# X_405082
# Advanced Computer Networks

## Introduction

Lin Wang (lin.wang@vu.nl)

Period 2, Fall 2020

VU VRIJE UNIVERSITEIT AMSTERDAM

Part of the content is adapted from P. Brighten Godfrey and Ankit Singla

# Online for COVID-19

All teaching activities will be **online**

- **Lectures via Zoom:** post your questions on Chat, or raise your hand to speak
- Note: online lectures will be **recorded** and posted on Canvas
- **Exam on Canvas:** timed quizzes at the end of the course

This is the first time for this course too, so please email us if you have ideas for how we can improve the online version of this course!

# Logistics

**Lin Wang (lecturer)**
Assistant Professor

**Vinod Nigade (TA)**
PhD researcher

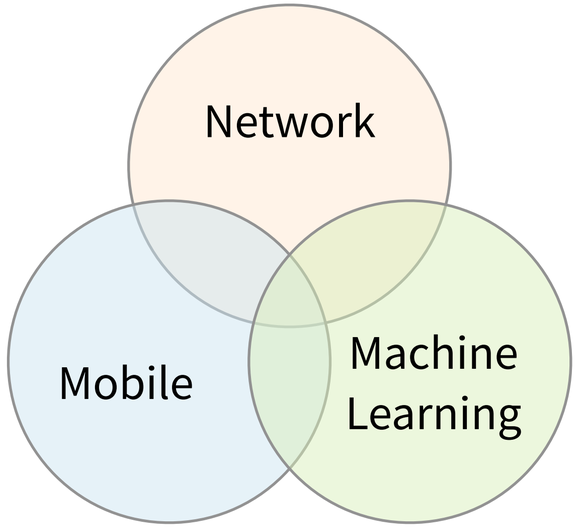
**Ramon Winder (TA)**
Graduated MSc student

For any course-related questions, please drop us an email via: **vu.acn.ta@gmail.com**

# Our research

We work in the areas of

- **Networked systems:** Distributed systems to support modern workloads like machine learning
- **Mobile computing:** Protocols to support mobile applications like Augmented Reality in 5G environments
- **Programmable networks:** How to teach an elephant (a switch) to dance (to learn)?
- **Battery-free computing?!** How to do computation and communication on a device without a battery?
- For more details, check https://linwang.info




Opportunities for TAs, theses, and research project works

# Goals of the course

To get familiar with the **state-of-the-art** of computer networking technologies

To be able to reason about the **designs/ principles** in networks and networked systems

To gain **hands-on experience** with networked systems programming and outlook for research

To practice the **art of reading** research papers

It is a **big** field, so we have to focus on just **a few** topics.

# Course basics

## Course name

- Last year, the course was called “Internet Programming” — an old name for a brand new course
- From this year on, we have a new name called “**Advanced Computer Networks**”

## Communication channel

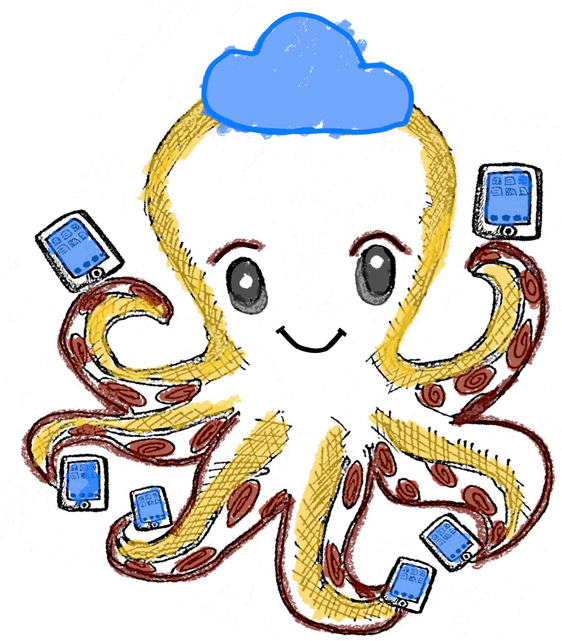
- All announcements and all material on **Canvas**

## Policy

- Attendance is strongly encouraged

## Office hours

- Every Wednesday 10:00 - 11:00, not mandatory but feel free to join



# Course grading

Project: 50 points

Final exam: 50 points

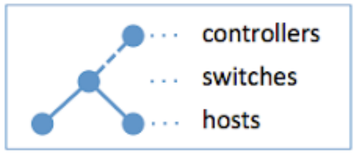
## PASS condition

- If you obtain no less than 25/50 points in **both** components

## Final grade scaling

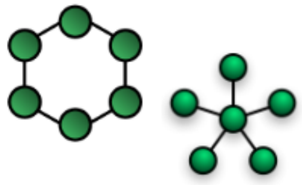
| | |
|---|---|
| [95, 100] → 10.0 | [68, 75) → 7.5 |
| [90, 95) → 9.5 | [62, 68) → 7.0 |
| [85, 90) → 9.0 | [56, 62) → 6.5 |
| [80, 85) → 8.5 | [50, 56) → 6.0 |
| [75, 80) → 8.0 | [0, 50) → FAIL |

# Project labs preview



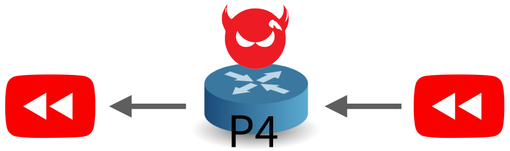

Lab0: get familiar with Mininet – a network emulator

Lab1: implement a learning switch



Lab2: generate and compare network topologies


Lab3: build a data center in Mininet




Lab4: video streaming interception

Your project ideas?

# Project labs organization

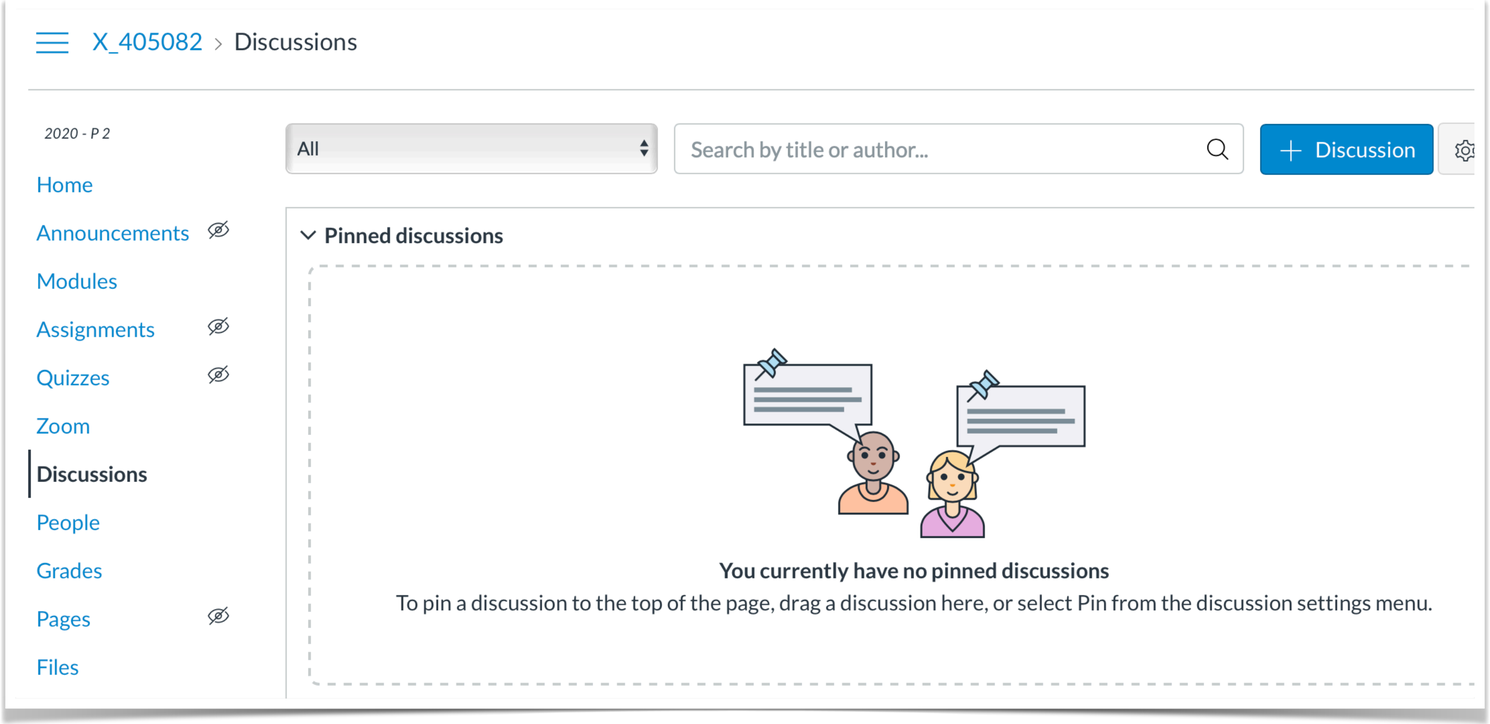
## Individual assignments for lab0 and lab1

- Lab0 is just a warm up, no points and no submission needed
- Lab1 will be assessed with Canvas quizzes, no code submission needed

## Group assignment for lab2 through lab4

- You work in a group of max. 2
- Choose your own teammate, deadline **Friday Nov 6, 2020**
- Split the work evenly, each of you needs to understand the entire code
- Submission: code + report in PDF, all in one zip file

# Peer discussions are encouraged




You can post general questions/doubts in the discussion and get help from each other, but please do not post your code or spoil answers directly.

