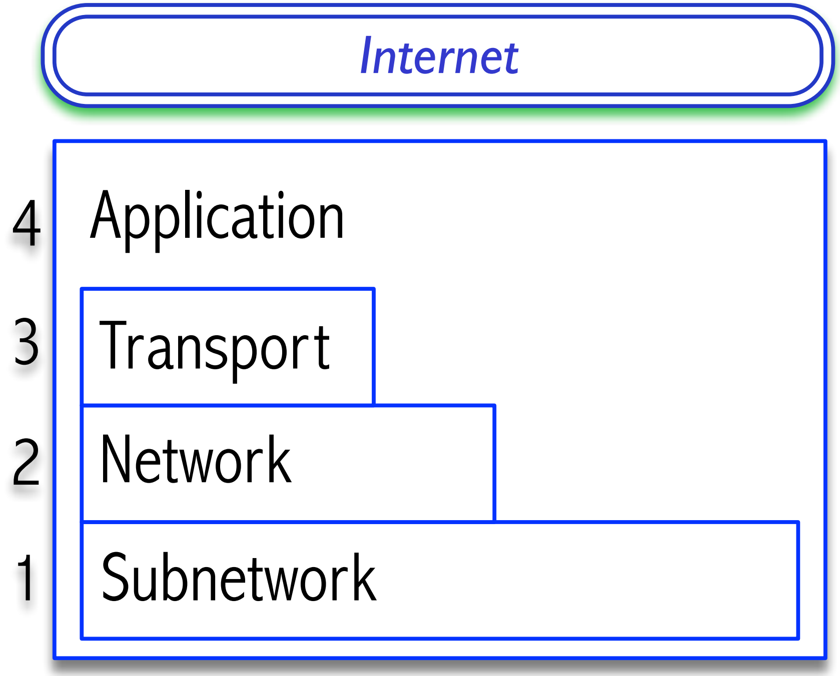
How to **hide** network **complexity** from application **programmers?**

Layering in hosts and network



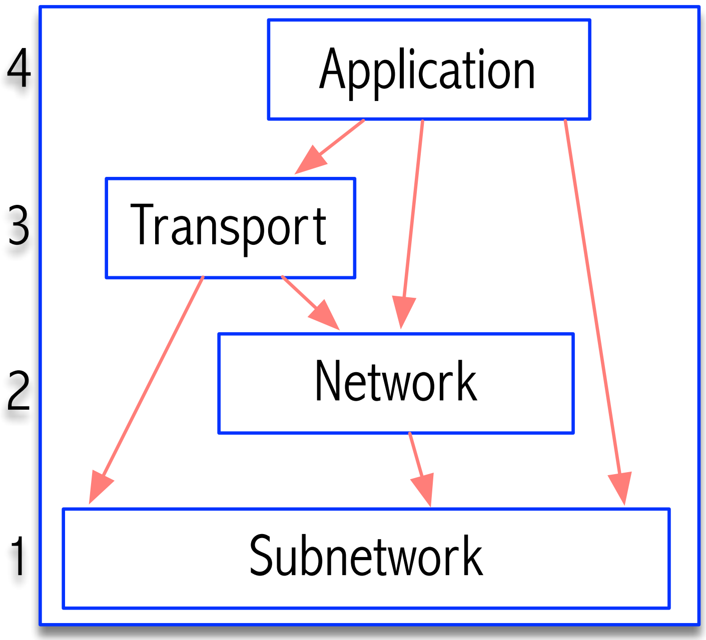
Internet Architecture

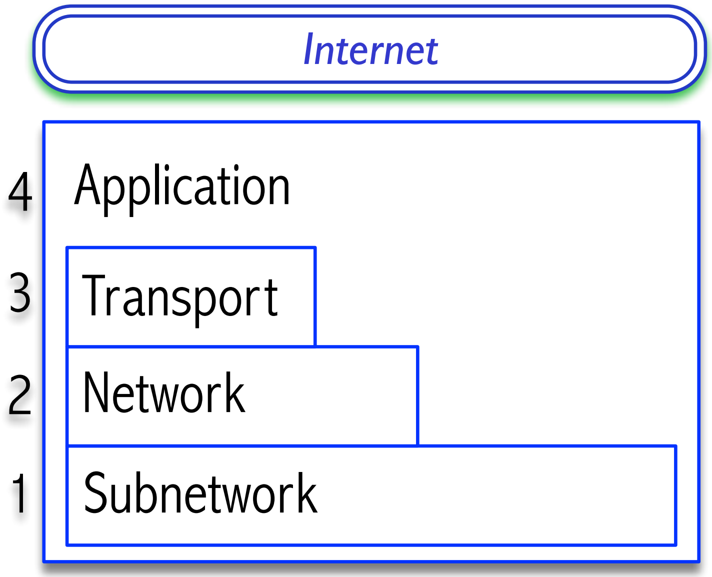
- Network complexity is broken down into 4 layers
  - Each *layer*
    - Offers a set of services to the upper layers
    - The mechanism that attains each service is a protocol
    - An upper layer avails one service from a lower layer by calling its interface



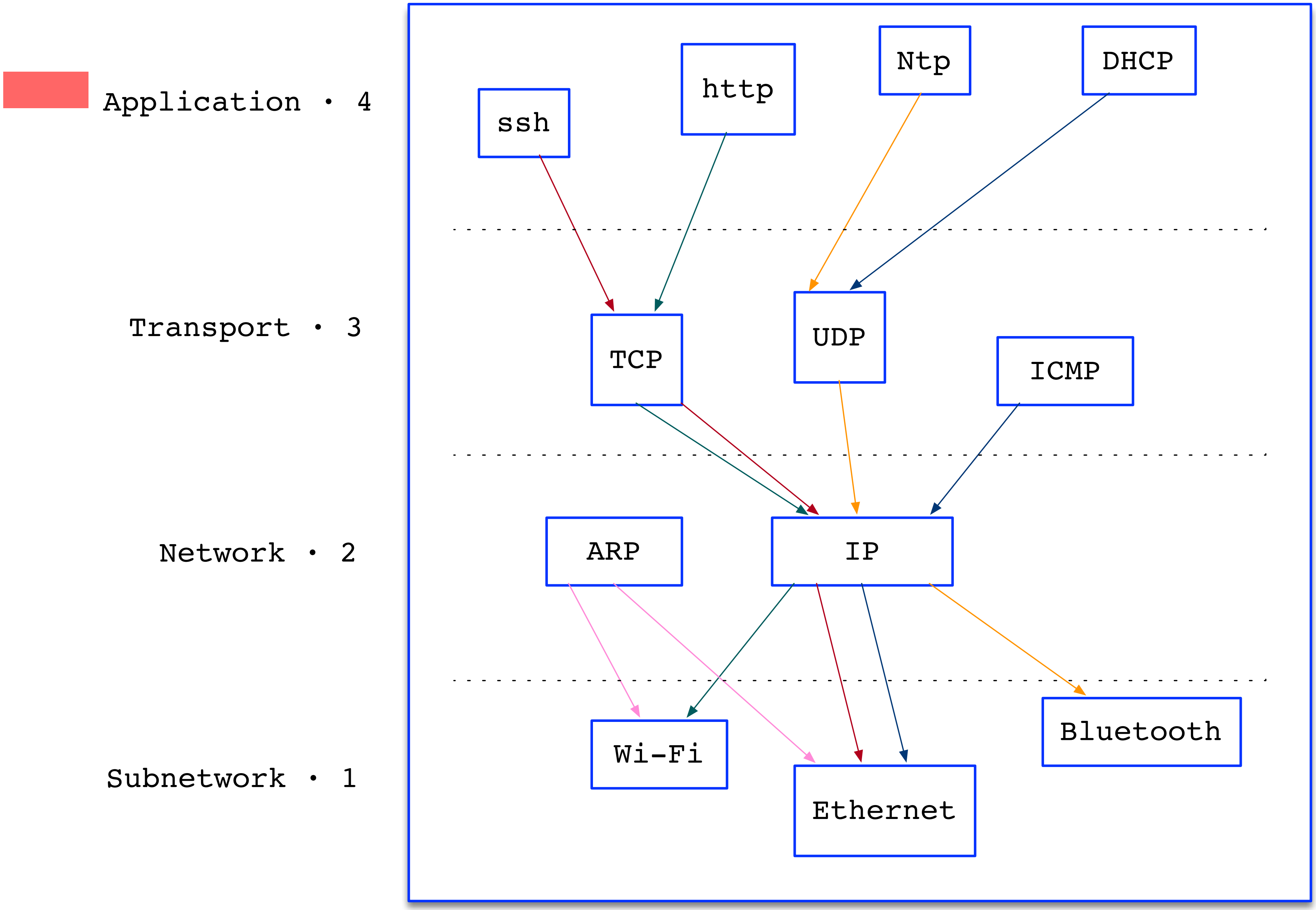
- 1. Subnetwork: Ethernet, Wi-Fi, Bluetooth
- 2. Network: Only IP !!!
- 3. Transport: TCP and UDP
- 4. Application: Whatsup and innumerably others

