

Chapter 1: Conceptual Basis

Section 1

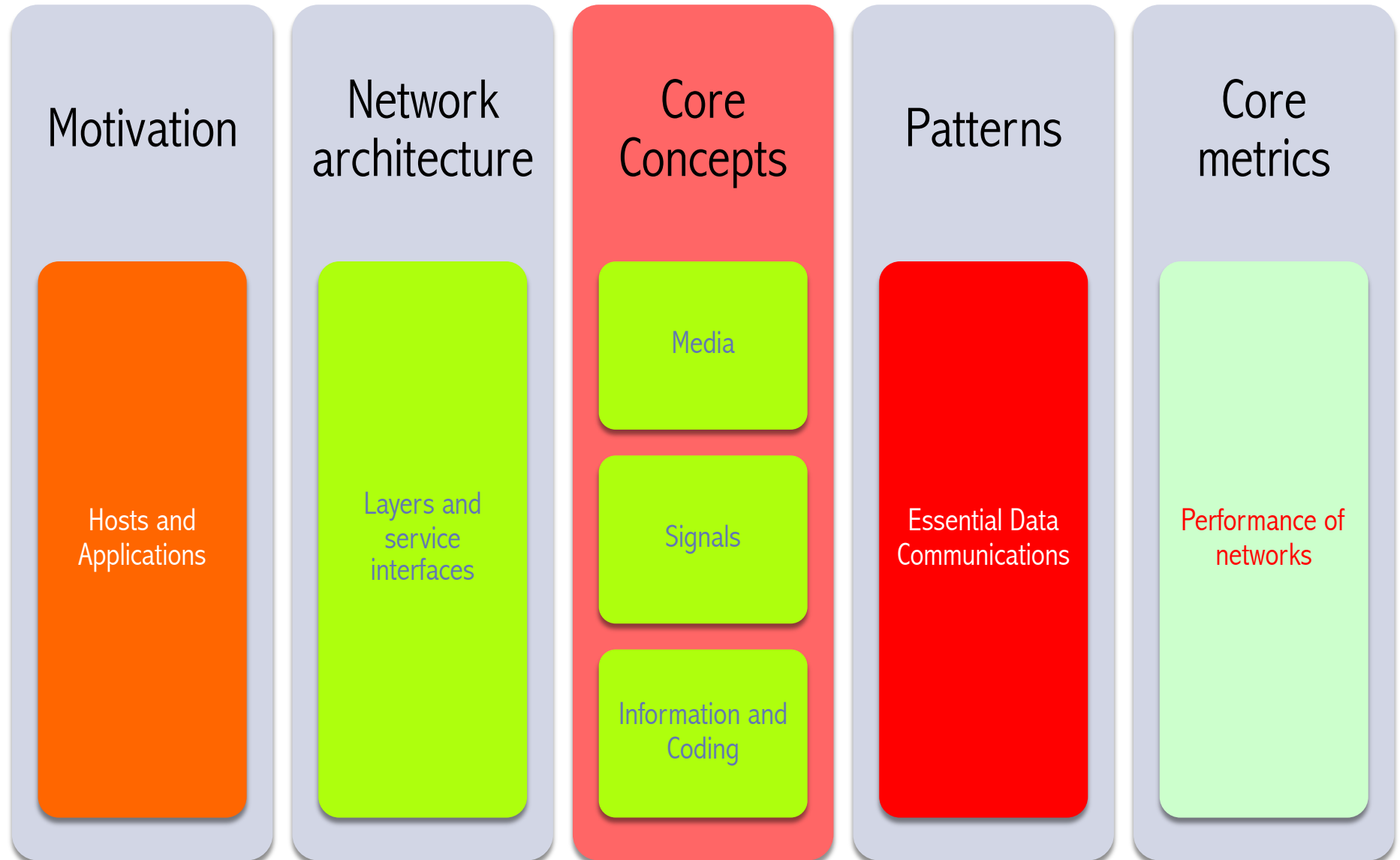
Leading questions

2

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

Flow of topics

3

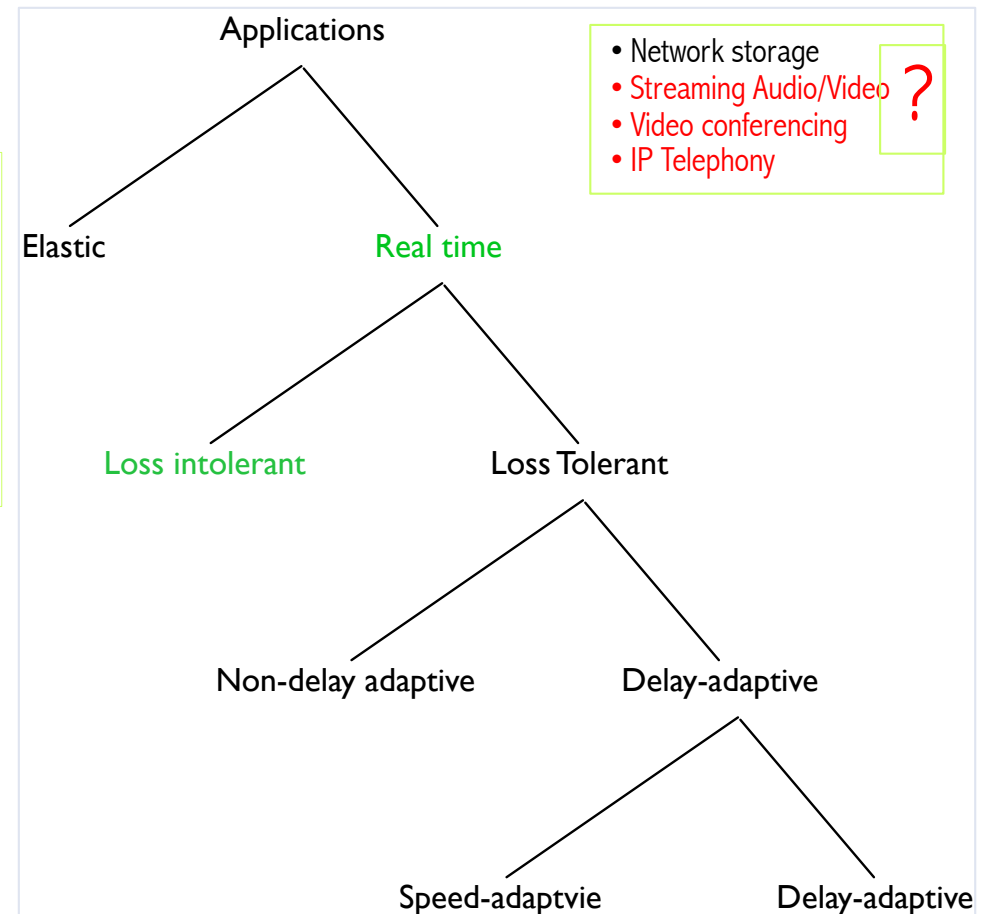


Cooperating host applications

4

- Applications are computer programs
- Communicate over the Internet
- At work, at home and mobile
- Vastly differing requirements

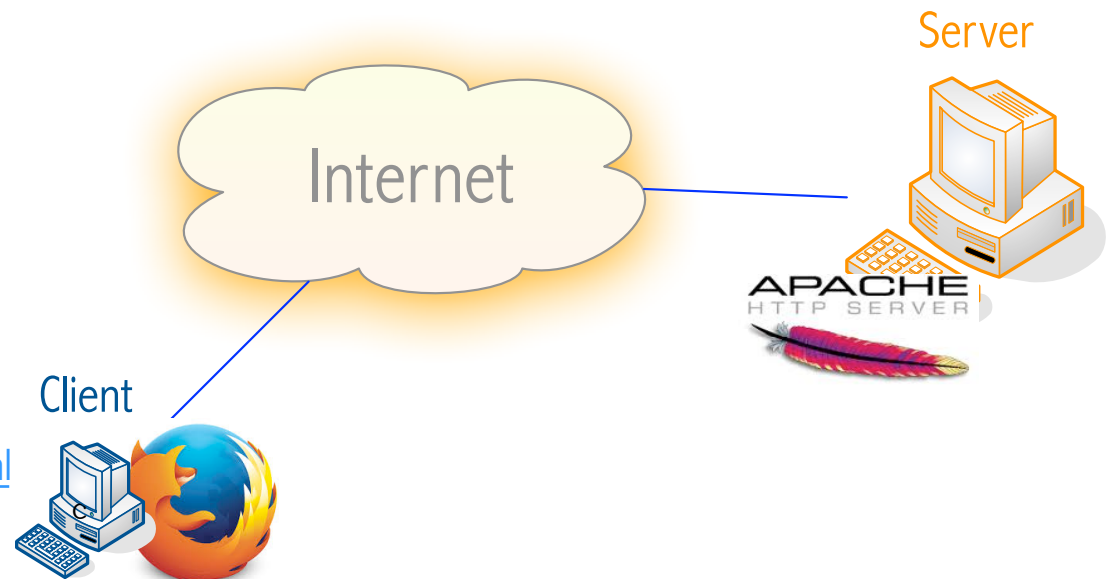
- e-mail: smtp, pop3, imap
- File Sharing, file transfer: ftp, rcp, scp
- Printer sharing
- Virtual terminal: telnet, ssh (Secure Shell)
- e-commerce
- Geolocation
- **World Wide Web (www)**
- Social Networks
- Instant Messaging (Whatsup, ...)



Essential Internet service: www

5

- Web pages are downloaded by the client from the **server**
 - Client and server speak the **http** protocol
 - http = Hyper Text Transfer Protocol
- **www** = World Wide Web:
 - A distributed, Client/Server application
 - **Server** program (e.g., Apache)
 - **Client** program (e.g., Firefox)
- URL
 - Uniform Resource Locator
 - <http://palauto.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

6

□ 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})

□ 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

7

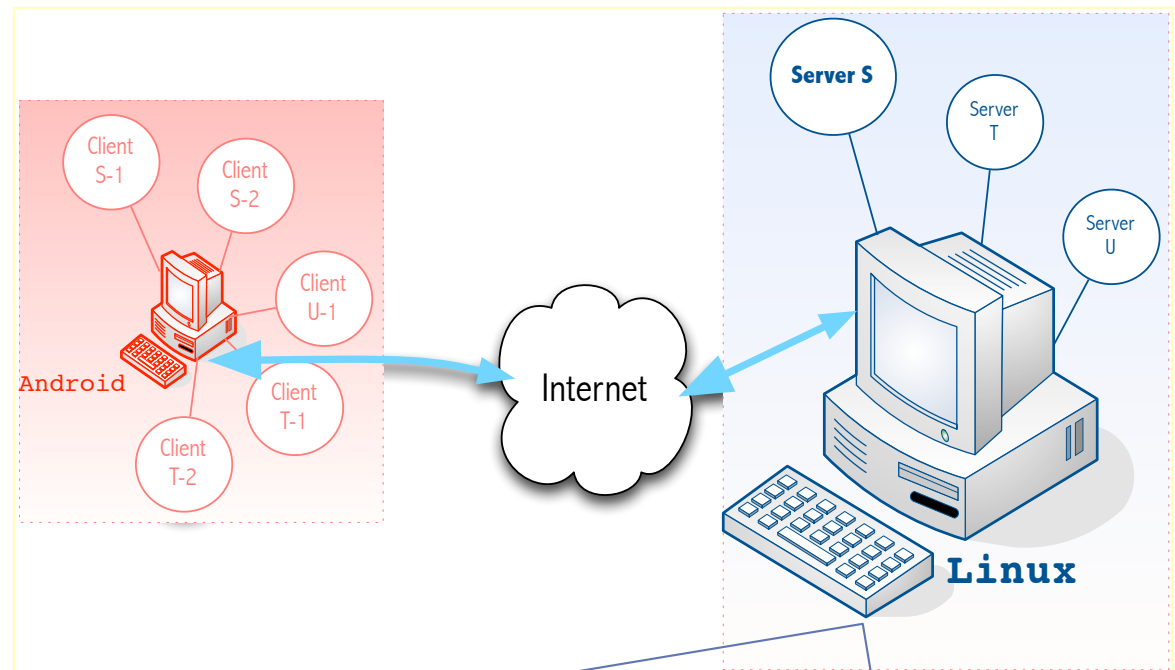
Network Architecture

Manage the complexity of networks

Logical channels

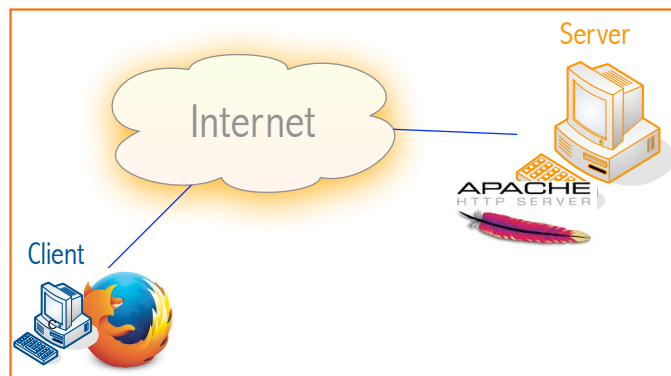
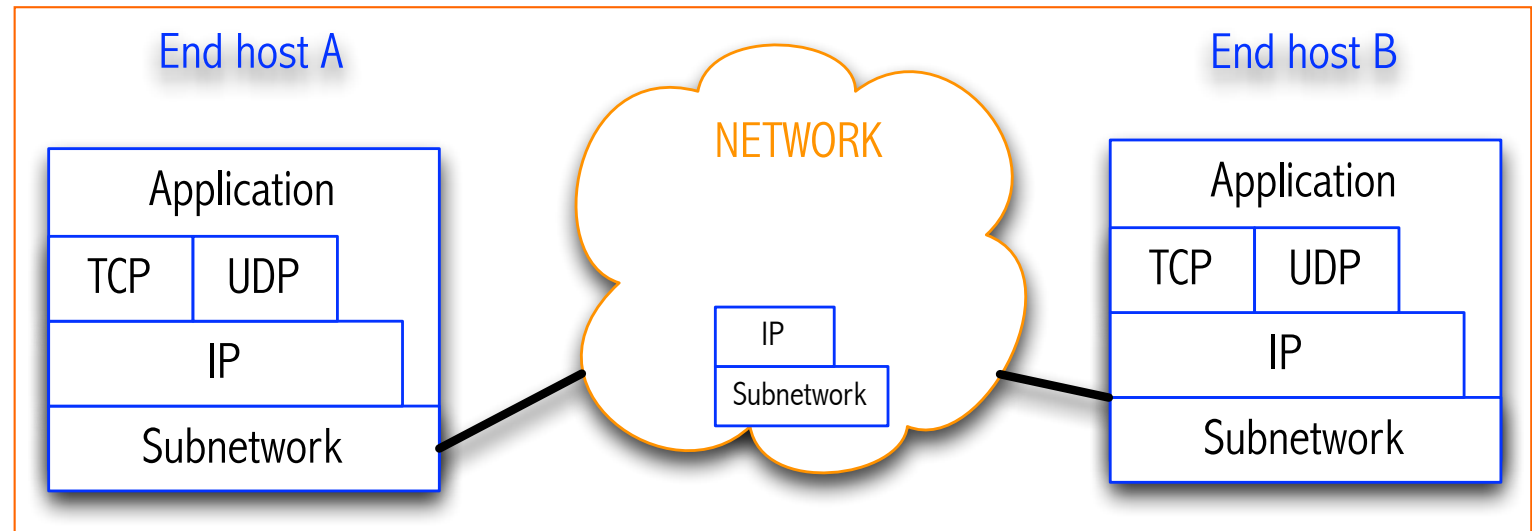
8

- 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

10

- Network complexity is organized into 4 layers

- Each *layer*

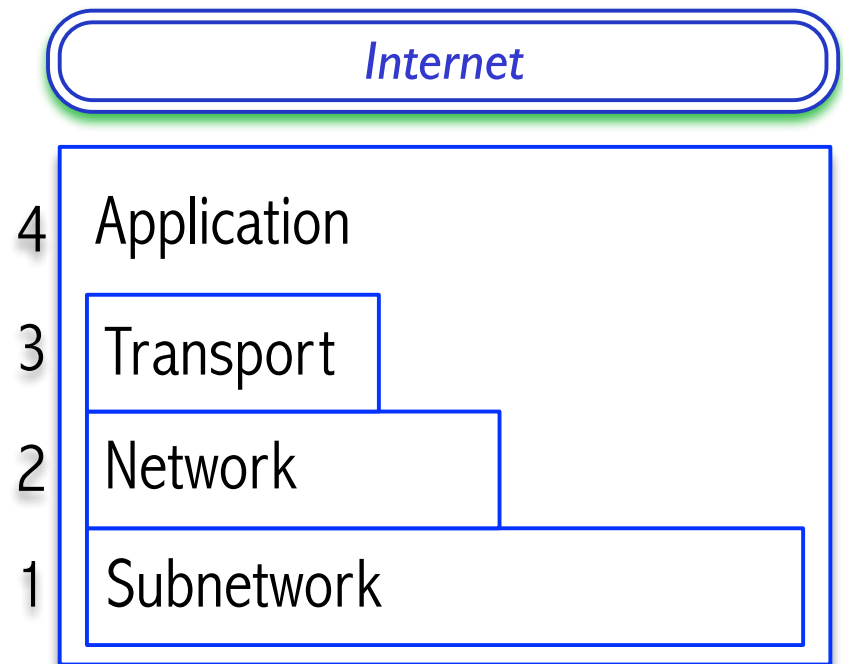
- Offers a set of services to the upper layers
 - The mechanism that attains each *service* is a protocol
 - An upper layer avails one service from a lower layer by calling its *interface*

- 1. Subnetwork: Ethernet, Wi-Fi, Bluetooth

- 2. Network: Only IP !!!

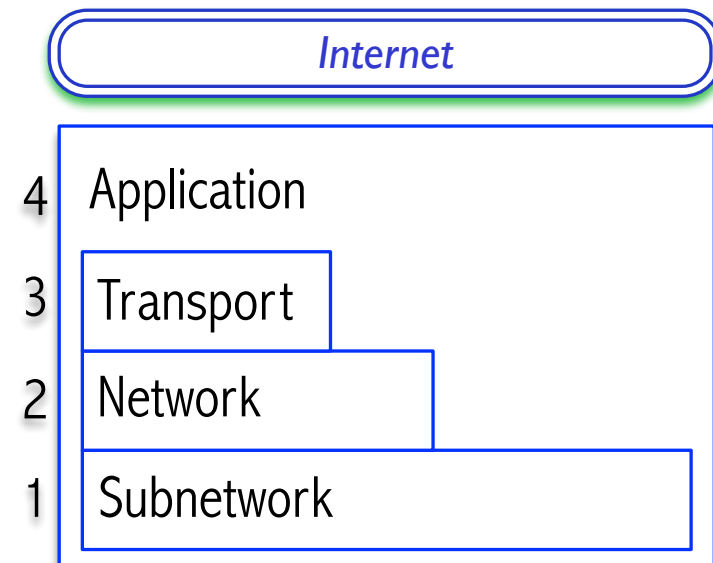
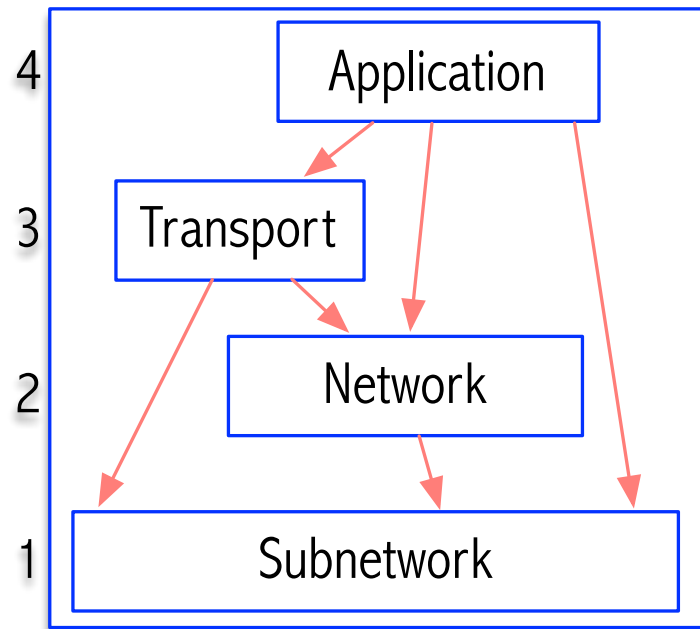
- 3. Transport: TCP and UDP