# Integrity

Zero tolerance → You should **not plagiarize anything** in this course (and other courses)

The following are considered plagiarism

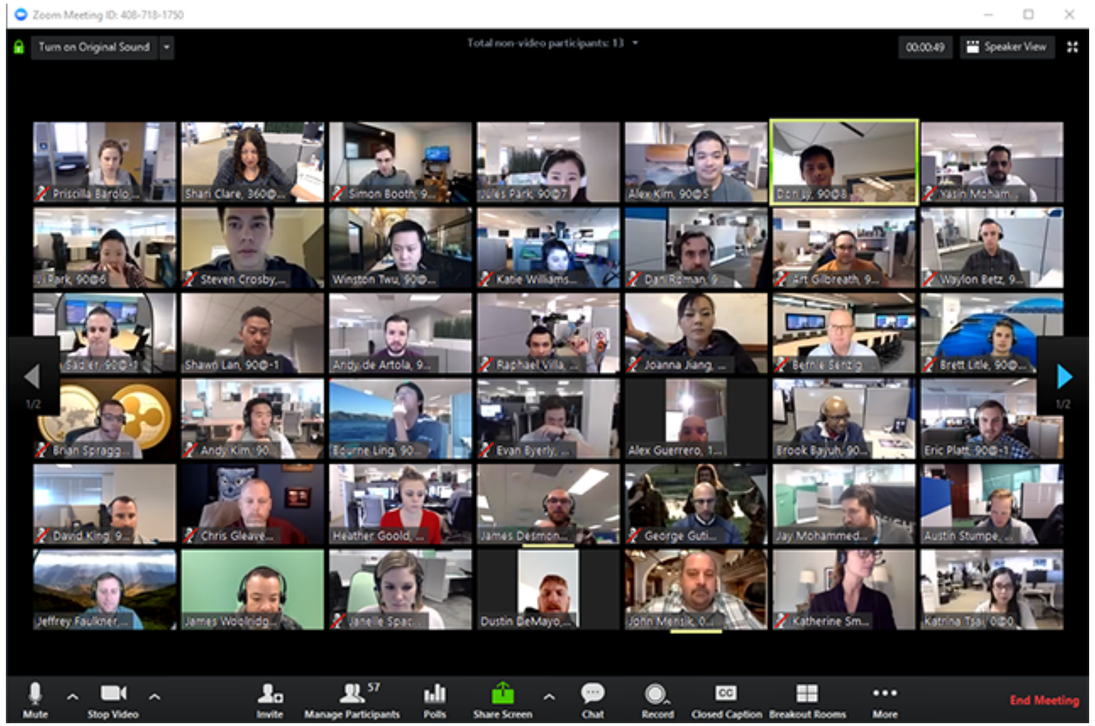
- Copy (part of) a solution from another team or from the Internet
- Buy a solution from any source
- Copy + make changes to any of the above

What happens if someone commits plagiarism

- The case will be reported to the exam committee
- It is up to them to decide on disciplinary actions

# Questions?

# Why this course?


To understand how hard your computer is doing these days!

# Why this course?

UW NEWS

ENGINEERING | NEWS RELEASES | RESEARCH | SCIENCE | TECHNOLOGY

July 5, 2017

## First battery-free cellphone makes calls by harvesting ambient power

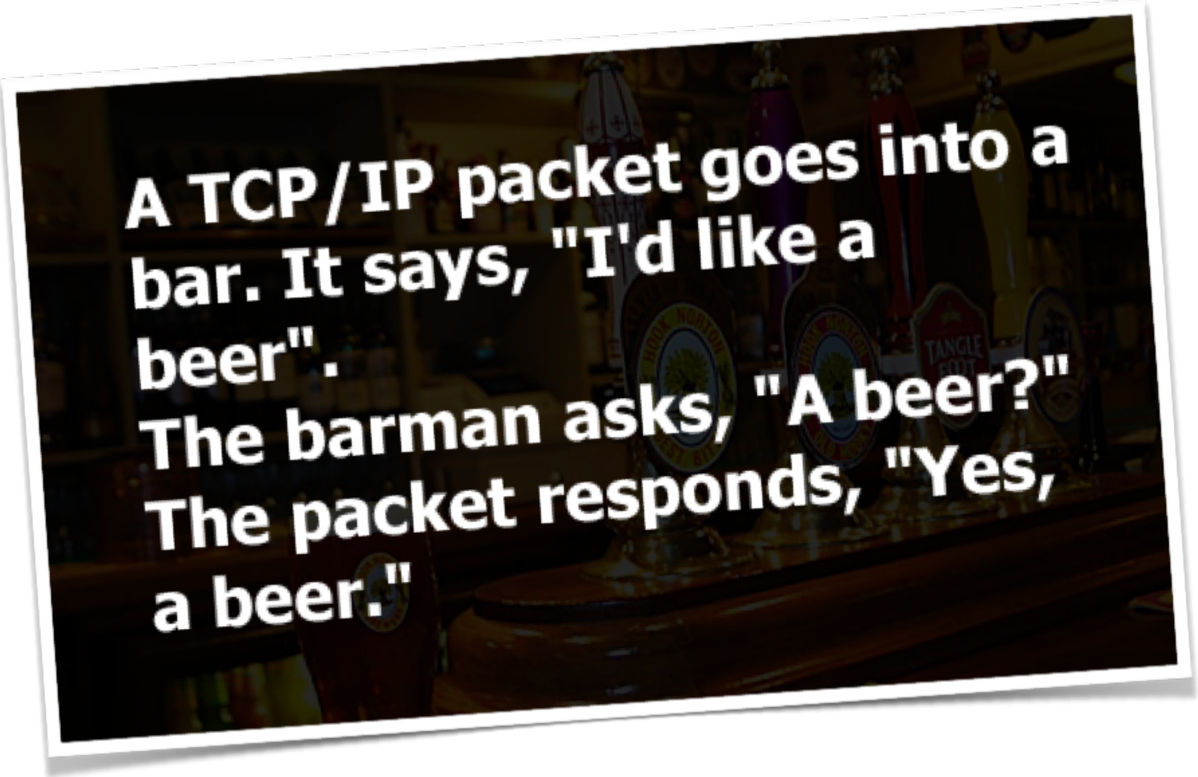
Jennifer Langston
UW News

University of Washington researchers have invented a cellphone that requires no batteries — a major leap forward in moving beyond chargers, cords and dying phones. Instead, the phone harvests the few microwatts of power it requires from either ambient radio signals or light.



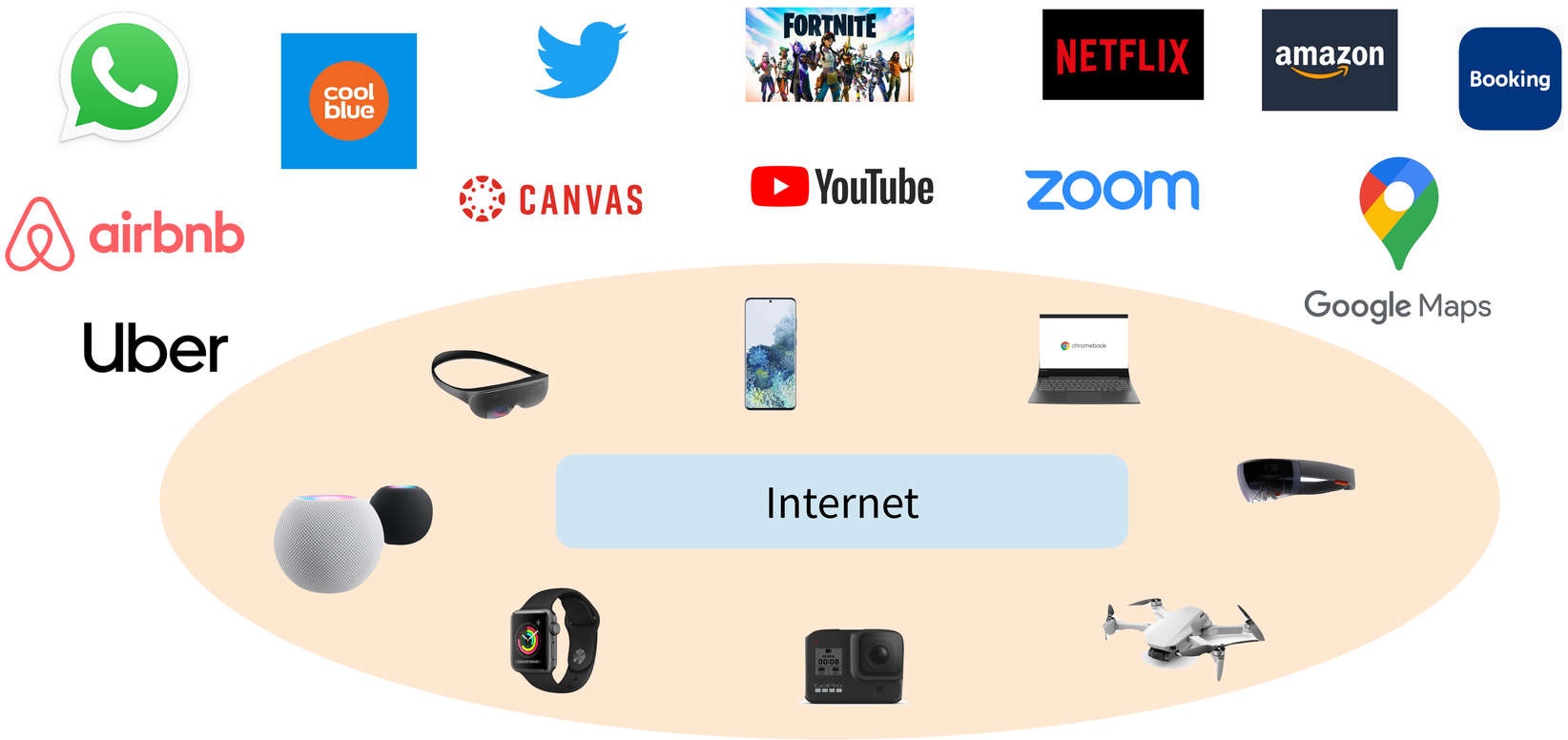

To have something to brag about next time when you meet a friend!

# Why this course?



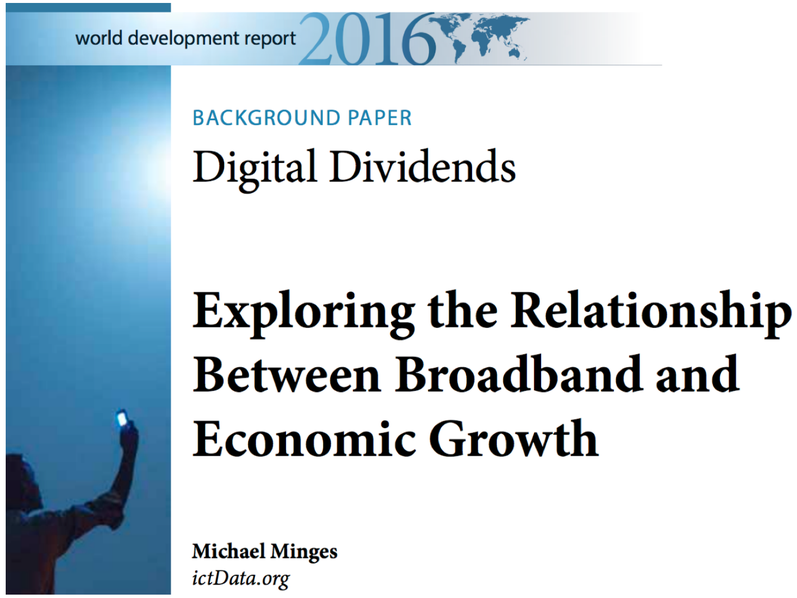

Or, just for the love of terrible jobs…

# Internet: a fundamental societal infrastructure




The Internet is behind most of our daily activities nowadays!