Internet Architecture

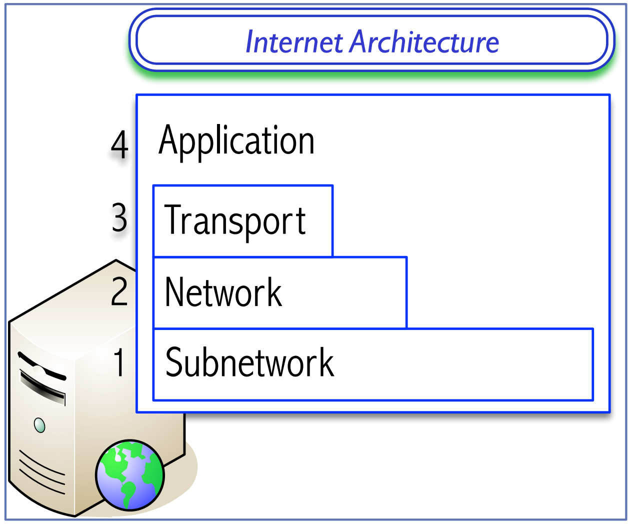


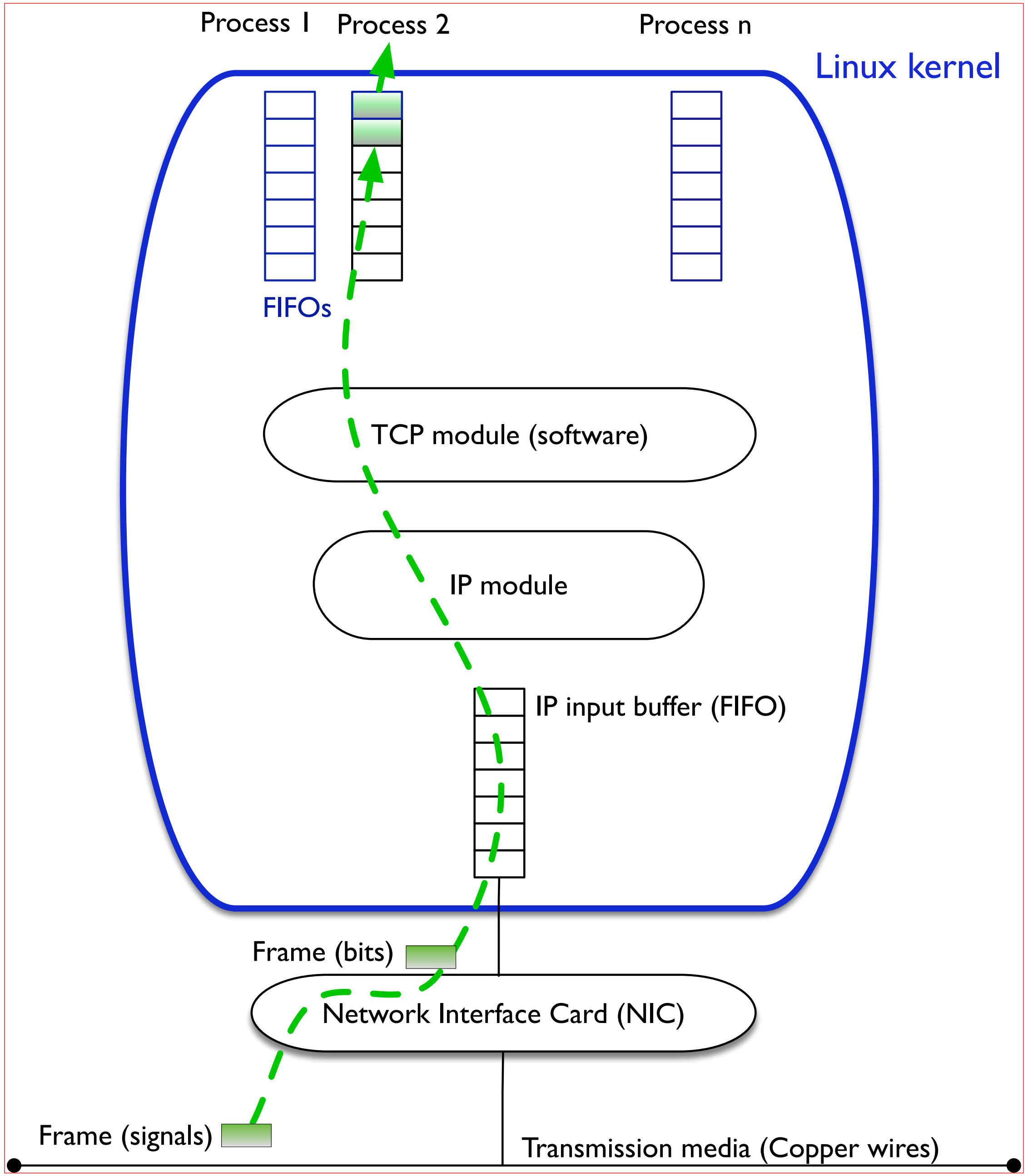


Typical Internet Protocol Stack



Implementation of protocols





Internet Architecture, standard

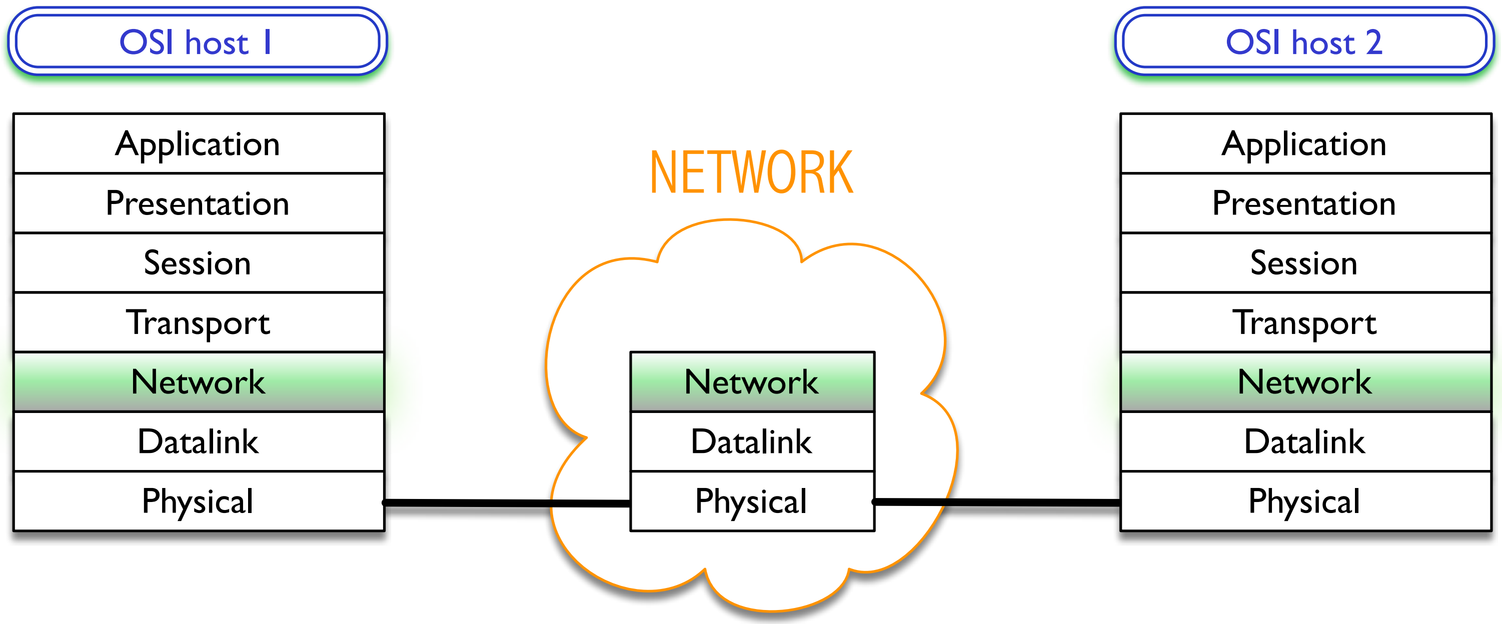
- Specified by Internet Engineering Task Force in 1970
- RFC 1287
- Derived from the TCP/IP Protocol suite
  - In any implementation of IA, programs can call any layer's service interface
  - Only one network protocol: IP
    - Many application protocols
    - A few transports
    - Many link protocols
    - A **glass-shaped architecture**
  - IETF accepts protocols officially if they offer one reference implementation at least

