

### What makes networks different from connected components in a single machine?

Examples of challenges:

1. Latency is unknown and/or unbounded
2. Data channels are unreliable
3. Sharing resources with multiple users
4. ...

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### Today's Lecture

1. Intro
2. **Computer Networking History**
3. From Waves to Bits
4. Course Structure and Logistics

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### The ARPANET Growth over time

Growth of the ARPANET.

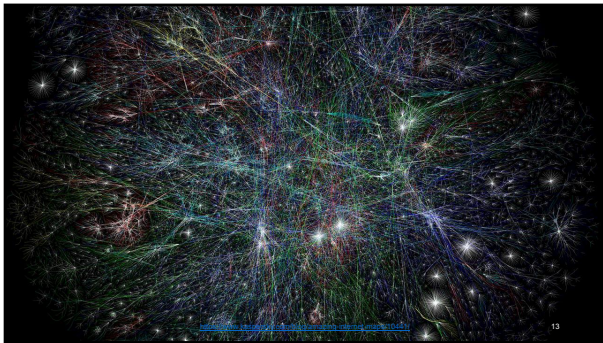
- (a) December 1969.
- (b) July 1970.
- (c) March 1971.

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### The ARPANET Network state in 1973

ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973

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## How scale affects networks design

Personal Area Network (PAN)

- Example: Bluetooth

Local Area Network (LAN)

- Examples: WiFi (802.11)

Metropolitan Area Network (MAN)

Wide Area Network (WAN)

The Internet

Interprocessor distance	Processors located in same	Example
1 m	Square meter	Personal area network
10 m	Room	
100 m	Building	Local area network
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	
1000 km	Continent	Wide area network
10.000 km	Planet	

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## How the medium affects network design

Different frequencies have different physical properties!

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## Layered architecture

Q: Discuss the concept of a (layered) architecture; Give one advantage and one disadvantage

Can be found in...

...computer networks... NETFLIX

...and other domains

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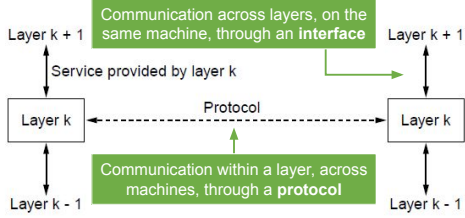
## Layered architecture in computer networks: an analogy

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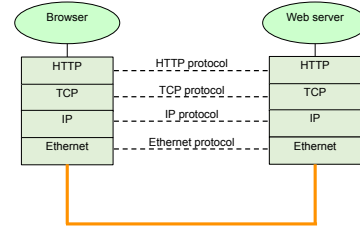
## Layered architecture in computer networks: an overview

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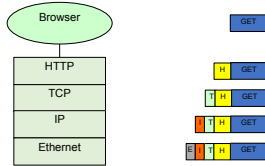
## Illusion of direct communication



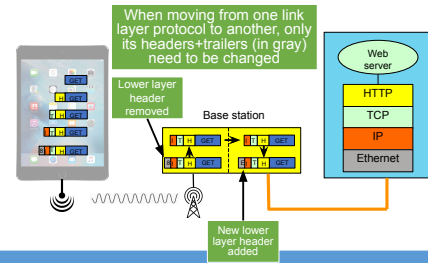
## An example protocol



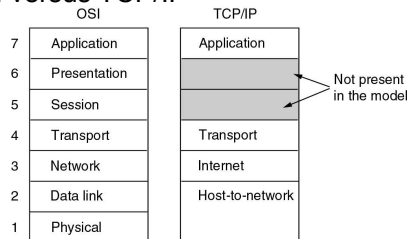
## Encapsulation in a protocol stack



## The power of a layered design



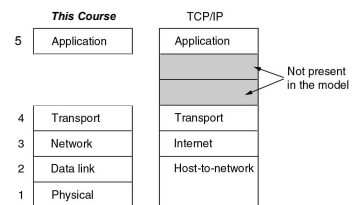
## OSI versus TCP/IP



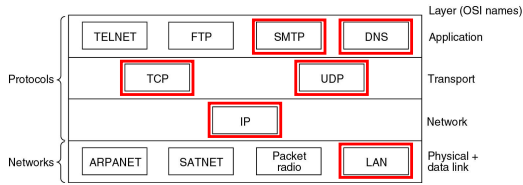
## The model used in this course

The OSI model is well-designed, but, in practice,\* layer 5 and 6 are almost empty

So we skip them!