# Huge societal impact


The Internet has a YUUUUGE impact on our society.

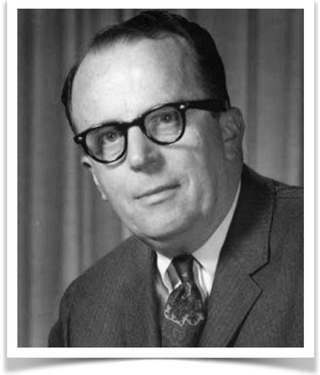
# History of Internet: visions at that time

## Memex

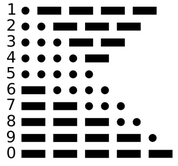
- Vannevar Bush, “As we may think”, 1945
- A hypothetical proto-hypertext system in which individuals would compress and store all of their books, records, and communications

## Galactic network

- J.C.R. Licklider, “Galactic network”, 1962
- Concept of a global network of computers connecting people with data and programs
- First head of DARPA computer research, October 1962

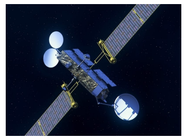


# History of Internet: telephone network




1838: Morse code

1927: first telephone service (US-UK)



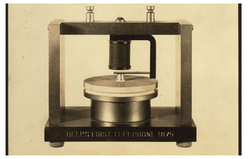
1962: satellite in telecommunications

1981: first commercial cellular network (1G)

2G, 3G, 4G, 5G…

1672: first acoustic telephone

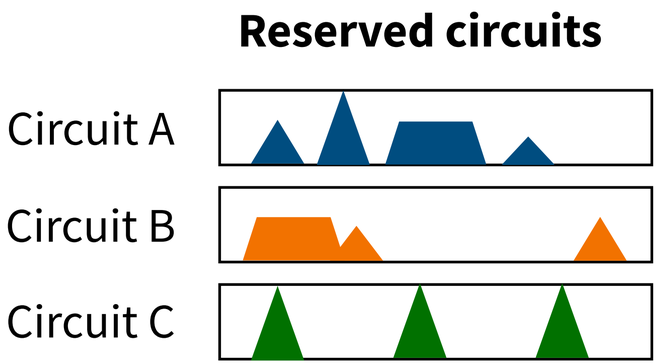
1876: first telephone by Bell

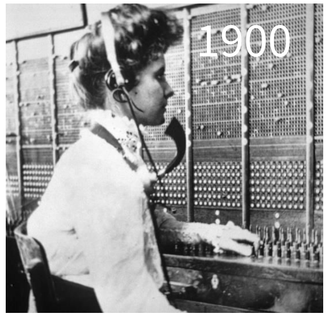


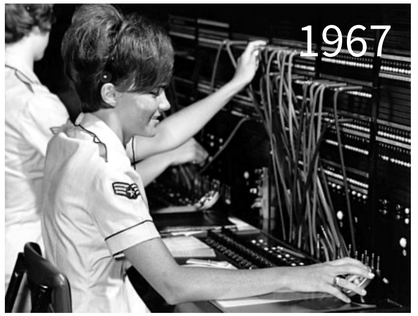
1934: first radio telephone call

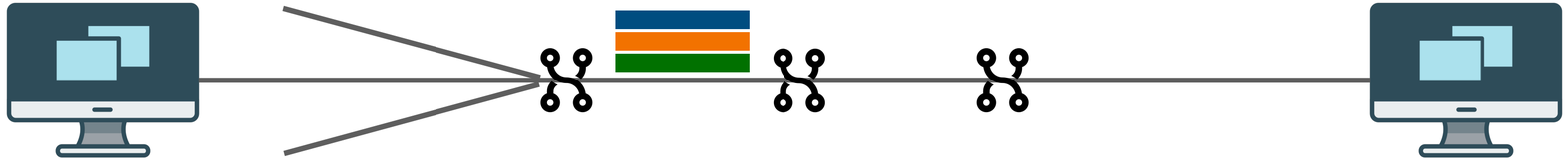
1973: first cellular mobile call

# Circuit switching



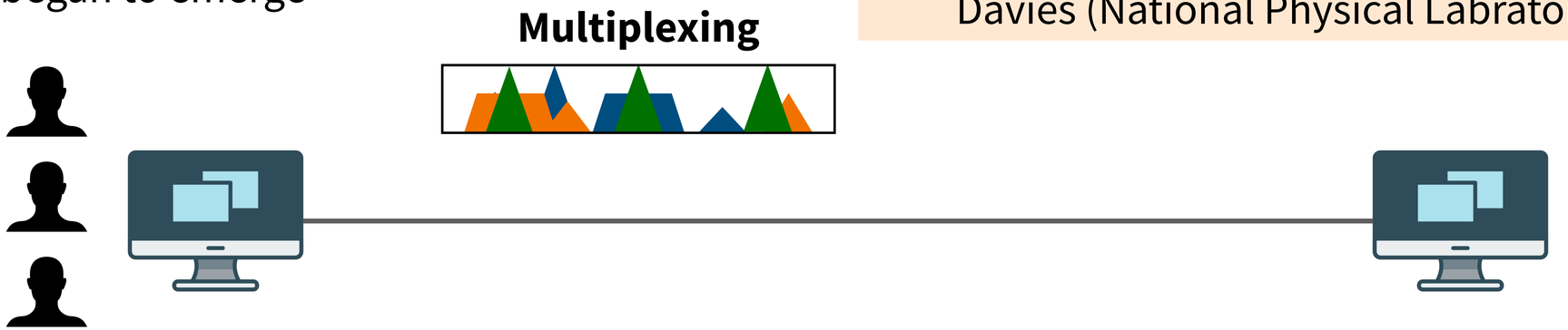
- Physical channel carrying stream of data from source to destination
- Three phases: setup, data transfer, tear-down
- Data transfer involves no routing

# Packet switching

**Leonard Kleinrock:** queueing-theoretic analysis of packet switching in MIT PhD thesis (1961-63) demonstrated value of statistical multiplexing

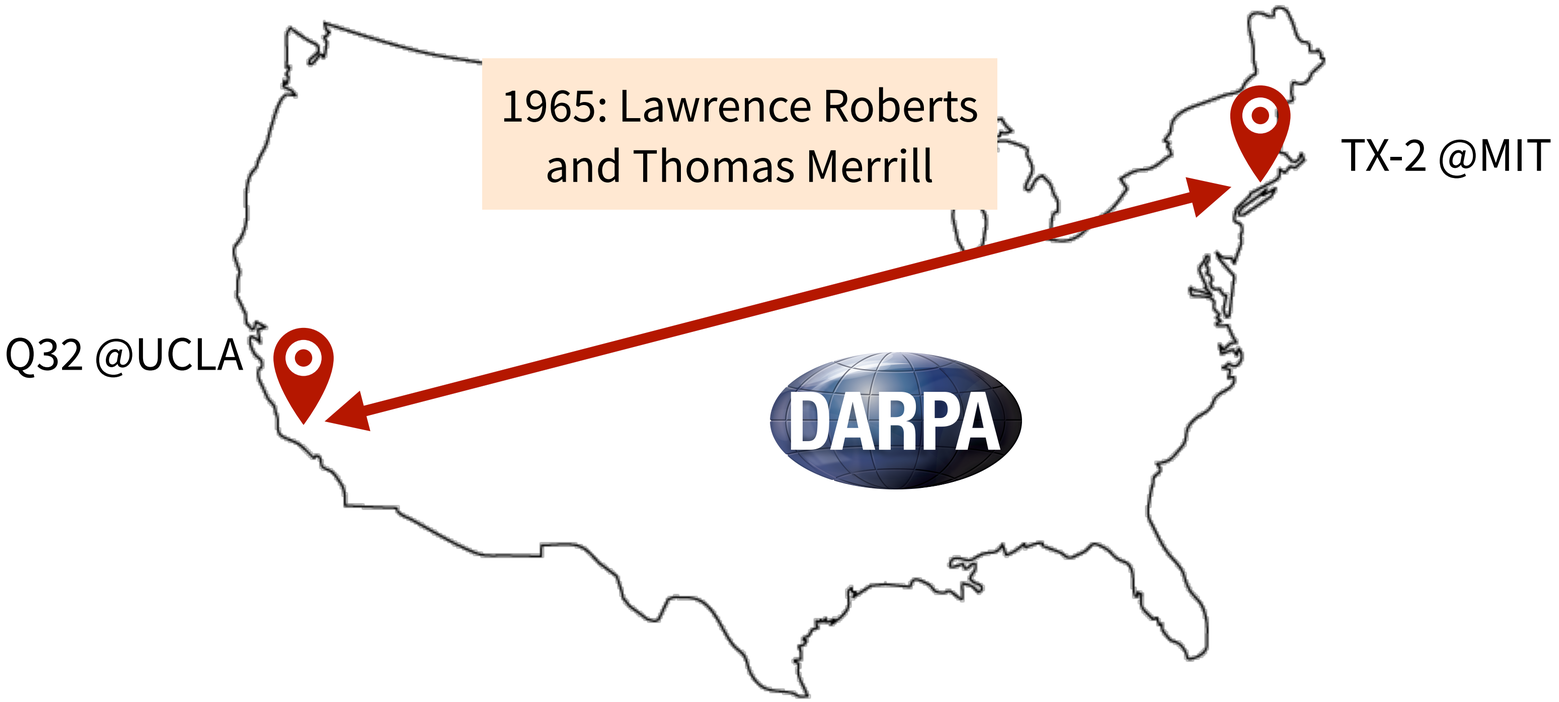
Concurrent work from Paul Baran (RAND), Donald Davies (National Physical Labratories, UK)

1960s: Time-sharing operating systems began to emerge




- Message broken into short packets, each handled separately
- One operation: send packet
- Packets stored/queued in each router, forwarded to appropriate neighbor

# History of Internet: first computer network




Connection is though the telephone line – it works, but it is inefficient and expensive – confirming the motivation for packet switching