17 Protocols and their Services

Protocols offer services

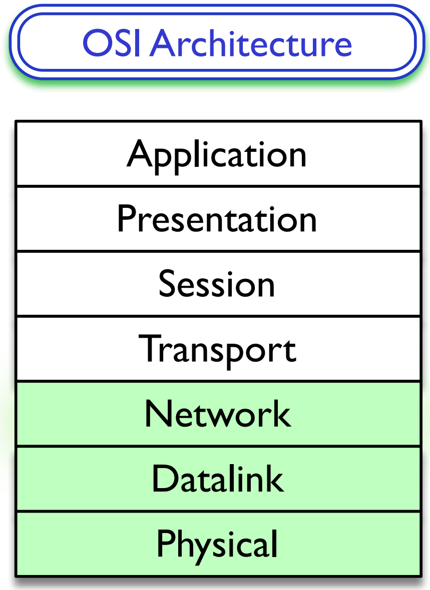
7-layer OSI Architecture

- A Reference Model, actually
- Use of this architecture is limited to some specific protocols
  - IEEE 802.3, 802.1Q, 802.1P, 802.11 (Wifi), 802.15 (WiMax)
- Layering is strict



Description of OSI Layers

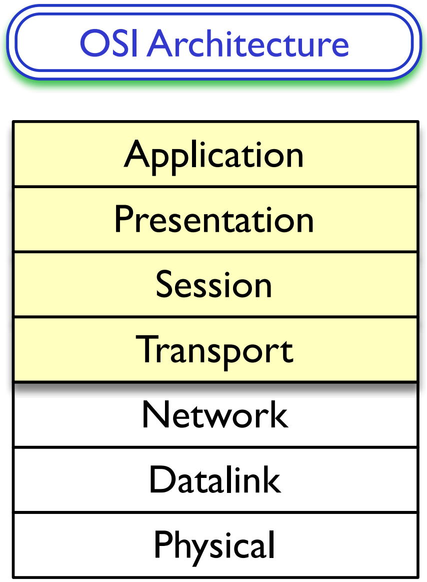
- Physical Layer
  - Handles the transmission of raw bits over a communication link
- Data Link Layer
  - Collects a stream of bits into a larger aggregate called a *frame*
  - Network adaptor along with device driver in OS implement the protocol in this layer
  - Frames are actually delivered to hosts
- Network Layer
  - Handles routing among nodes within a packet-switched network
  - Unit of data exchanged between nodes in this layer is called a *packet*



The lower three layers are implemented **on all network nodes**

Description of OSI Layers

- Transport Layer
  - Implements a process-to-process channel
  - Unit of data exchanges in this layer is called a *message*
- Session Layer
  - Provides a name space that is used to tie together the potentially different transport streams that are part of a single application
- Presentation Layer
  - Concerned about the format of data exchanged between peers
- Application Layer
  - Standardize common type of exchanges

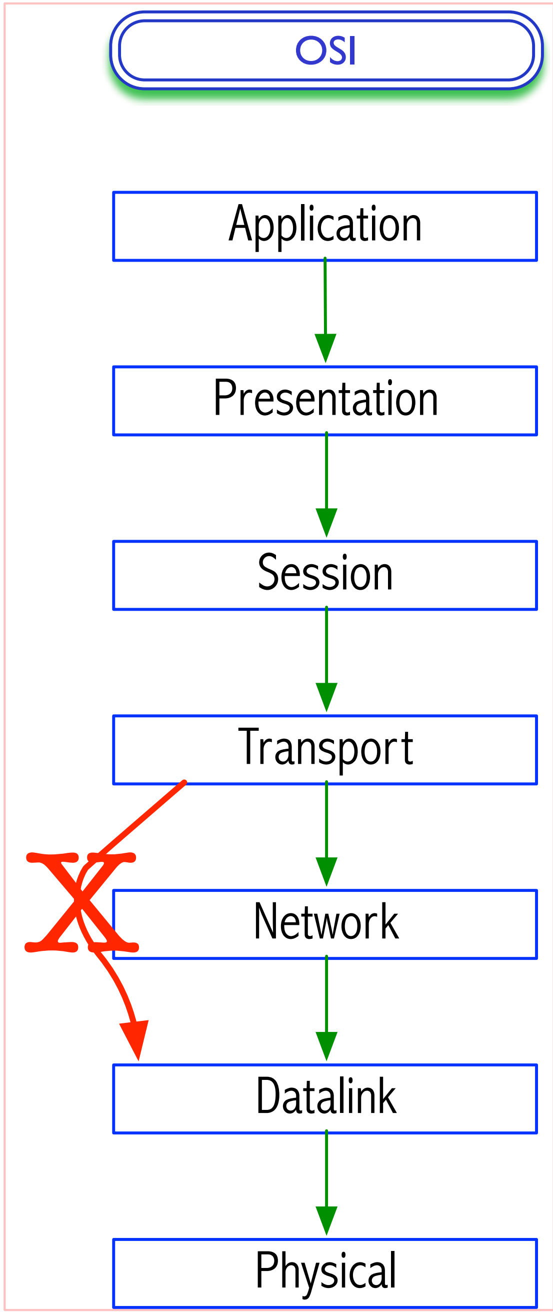


The transport layer and the higher layers typically run only on end-hosts and not on the intermediate switches and routers

OSI, strict layering

A layer only uses the services provided by the layer below

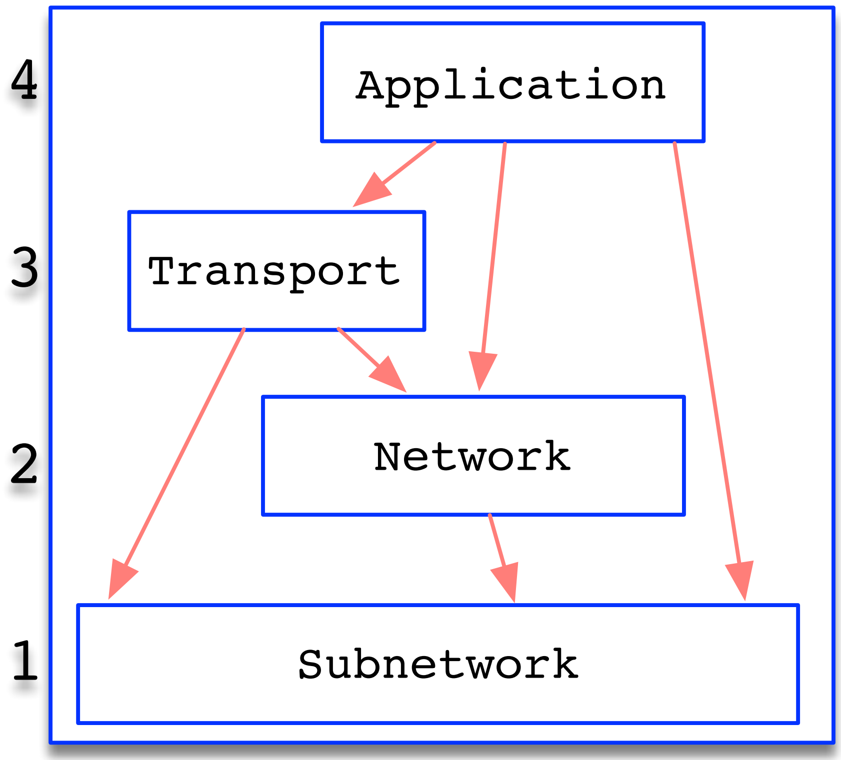
- The internal mechanisms of each layer remain hidden
  - Layer N+1 knows nothing about the internal mechanisms of layer N
- Example:
  - Transport layer can only use the Network layer



