The Internet

Miguel Rio

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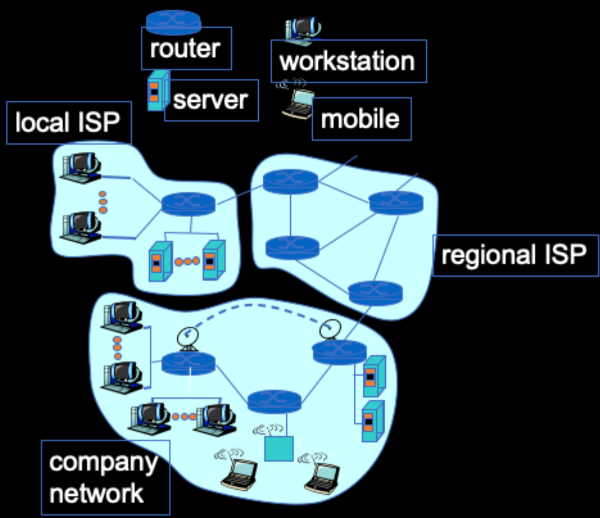
Outline

- History
- Internet design principles
- Future applications
- Examples of Networks

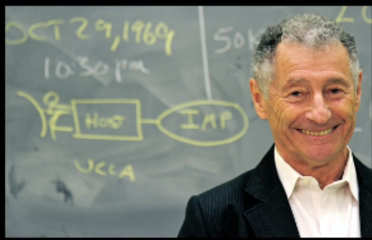
What is the Internet ?

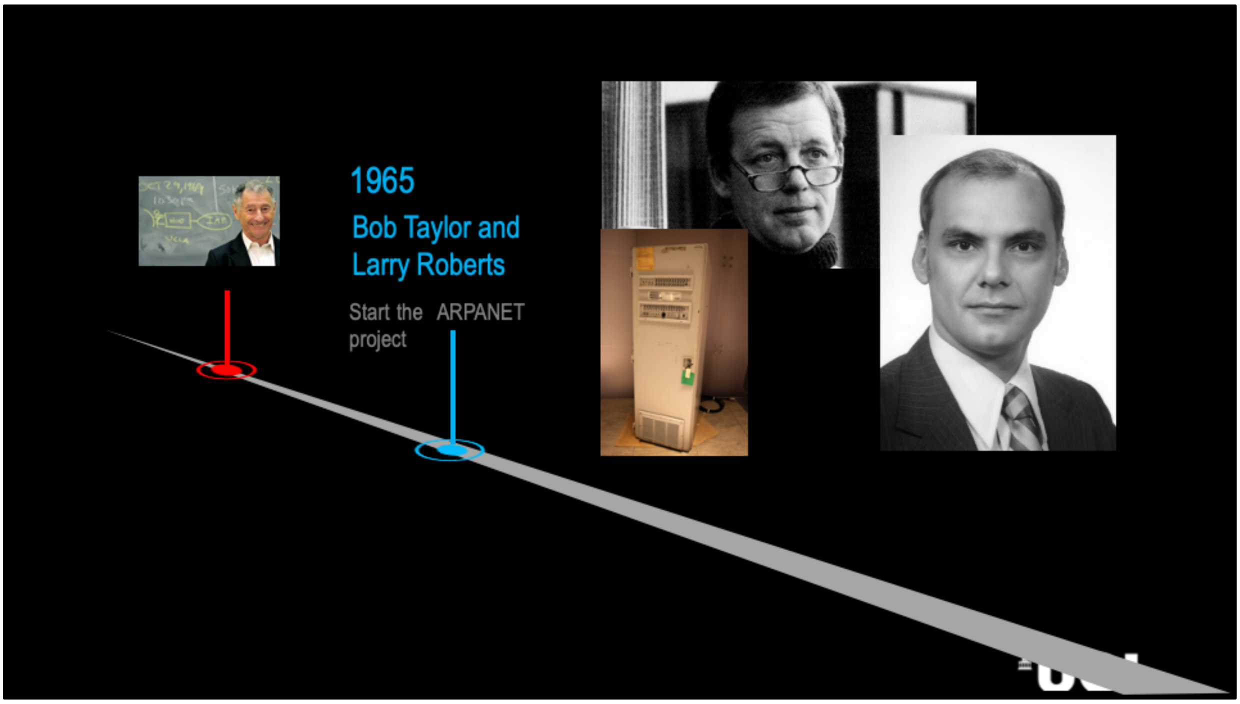
- Millions of connected computing devices: hosts, end-systems
  - PCs, workstations, servers
  - smartphones, toasters, things
  - running network apps
- communication links
  - fiber, copper, radio, satellite
  - transmission rate = bandwidth
- routers: forward packets (chunks of data)