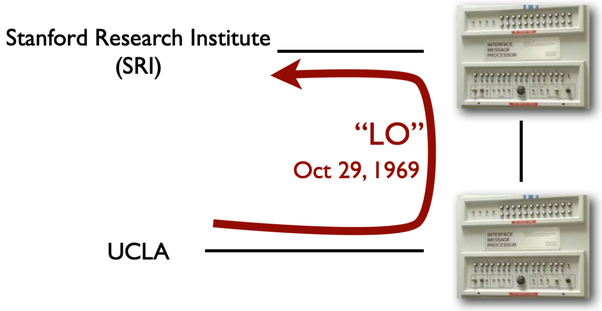
# History of Internet: ARPANET

**1966** Roberts joins DARPA

**1967** Roberts publishes plan for the ARPANET computer network

**1968** Bolt, Beranek, and Newman (BBN) wins bid to build packet switch, the Interface Message Processor (IMP)

**1969** BBN delivers first IMP to Kleinrock's lab at UCLA




**Oct 29, 1969:** ARPANET went live!

The intended message was "login", but the system crashed after "o"

# History of Internet: ARPANET grows

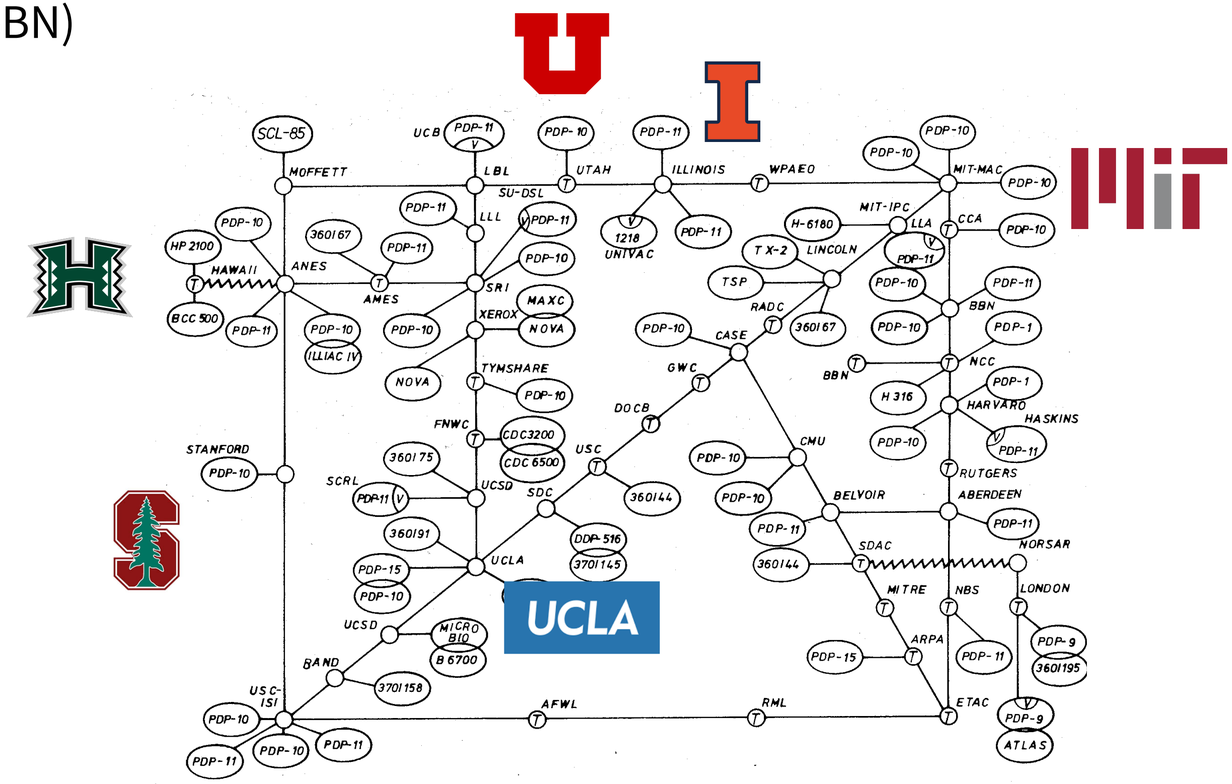
**1970** ARPANET Network Control Protocol (NCP)

**1971** Telnet, FTP

**1972** Email (Ray Tomlinson, BBN)

**1979** USENET

Originally for military computer networking, later expanded for universities

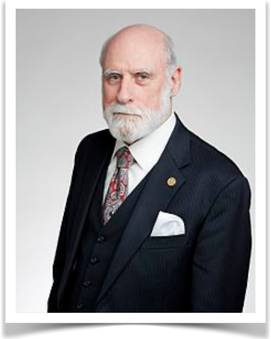



**ALSO GOOD TO KNOW**
ALOHAnet@Hawaii: first public wireless data network (inspiration for Ethernet and WiFi networks)

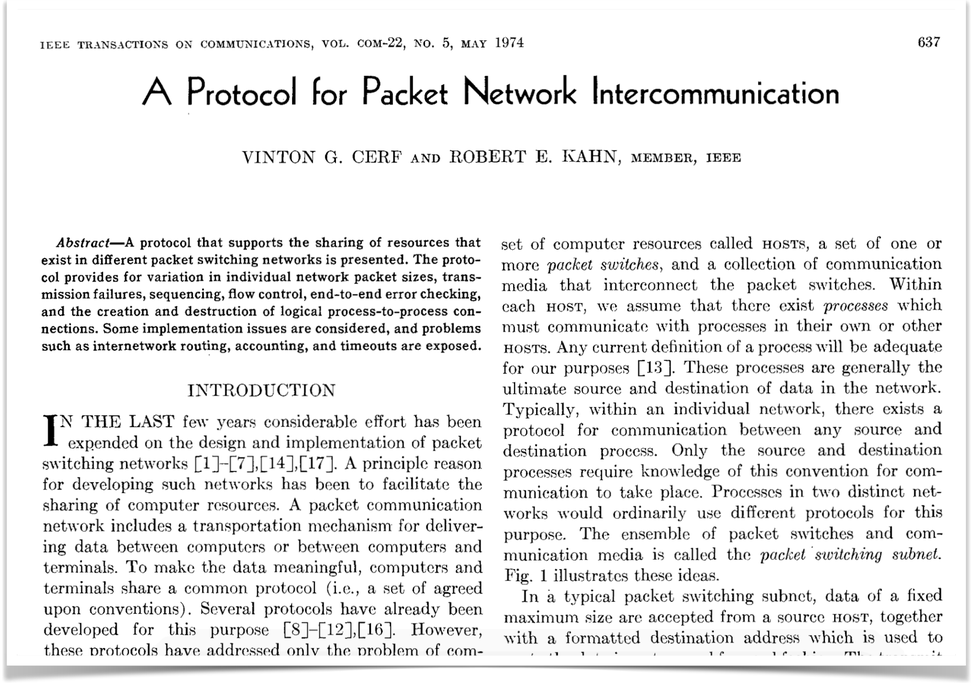
# History of Internet: network of networks

In the mean time of ARPANET

- Other networks, such as PRnet, SATNET developed
- May 1973: Vinton G. Cerf and Robert E. Kahn present first paper on interconnecting networks



Concept of **connecting diverse networks**, unreliable datagrams, global addressing, etc. → became TCP/IP



IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. COM-22, NO. 5, MAY 1974 637

A Protocol for Packet Network Intercommunication

VINTON G. CERF AND ROBERT E. KAHN, MEMBER, IEEE

*Abstract*—A protocol that supports the sharing of resources that exist in different packet switching networks is presented. The protocol provides for variation in individual network packet sizes, transmission failures, sequencing, flow control, end-to-end error checking, and the creation and destruction of logical process-to-process connections. Some implementation issues are considered, and problems such as internetwork routing, accounting, and timeouts are exposed.

INTRODUCTION

IN THE LAST few years considerable effort has been expended on the design and implementation of packet switching networks [1]–[7],[14],[17]. A principle reason for developing such networks has been to facilitate the sharing of computer resources. A packet communication network includes a transportation mechanism for delivering data between computers or between computers and terminals. To make the data meaningful, computers and terminals share a common protocol (i.e., a set of agreed upon conventions). Several protocols have already been developed for this purpose [8]–[12],[16]. However, these protocols have addressed only the problem of com-

set of computer resources called HOSTS, a set of one or more *packet switches*, and a collection of communication media that interconnect the packet switches. Within each HOST, we assume that there exist *processes* which must communicate with processes in their own or other HOSTS. Any current definition of a process will be adequate for our purposes [13]. These processes are generally the ultimate source and destination of data in the network. Typically, within an individual network, there exists a protocol for communication between any source and destination process. Only the source and destination processes require knowledge of this convention for communication to take place. Processes in two distinct networks would ordinarily use different protocols for this purpose. The ensemble of packet switches and communication media is called the *packet switching subnet*. Fig. 1 illustrates these ideas.

In a typical packet switching subnet, data of a fixed maximum size are accepted from a source HOST, together with a formatted destination address which is used to

http://pbg.cs.illinois.edu/courses/cs598fa09/readings/ck74.pdf


I didn't invent
the Internet
I did not
invent the Web

# History of Internet: standards

## TCP/IP: interconnecting networks

- TCP/IP implemented on mainframes by groups at Stanford, BBN, and UCL
- David Clark implements it on Xerox Alto and IBM PC
- 1982: International Organization for Standards (ISO) releases Open Systems Interconnection (OSI) reference model
- Jan 1, 1983: "**flag day**" NCP to TCP/IP transition on ARPANET