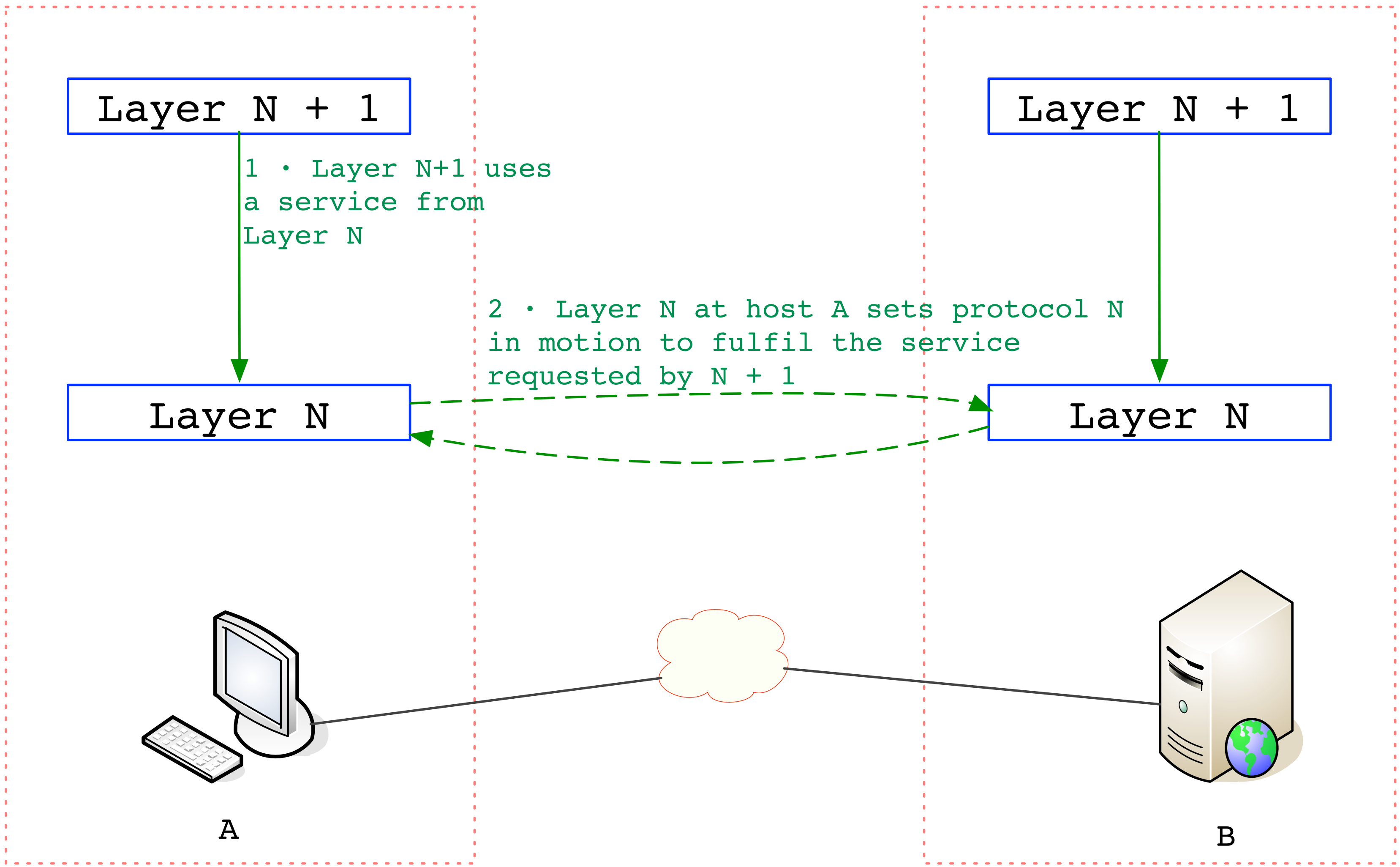
Layering in Internet Architecture is non-strict

A layer may use the services provided by *any* layer below

- The internal mechanisms of each layer remain hidden
  - Layer N+1 knows nothing about the internal mechanisms of layer N
- Example:
  - An Application protocol may use whichever lower layer



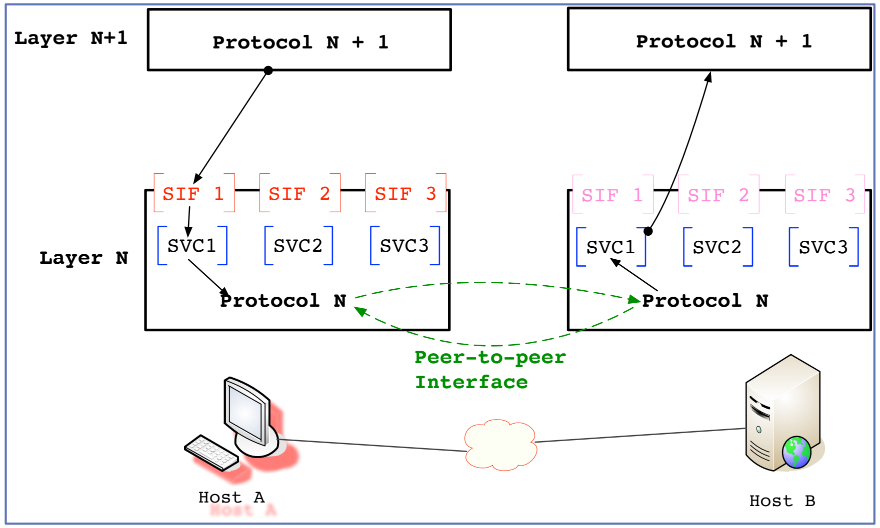
Protocol: The foreman of a service



N+1 represents *any* upper layer in IA (Internet Architecture)

Layer N+1 uses a service at Layer N

- Layer N
  - Several services: SVC1, SVC2
  - Each service is accessed through its **Service Interface:** SIF1, SIF2
  - The protocol N (Host A) fulfils the functionality offered by SVC by exchanging messages with protocol N at Host B
  - These messages comprise the **Peer-to-Peer Interface**

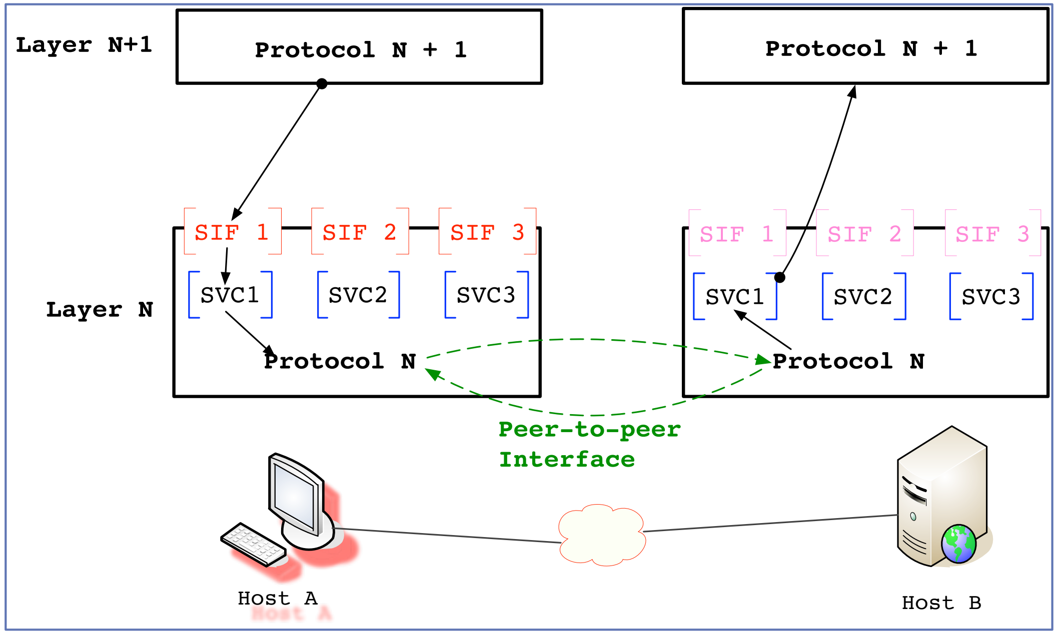


N+1 represents *any* upper layer in IA (Internet Architecture)

Example: A runs Linux; B runs Windows

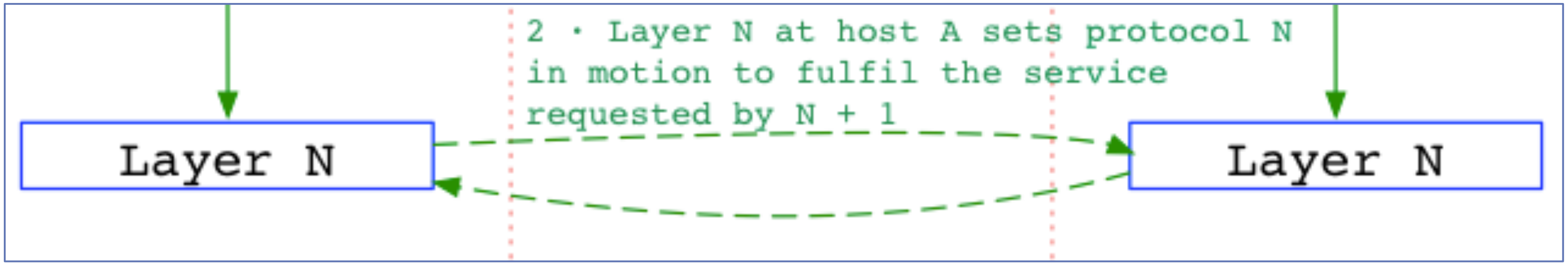
- Equal layers at A and B must implement the **same protocol**
  - *Same peer-to-peer interface*

- However, **Service Interfaces at A and B** might be present differences



Peer-to-peer interface

- The syntax and the semantics of the messages exchanged by the two peers must follow a formal specification
  - ASN.1, Abstract Syntax Notation
- Normally, we refer to the peer-to-peer interface with the same word: protocol
- Protocols of Internet are specified by the IETF
  - RFC: Request For Comments
  - Example: The ICMP protocol is specified in RFC 792



Encapsulation and Multiplexing: *Concept*

- What information is sent from N+1 to N through the SIF (Service Interface)?
  - Protocol N+1 sends a N+1 Data Unit to Protocol N
  - Protocol N encapsulates the N+1 Data Unit into a fresh N Data Unit:
    - Payload(N+1) + Header(N)
    - This scheme is reproduced at each service use
  - **Data Unit**: A bit string produced by a protocol
  - **Encapsulation**: Appending a Header to a Data Unit