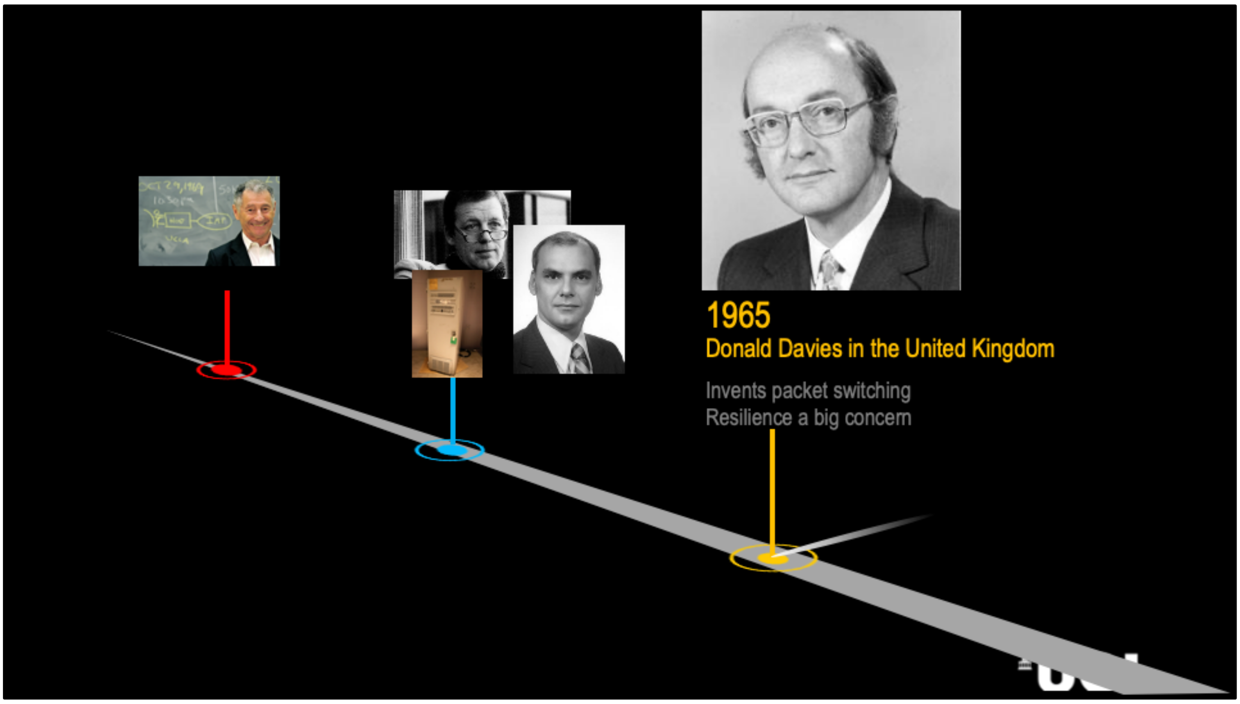


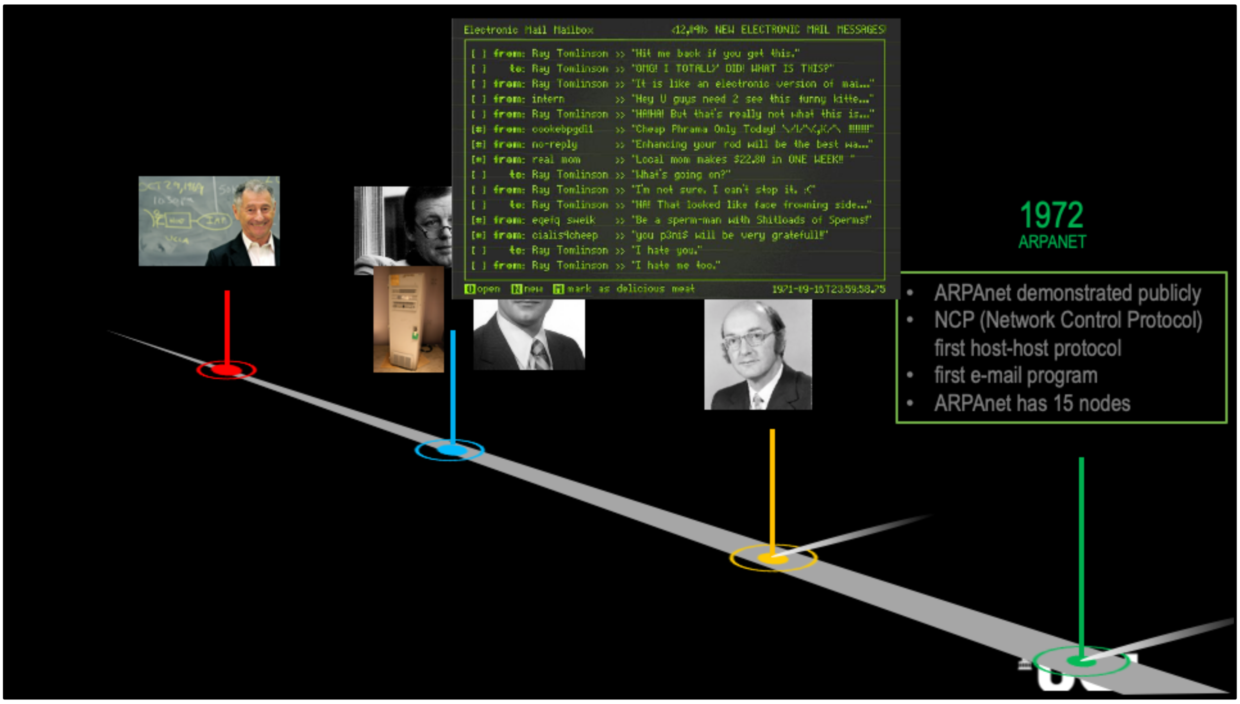
History

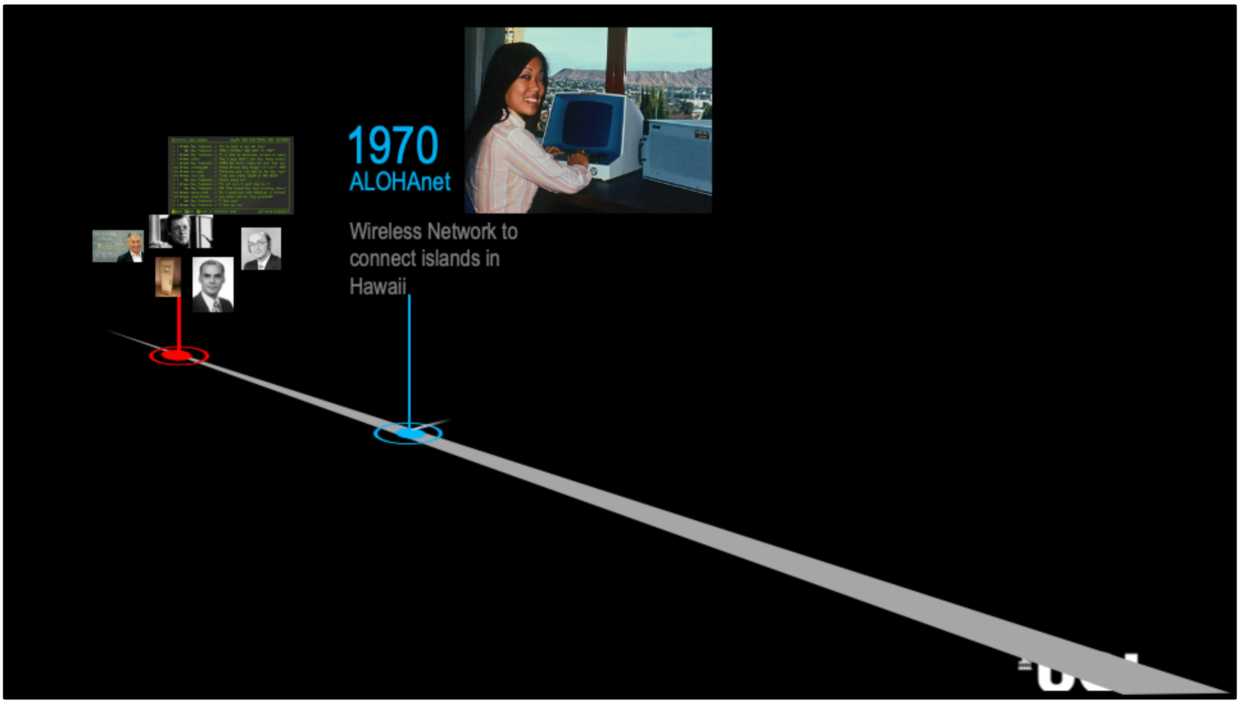
1961
Queuing Theory
Work By Leonard Kleinrock
Starts the theoretical foundations of packet switching, a fundamental concept for the Internet