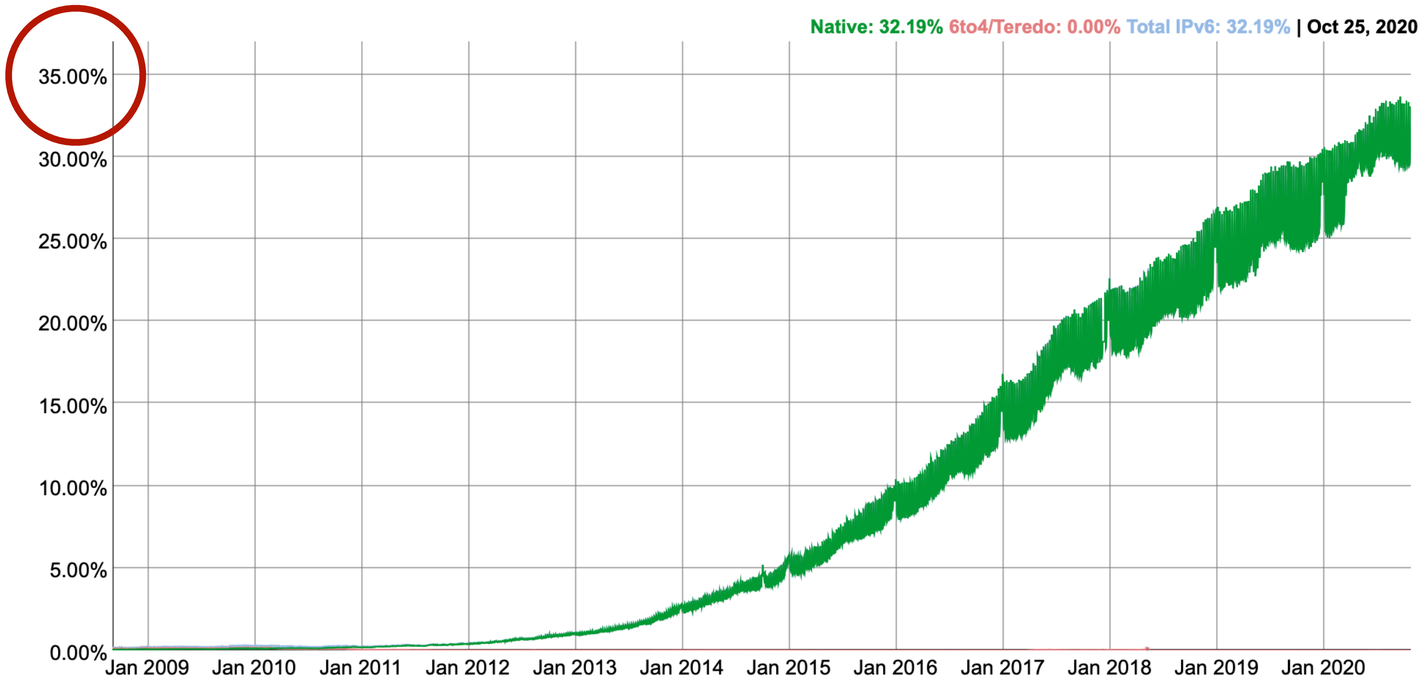
## Ethernet: local area networking

- 1976: R. Metcalfe and D. Boggs
- 1985: Radia Perlman, Spanning Tree Protocol (STP)

Likely what you have learned in the "Computer Networks" course

| OSI | TCP/IP |
|---|---|
| Application | Application |
| Presentation | |
| Session | |
| Transport | Transport |
| Network | Network |
| Data Link | Data Link |
| Physical | Physical |

# Another flag day is almost impossible nowadays




The global IPv4 → IPv6 transition is extremely low…

https://www.google.com/intl/en/ipv6/statistics.html

# History of Internet: fast development

**1980s** Many new networks: CSNET, BITNET, MFENET, SPAN (NASA)…

**1983** DNS developed by Jon Postel, Paul, Mockapetris (USC/ISI), Craig Partridge (BBN)

**1984** Hierarchical routing: EGP, IGP (later to become eBGP and iBGP)

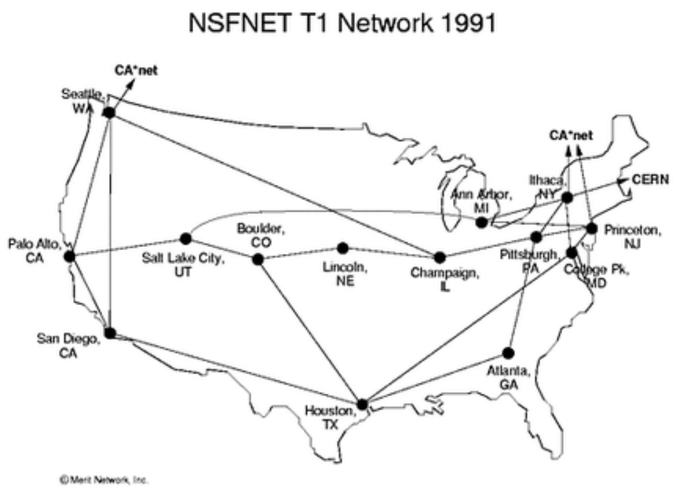
**1984** NSFNET for US higher education

- Serve many users, not just one field
- Encourage development of private infrastructure (e.g., backbone required to be used for research and education)
- Stimulated investment in commercial long-haul network

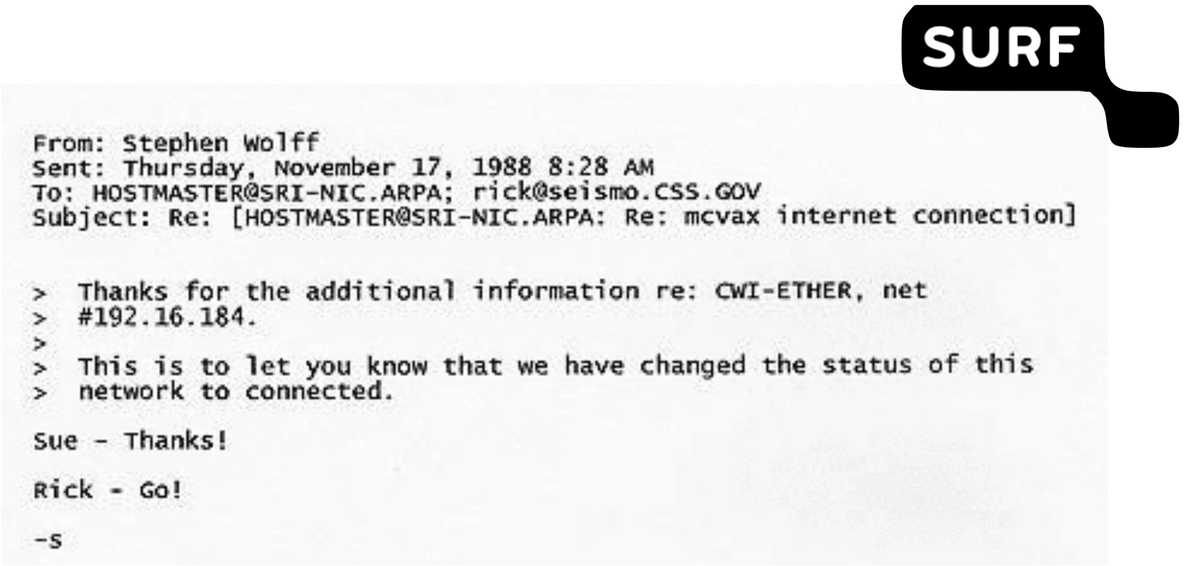
**1988** Morris worm – first computer worm

**1990** ARPANET ends

**1995** NSFNET decommissioned



# Internet in The Netherlands



From: Stephen Wolff
Sent: Thursday, November 17, 1988 8:28 AM
To: HOSTMASTER@SRI-NIC.ARPA; rick@seismo.CSS.GOV
Subject: Re: [HOSTMASTER@SRI-NIC.ARPA: Re: mcvax internet connection]

> Thanks for the additional information re: CWI-ETHER, net
> #192.16.184.
>
> This is to let you know that we have changed the status of this
> network to connected.

Sue - Thanks!

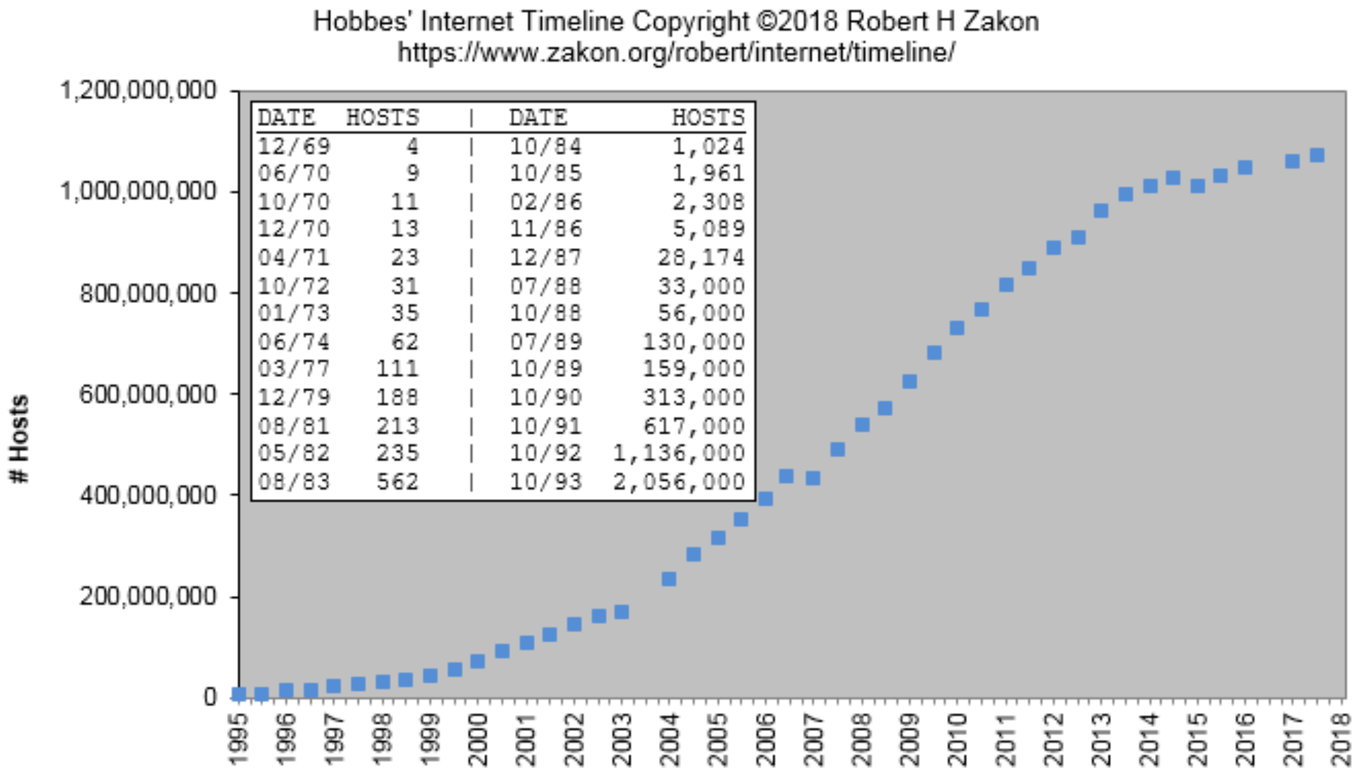
Rick - Go!