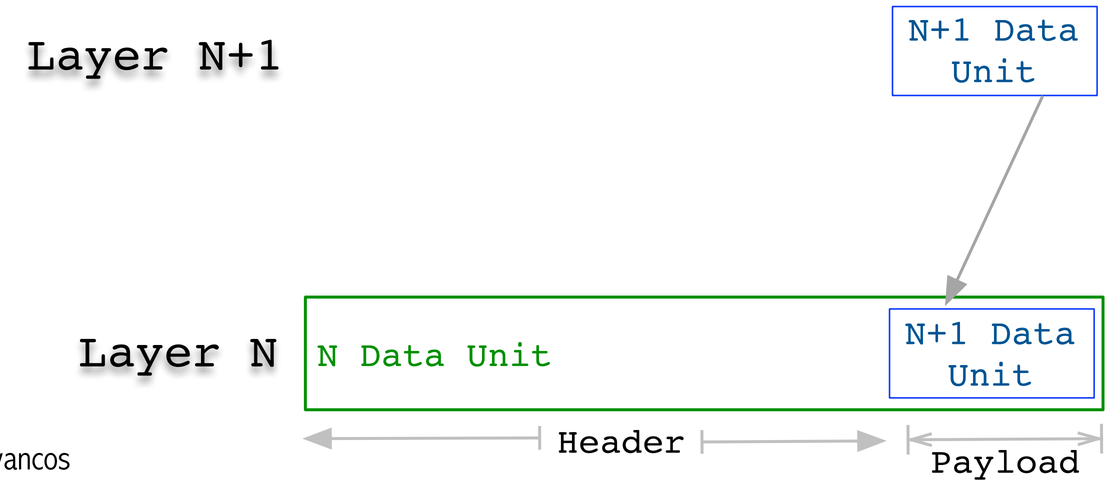
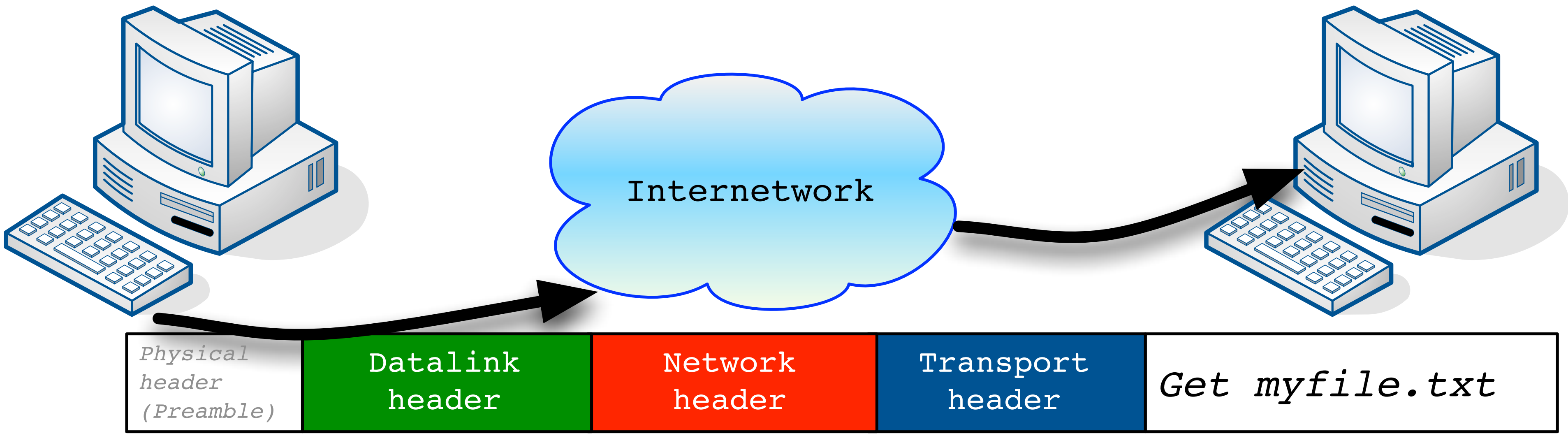
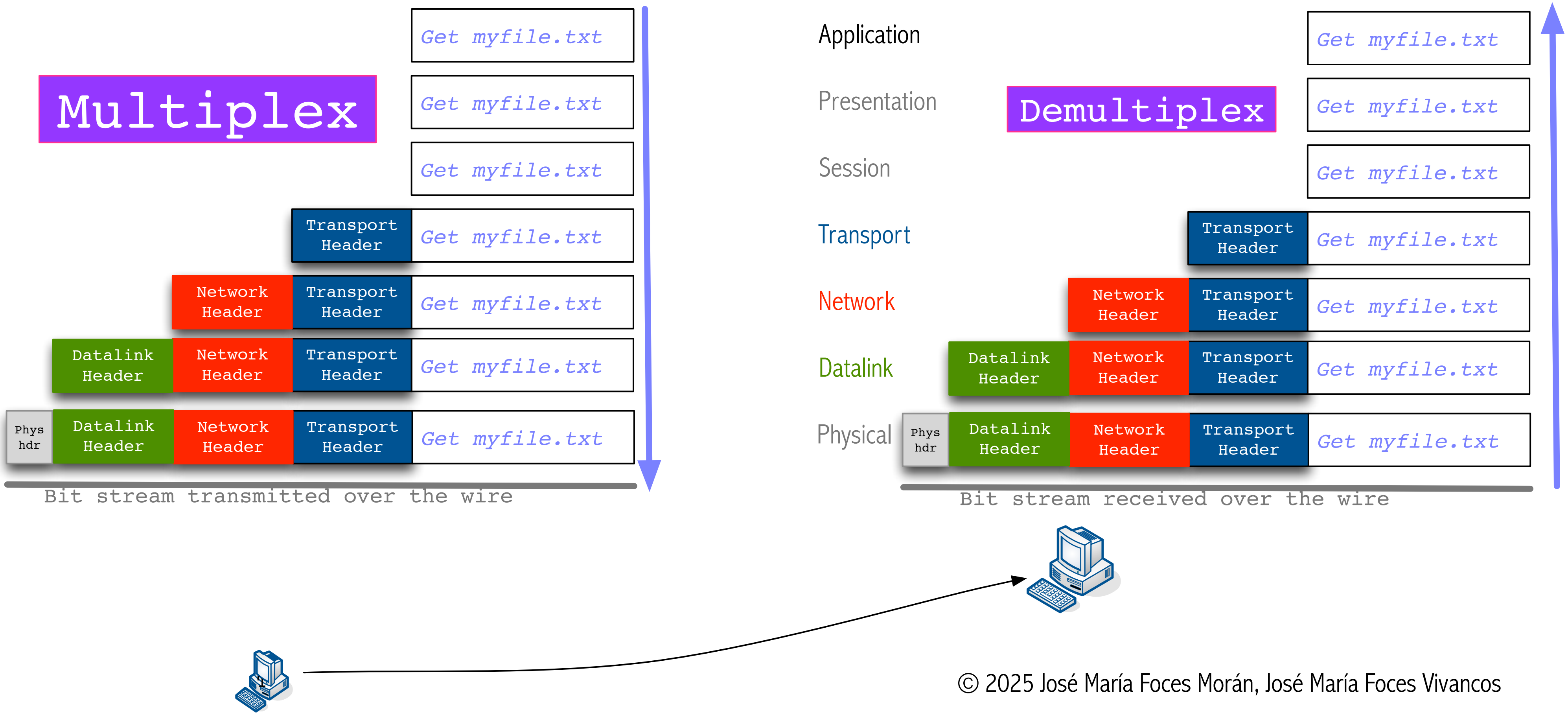


Illustration of encapsulation in OSI



Multiplexing

- Transmitter multiplexes several flows by having each layer add its header which contains addressing information