- 4. Application: Whatsup and innumerably others

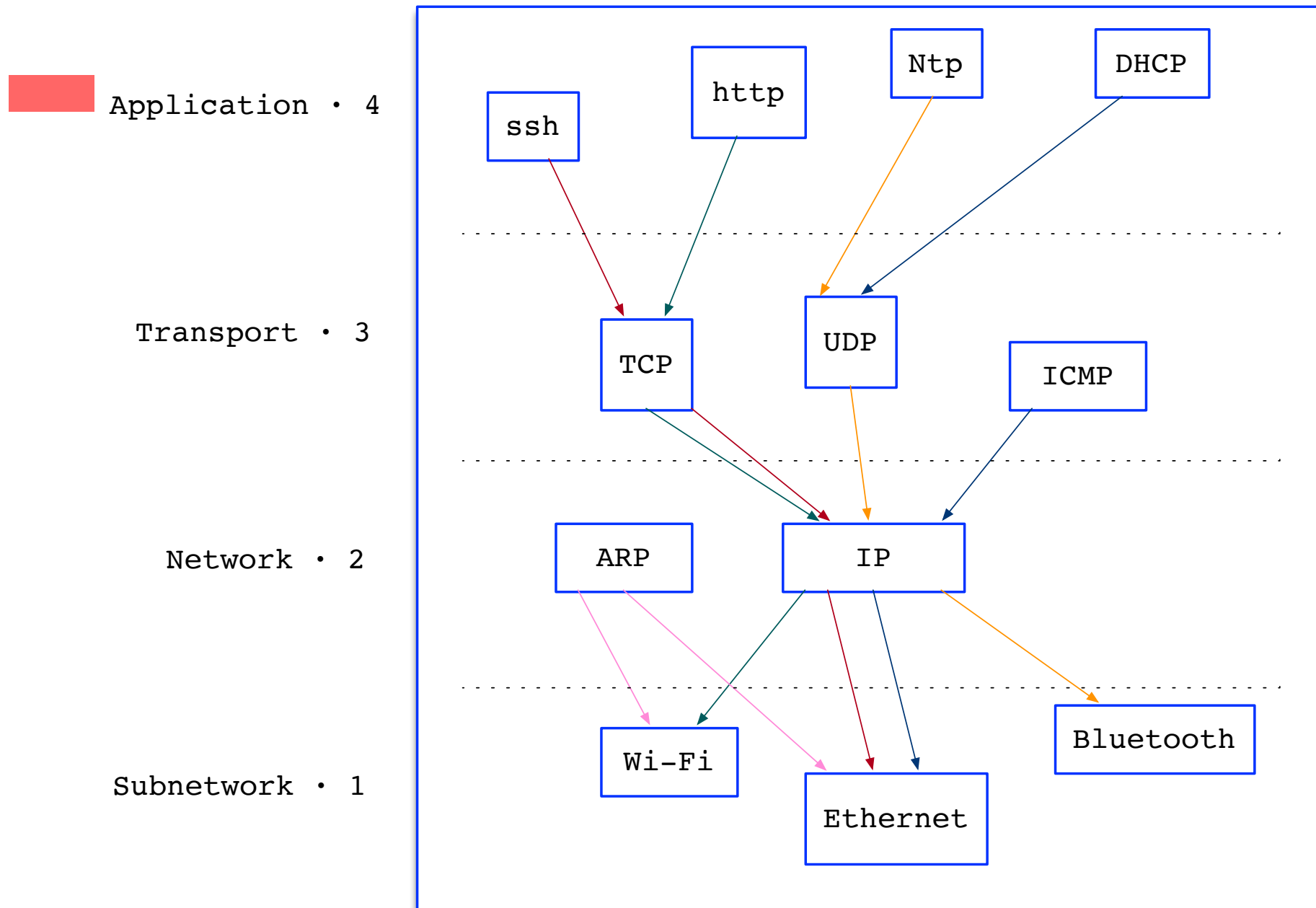


Internet Architecture

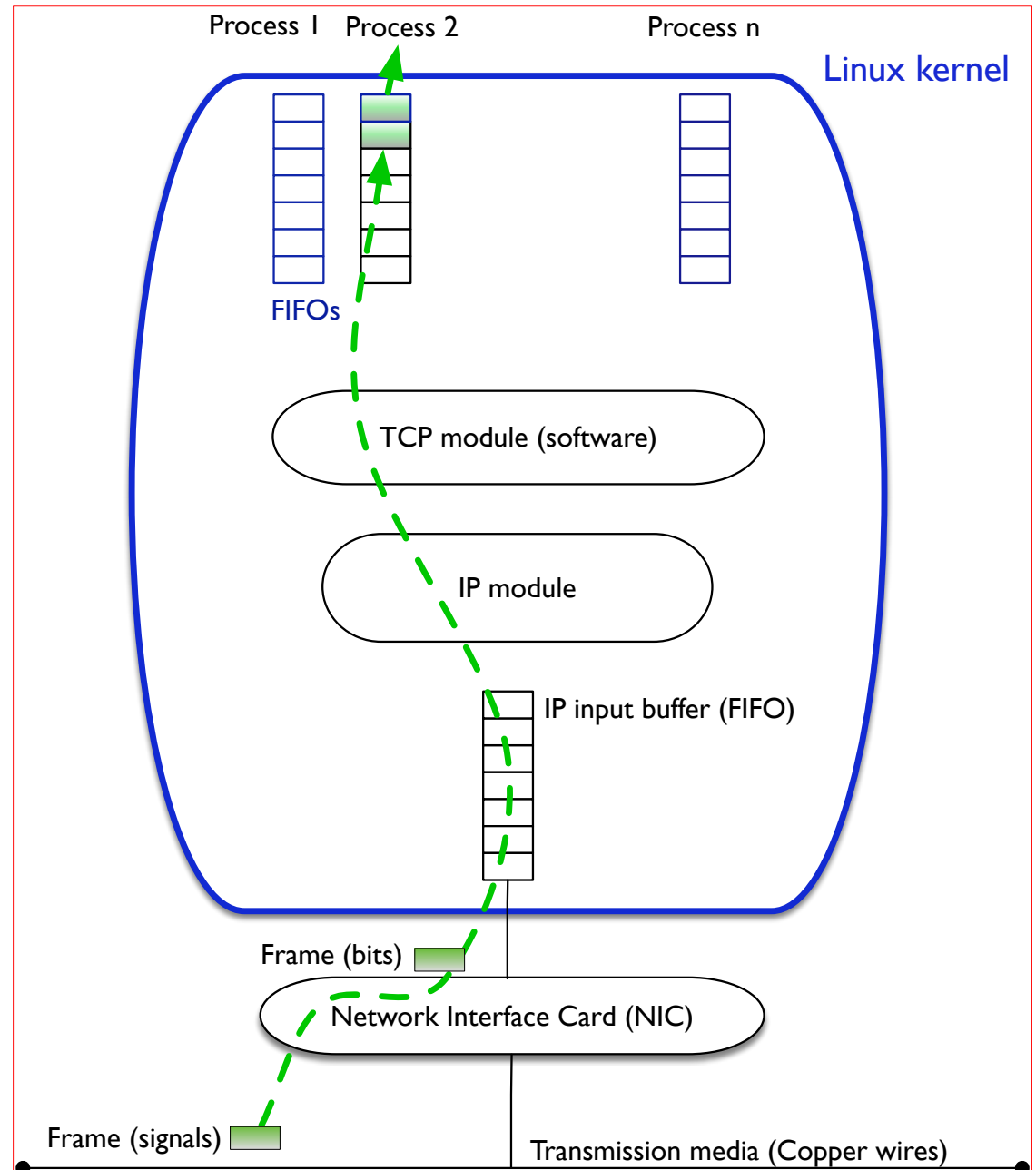
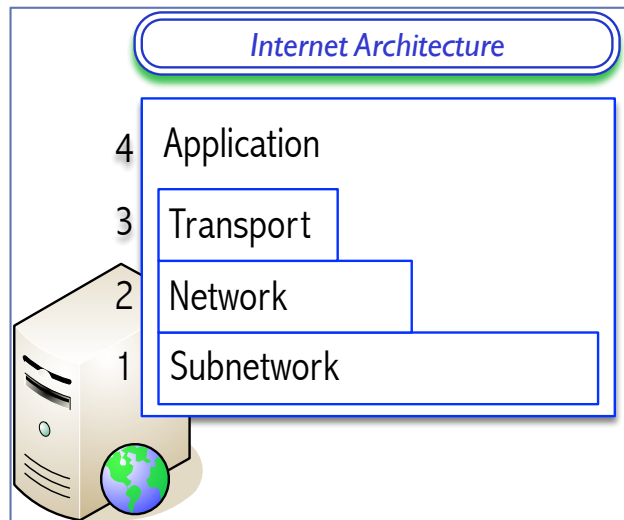
11



Typical Internet Protocol Stack



Implementation of protocols



Internet Architecture

14

- Defined by IETF (Internet Engineering Task Force)
- Three main features
 - ▣ Does **not** imply strict layering. The application is free to bypass the defined transport layers and to directly use IP or other underlying networks
 - ▣ An **hour-glass shape** — wide at the top, narrow in the middle and wide at the bottom. IP serves as the focal point for the architecture
 - ▣ In order for a new protocol to be officially included in the architecture, there needs to be both a protocol specification and at least one (and preferably two) representative implementations of the specification

15

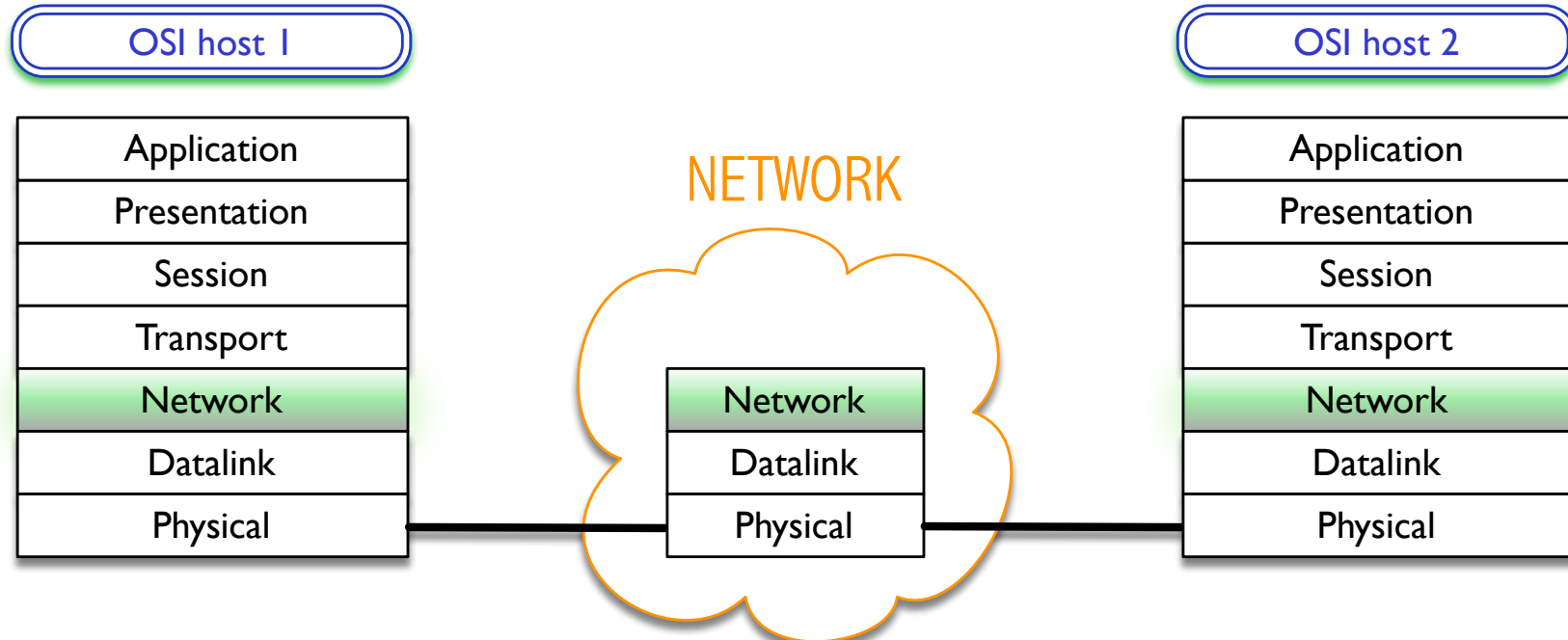
Protocols and their Services

Protocols offer services

7-layer OSI Architecture

16

- ❑ A Reference Model
- ❑ Not used today
- ❑ Layering is strict



Description of OSI Layers

17

□ 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**

OSI Architecture

| |
|--------------|
| Application |
| Presentation |
| Session |
| Transport |
| Network |
| Datalink |
| Physical |

Description of OSI Layers

18

□ 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

OSI Architecture

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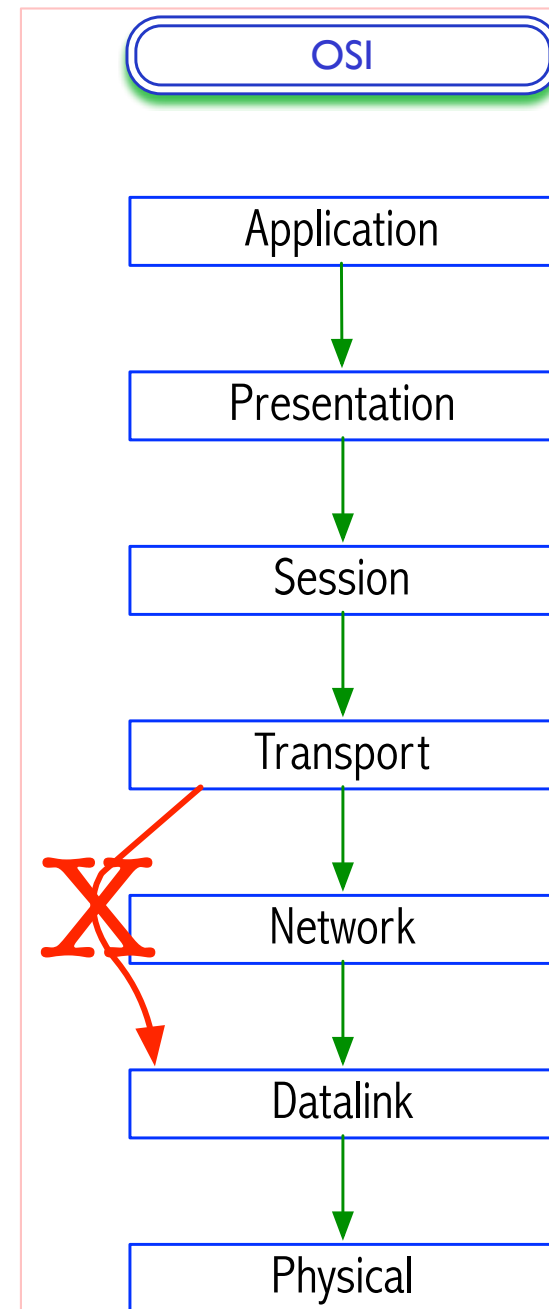
The transport layer and the higher layers typically run only **on end-hosts** and not on the intermediate switches and routers

OSI, strict layering

19

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

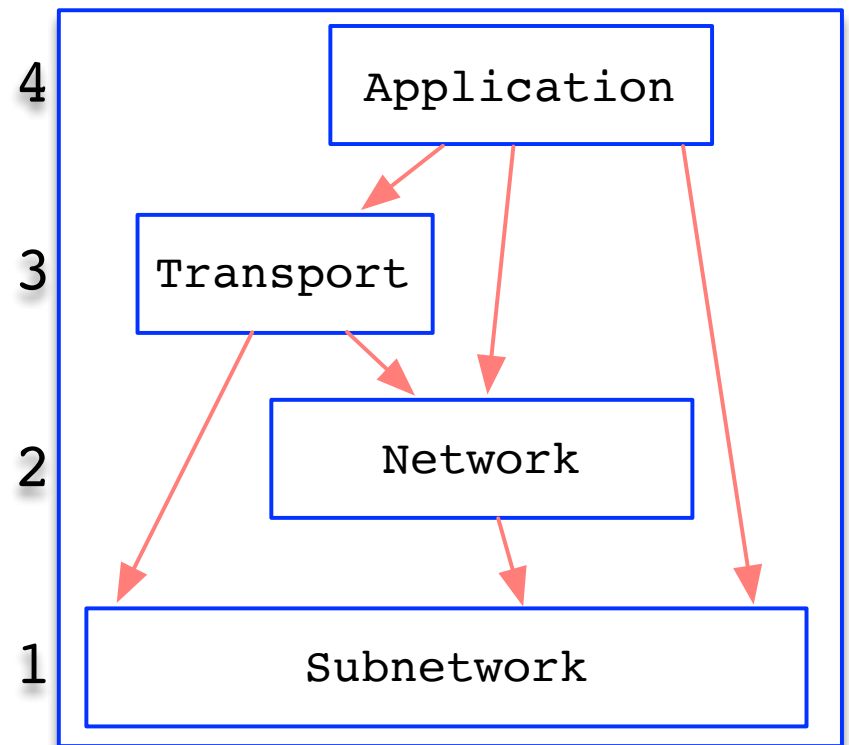


Layering in Internet, non-strict

20

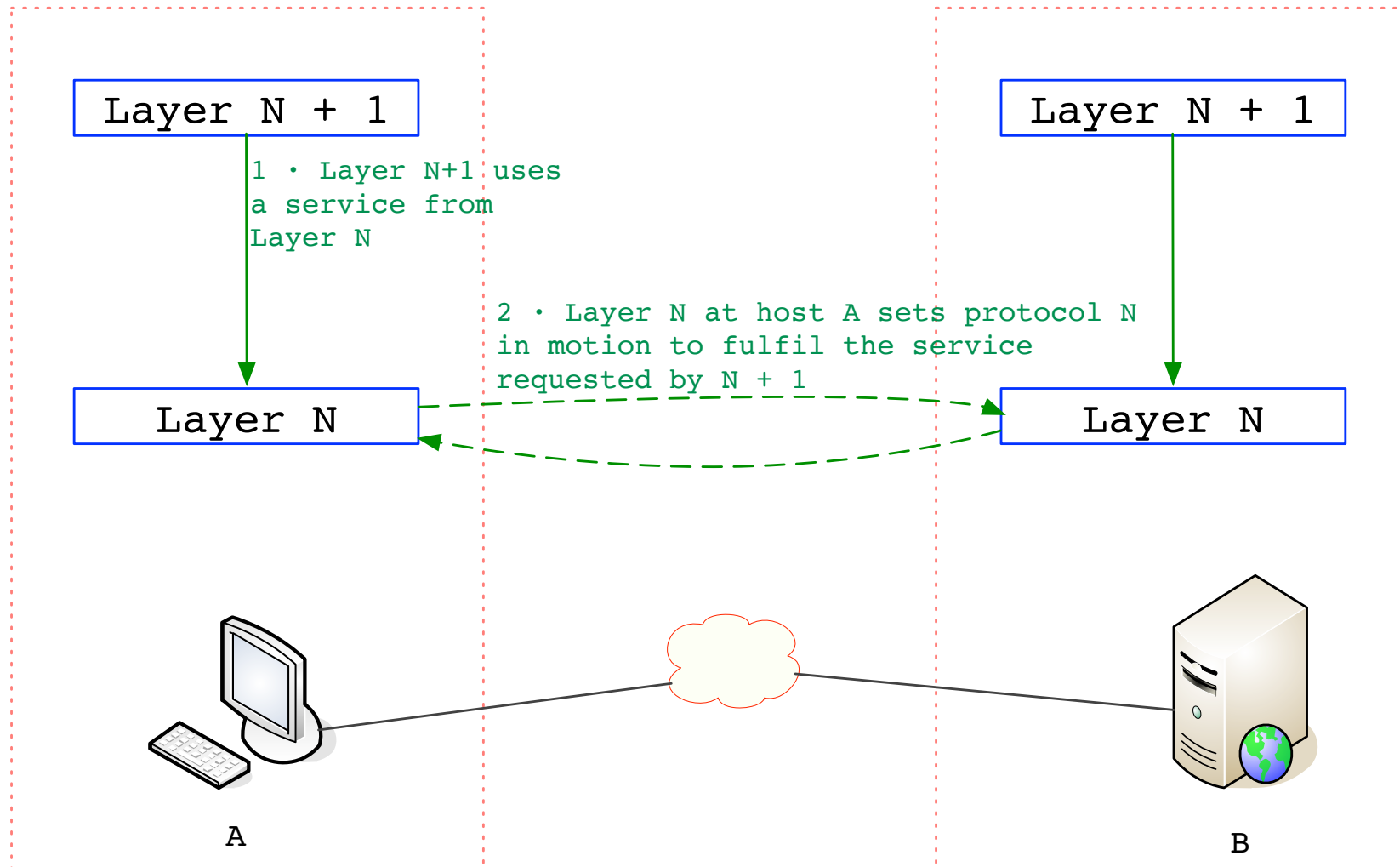
A layer may use the services provided by *any* layer below

- 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

21

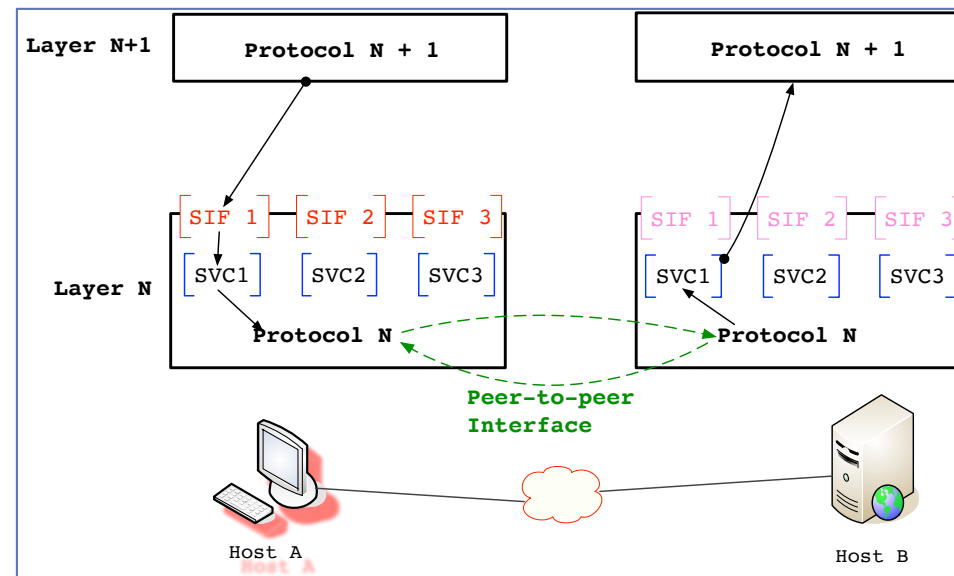


Layer N+1 uses a service at Layer N

22

□ Layer N

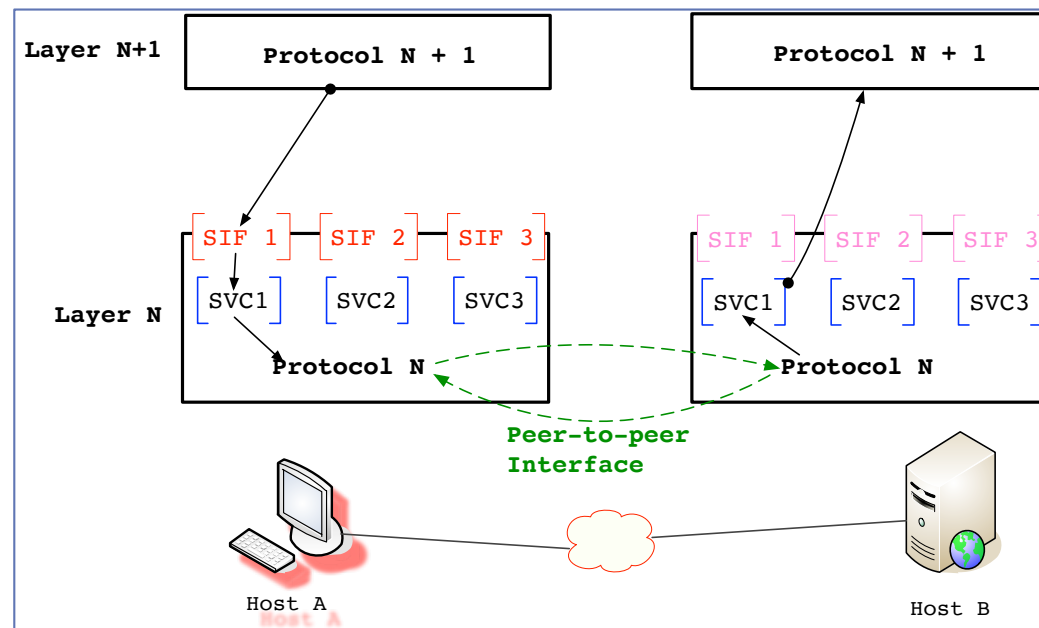
- ▣ Several services: SVC1, SVC2
- ▣ Each service is accessed through its **Service Interface: SIF1, SIF2**
- ▣ The protocol N (Host A) fulfils the functionality offered by SVC by exchanging messages with protocol N at Host B
- ▣ These messages comprise the **Peer-to-Peer Interface**