# Protocols and Networks from the TCP/IP model

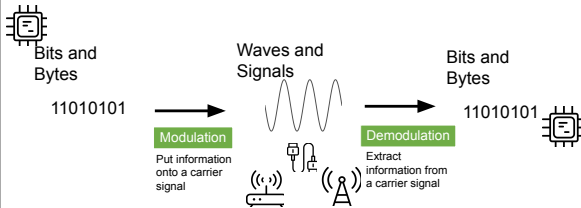


# Today's Lecture

1. Intro
2. Computer Networking History
- 3. From Waves to Bits**
4. Course Structure and Logistics

# Digital Modulation

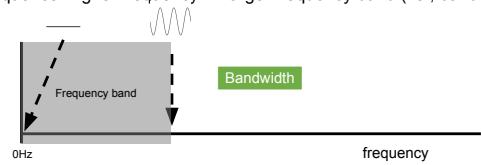
Q: How to communicate bit strings (e.g., 101011101) between computer systems?



# Bandwidth (analog, in Hz)

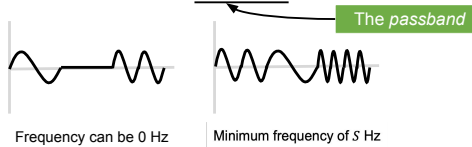
This implies: higher frequency → higher bitrate

Assumption: frequency starts from 0  
Consequence: higher frequency → larger frequency band (i.e., bandwidth)



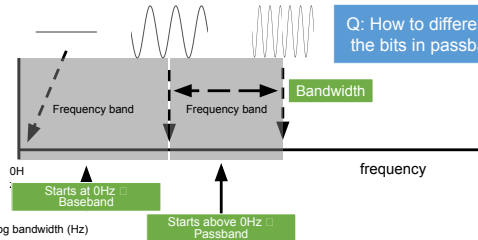
# Passband transmission

Wireless signals cannot start from 0Hz (why not?)  
Solution: move from [0, B] Hz to [S, S+B] Hz.



# Baseband, Passband, and Bandwidth\*

Q: How to differentiate the bits in passband?



## Digital Modulation

0 1 0

Binary signal

Frequency Shift Keying (FSK)

Phase Shift Keying (PSK)

time □

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## Nyquist's Theorem

Computing the maximum data rate for a noiseless channel

$$R = 2B \log_2(V)$$

R = maximum data rate (in bits per second)  
 B = bandwidth (in Hz)  
 V = number of discrete signal levels

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## Nyquist's Theorem Example

A signal that uses 4 signal levels over a wired channel with 500kHz bandwidth

$R = 2B \times \log_2(V)$   
 $B = 500,000 \quad V = 4$   
 $R = 2 \times 500,000 \times \log_2(4)$   
 $R = 2,000,000$   
 $R = 2\text{Mbps}$

Q: Can we exceed the maximum Nyquist data rate? Under what assumptions does this model hold?

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## Shannon's Theorem

Q: Should we reduce noise or increase bandwidth?

Shannon's Theorem + signal attenuation □ limited cable length

In practice, *noise* reduces the maximum data rate.

$$R = B \times \log_2 \left( 1 + \frac{S}{N} \right)$$

The signal to noise ratio ( $S/N$  or SNR) is expressed in decibel.  
 SNR of 40 dB means  $S/N = 10^4$

Q: Why use decibels? I.e., Signal power is 10,000 times stronger than Noise power

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## Shannon's Theorem Example

Signal level not used!

Consider the signal and channel from before (4 signal levels, 500kHz bandwidth). What happens if the SNR is 40dB?