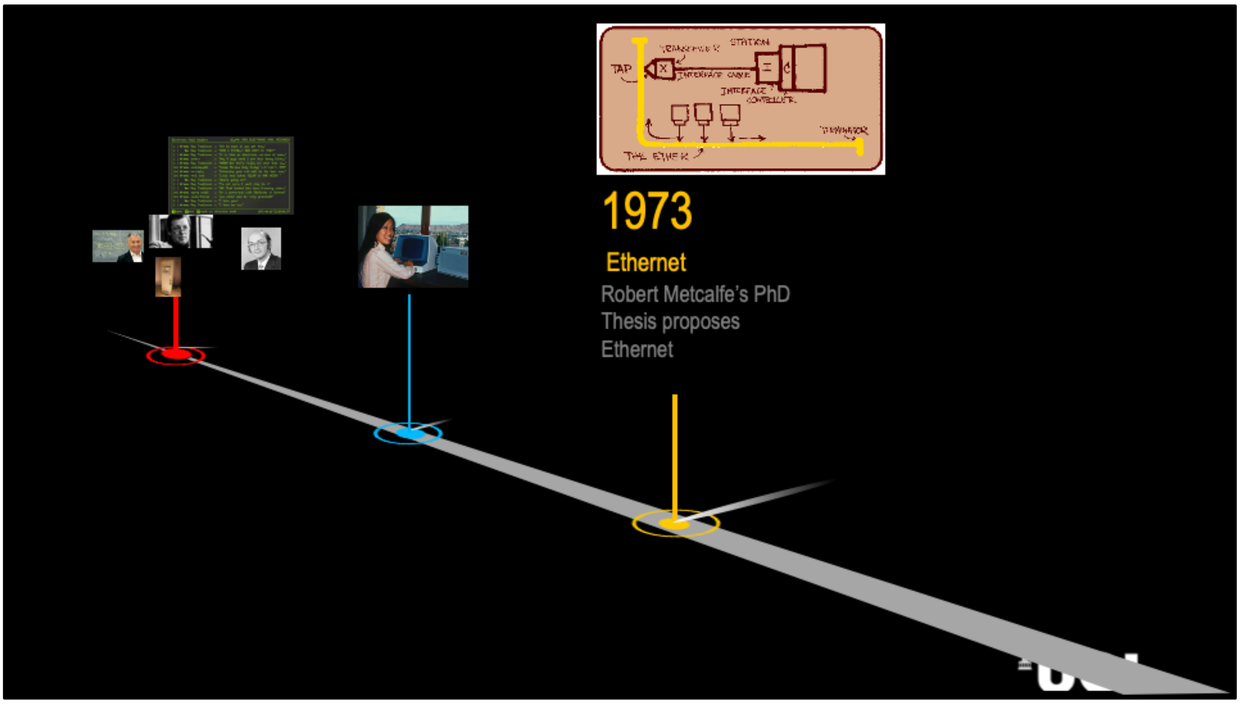



1965
Bob Taylor and
Larry Roberts
Start the ARPANET
project

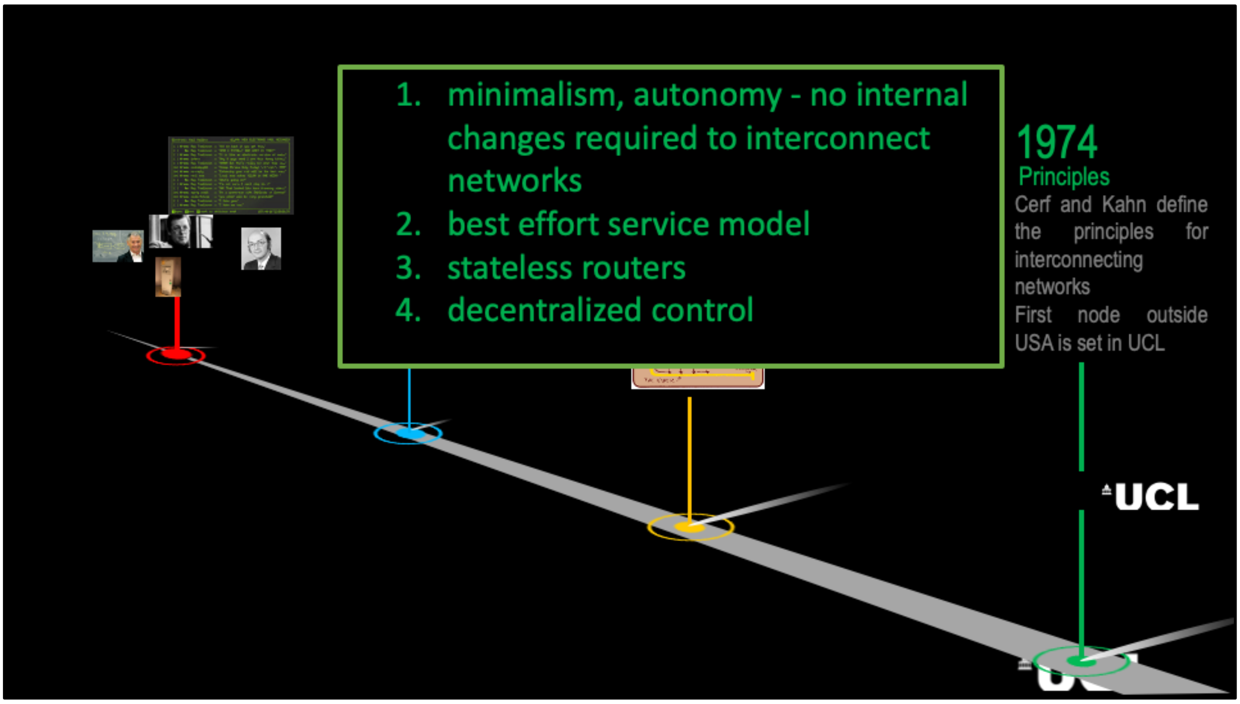

1965
Donald Davies in the United Kingdom
Invents packet switching
Resilience a big concern