Example: A runs Linux; B runs Windows

23

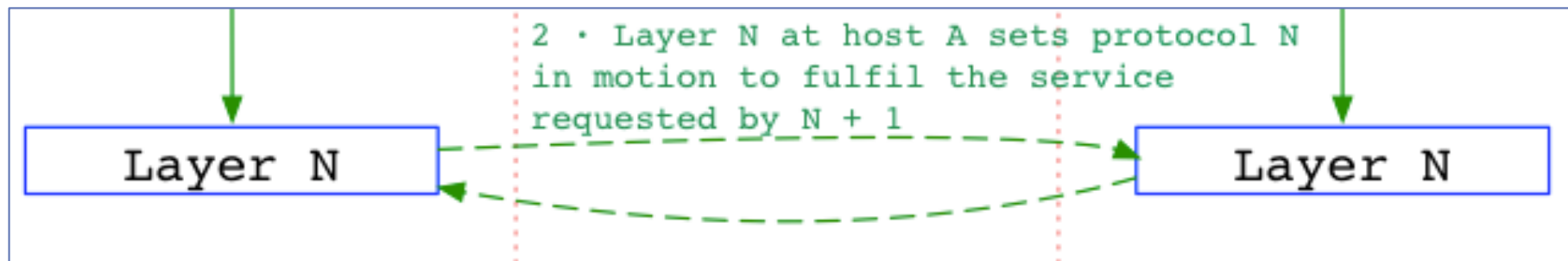
- Equal layers at A and B must implement the **same protocol**
 - ▣ *Same peer-to-peer interface*
- However, **Service Interfaces** at A and B might be present differences



Peer-to-peer interface

24

- 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

25

- 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

Layer N+1

Layer N

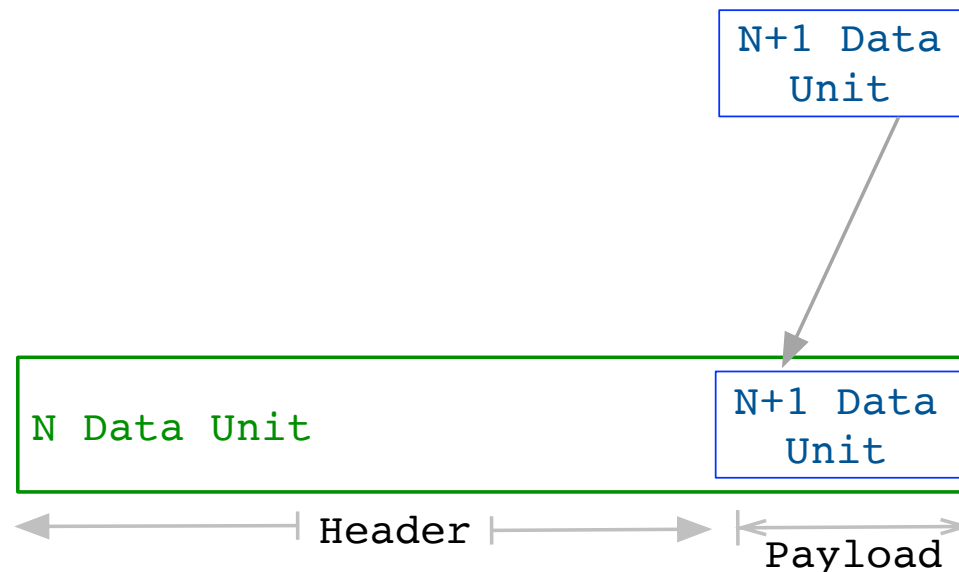
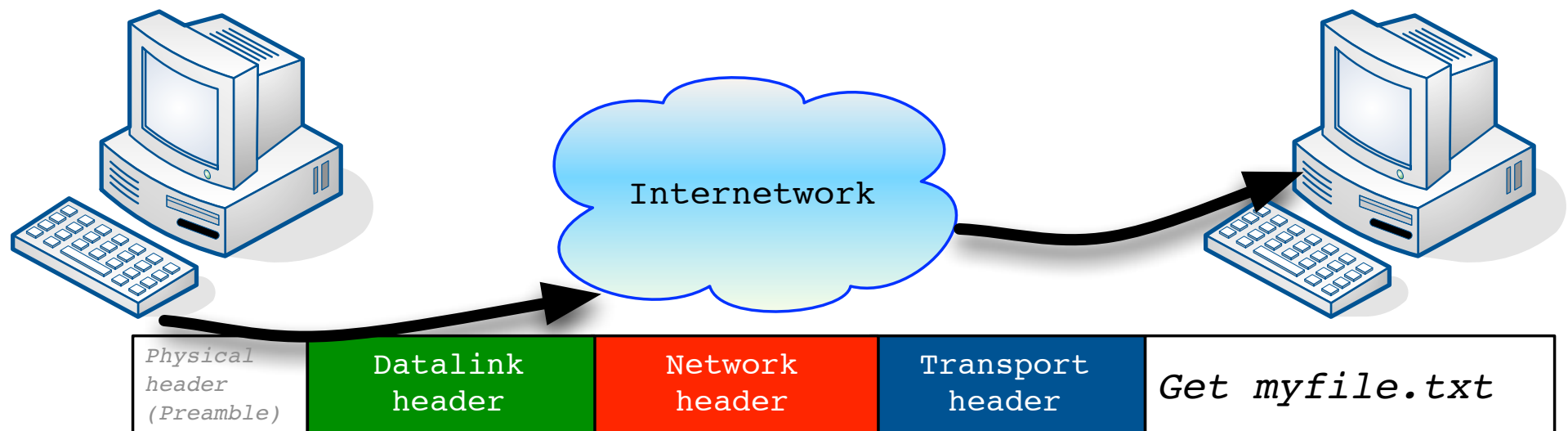


Illustration of encapsulation in OSI





Get myfile.txt

Application

Presentation

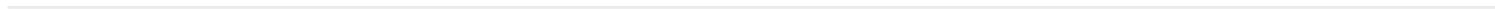
Session

Transport

Network

Datalink

Physical





Get myfile.txt

Get myfile.txt

Application

Presentation

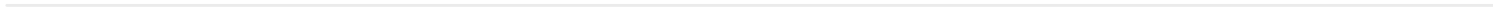
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Get myfile.txt

Presentation

Get myfile.txt

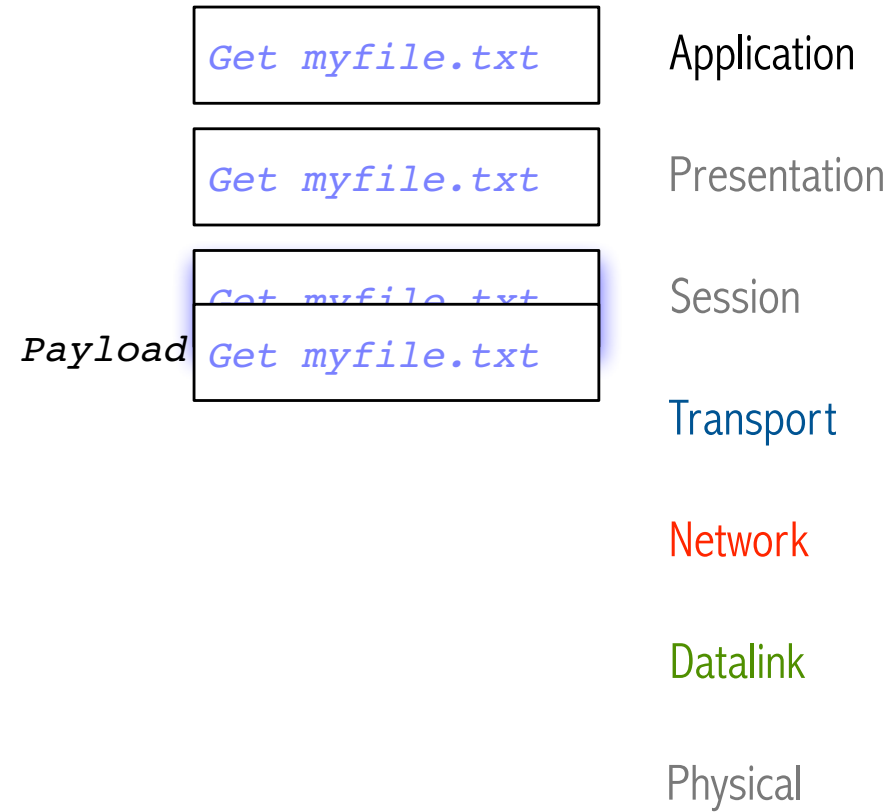
Session

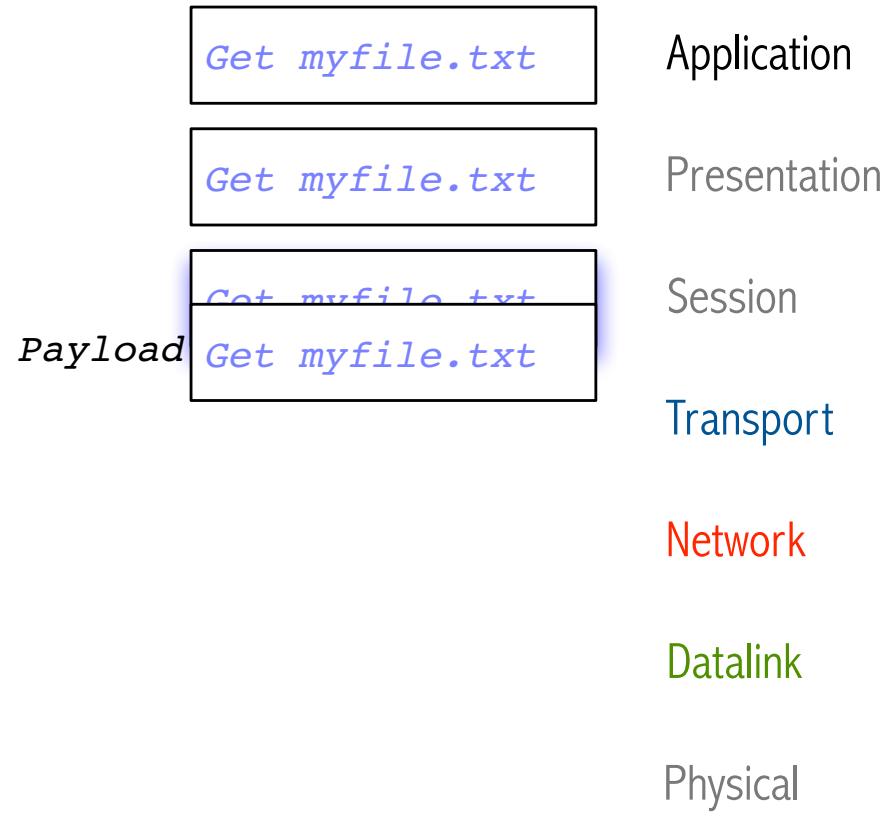
Transport

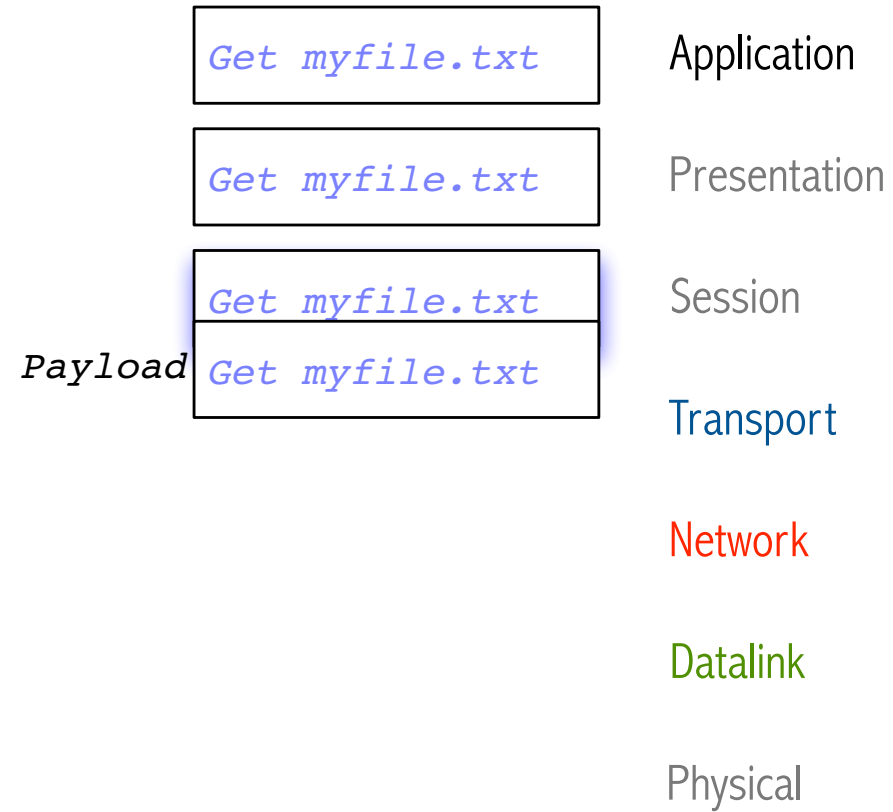
Network

Datalink

Physical









Get myfile.txt

Application

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Presentation

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Transport
Header

Get myfile.txt

Get myfile.txt

Get myfile.txt

Get myfile.txt

Application

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Transport
Header

Get myfile.txt

Get myfile.txt

Get myfile.txt

Get myfile.txt

Application

Presentation

Session

Transport

Network

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Physical

Encapsulation at layer 4



Get myfile.txt is encapsulated into a
Transport Protocol Data Unit (TPDU)
=
Transport Header + Payload(Get myfile.txt)

Transport
Header

Get myfile.txt

Get myfile.txt

Get myfile.txt

Get myfile.txt

Application

Presentation

Session

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Physical

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Application

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Transport
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Get myfile.txt

Get myfile.txt

Get myfile.txt

Get myfile.txt

Application

Presentation

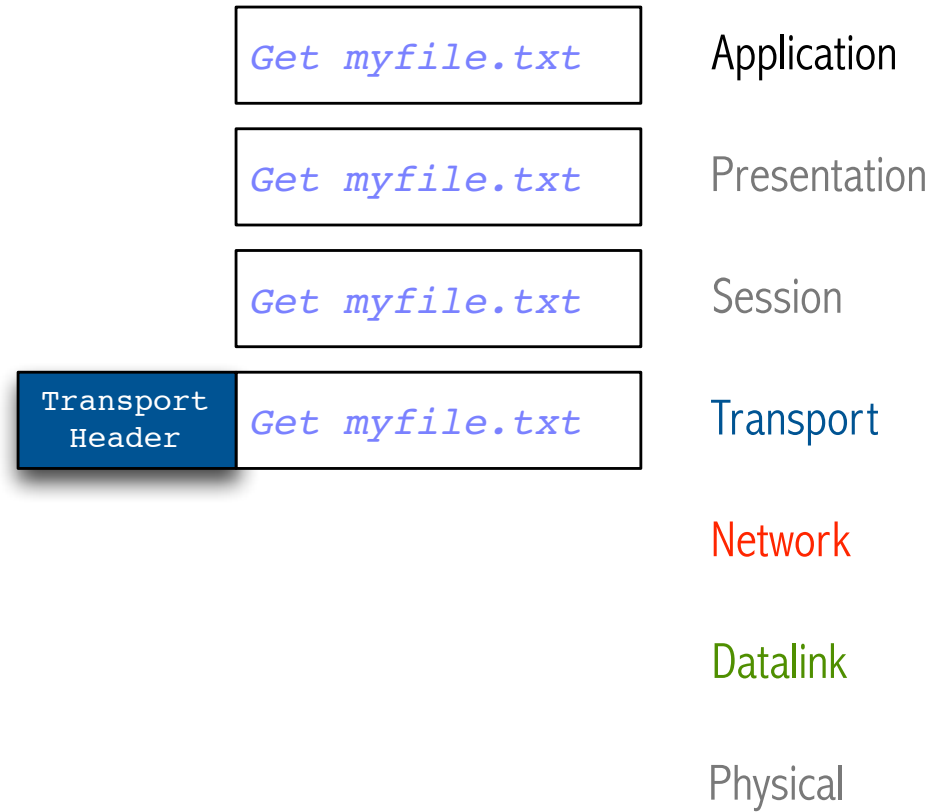
Session

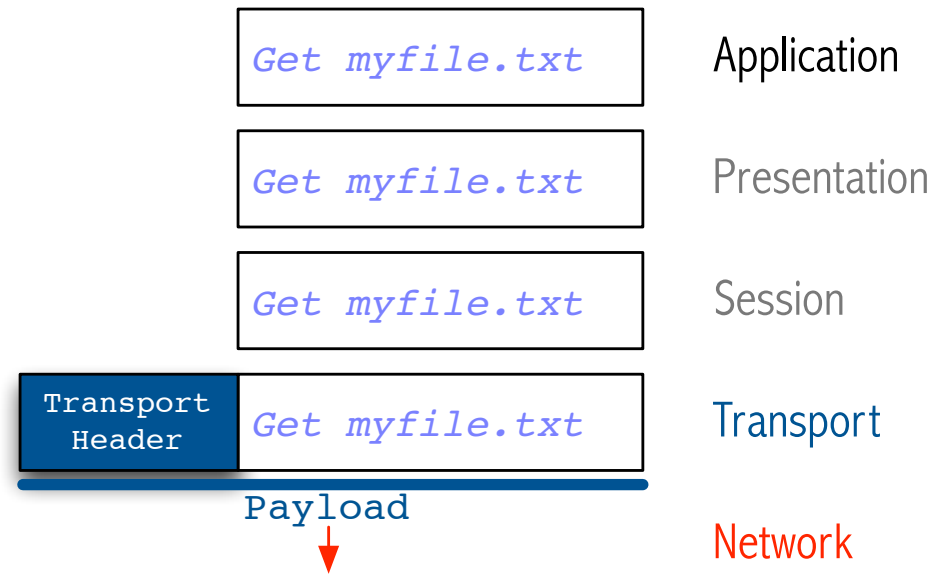
Transport

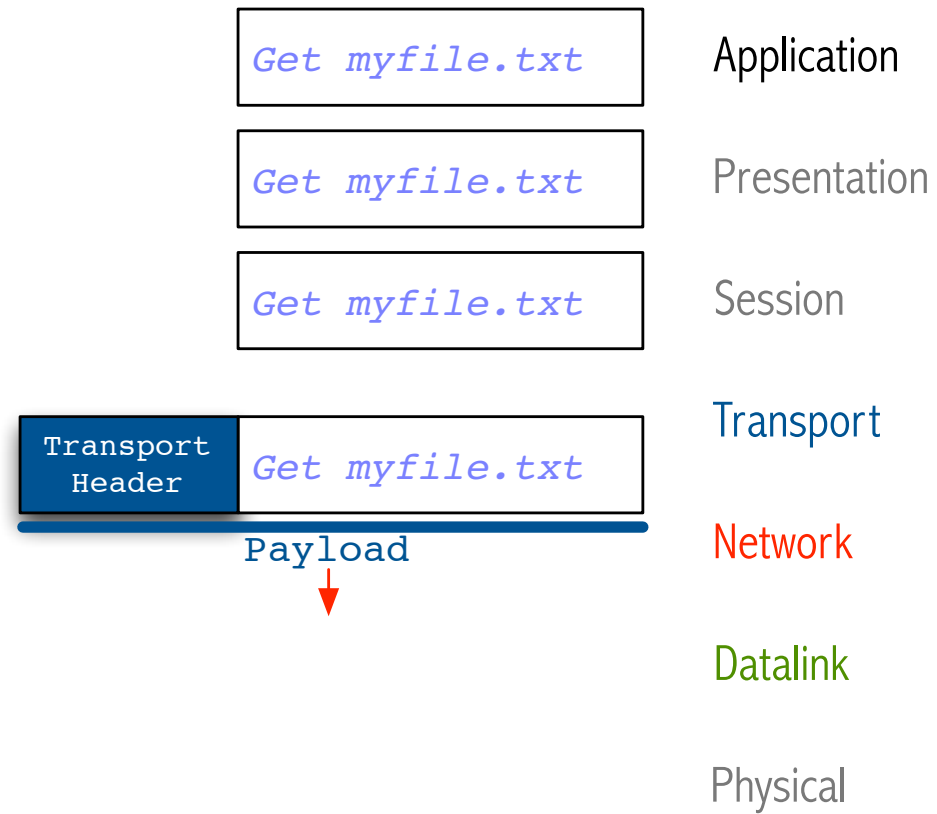
Network

Datalink

Physical









Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

| | |
|---------------------|-----------------------|
| Transport Header | <i>Get myfile.txt</i> |
|---------------------|-----------------------|