-s

First email via the first transatlantic connection (Nov 17, 1988)

Piet Beertema (CWI): https://godfatherof.nl

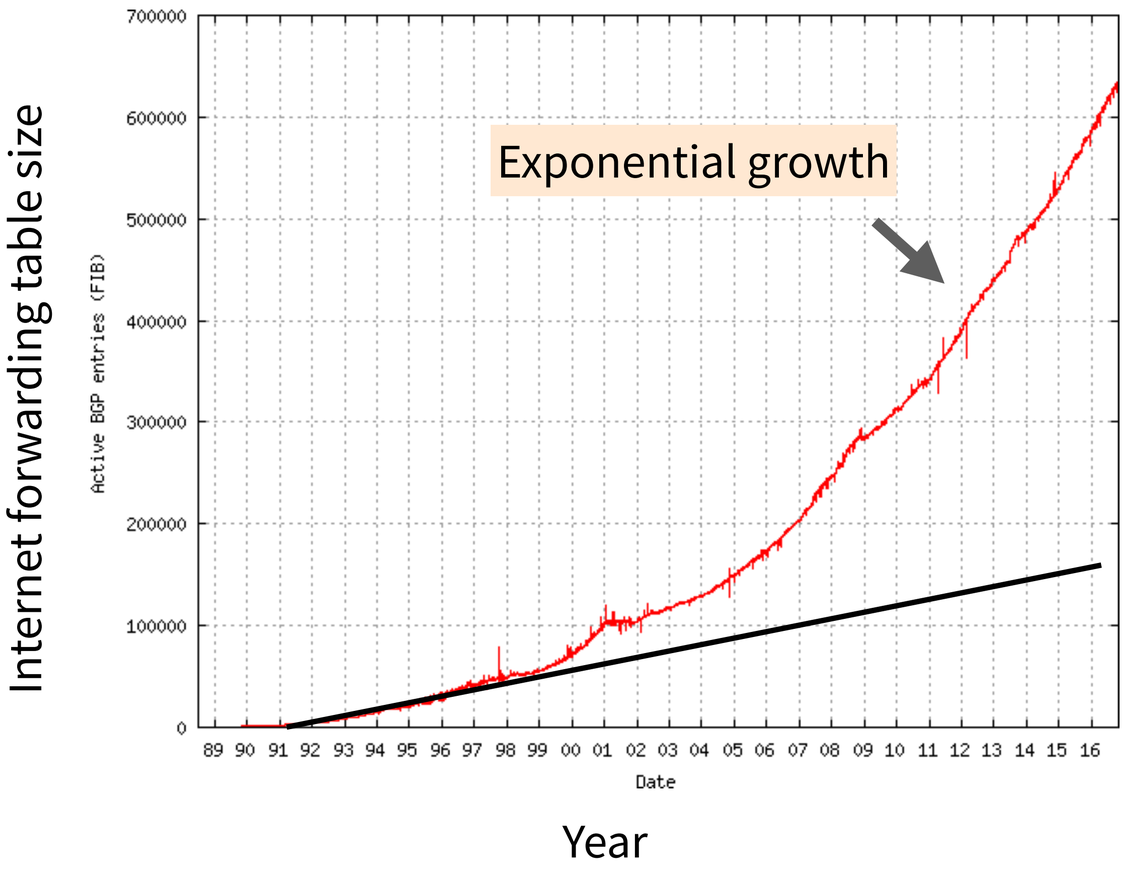
# Internet growth: #hosts




| DATE | HOSTS | DATE | HOSTS |
|---|---|---|---|
| 12/69 | 4 | 10/84 | 1,024 |
| 06/70 | 9 | 10/85 | 1,961 |
| 10/70 | 11 | 02/86 | 2,308 |
| 12/70 | 13 | 11/86 | 5,089 |
| 04/71 | 23 | 12/87 | 28,174 |
| 10/72 | 31 | 07/88 | 33,000 |
| 01/73 | 35 | 10/88 | 56,000 |
| 06/74 | 62 | 07/89 | 130,000 |
| 03/77 | 111 | 10/89 | 159,000 |
| 12/79 | 188 | 10/90 | 313,000 |
| 08/81 | 213 | 10/91 | 617,000 |
| 05/82 | 235 | 10/92 | 1,136,000 |
| 08/83 | 562 | 10/93 | 2,056,000 |

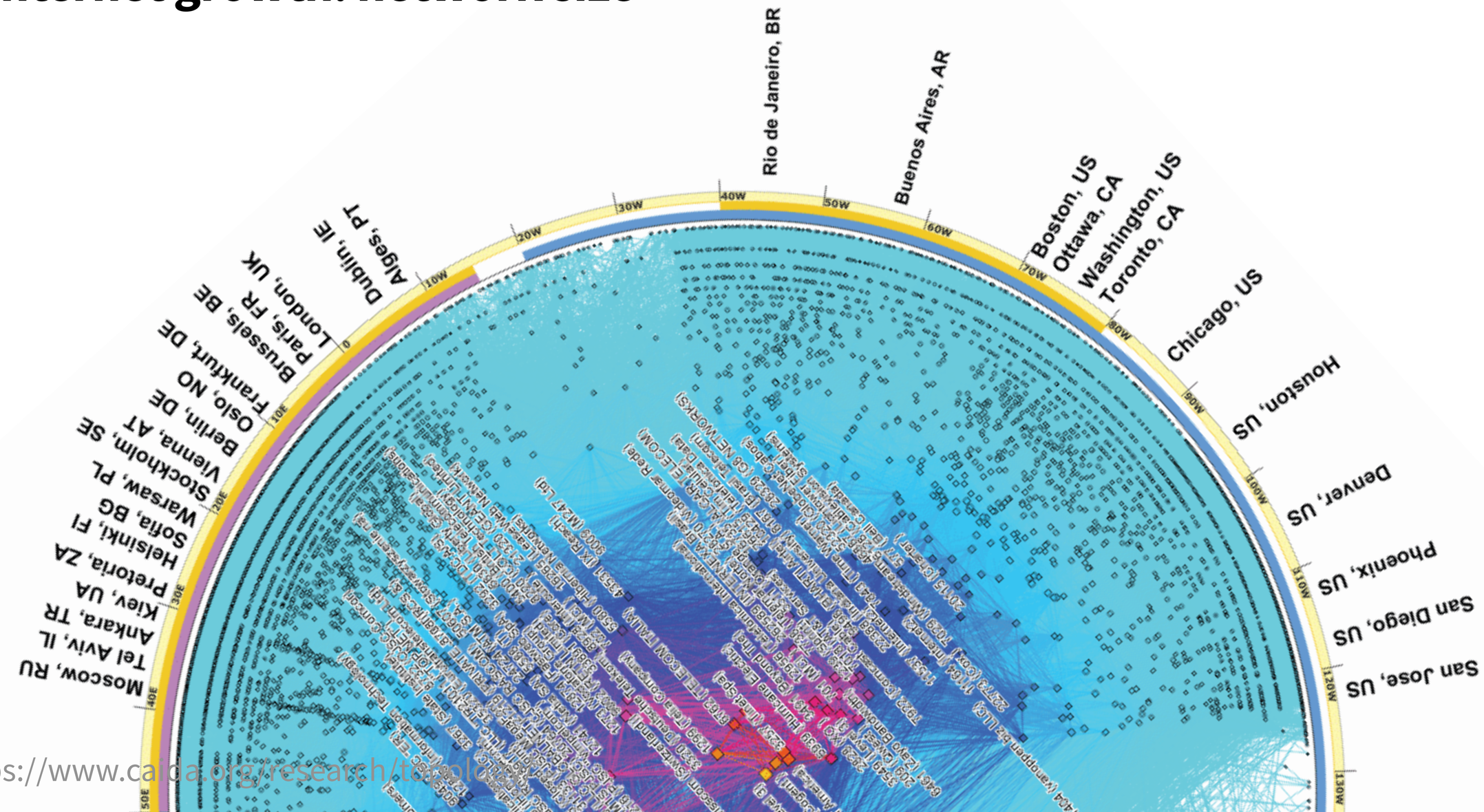
https://www.zakon.org/robert/internet/timeline/

# Internet growth: size of forwarding table




https://www.redpill-linpro.com/sysadvent/2016/12/09/slimming-routing-table.html

# Internet growth: network size




https://www.caida.org/research/topology/

# Internet growth: devices and applications

**Devices**

65 million times as many devices
Link speeds 200,000x faster
NATs and firewalls
Wireless everywhere
Mobile everywhere
Tiny devices (smartphone, smartwatches)
Giant devices (data centers)

**Applications**

Morris Internet Worm (1988)
World wide web (1989)
MOSAIC browser (1992)
Search engines: Google
Peer-to-peer
Video streaming
Social networking
Video conferencing

# Questions?

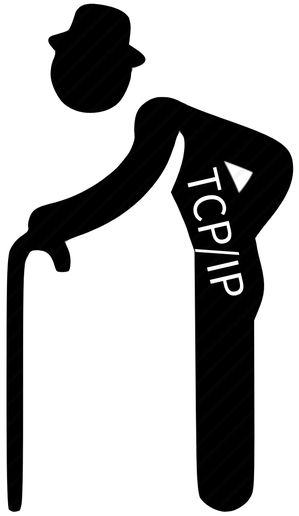
# Internet: current status

## Internet is there for more than 50 years

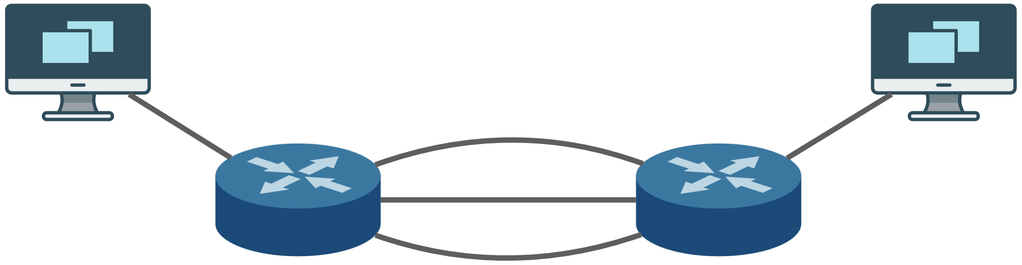
- Networks keep growing and more applications are developed
- TCP/IP is the norm: to program a network application, you simply use the socket APIs

## So, the network will keep growing with the same set of technologies?

- There are many new developments
- This course is to reveal the state-of-the-art of computer networking