Demultiplexing

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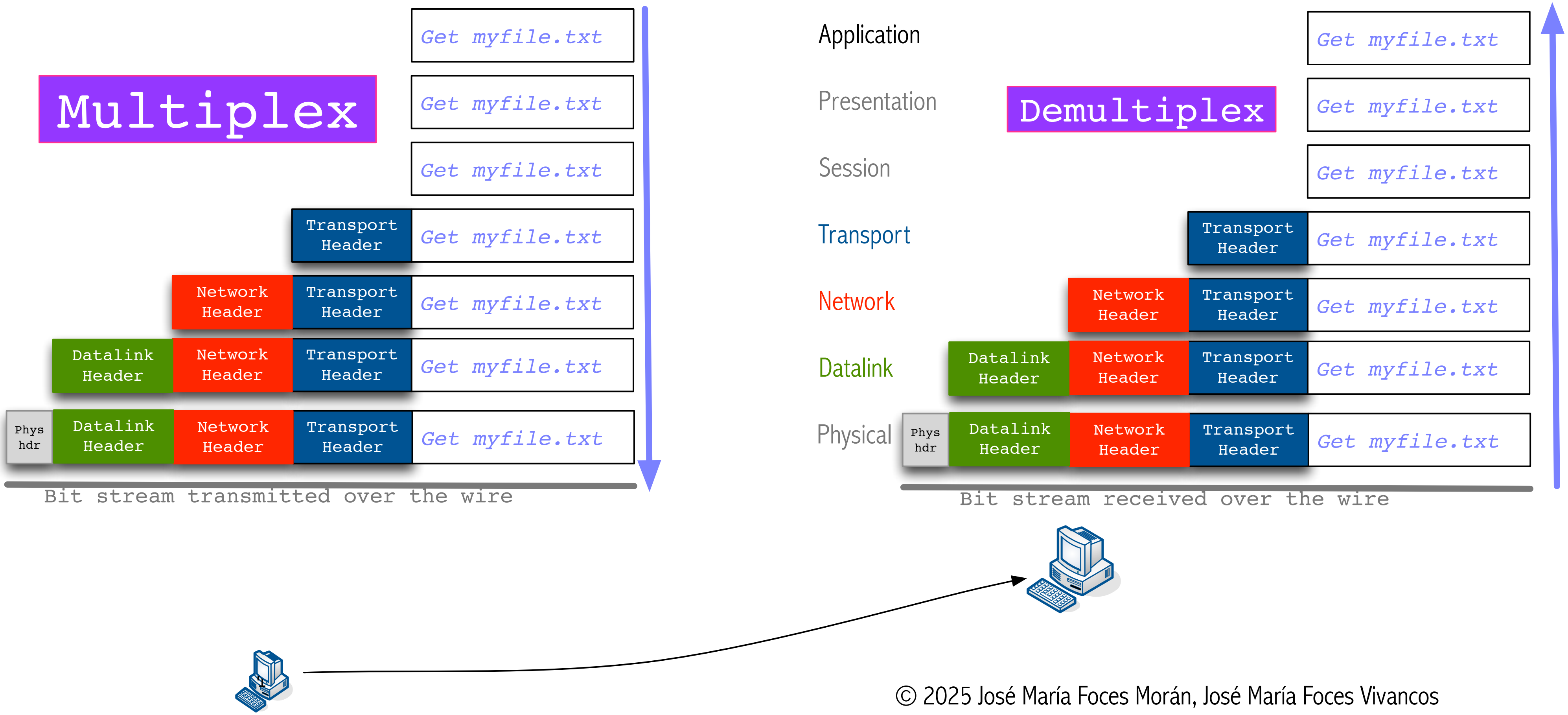
- Receiver demultiplexes several flows by having each layer analyze its header which contains addressing information about the upper-layer protocol that is to receive the payload



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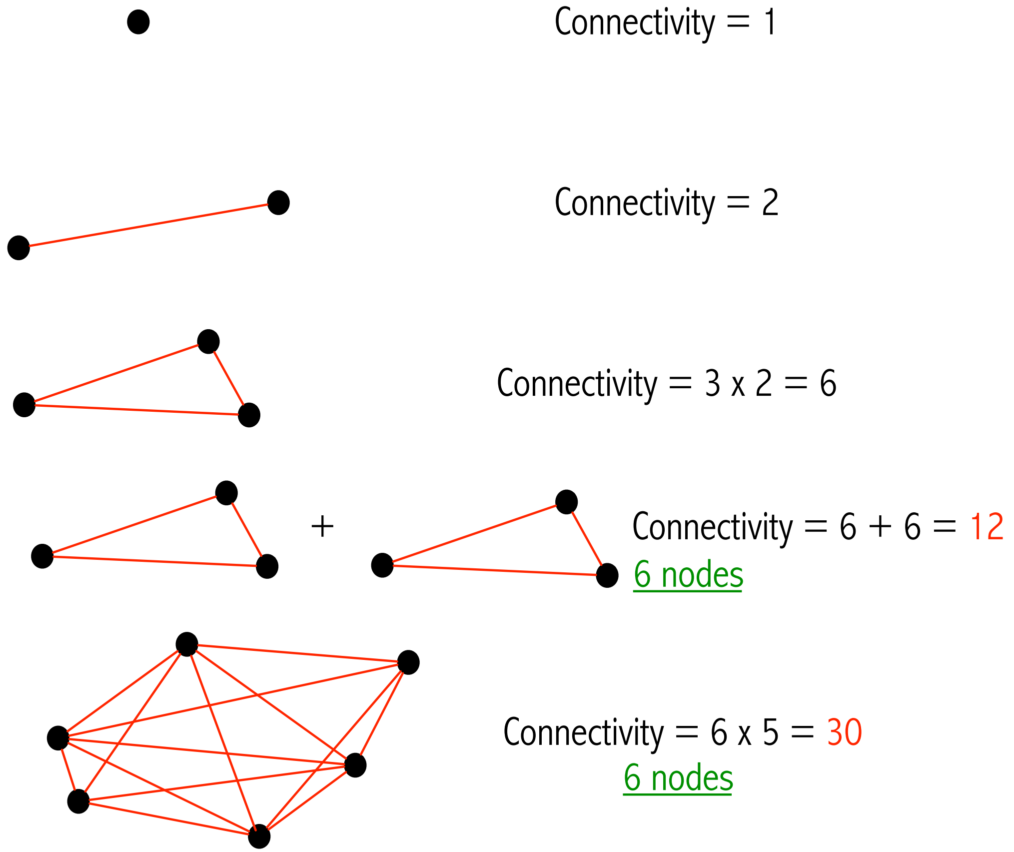
Connectivity

Computer Networks connect computers; the many more, the better, with a limit!

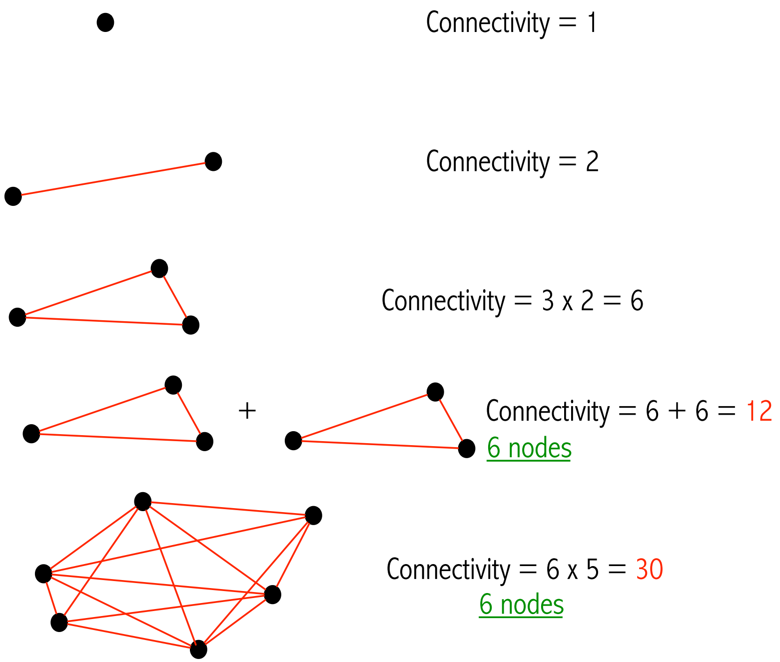
Theoretical connectivity

- Connectivity is the capacity of connection of a network
- If a network has N hosts, its connectivity is: N·(N-1) ≅ **N^2**
- Metcalf's law: The connectivity of a network grows fast as we add more nodes (**N^2**)



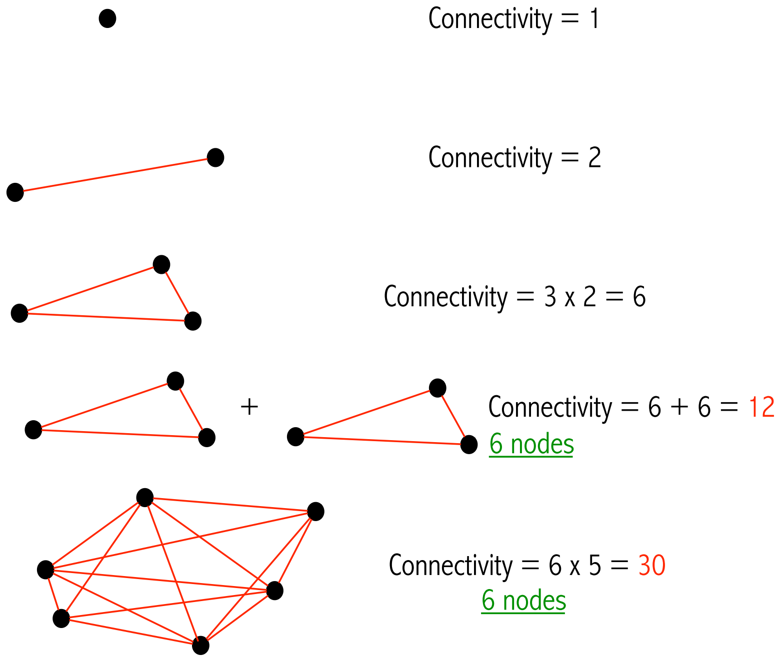
Increasing connectivity whilst preserving the capability for communication

- Metcalf's law
  - Increased connectivity means increased value
- Nodes communicate by sending/receiving messages
  - The bandwidth available at each link is limited
  - Links at highly demanded locations may become a bottleneck
- What's a figure of merit that will tell whether communication has been preserved after increasing the connectivity?
  - Is connectivity scalable?