$R = B \log_2 \left( 1 + \frac{S}{N} \right)$   
 $B = 500,000$   
 $\frac{S}{N} = 40\text{dB} = 10^{40/10} = 10,000$   
 $R = 500,000 \log_2(1 + 10,000)$   
 $R \approx 500,000 \times 13 = 6,500,000\text{bps} = 6.5\text{Mbps}$

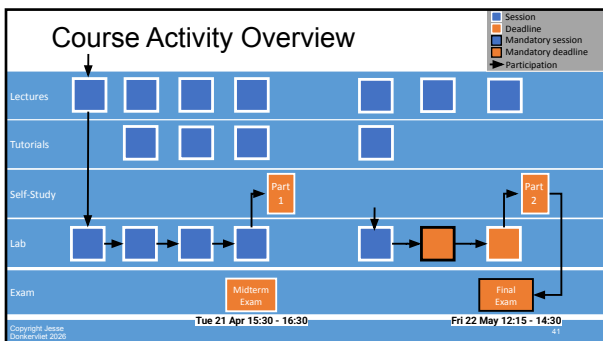
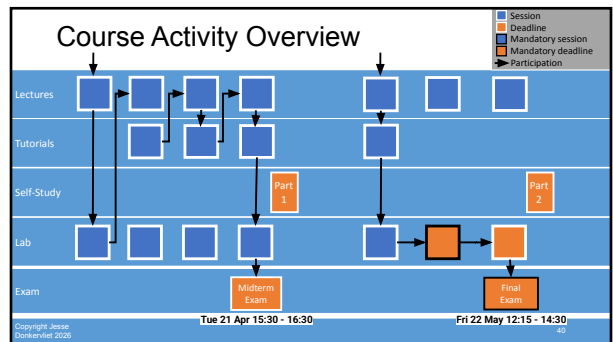
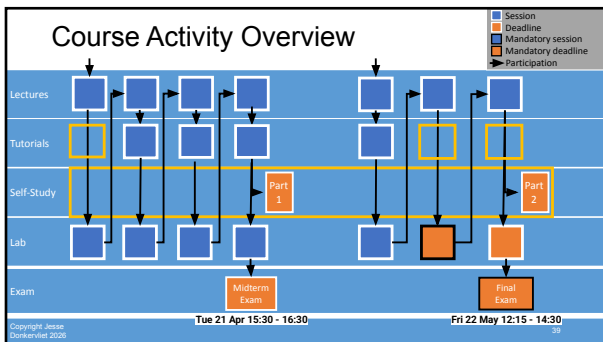
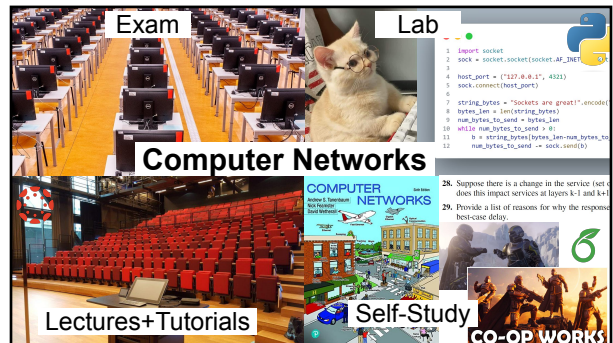
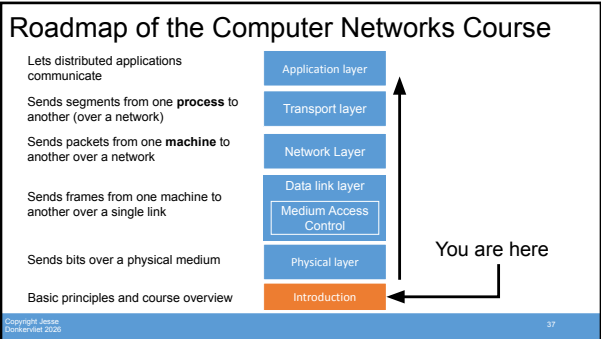
$\log_2 10001 \approx 13.29 \approx 13$   
 $2^{10} = 1024, 2^3 = 8, 2^4 = 16$   
 $2^{13} = 8192, 2^{14} = 16384$

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## How Am I Graded?

$$\text{grade} = \frac{\text{exam} + \text{lab} + \text{in class} + \text{self study}}{1000}$$

\*Additional conditions apply, such as passing the mandatory lab assignments (A1+A2) and the final exam. For details, see the [course grading page](#).