Network

Payload

Datalink

Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network
Header

Transport
Header

Get myfile.txt

Network

Datalink

Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network
Header

Transport
Header

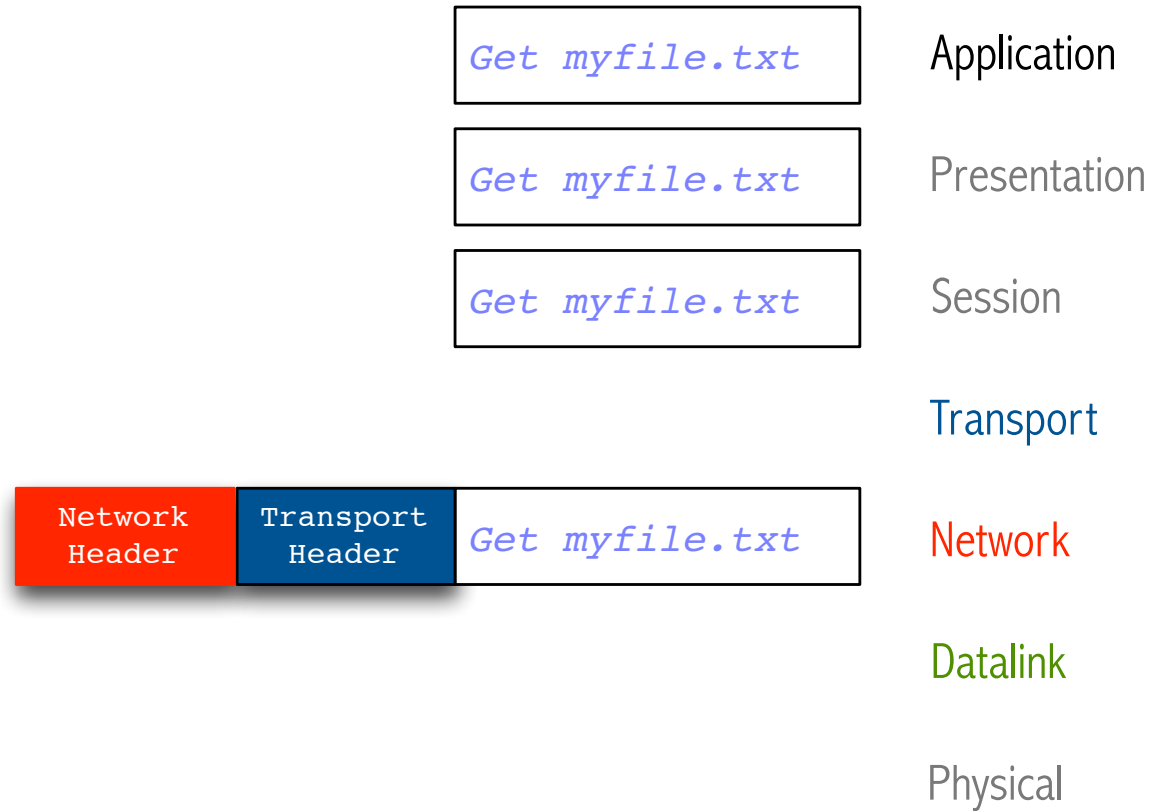
Get myfile.txt

Network

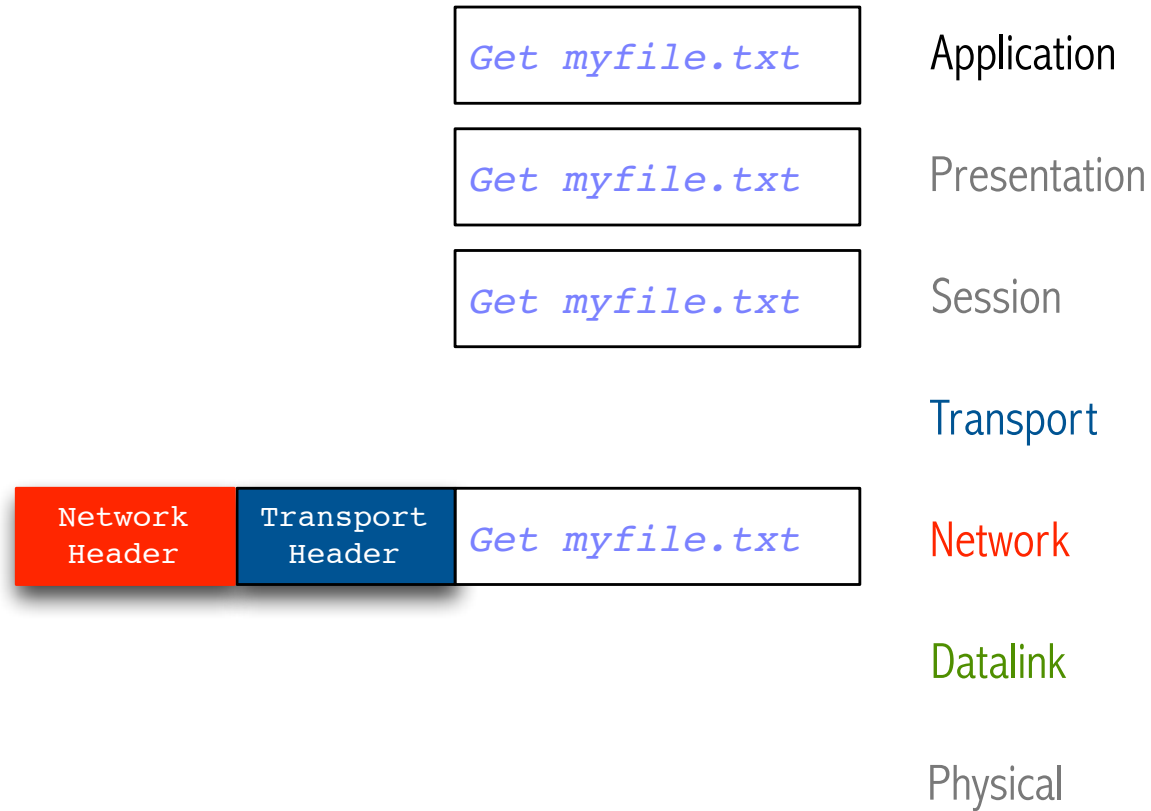
Datalink

Physical

Encapsulation at layer 3



Encapsulation at layer 3





Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport



Network

Payload



Datalink

Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport



Network



Datalink

Payload



Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport



Network

Datalink

Payload



Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network



Datalink

Payload



Physical





Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network



Datalink

Physical



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

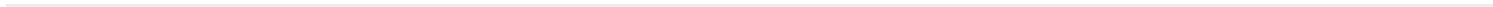
Transport

Network



Datalink

Physical





Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network

Datalink
Header

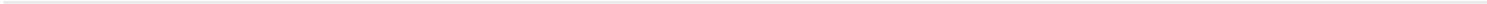
Network
Header

Transport
Header

Get myfile.txt

Datalink

Physical





Get myfile.txt

Application

Get myfile.txt

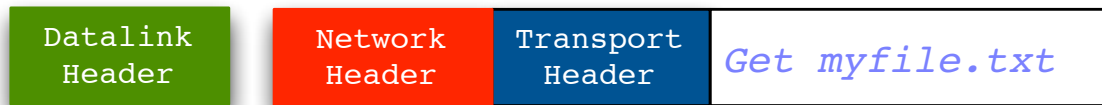
Presentation

Get myfile.txt

Session

Transport

Network



Datalink

Physical

Encapsulation at layer 2



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network

Datalink
Header

Network
Header

Transport
Header

Get myfile.txt

Datalink

Physical



Encapsulation at layer 2



Get myfile.txt

Application

Get myfile.txt

Presentation

Get myfile.txt

Session

Transport

Network

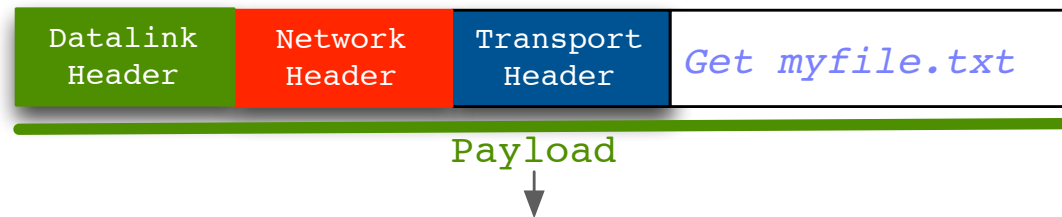


Datalink

Physical



Encapsulation at layer 2



Application

Presentation

Session

Transport

Network

Datalink

Physical



Application

Presentation

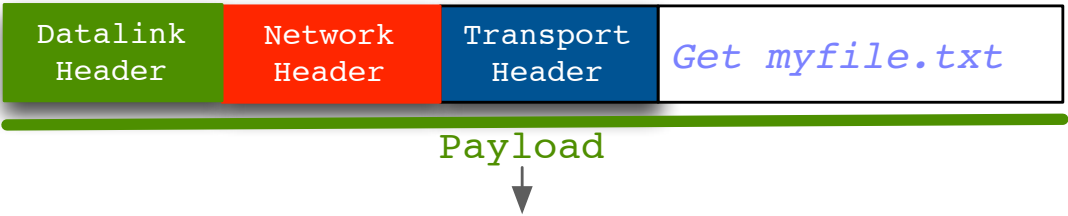
Session

Transport

Network

Datalink

Physical





Application

Presentation

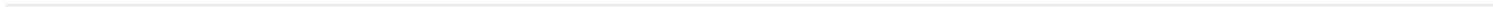
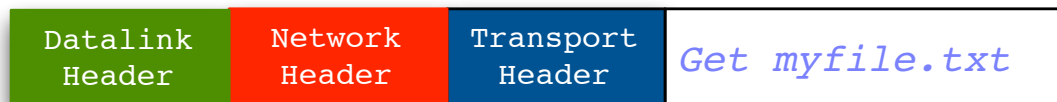
Session