Increasing connectivity whilst preserving the capability for communication

- The total number of packets per second that successfully make it to their destinations is known as:
  - Throughput, the figure of merit
  - Overall network productivity
  - Overall bps, or pps (packets per second), etc.



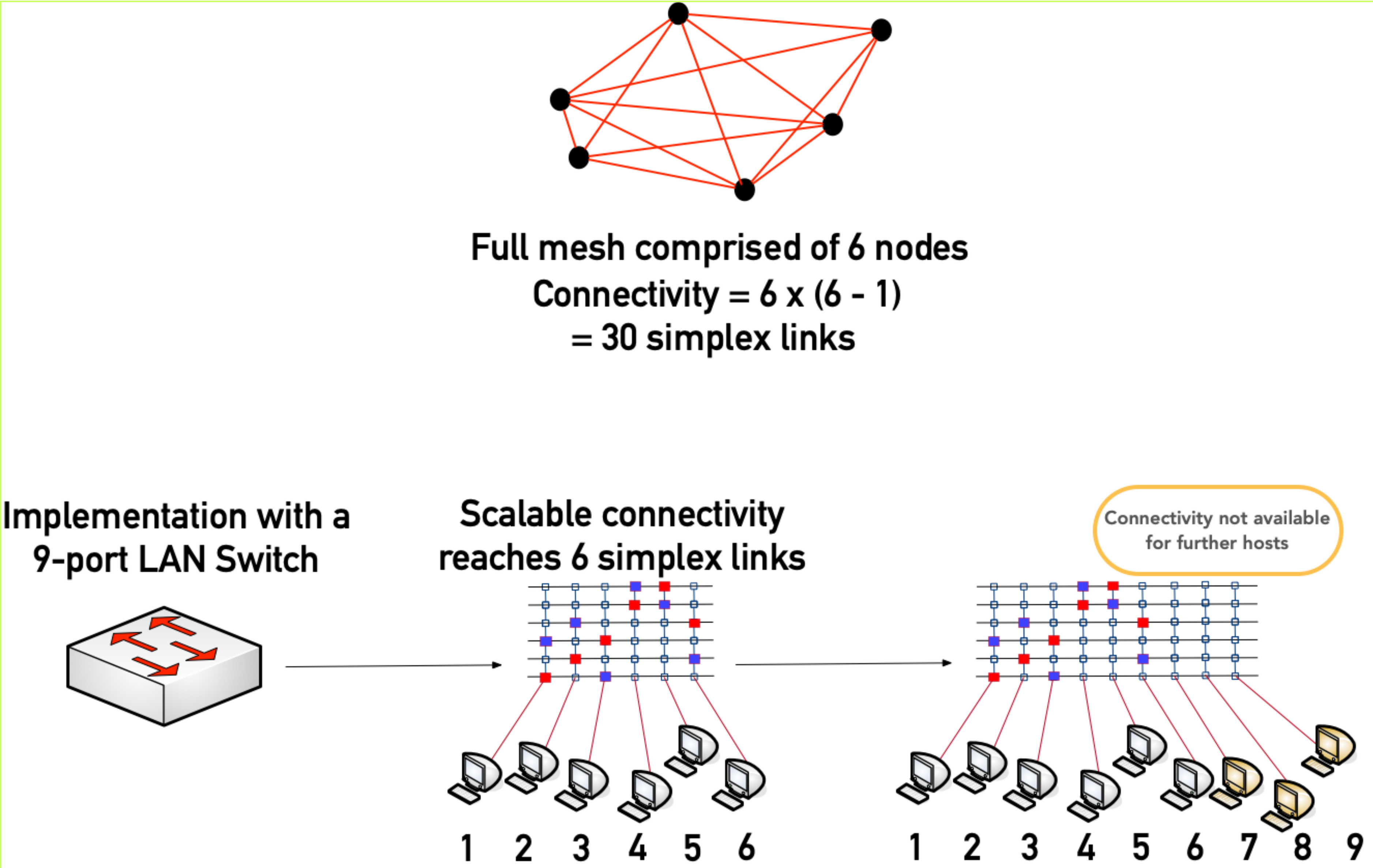
Scalable connectivity

- Not all network technologies use the available connectivity with the same efficiency

- Ethernet can function efficiently up to certain network size: we say that Ethernet scales well up to that limit.

- Then, how come the Internet has **4000M** hosts? How can the Internet scale to such a huge size so well?
  - Each network has a limited size
  - Interconnecting networks is the key:
    - With IP gateways
    - IP protocol

Switch won't scale to 9 hosts



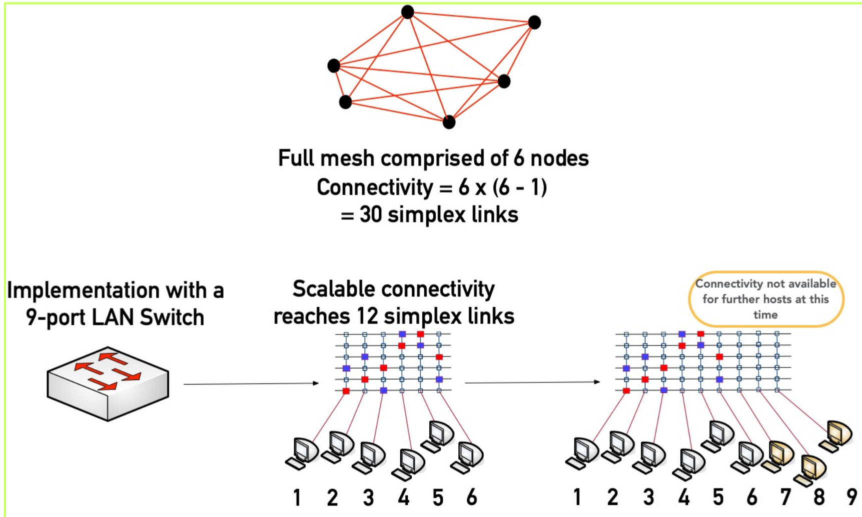
Based on textbook *Conceptual Computer Networks* by:

Switch won’t scale to 9 hosts

6 full-duplex communication flows are possible

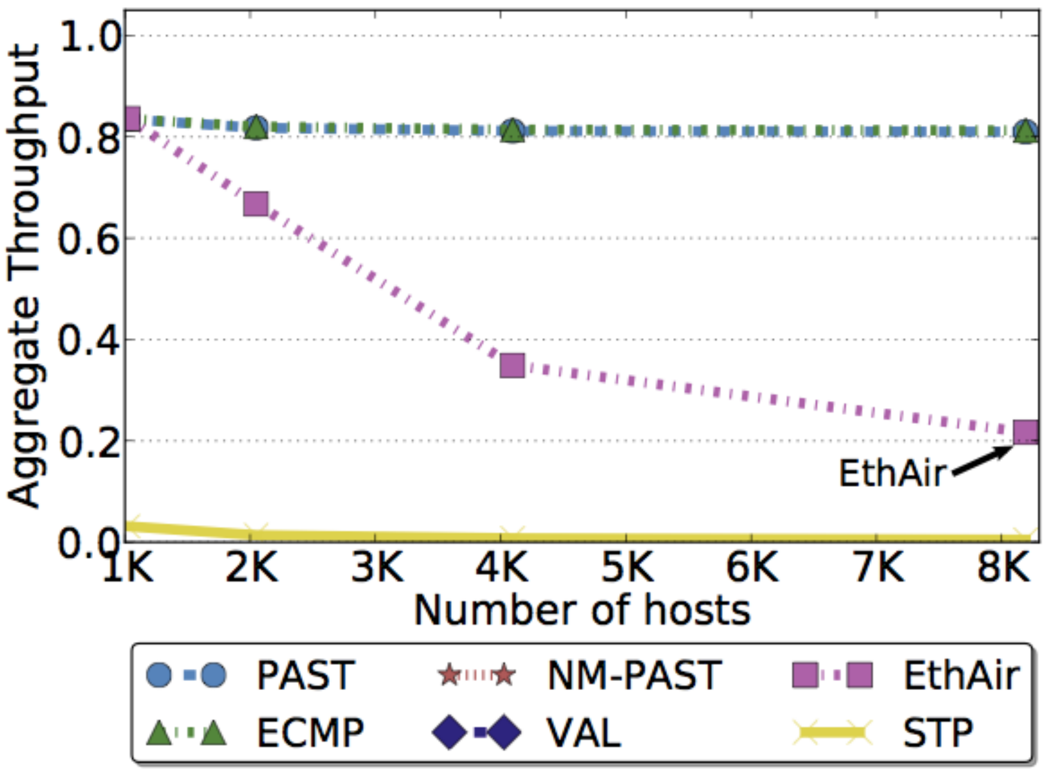
- The overall productivity of this switch will be bounded by
  - The available number of connection points
  - The available number of horizontal lines
- Throughput, the total pps or bps will be bounded by the limited switch resources
  - PPS = Average number of Packets Per Second that the switch can successfully deliver
  - Bps = Average number of bits per second that the switch can successfully deliver