## Exam Content and Grades

	Chapter 1	2	3	4	5	6	7
Midterm	✓	~	✓	✓			
Final	✓	~	✓	✓	✓	✓	✓
Resit	✓	~	✓	✓	✓	✓	✓
Final Exam Grade:	max			+	max		

## Lab

Logistics

## Lab

Labs on Tuesdays and Fridays [Starting Next week], 09:00 – 12:45.  
**This week (tomorrow):** Lab setup session, 09:00 – 12:45.

Use the Canvas groups page to enroll for the one of the sessions.

**Deadline for registration:** Friday, April 3rd, 23:59

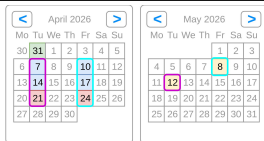
**Warning:** different deadlines based on registration.

## Lab — passing the course

Lab Manual specifies several optional assignments.

*Assignment 1 and 2 are **mandatory** to pass the course*

For assignment descriptions, see the **Lab Manual** on the course website.



- Lab setup session
- Regular lab session
- Mandatory lab assignments deadline
- Extra lab assignments deadline

i Your lab deadline depends on the session (Tuesday/Friday) that you registered for. You may not exceed the deadline for your registered session.

□ = Tuesday session □ = Friday session

## Lab

Collect points by completing Lab assignments.

- Small reward for the mandatory assignments **[500 points]**
- Larger rewards for the optional assignments **[up to 4000 points]**
- Many potential small rewards for active participation during the labs

# How to Hand in Lab Assignments

## Submission System:

1. Complete assignment.
2. Upload to CodeGrade, pass all the tests
3. Enter Queue ➡
4. Interview with TA [limited number of attempts]
5.  Assignment approved.  
-or-  
 Go to step 1.

Computer Networks - Lab Queue

Fill in this form to get in the queue for asking questions or submitting an assignment.

**IMPORTANT:**  
\* Please upload your source code files to Canvas before entering this queue (one person per group is sufficient).

View the live queue at <https://docs.google.com/spreadsheets/d/2E2338150e4m4m5R9U9e0fDv4v6IKDm3vUc4t1y9v0004>

\* Required

---

Your Canvas Group Number \*

Your answer \_\_\_\_\_

# How to Hand in Lab Assignments

We use a **queue**, which means First-Come, First-Serve (FCFS)  
Important:

1. Queue closes **before** the end of the lab session.
2. Closed queue not a valid excuse for not completing assignments.

Enqueue on time

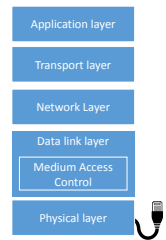
Do not wait until last session before the deadline

# Lab Assignments

Getting Started

# Network layer services

- Sends segments from one **process** to another (over a network)
- Sends packets from one **machine** to another over a network
- Sends frames from one machine to another over a single link
- Sends bits over a physical medium



# Network layer services

Sends segments from one **process** to another (over a network)



This is the service used by your application

What kind of interface does it use?

# Socket Primitives in TCP

**Socket** – create a new communication *endpoint*.

**Connect** – connect to a remote *listening* socket.

Q: Are we missing something?

**Send** – send data to the other application.

**Receive** – receive data from the other application.

**Close** – close the connection.

Used to allow incoming connections

**Bind** – assign a *local address* to the socket.

**Listen** – wait for a connection.

**Accept** – passively accept an incoming *connection request*.

## TCP Sockets in Python

```
# Import the socket library.
import socket

# Create a new socket.
s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)

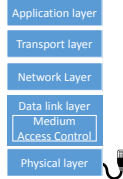
# Connect to another application.
s.connect(("hostname", port_number))

# Send bytes.
num_bytes_sent = s.send(buffer)
s.sendall(buffer)

# Receive bytes.
buffer = s.recv(2048)

# Close connection.
s.close()
```

Network layer protocol    Transport layer protocol



Max number of bytes to receive

## TCP provides a reliable byte-stream

Q: What does this mean for your application?