Transport

Network

Datalink

Physical





Application

Presentation

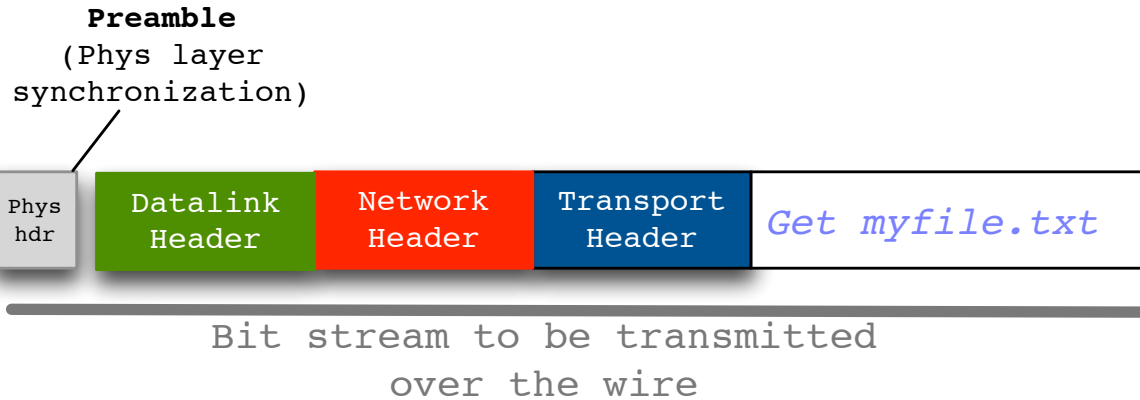
Session

Transport

Network

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Physical





Application

Presentation

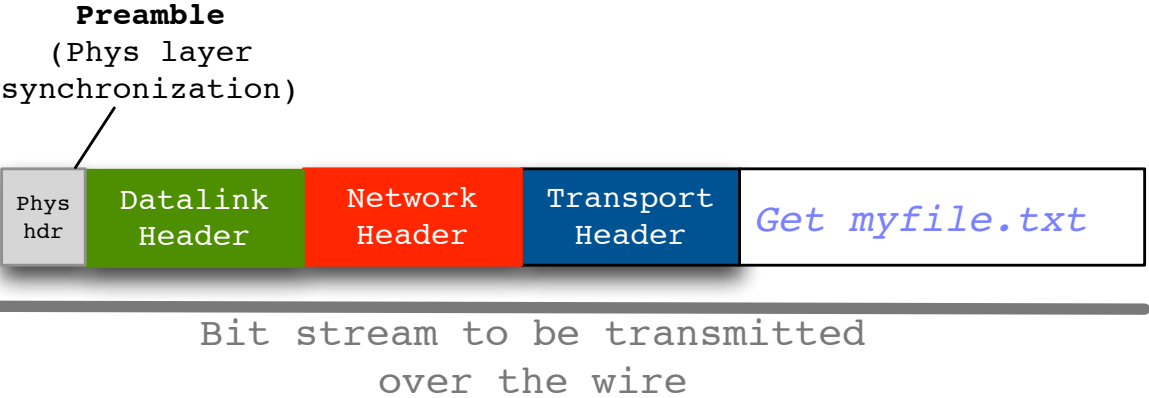
Session

Transport

Network

Datalink

Physical





Application

Presentation

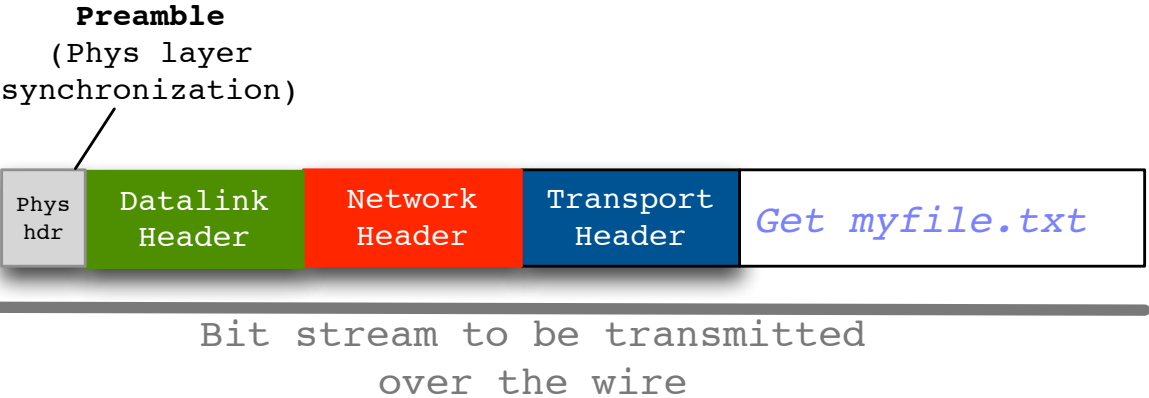
Session

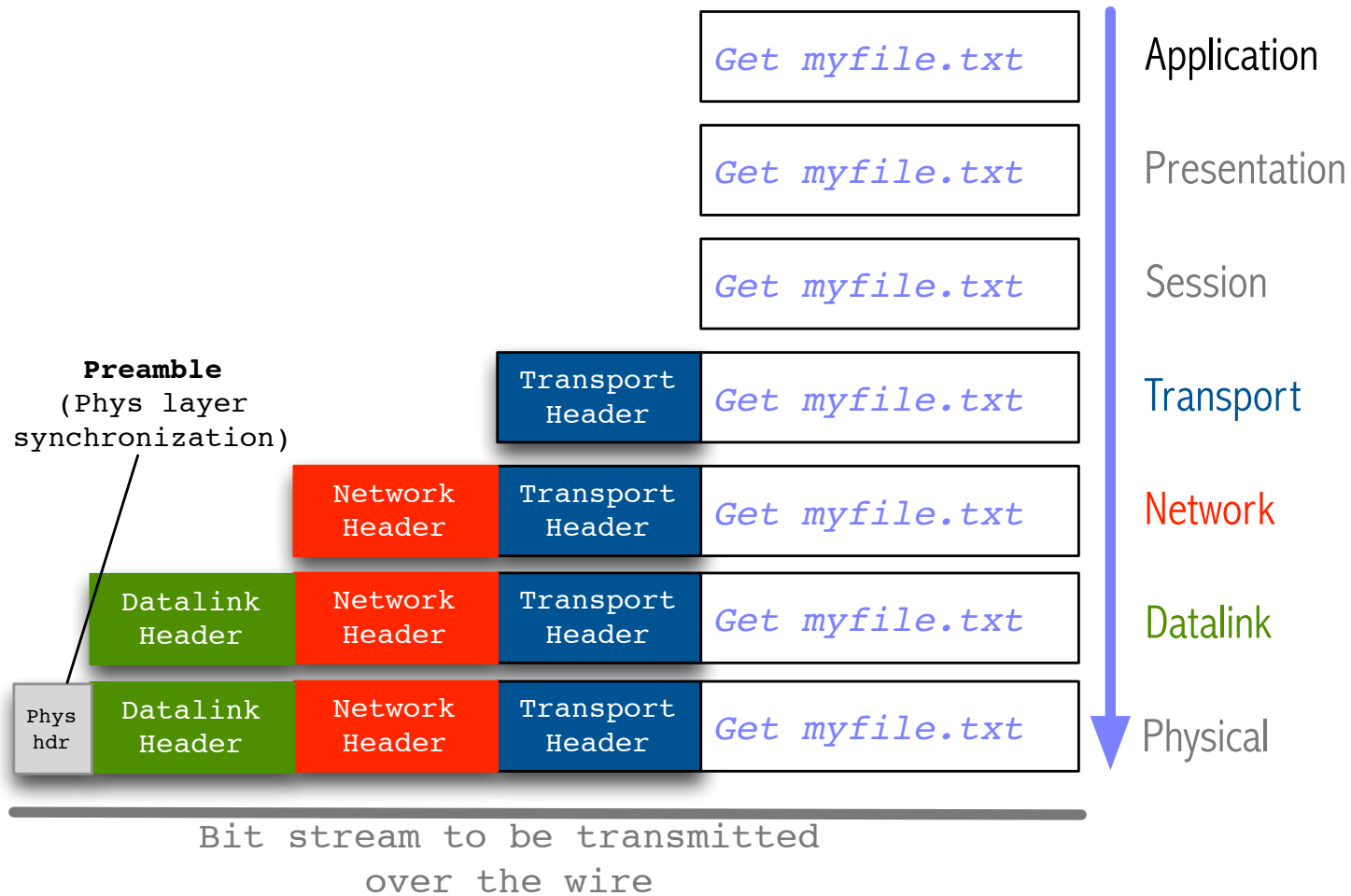
Transport

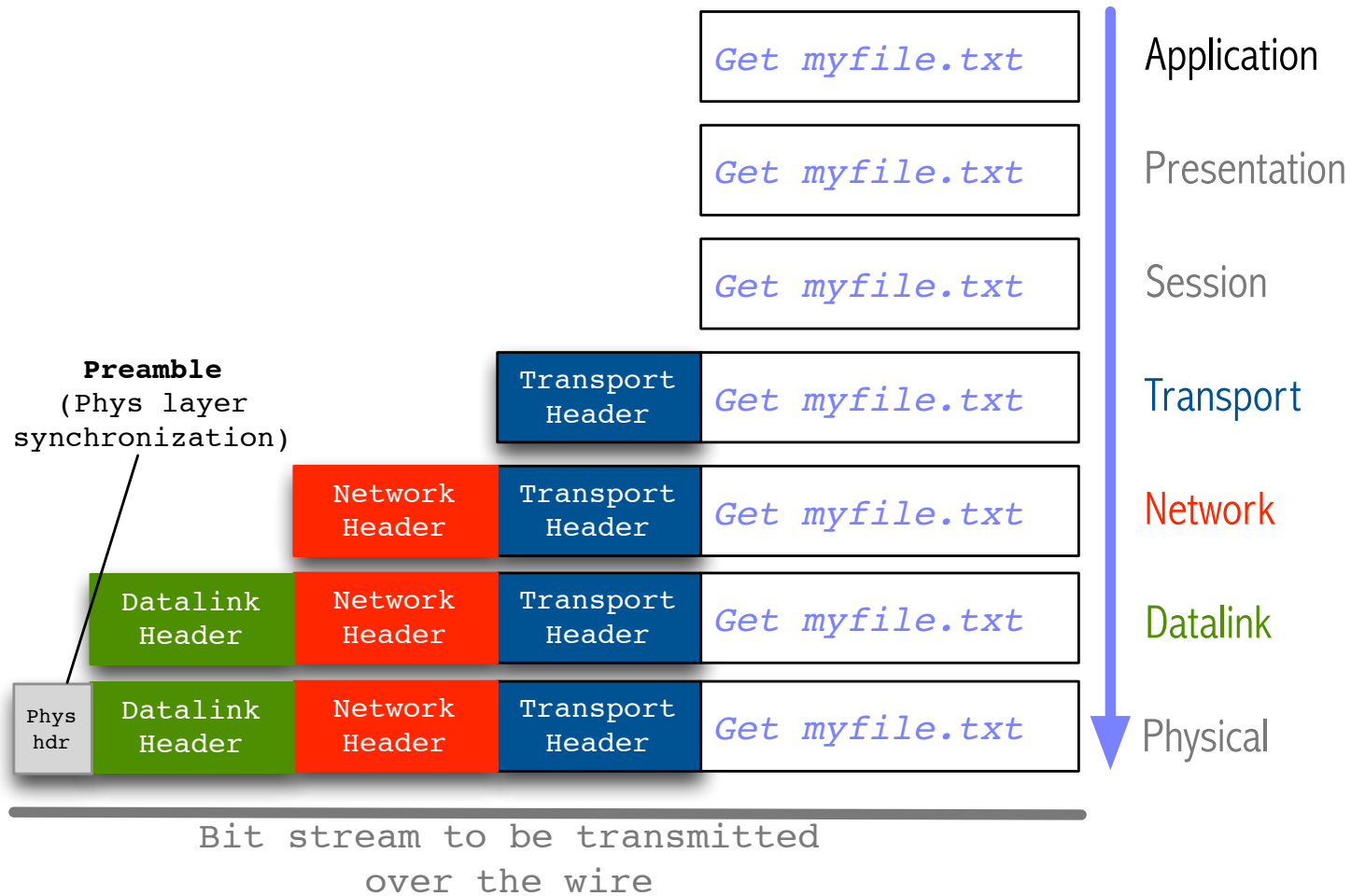
Network

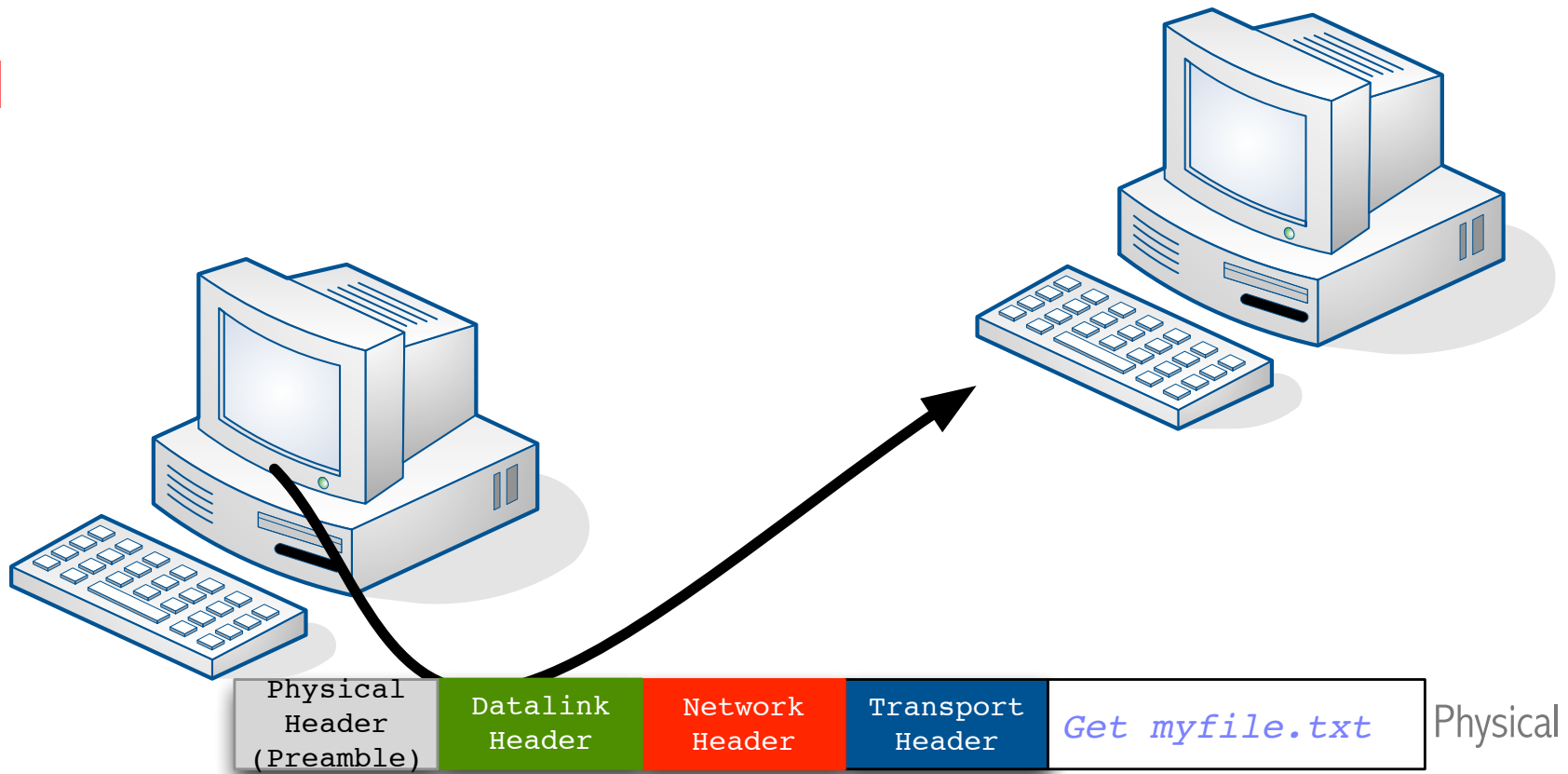
Datalink

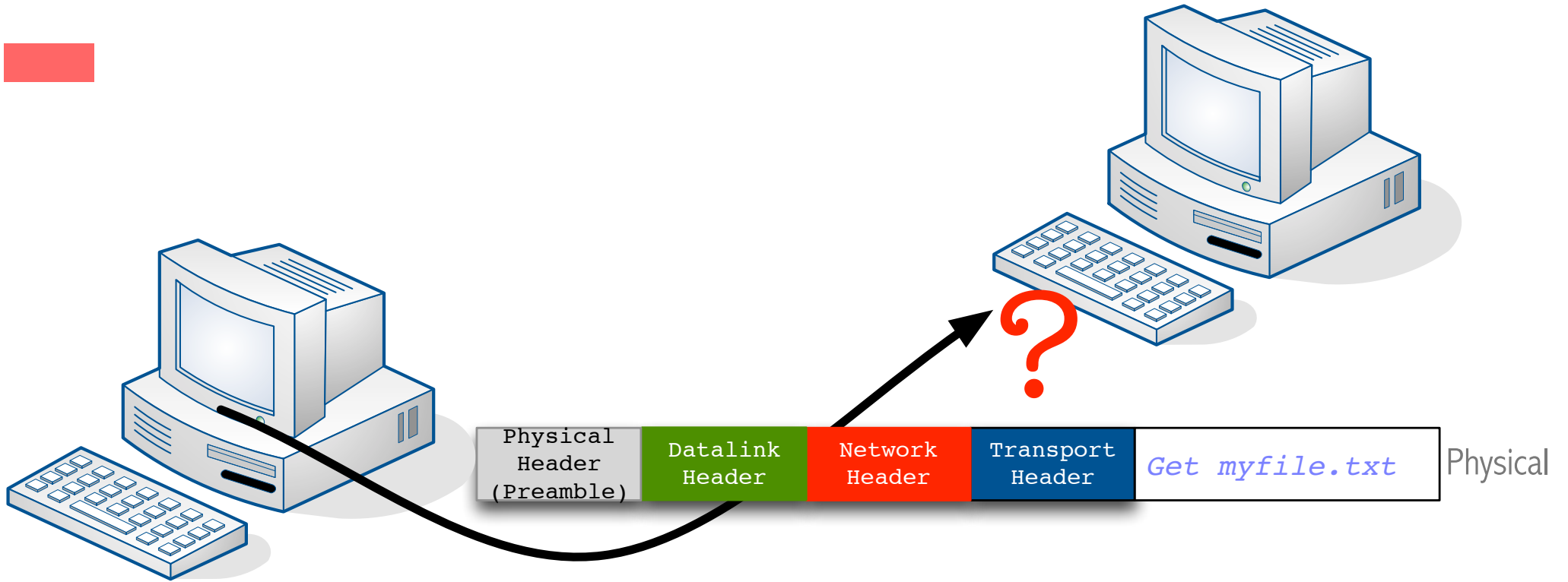
Physical

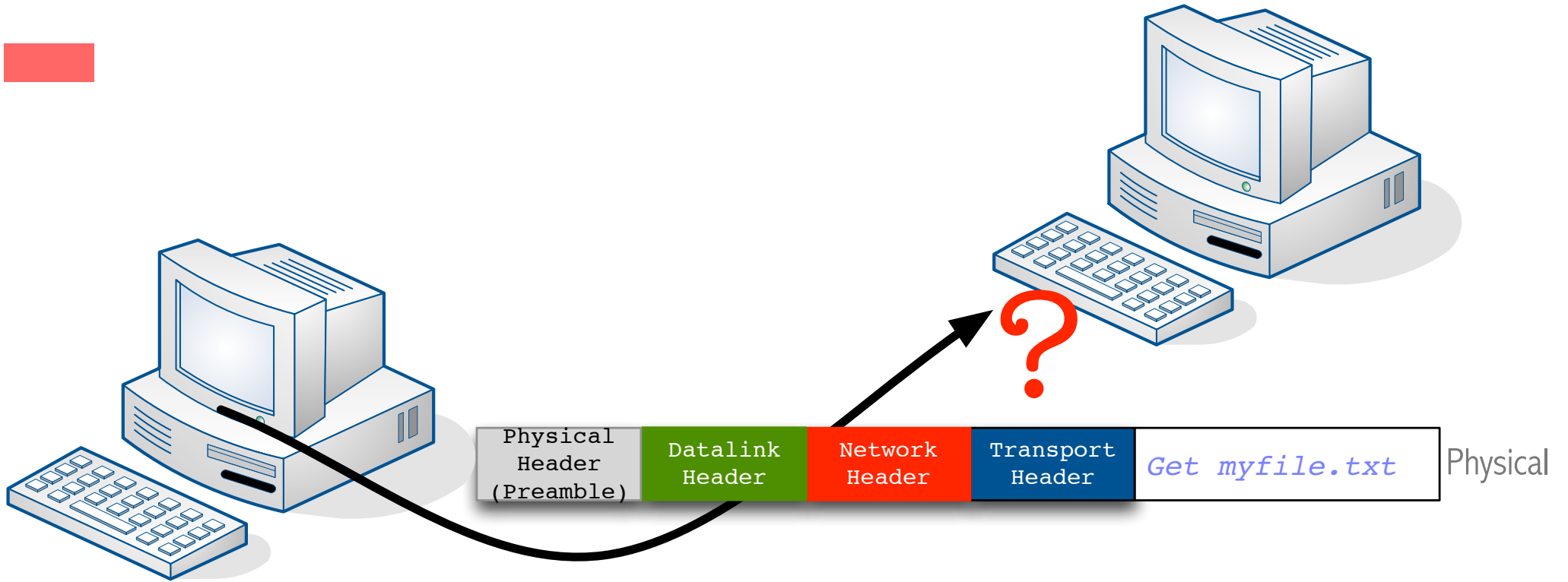




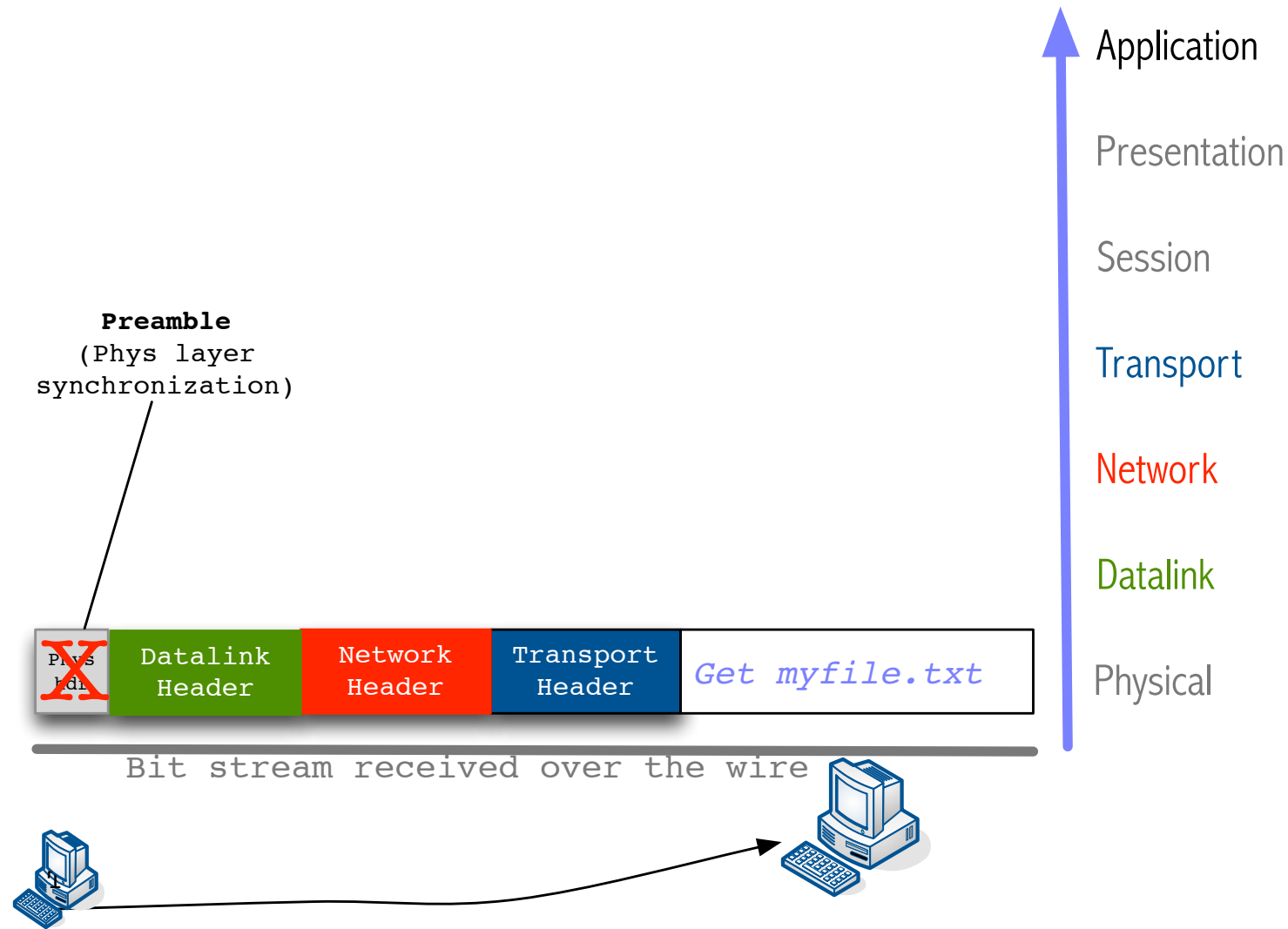




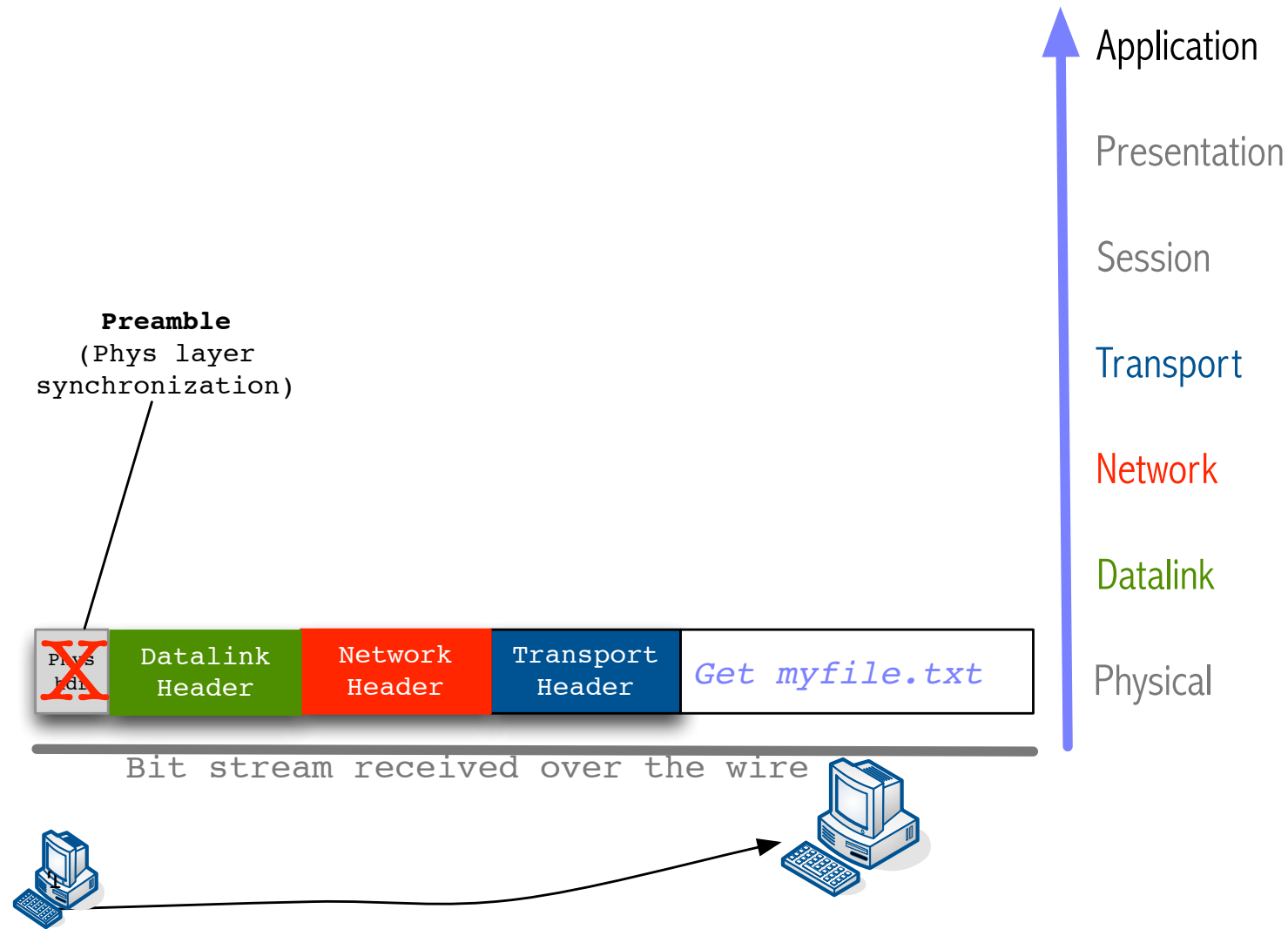


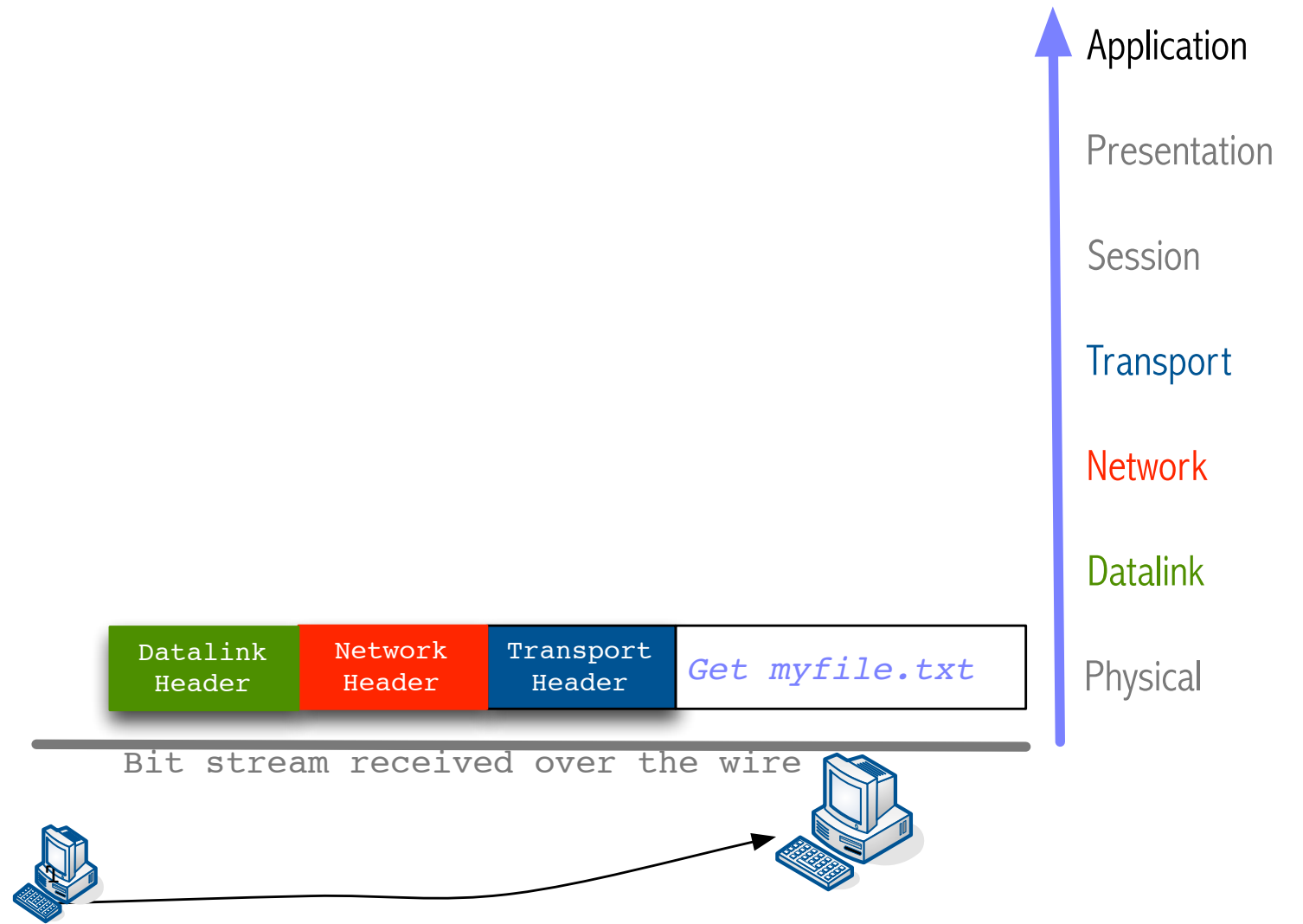


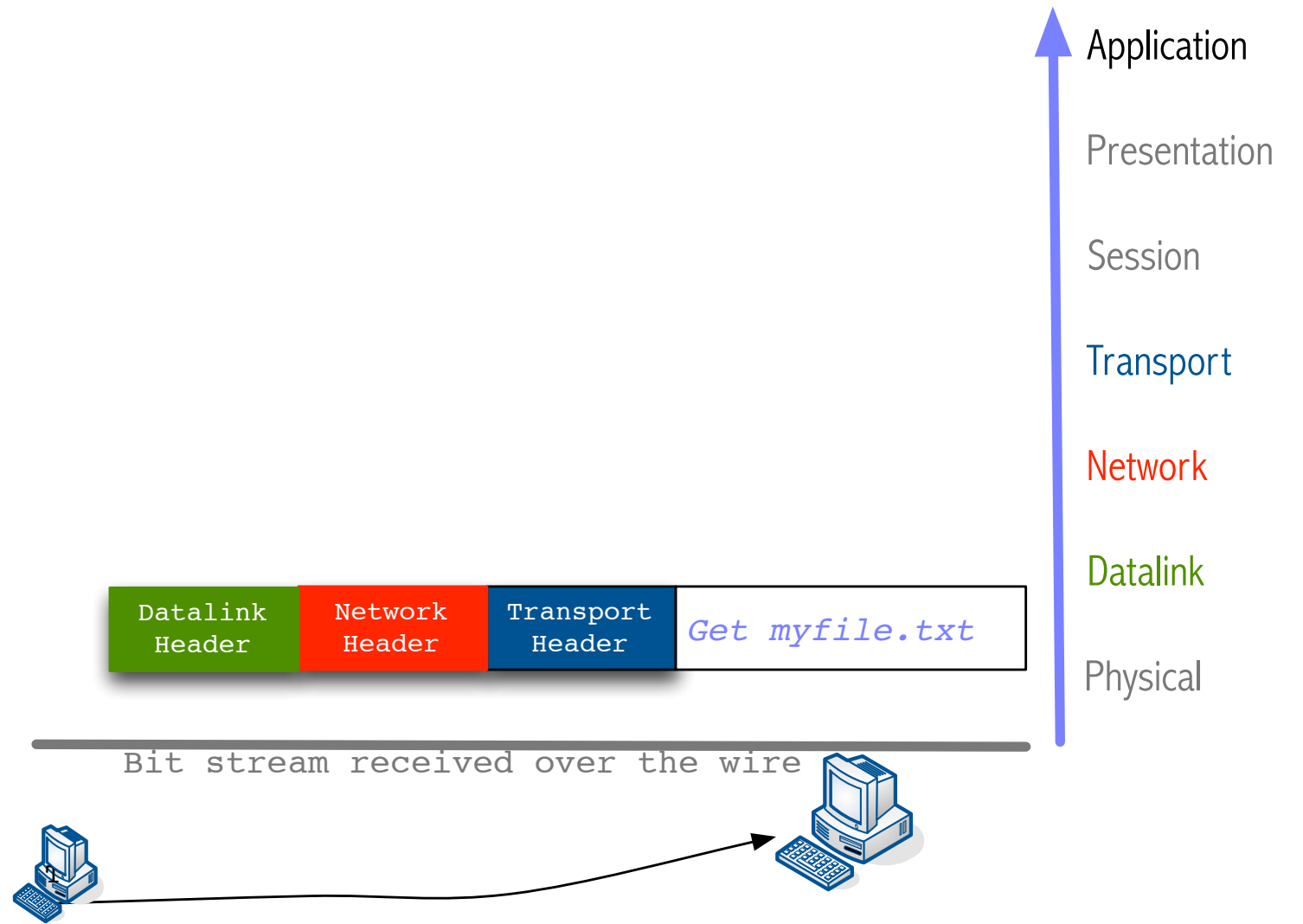
De-encapsulation at layer 1 (Suppress the preamble)