Physically connecting more than 6 hosts will not achieve a Throughput improvement



Example: Network Throughput of various wireless technologies

EthAir scales poorly



Example: Response time (s) of a multi-server application

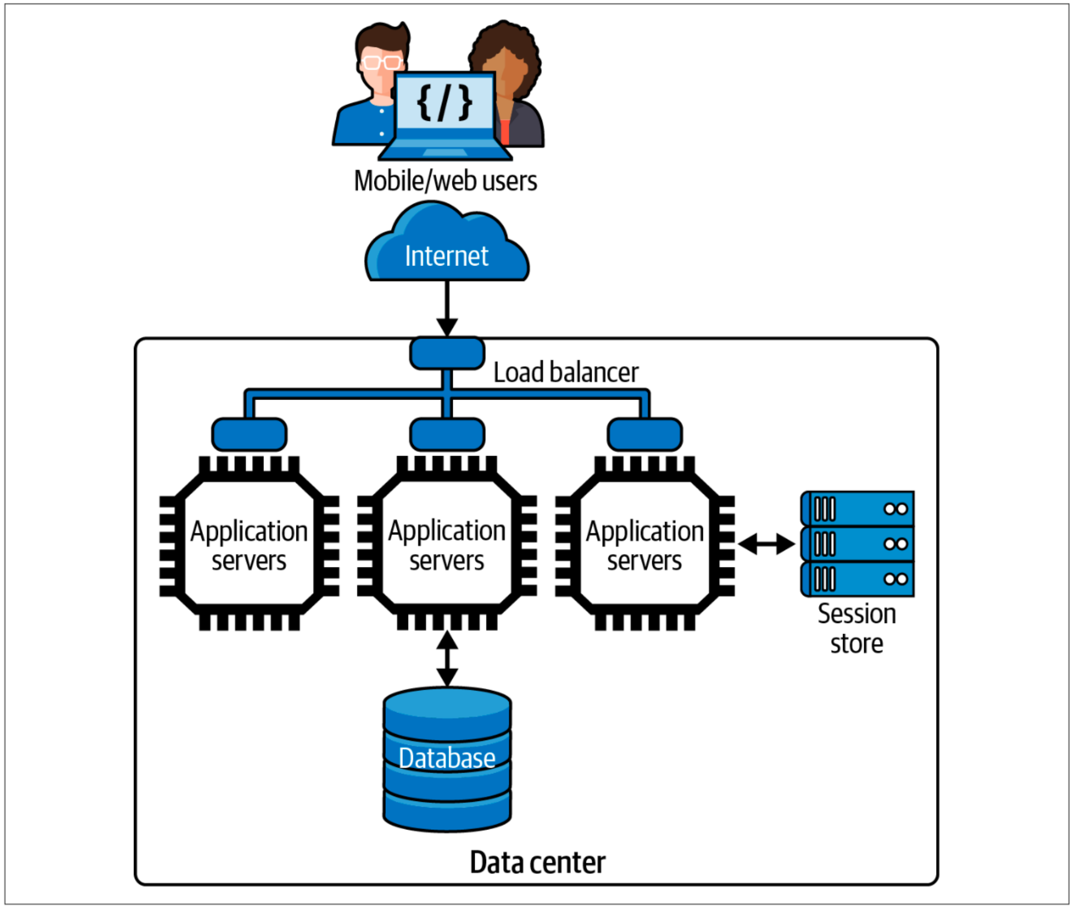


Figure 2-2. Scale-out architecture

Foundations of Scalable Systems
by Ian Gorton

Printed in the United States of America.

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Example: Mean response time (s) of an application vs. offered load (Requests/s)

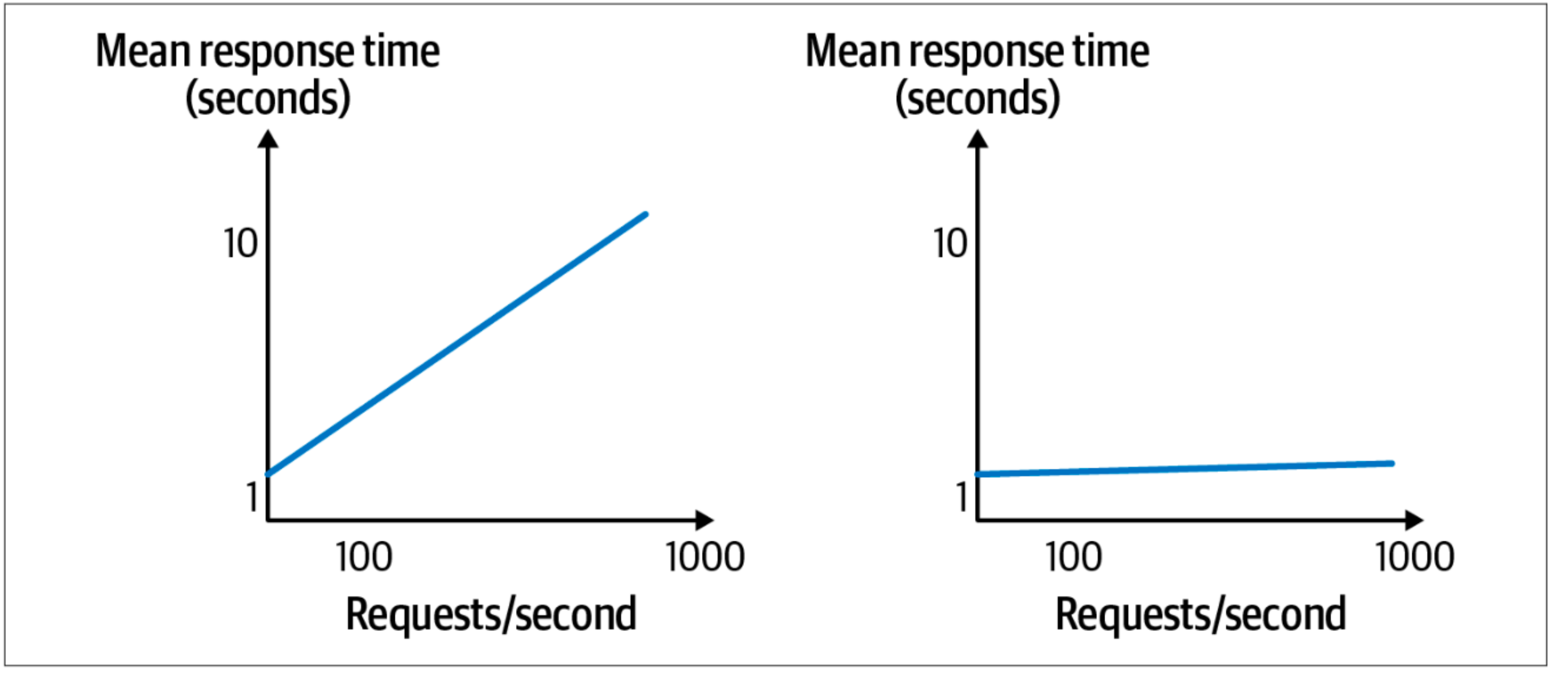

Figure 1-2. Scaling an application; non-scalable performance is represented on the left, and scalable performance on the right

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Examples (1/2)

- Mesh connectivity of a 5-node mesh network

- Draw the 5-node mesh

- The throughput of a network is 10^6 packets/s. Average packet size is 30 Bytes. Calculate the average network throughput in bps

Examples (2/2): transmission speed of a WIFI

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Support Knowledge Base

Different Wi-Fi Protocols And Data Rates

Content Type: Product Information & Documentation | Article ID: 000005725 | Last Reviewed: 10/28/2021

Click ⌄ or the topic for details:

▼ **IEEE 802.11 Wi-Fi protocol summary**

Protocol	Frequency	Channel Width	MIMO	Maximum data rate (theoretical)
802.11ax	2.4 or 5GHz	20, 40, 80, 160MHz	Multi User (MU-MIMO)	2.4 Gbps[1]
802.11ac wave2	5 GHz	20, 40, 80, 160MHz	Multi User (MU-MIMO)	1.73 Gbps[2]
802.11ac wave1	5 GHz	20, 40, 80MHz	Single User (SU-MIMO)	866.7 Mbps[2]
802.11n	2.4 or 5 GHz	20, 40MHz	Single User (SU-MIMO)	450 Mbps[3]
802.11g	2.4 GHz	20 MHz	N/A	54 Mbps
802.11a	5 GHz	20 MHz	N/A	54 Mbps
802.11b	2.4 GHz	20 MHz	N/A	11 Mbps
Legacy 802.11	2.4 GHz	20 MHz	N/A	2 Mbps

[1] 2 Spatial streams with 1024-QAM modulation.
[2] 2 Spatial streams with 256-QAM modulation.
[3] 3 Spatial streams with 64-QAM modulation.

Feedback

End of Ch 1 Section 1