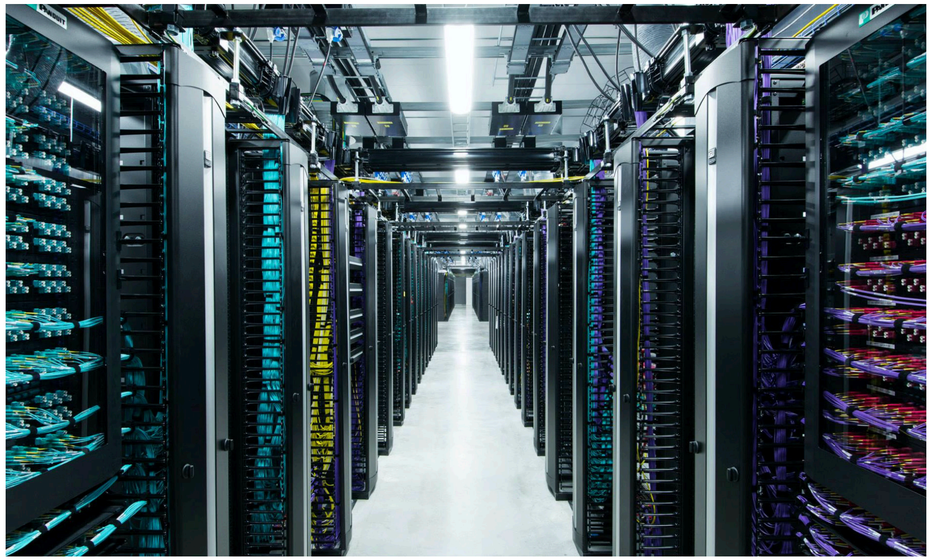


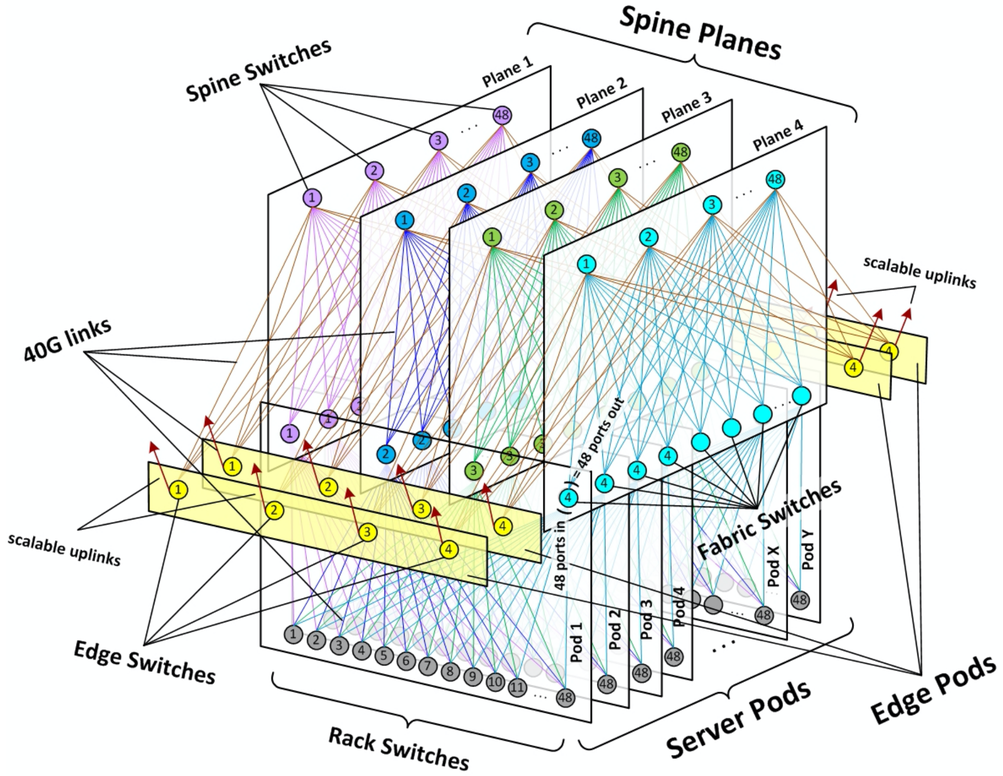
# Innovation in network protocols



Multipath TCP, BBR/PCC congestion control, QUIC

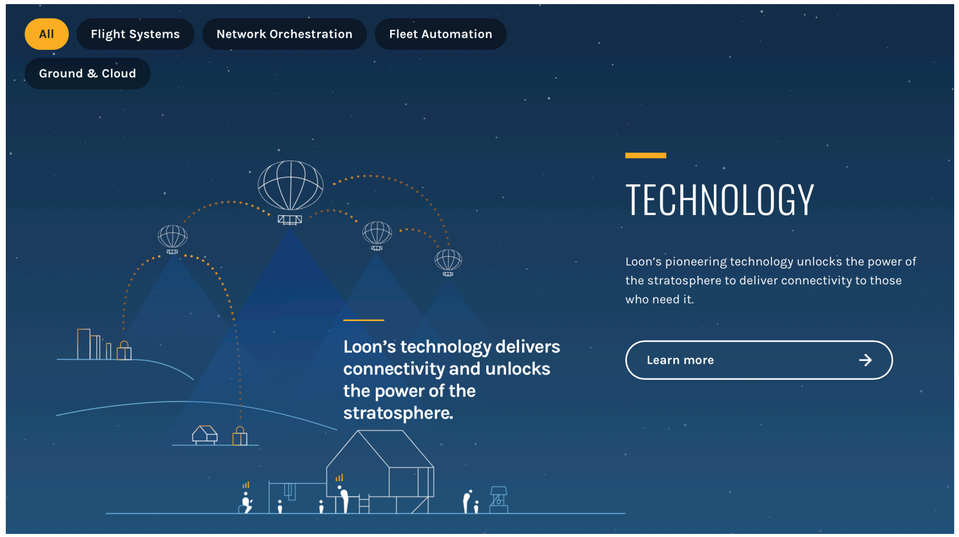
# Innovations in network design



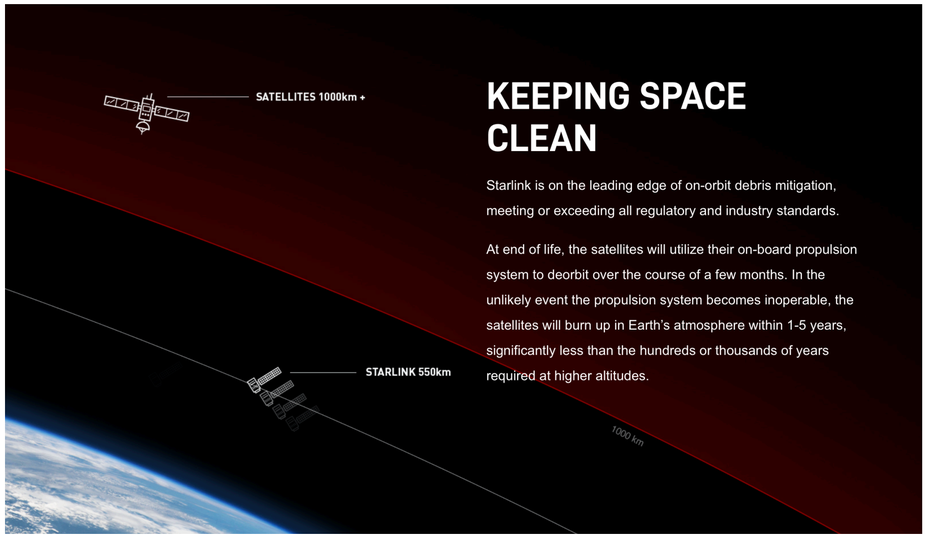



https://engineering.fb.com/production-engineering/introducing-data-center-fabric-the-next-generation-facebook-data-center-network/