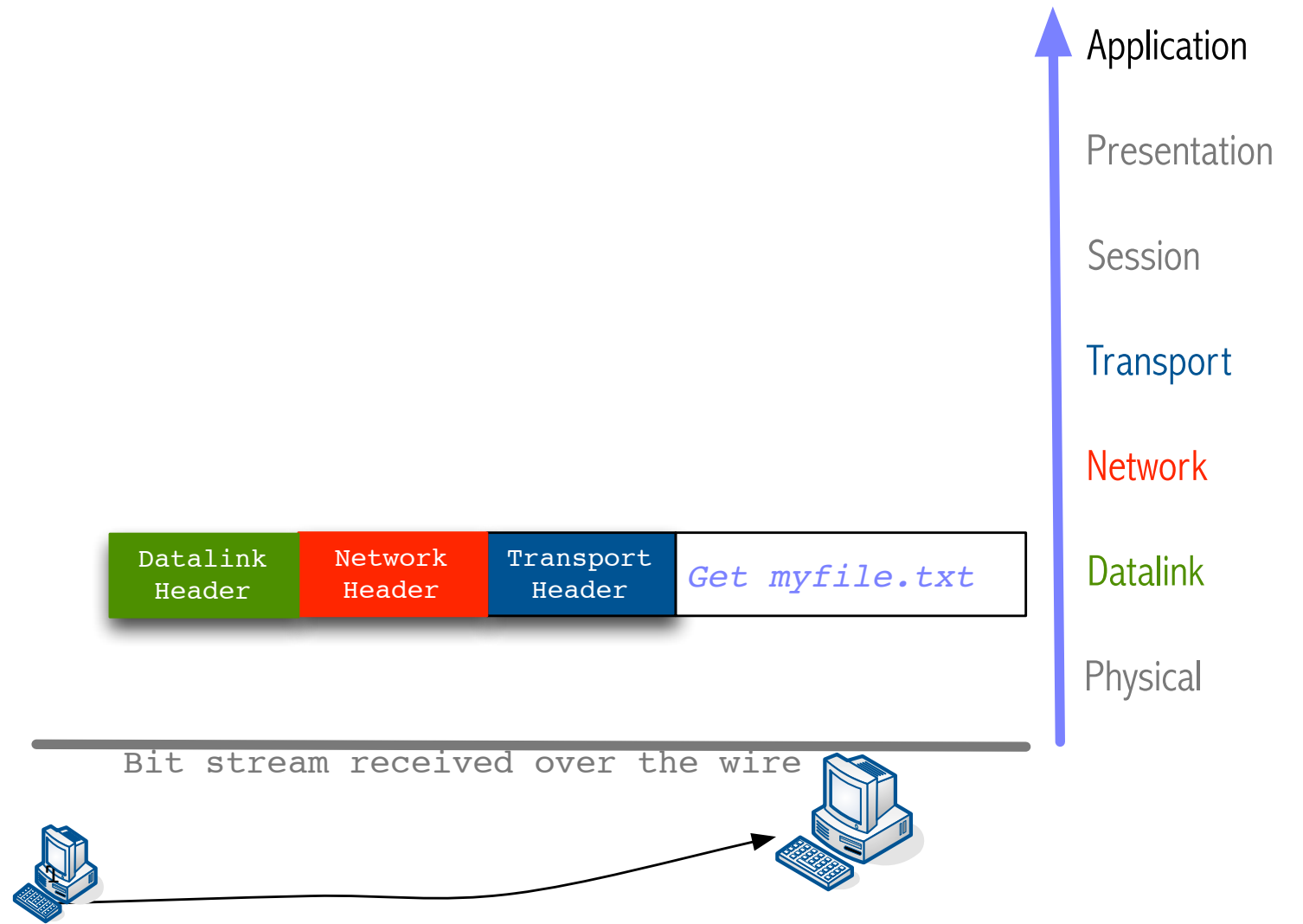


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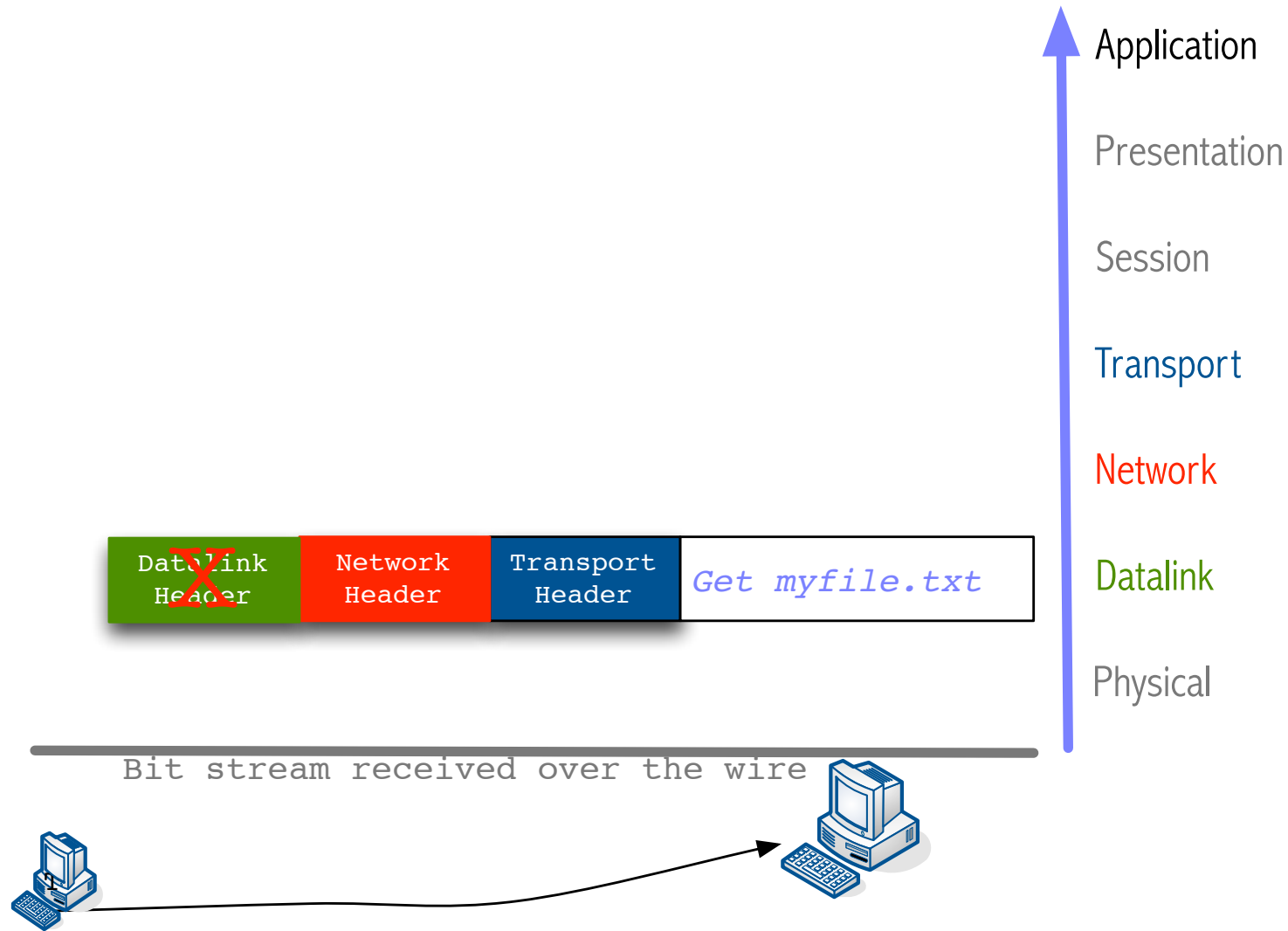