1. The program waits until data is available
2. It may return an arbitrary number of bytes

```
s.recv(2048)
HELLO - F R O M J E S
s.recv(2048)
S E \n W H O \n
s.recv(2048)
S E N D E C H O B O T H
s.recv(2048)
E L L O W O R L D \n
```

## Threading Python

```
# Import threading library.
import threading

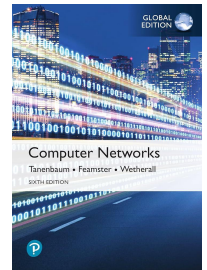
# A regular call to print.
print("Hello", "World")

# A threaded call to print.
t = threading.Thread(target=print, args=("Hello", "World"))
# Run target in new thread.
t.start()
# Wait 100ms for thread to finish.
t.join(0.1)
```

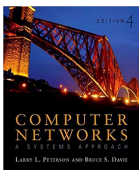
## Course Material

Course Material:

1. Course Slides
2. Book: Computer Networks, 6th edition, Andrew S. Tanenbaum, Nick Feamster, and David J. Wetherall



## Other Computer Networks Books



Peterson and Davie

Available for free at <https://book.systemsapproach.org>



Kurose and Ross

## Meet the Team!



## Next steps

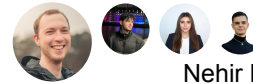
1. Participate in the Entry Quiz! Earn your first points!
2. Read the course Website
3. Obtain a copy of the book
4. Find a lab partner.  
The lab is done in teams of 2 students.
  1. Register your group on Canvas
  2. Can't find a partner? Look for one on the Canvas discussion board
  3. Contact the Computer Networks team
5. Start looking for a self-study team

# Computer Networks

@Large Research  
Massivizing Computer Systems

## X\_400487

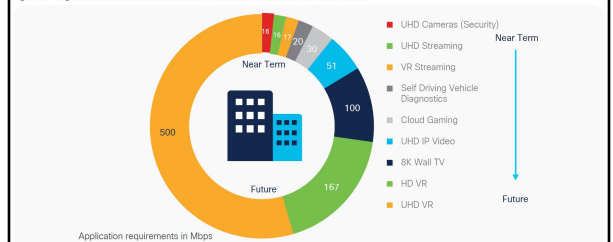
Lecture 1: Introduction to Computer Networks  
(+ a tiny bit of Chapter 2)



Lecturers: Jesse Donkervliet,  
Gonçalo Amado Mesquita,  
Nehir Kirkgöz, Daniel-Ştefan Halasz

## Extra Slides

Figure 13. Significant demand for bandwidth and video in the connected home of the future

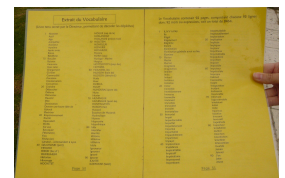
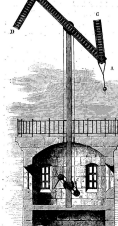


## Eve Online is getting crushed by its own success

In a [blog post on Jan. 4](#), just hours after the fateful battle, CCP Games essentially threw its hands in the air, saying that it can no longer "predict the server performance in these kinds of situations."

"Both during and after the fight, players experienced things that don't happen under normal circumstances," CCP said in its blog post. "Things like ships disappearing, ships reappearing, ships not appearing in the right systems — even after going through the jump tunnel."

## Writing at a distance (telegraph)



Optical telegraph in use until 1850

# Electrical Telegraph

Make possible through scientific and engineering advances in electricity

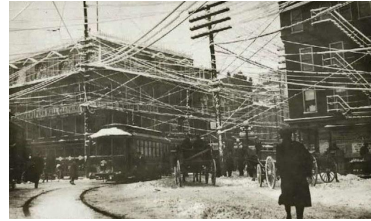
- Used to control train traffic, disseminating news
- International Morse Code was adopted in 1851
- Sounder replaced register by 1856
- Duplex transmission system completed in 1871

**Telephone patented by Alexander Graham Bell in 1876**



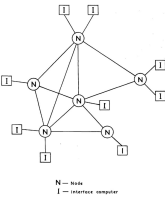
Morse key

# Early telephone system



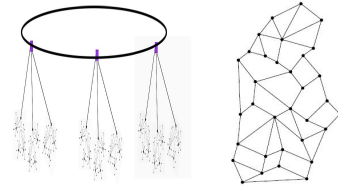
# Network designed by the National Physical Laboratory

- NPL paper cited Baran but went further
- **Divided files into chunks called packets**
- **Store-and-forward packet switching network**



They did not build a prototype, but described its design.

# The ARPANET A mesh-structured network



# The ARPANET Fault tolerance