# Innovations in network design

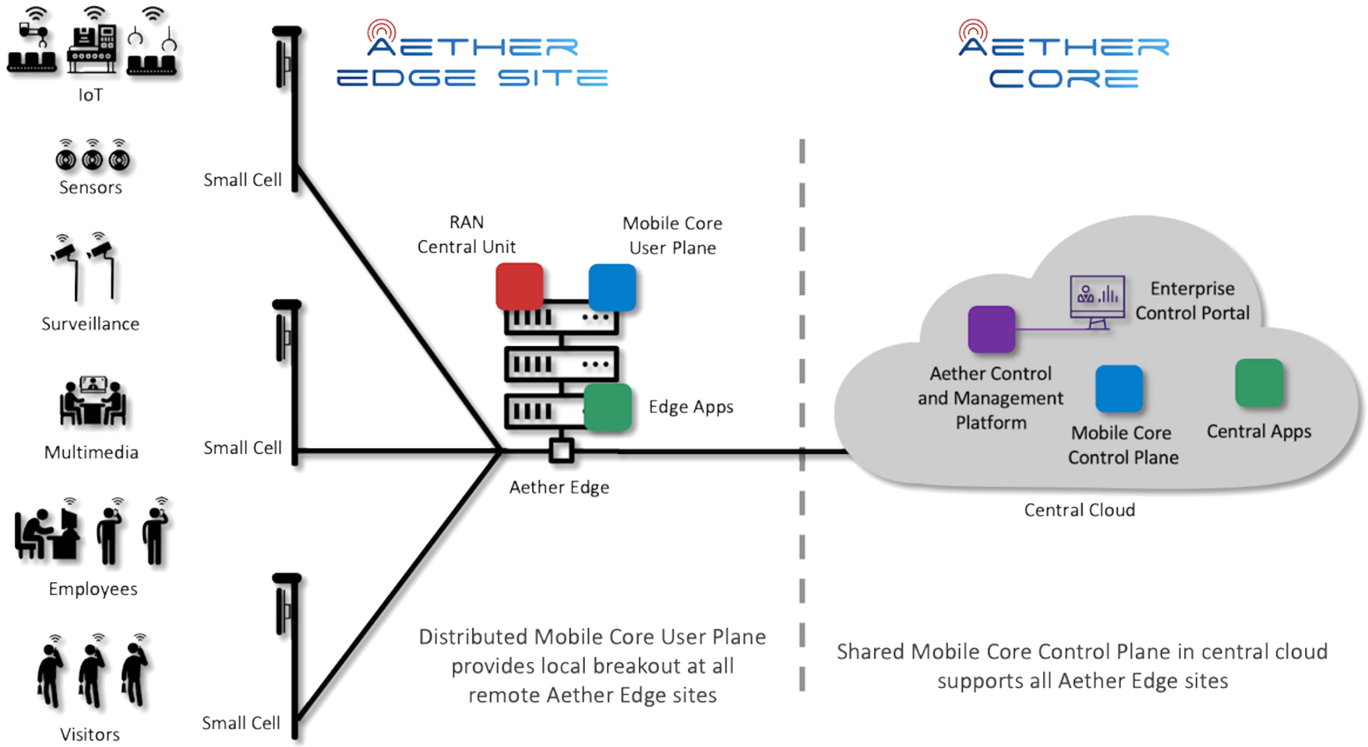


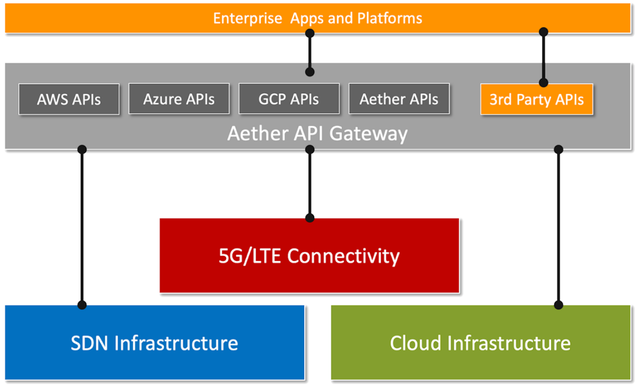

https://loon.com




https://www.starlink.com

# Innovations in network architectures




https://www.opennetworking.org/aether/

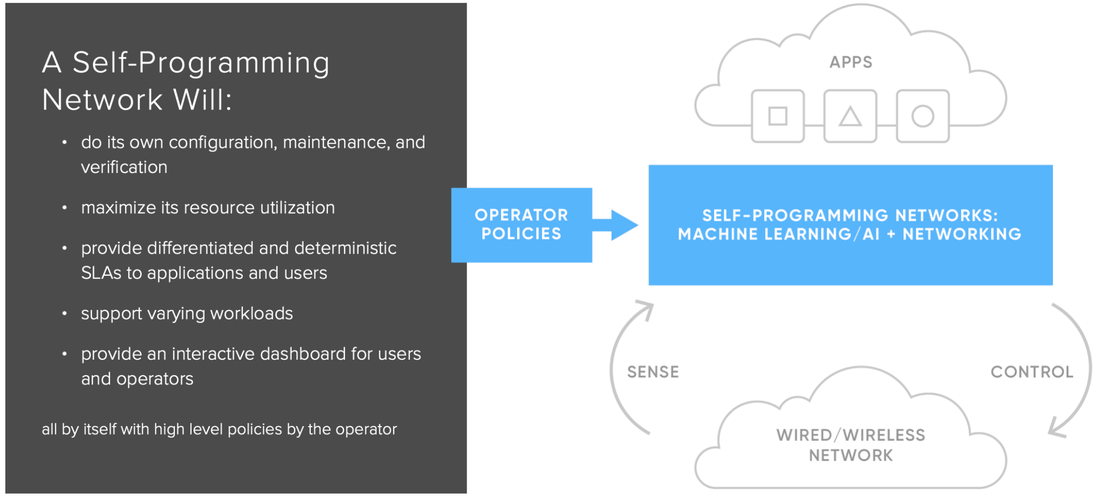
# Innovations in networked applications

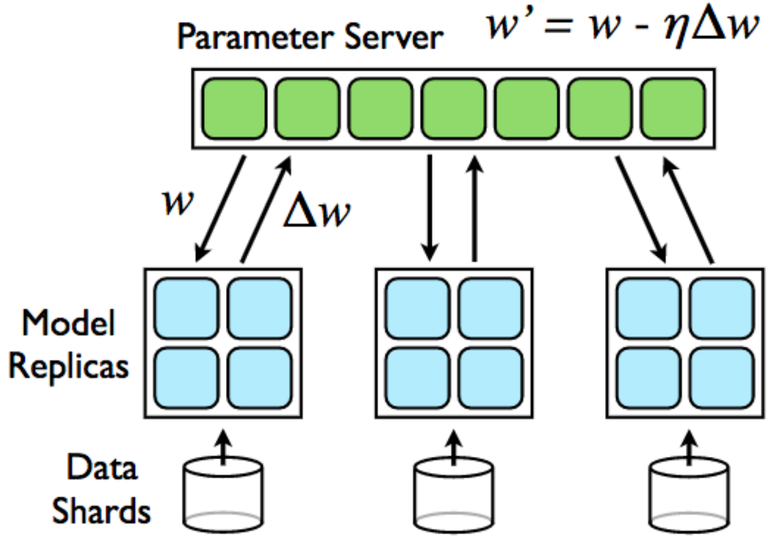

Video streaming


Mobile AR

# When ML meets networking

Imagine a network that can program itself
based on high level policies of its operator



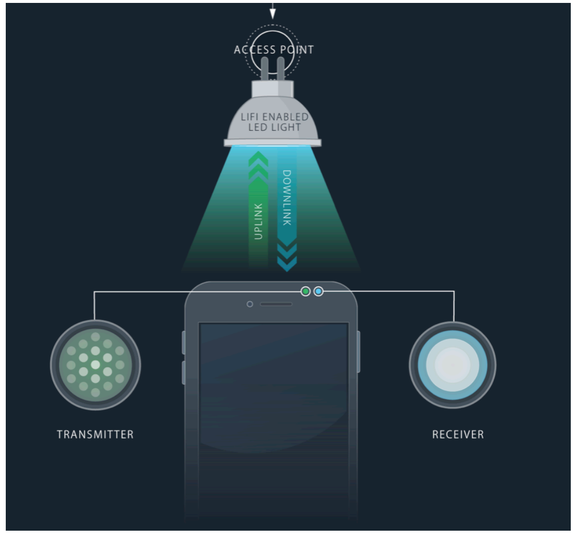




ML training with Parameter Server

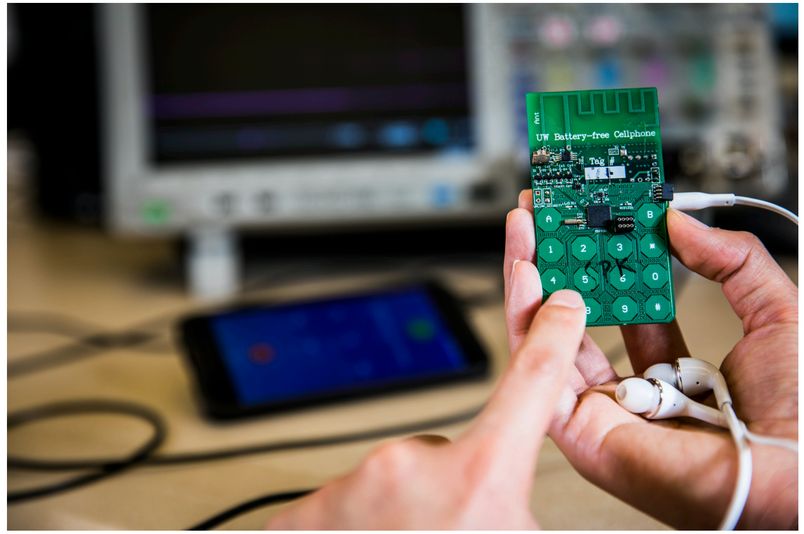
https://platformlab.stanford.edu/platform-self-programming-networks.php

# Innovations in wireless/mobile networking

https://www.media.mit.edu/projects/oceans/overview/



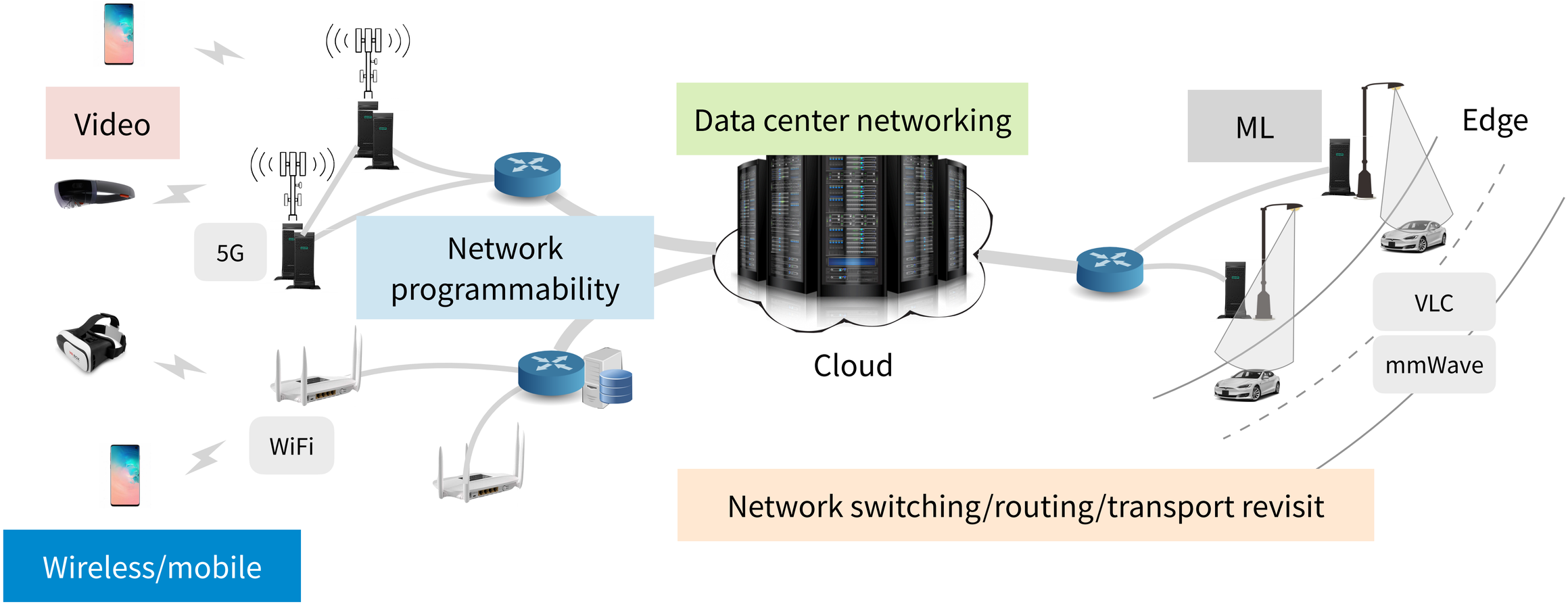





https://purelifi.com/lifi-technology/

https://batteryfreephone.cs.washington.edu

# Course coverage



# Course structure

**Introduction** (Internet history, course logistics and structure)

**Fundamentals** (design principles and useful data structures)

**Forwarding and routing** (L2 forwarding, L3 routing, end-host networking)

**Network transport** (congestion control, multi-path, QUIC)

**Data center networking** (architectures, flow scheduling)

**Data center transport** (congestion control, RDMA)

**Software defined networking** (network control/management, SDN architecture, applications)

**Programable forwarding** (data plane programmability, P4, applications)

# Course structure

| | |
|---|---|
| **Video streaming** (encoding, protocols, ABR, DASH) | **Video stream analytics** (architectures, protocols, applications) |
| **Networking for ML** (machine learning training, inference) | **ML for networking** (packet classification, streaming) |
| **Wireless and Mobile** (backscatter communication, battery-free networking) | **Reserved** (guest lecture or course summary) |
| Exam | Bonus project deadline |

# Next time: networking fundamentals