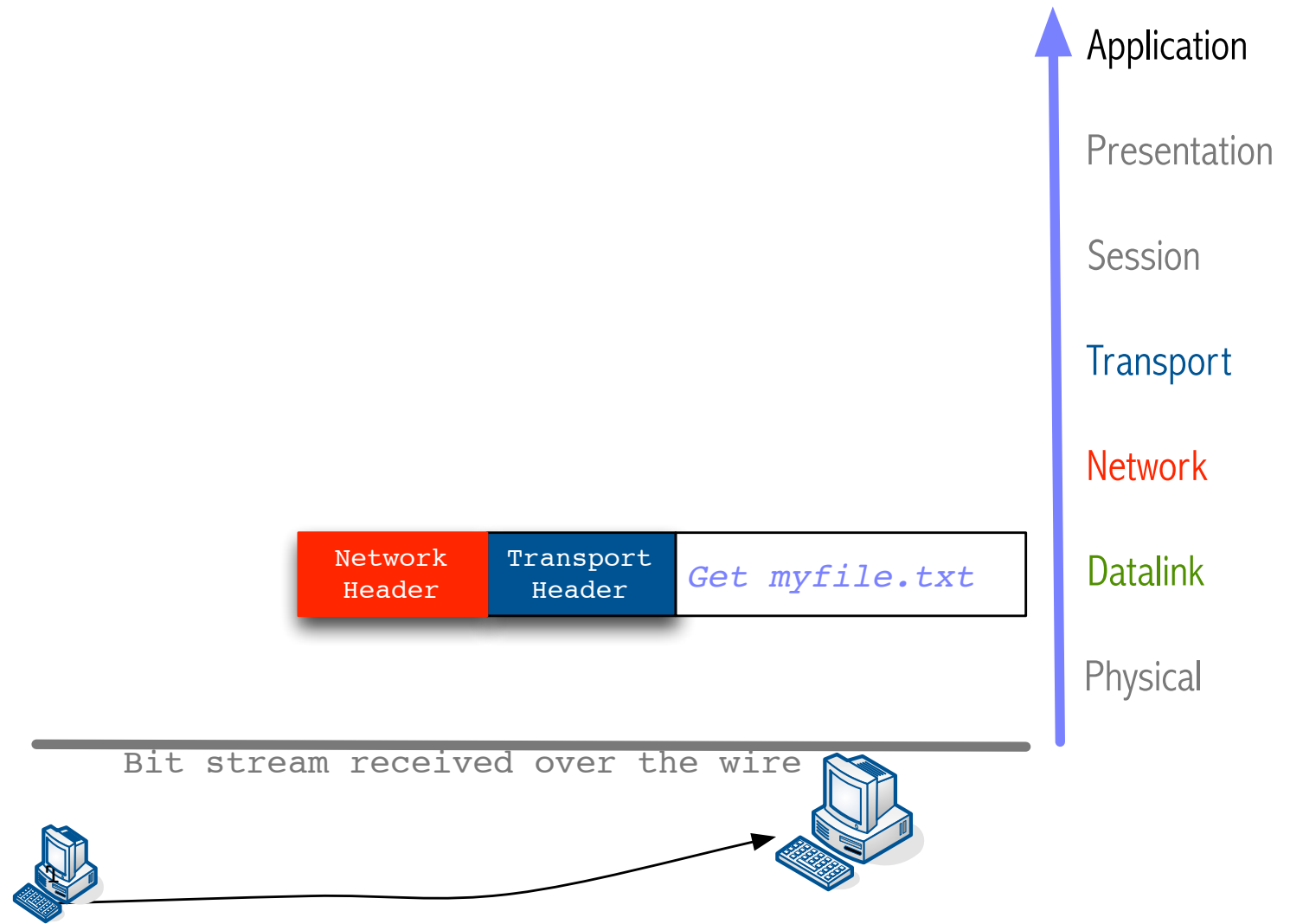


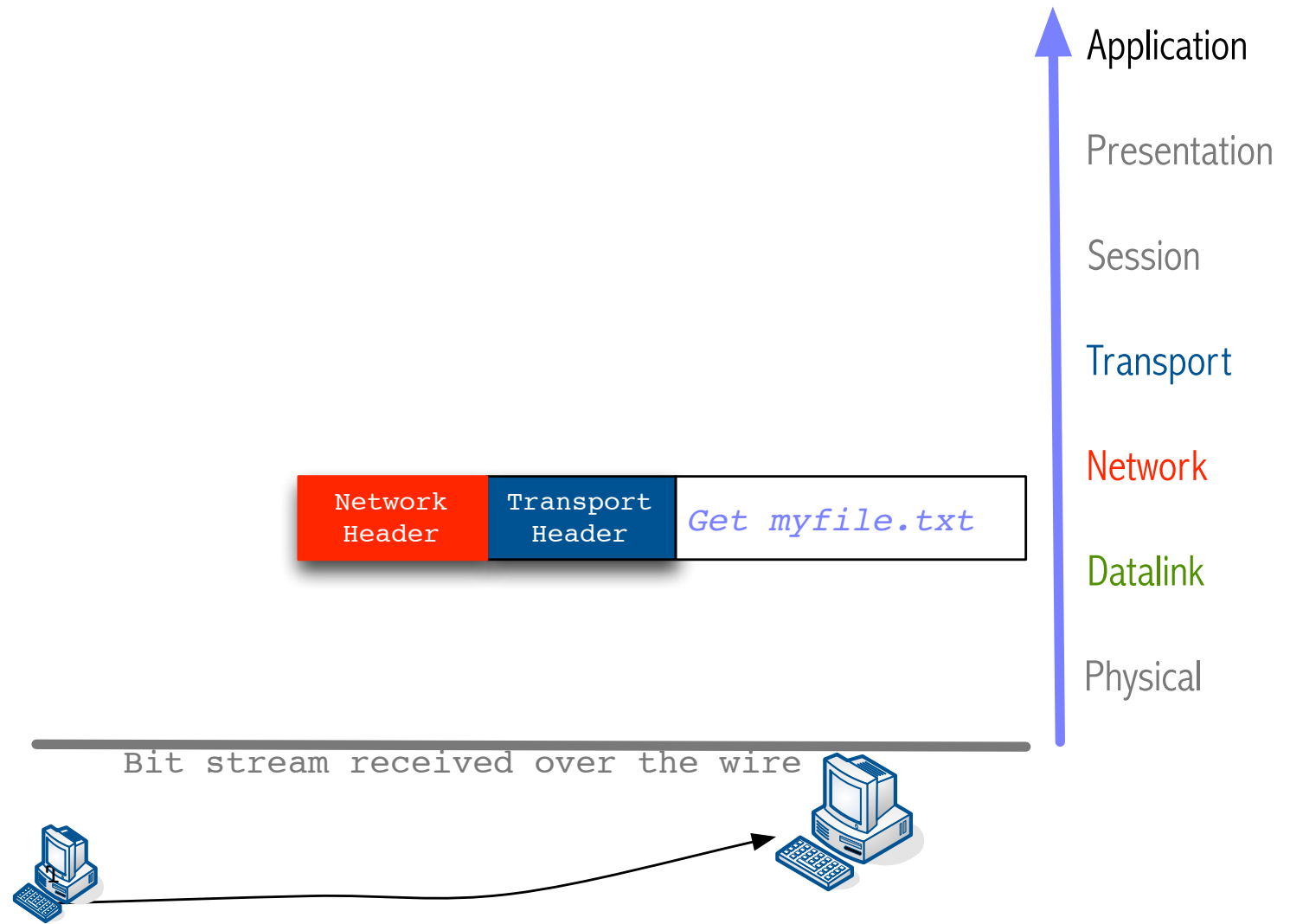


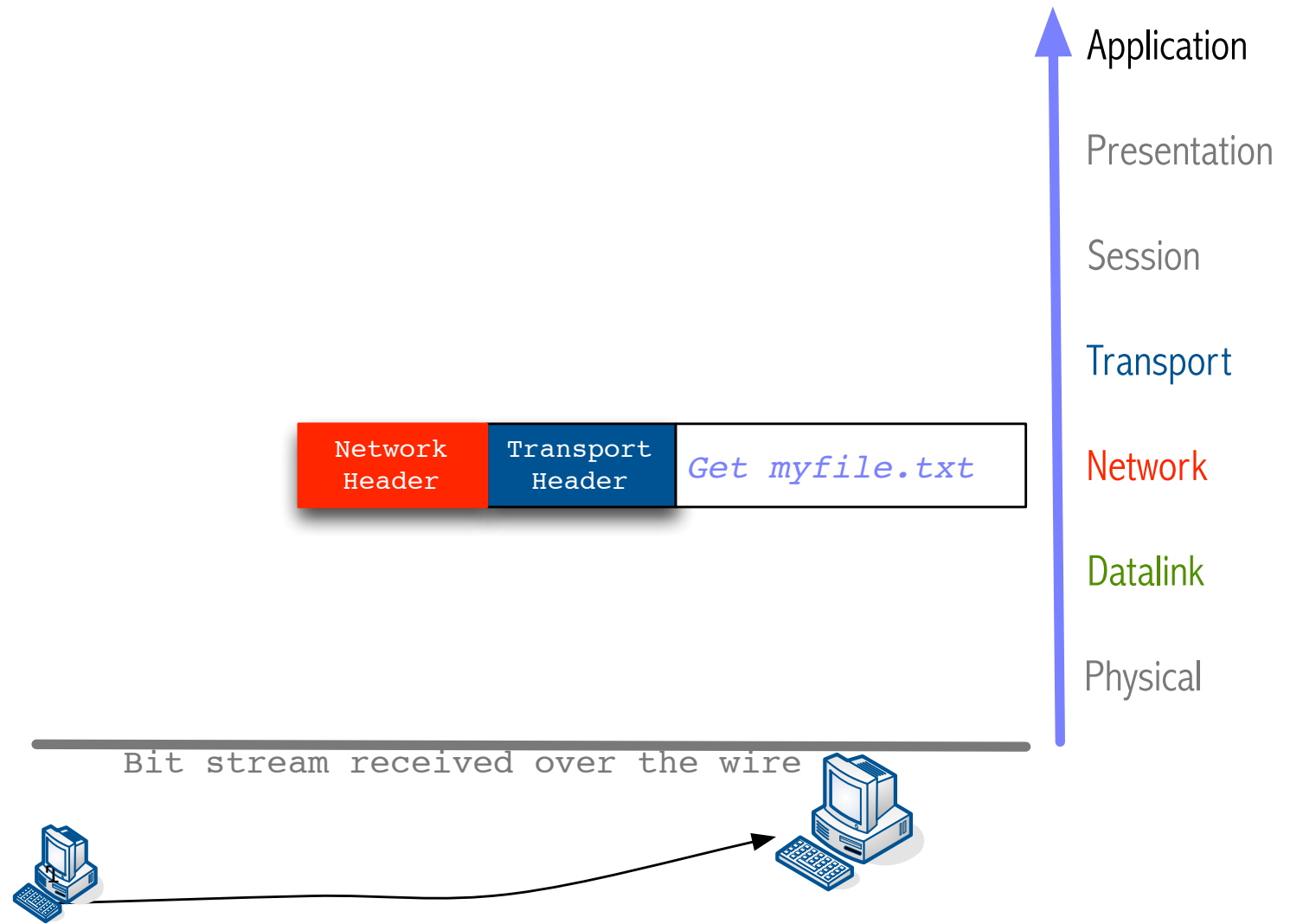


De-encapsulation at layer 2

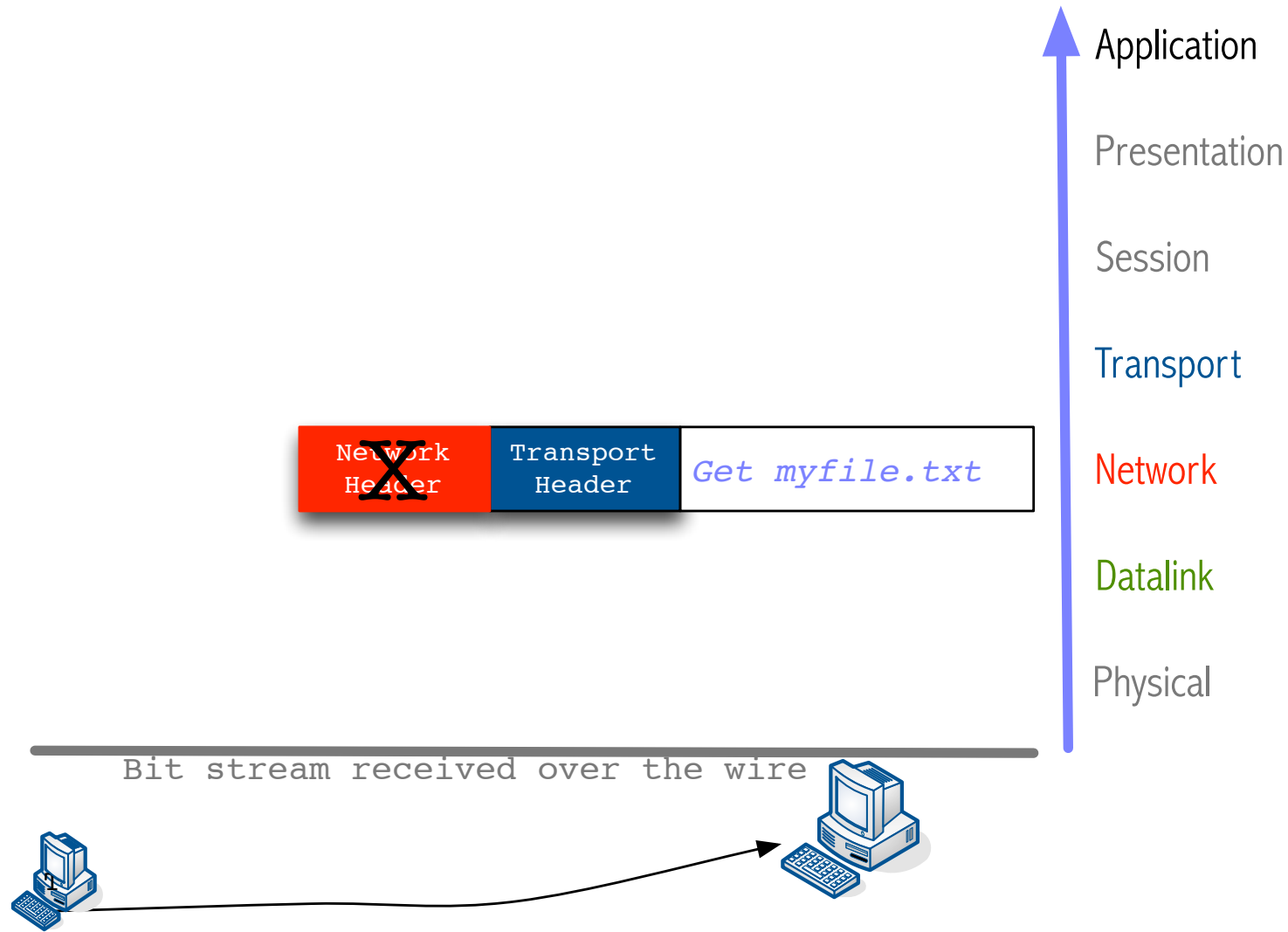


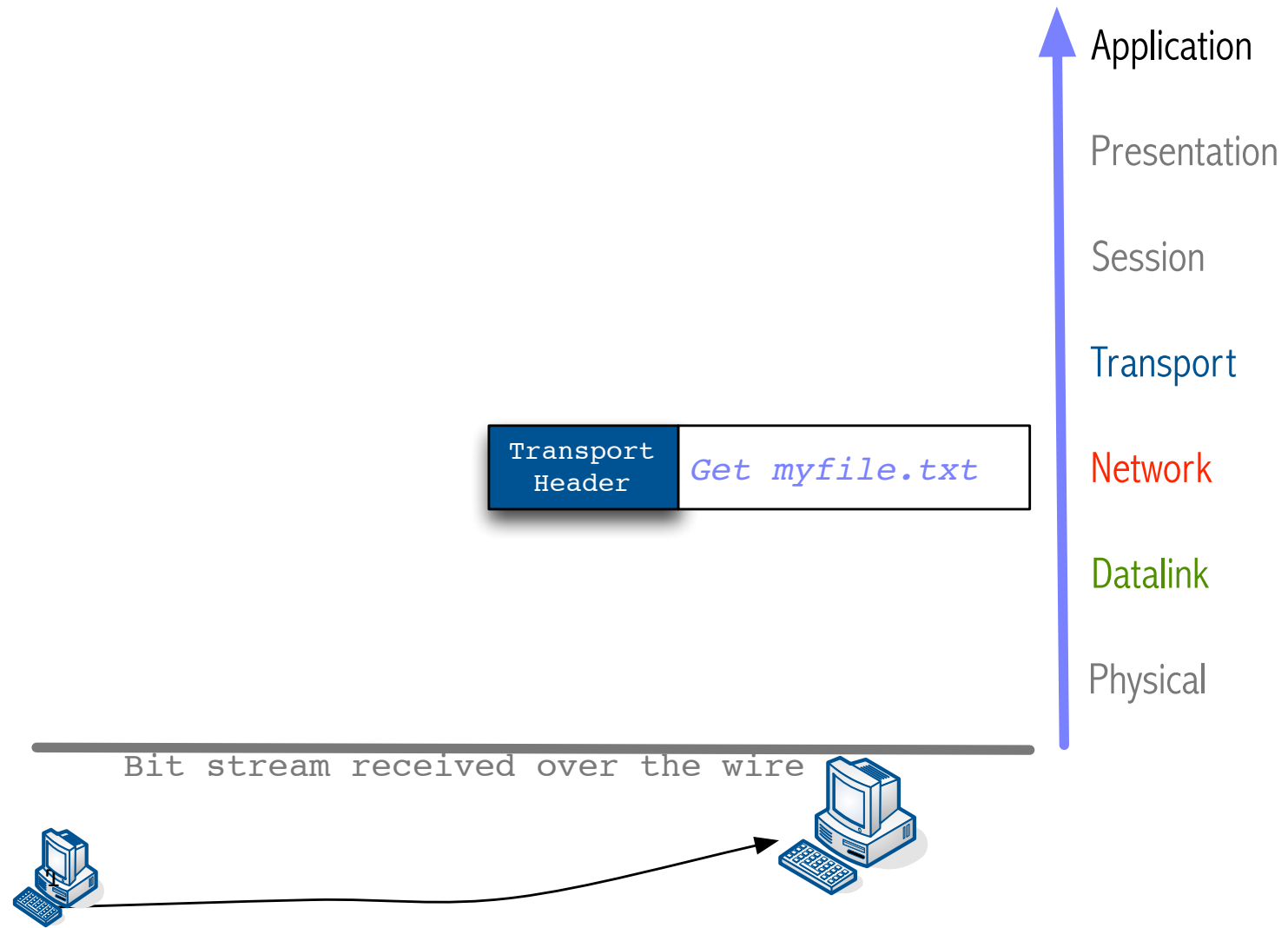


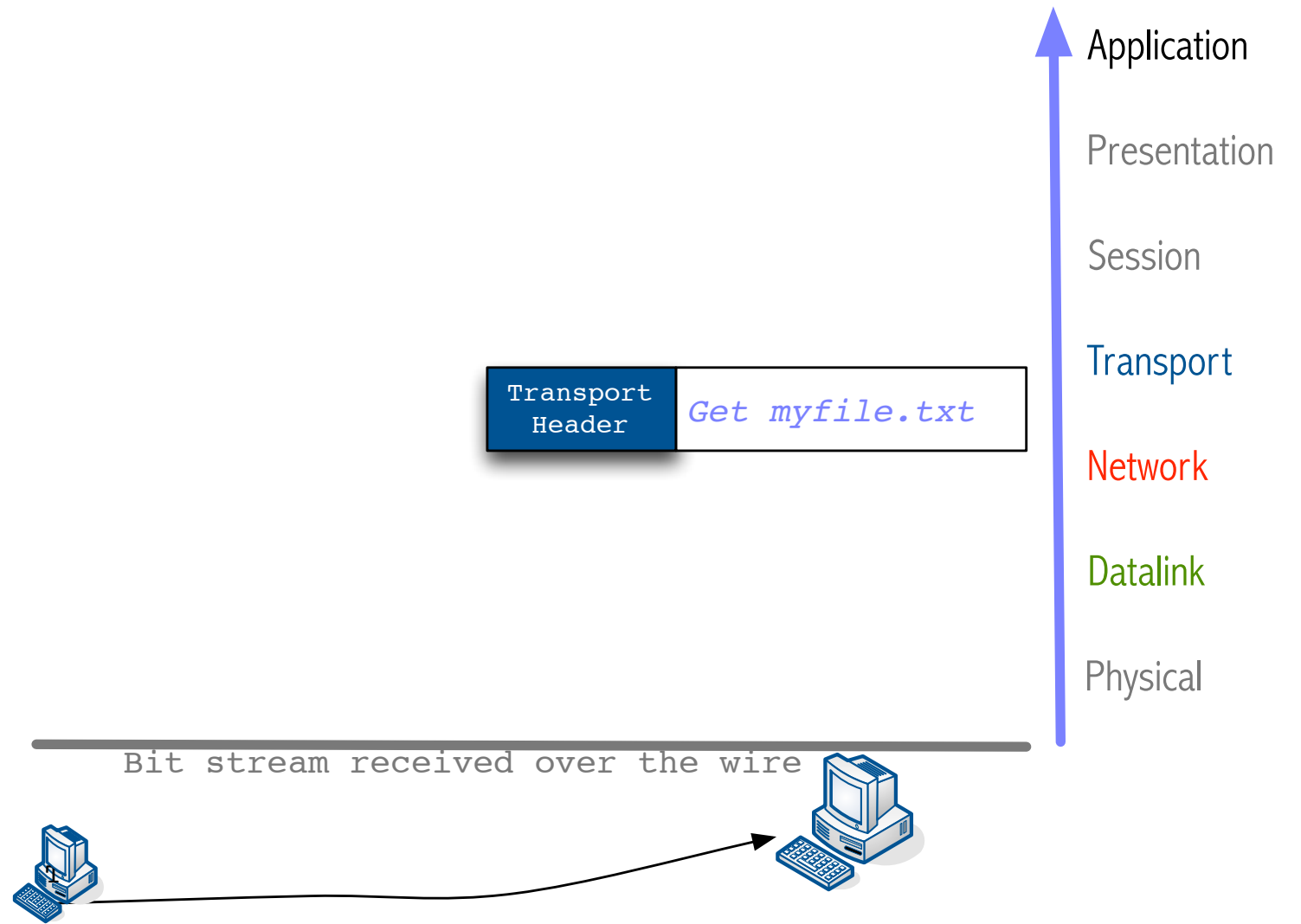


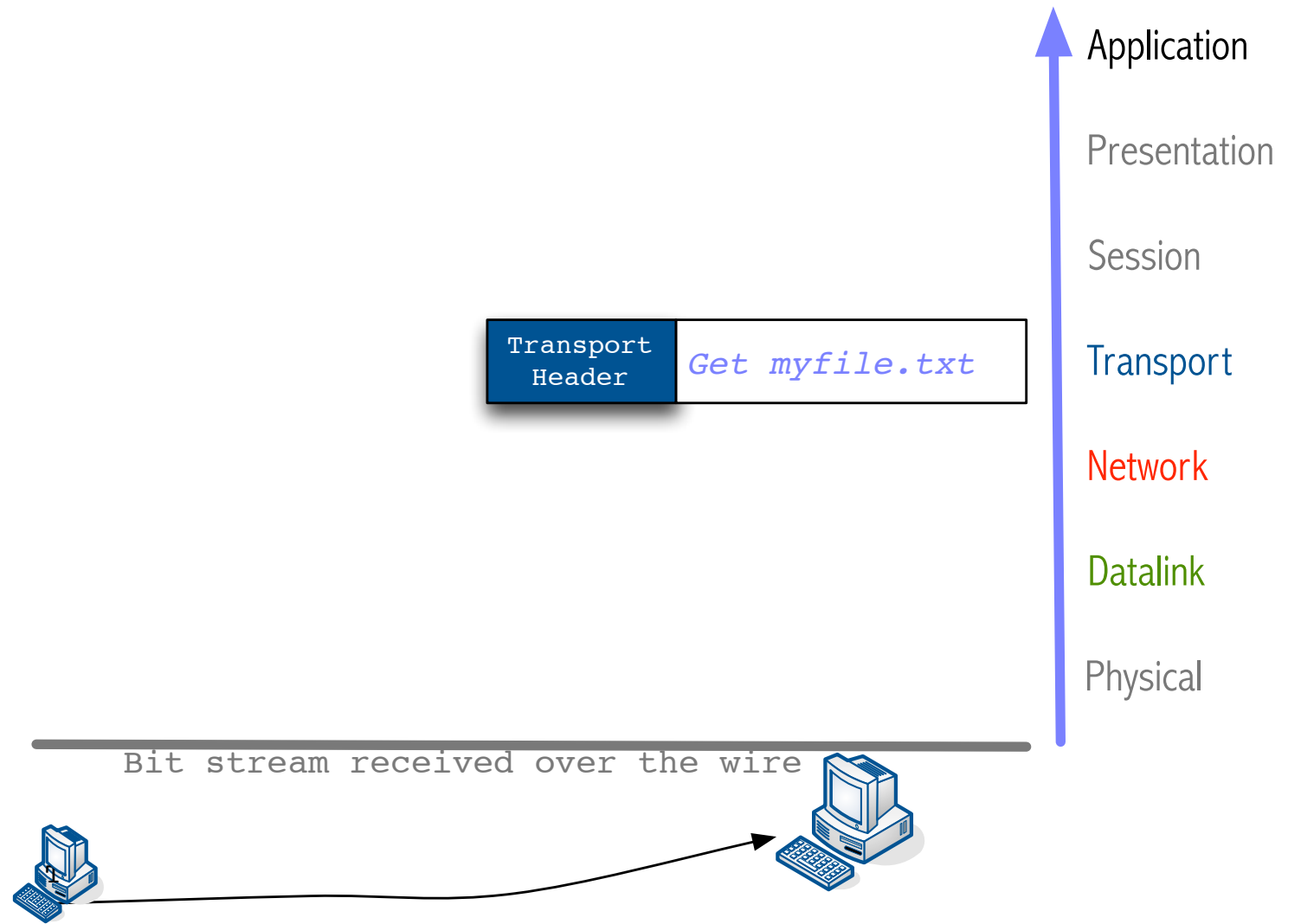


De-encapsulation at layer 3

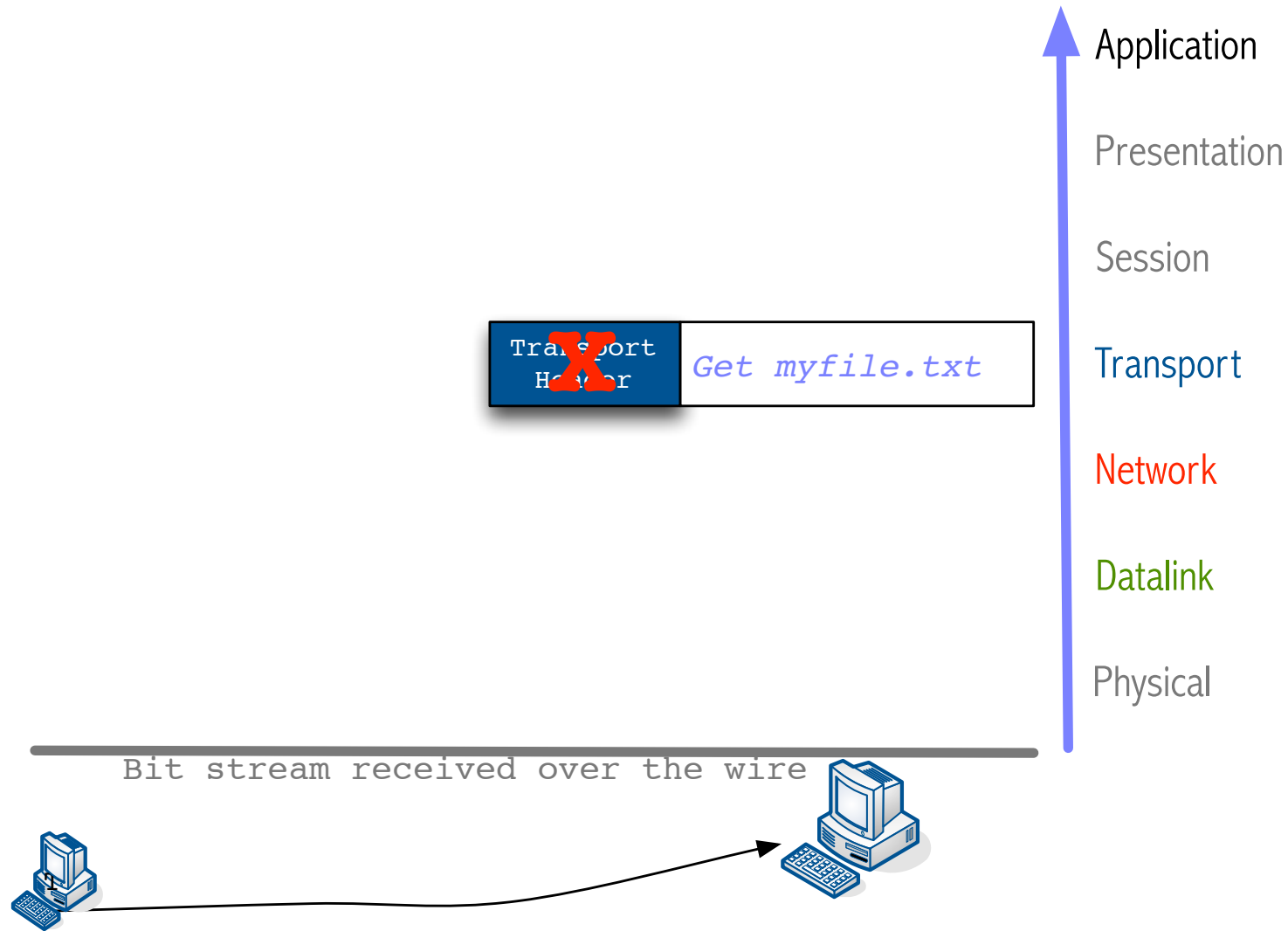


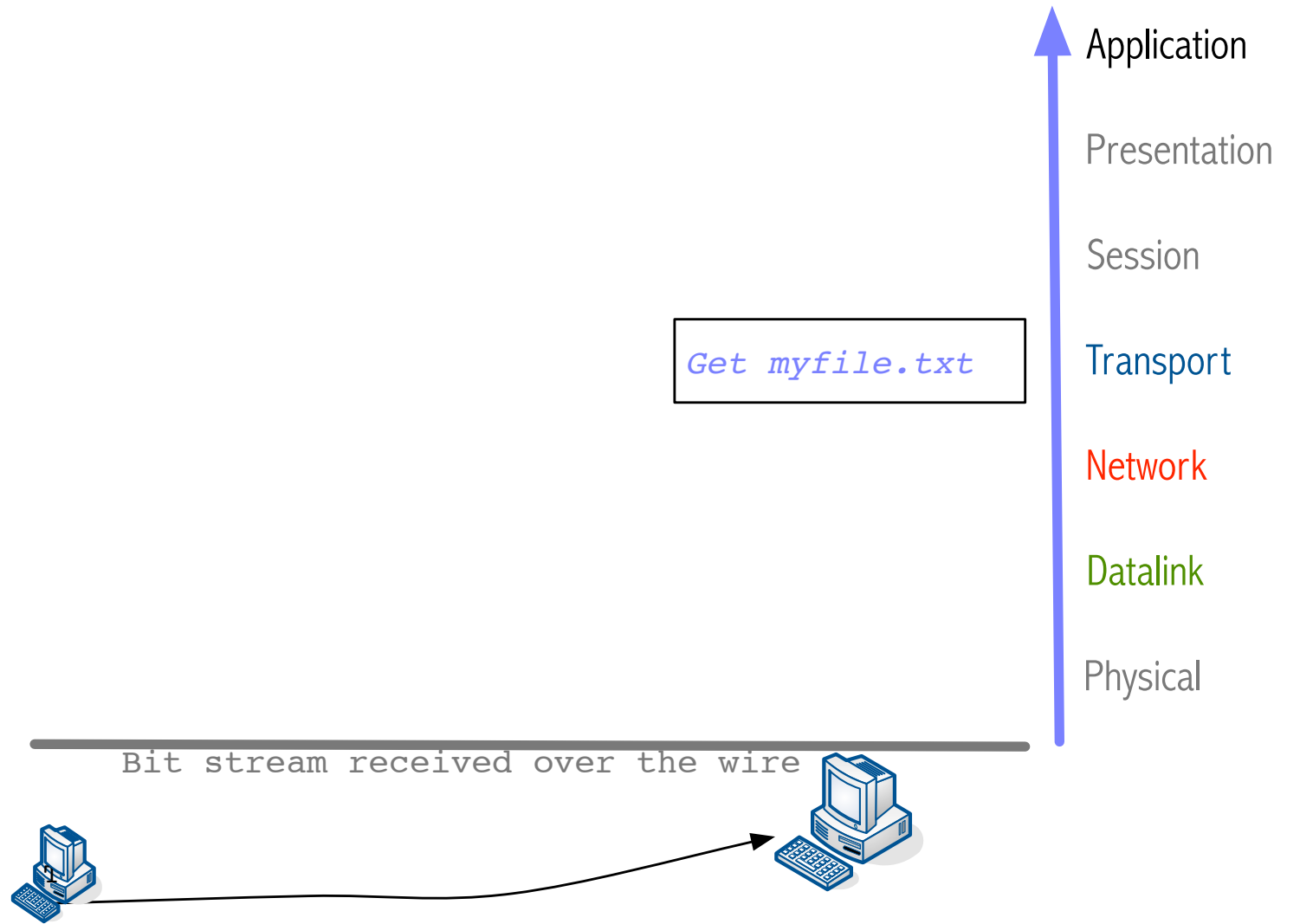


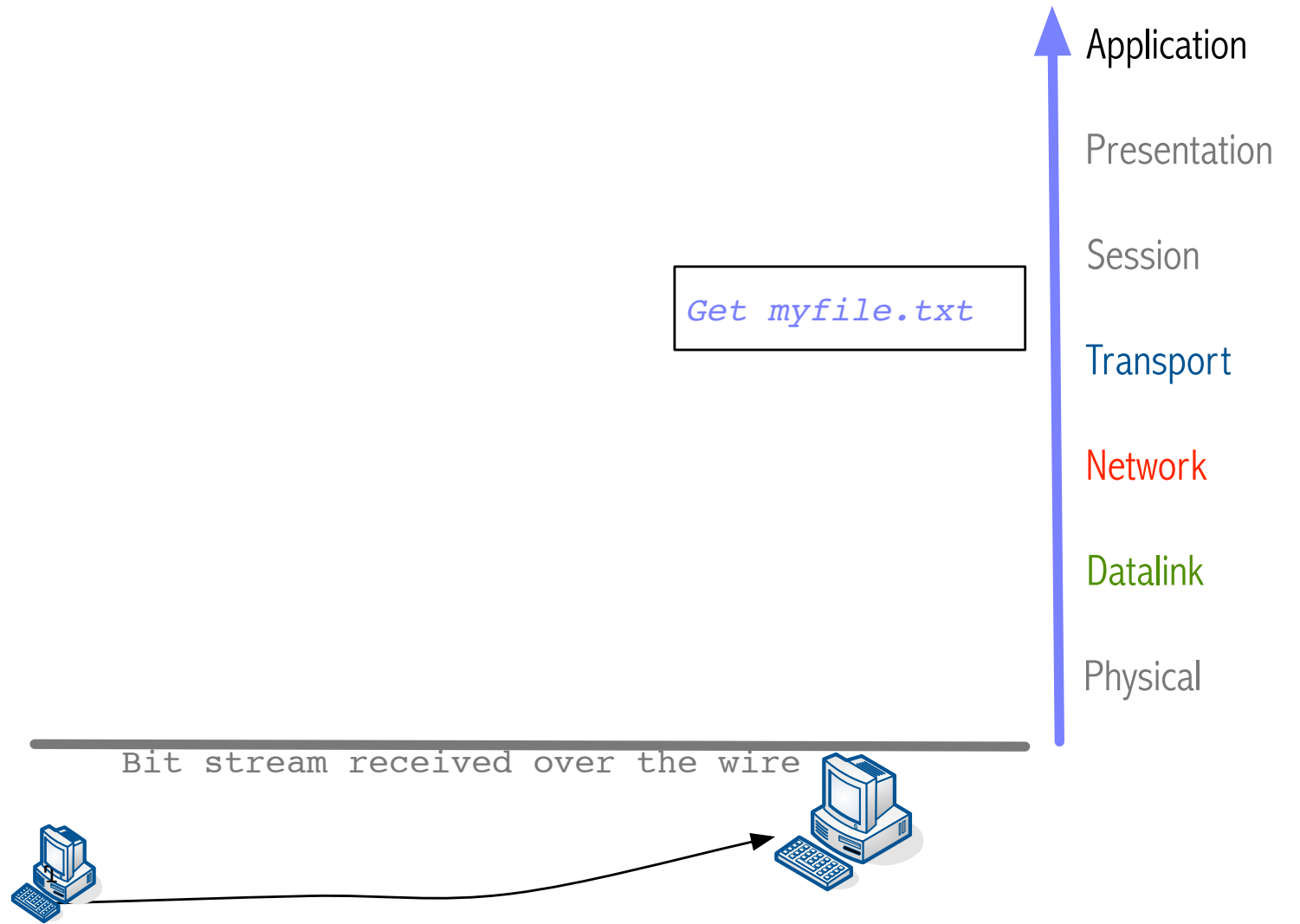




De-encapsulation at layer 4









Get myfile.txt

Application

Presentation

Session

Transport

Network

Datalink

Physical

Bit stream received over the wire





Get myfile.txt

Application

Presentation

Session

Transport

Network

Datalink

Physical

Bit stream received over the wire





Get myfile.txt

Application

Presentation

Session

Transport

Network

Datalink

Physical

Bit stream received over the wire





Get myfile.txt

Application

Presentation

Session

Transport

Network

Datalink

Physical

Bit stream received over the wire

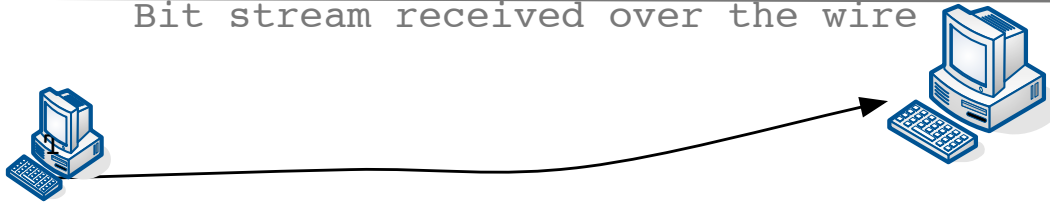


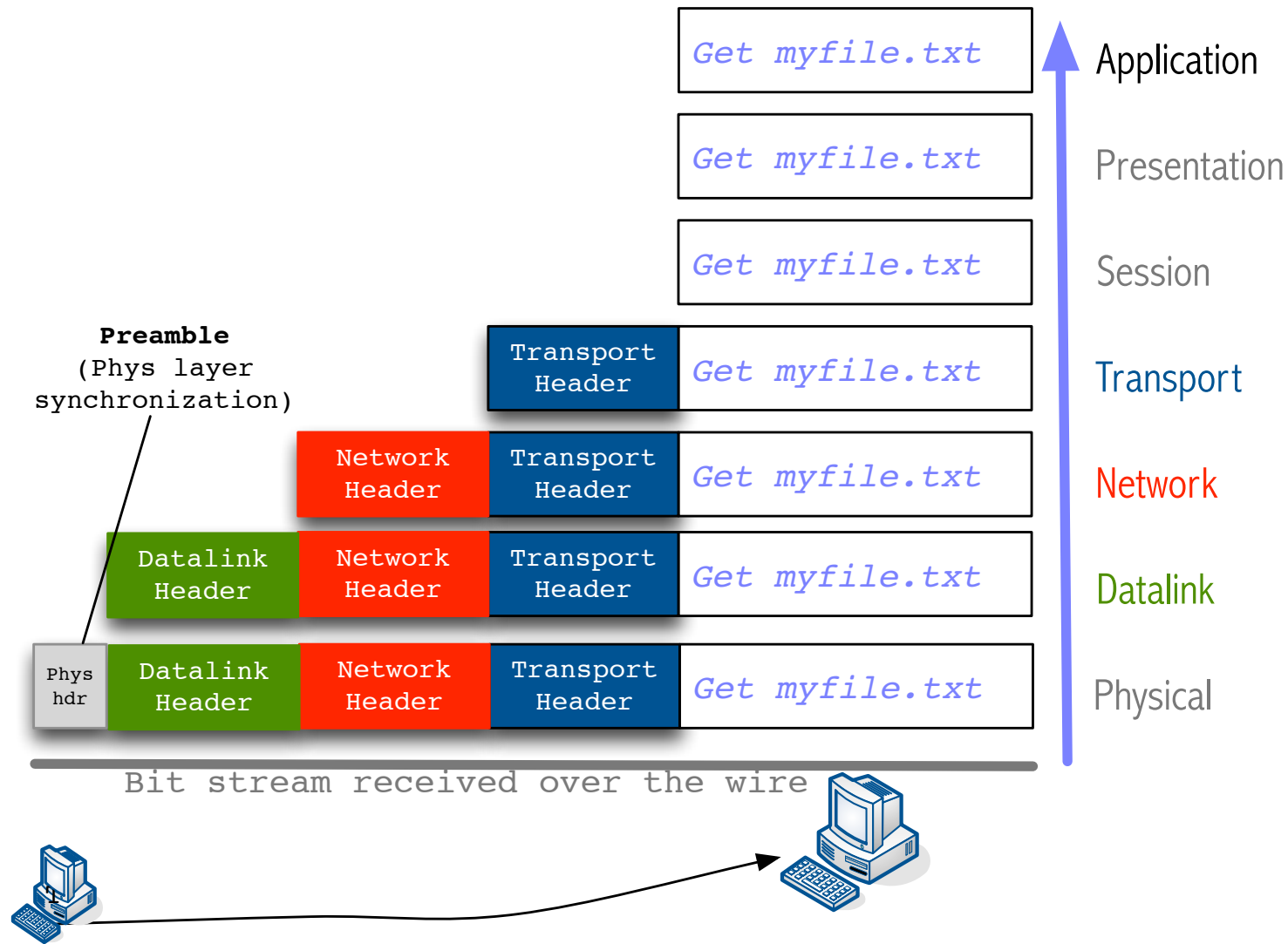


Get myfile.txt

- Application
- Presentation
- Session
- Transport
- Network
- Datalink
- Physical

Bit stream received over the wire

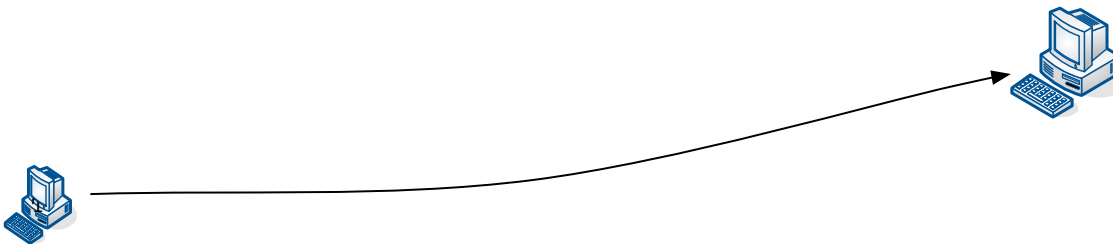
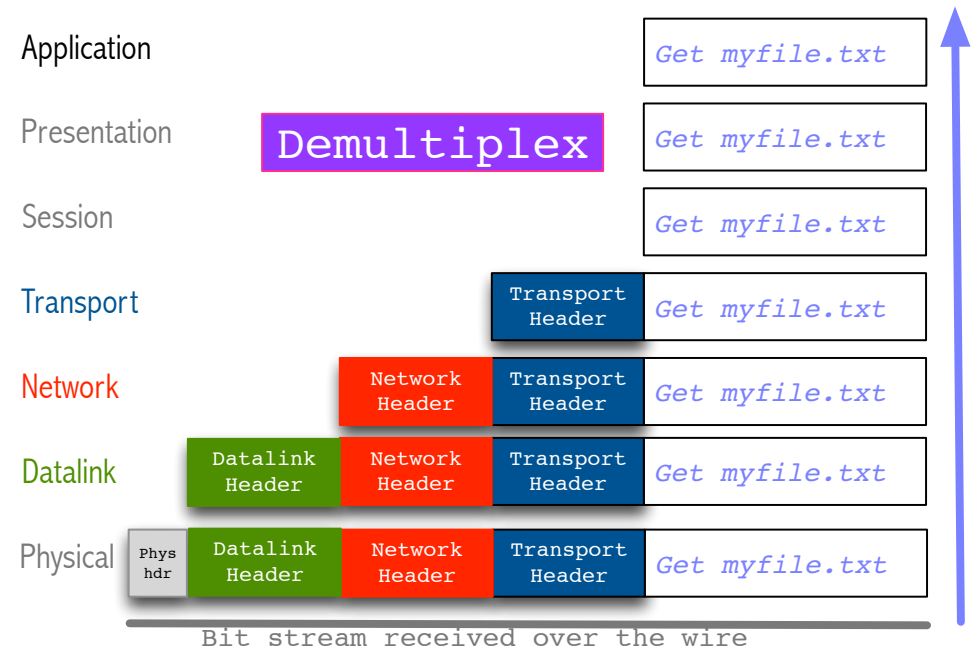
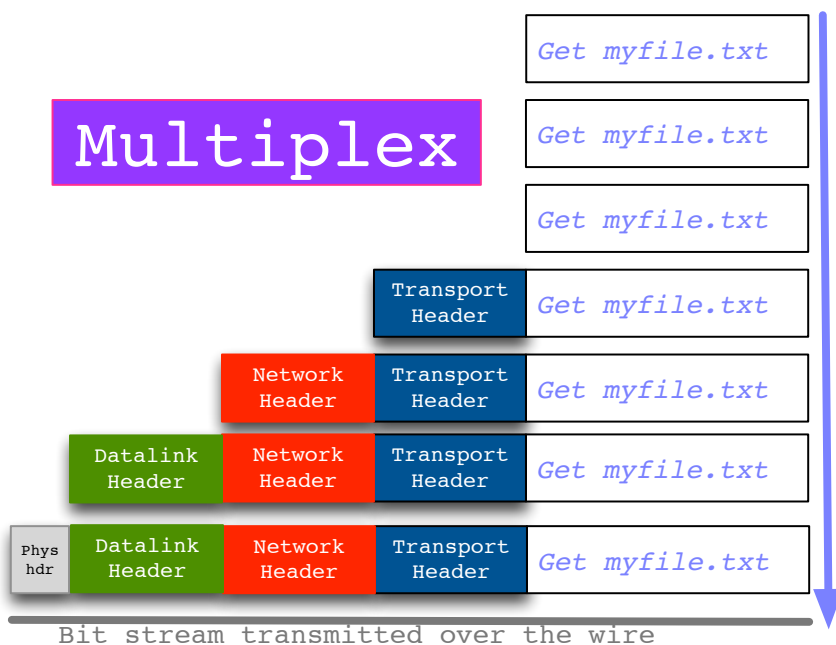




Multiplexing

90

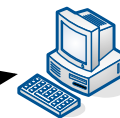
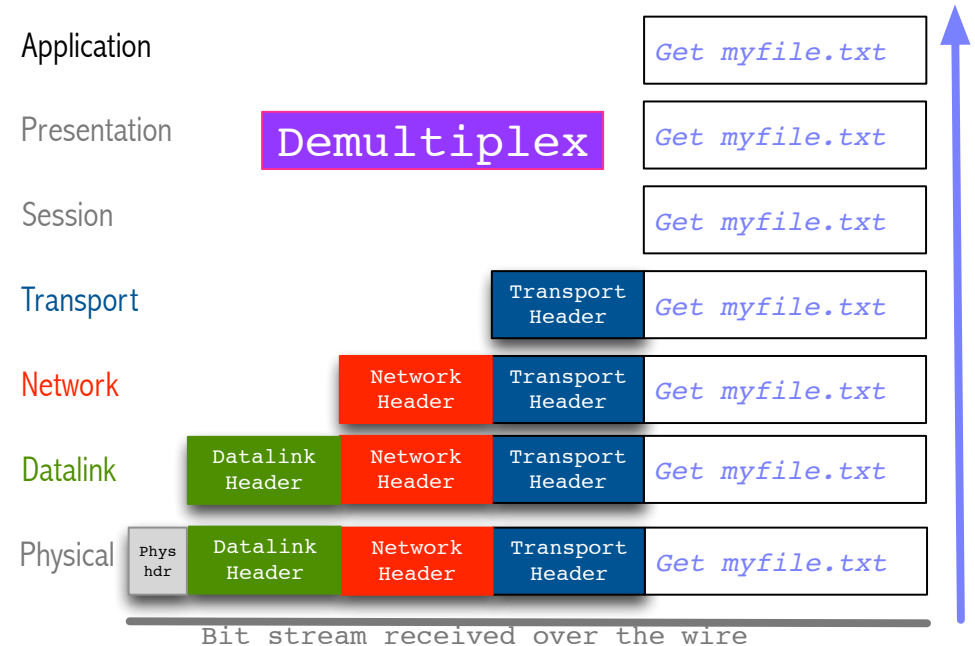
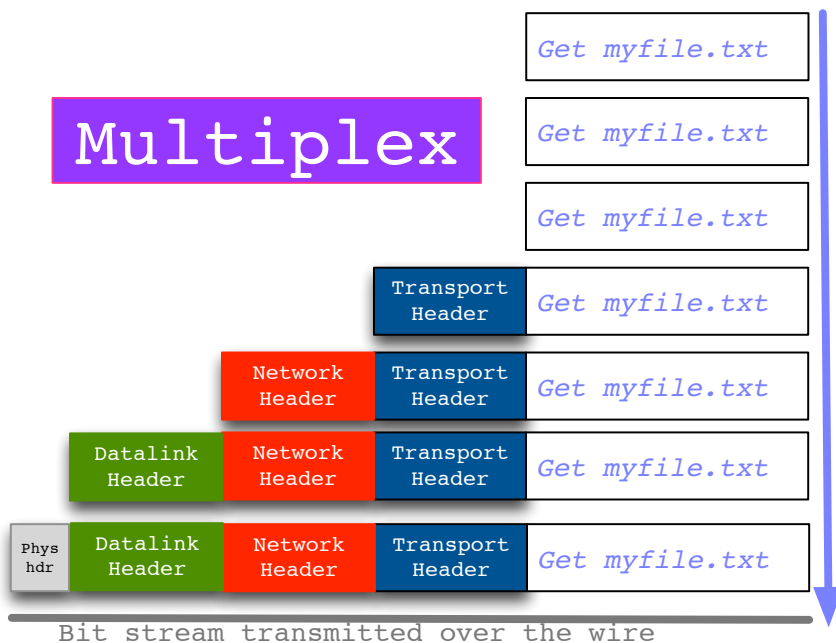
- Transmitter multiplexes several flows by having each layer add its header which contains addressing information



Demultiplexing

91

- 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



92

Connectivity

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

Theoretical connectivity

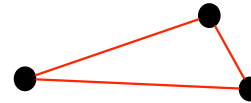
- Connectivity is the capacity of connection of a network
- If a network has N hosts, its connectivity is: $N \cdot (N-1) \cong N^2$
- Metcalf's law: The connectivity of a network grows fast as we add more nodes (N^2)



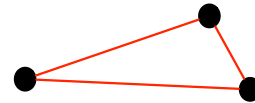
Connectivity = 1



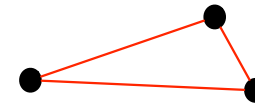
Connectivity = 2



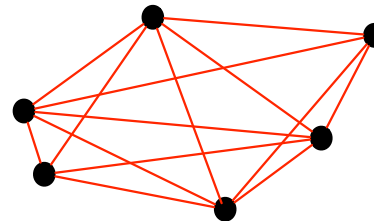
Connectivity = $3 \times 2 = 6$



+



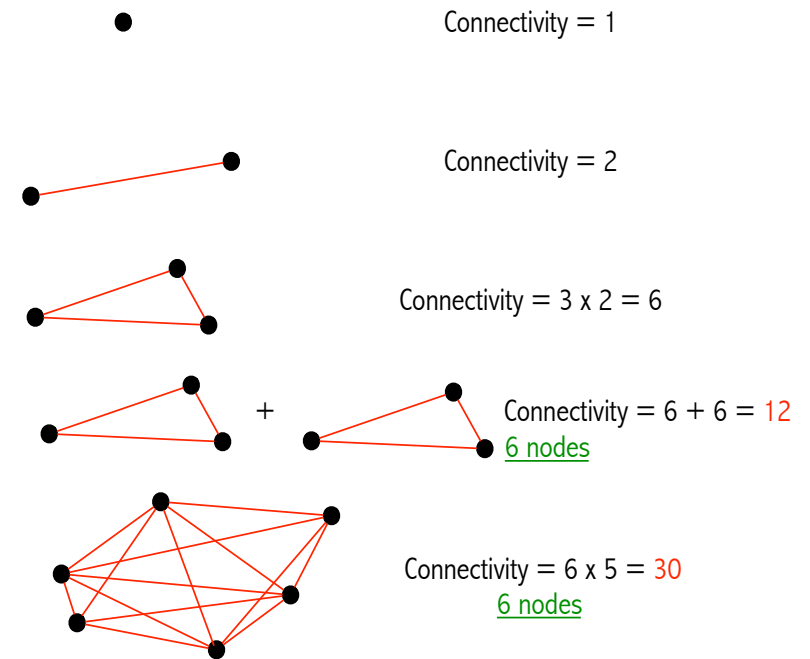
Connectivity = $6 + 6 = 12$
6 nodes



Connectivity = $6 \times 5 = 30$
6 nodes

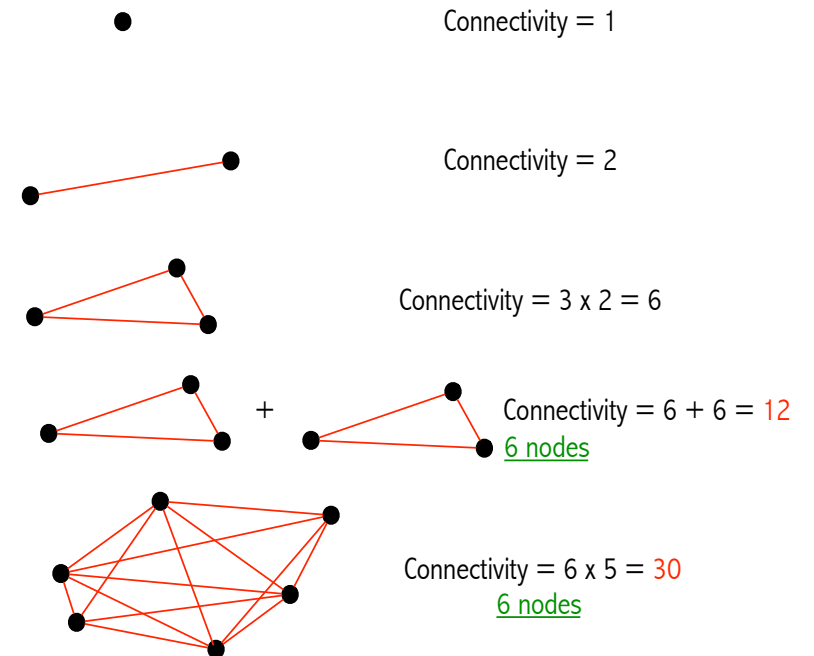
Increasing connectivity whilst preserving the capability for communication

- 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

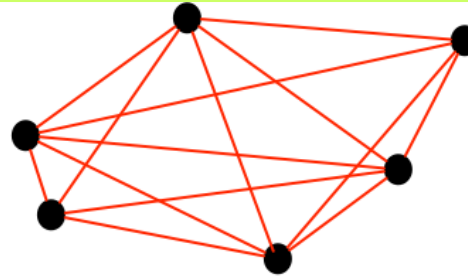
- The total number of packets per second that successfully make it to their destinations is known as:
 - ▣ Throughput, the figure of merit
 - ▣ Overall network productivity
 - ▣ Overall bps, or pps (packets per second), etc.



Scalable connectivity

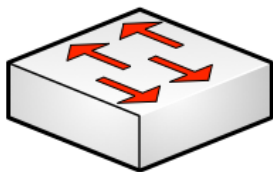
- 
- Not all network technologies use the available connectivity with the same efficiency
 - Ethernet can function efficiently up to certain network size: we say that Ethernet scales well up to that limit.
 - Then, how come the Internet has 4000M hosts? How can the Internet scale to such a huge size 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

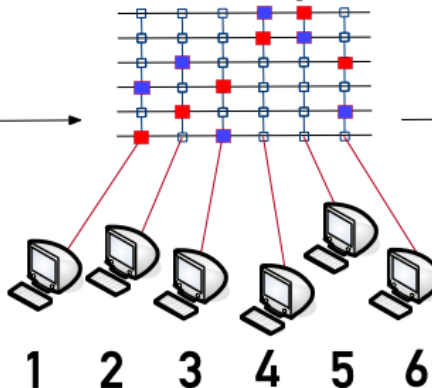


Full mesh comprised of 6 nodes
Connectivity = $6 \times (6 - 1)$
= 30 simplex links

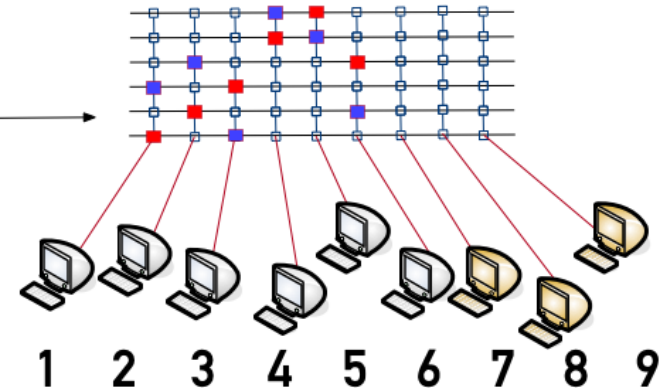
Implementation with a
9-port LAN Switch



Scalable connectivity
reaches 6 simplex links



Connectivity not available
for further hosts



Based on textbook *Conceptual Computer Networks* by:

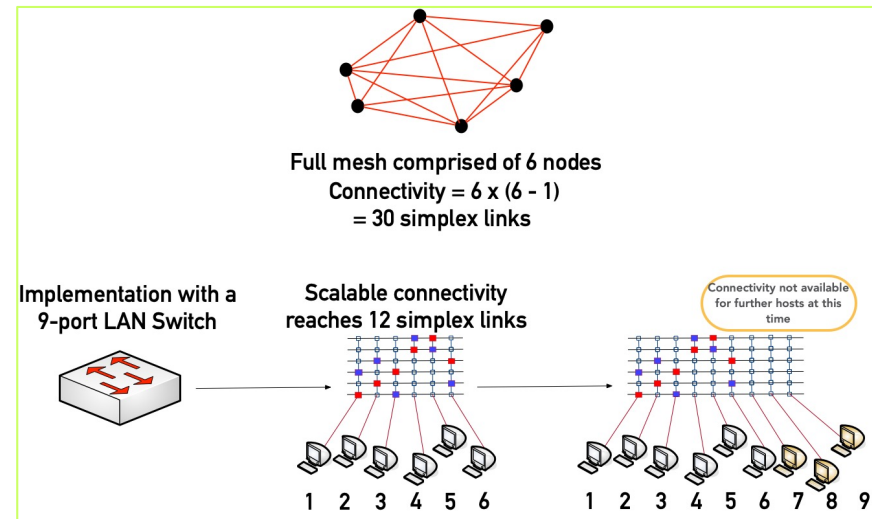
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Switch won't scale to 9 hosts

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



Network Throughput of various wireless technologies

EthAir scales poorly