1972
ARPANET
ARPAnet demonstrated publicly
NCP (Network Control Protocol)
first host-host protocol
first e-mail program
ARPAnet has 15 nodes

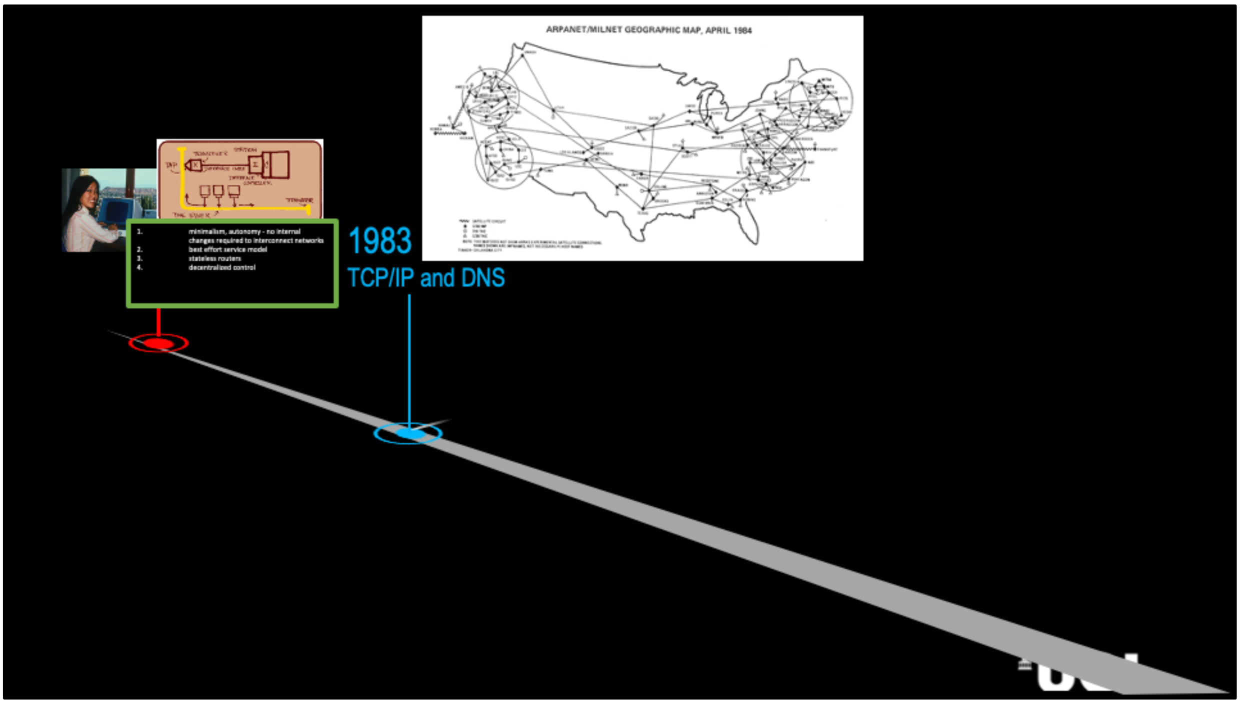

1970
ALOHAnet
Wireless Network to
connect islands in
Hawaii

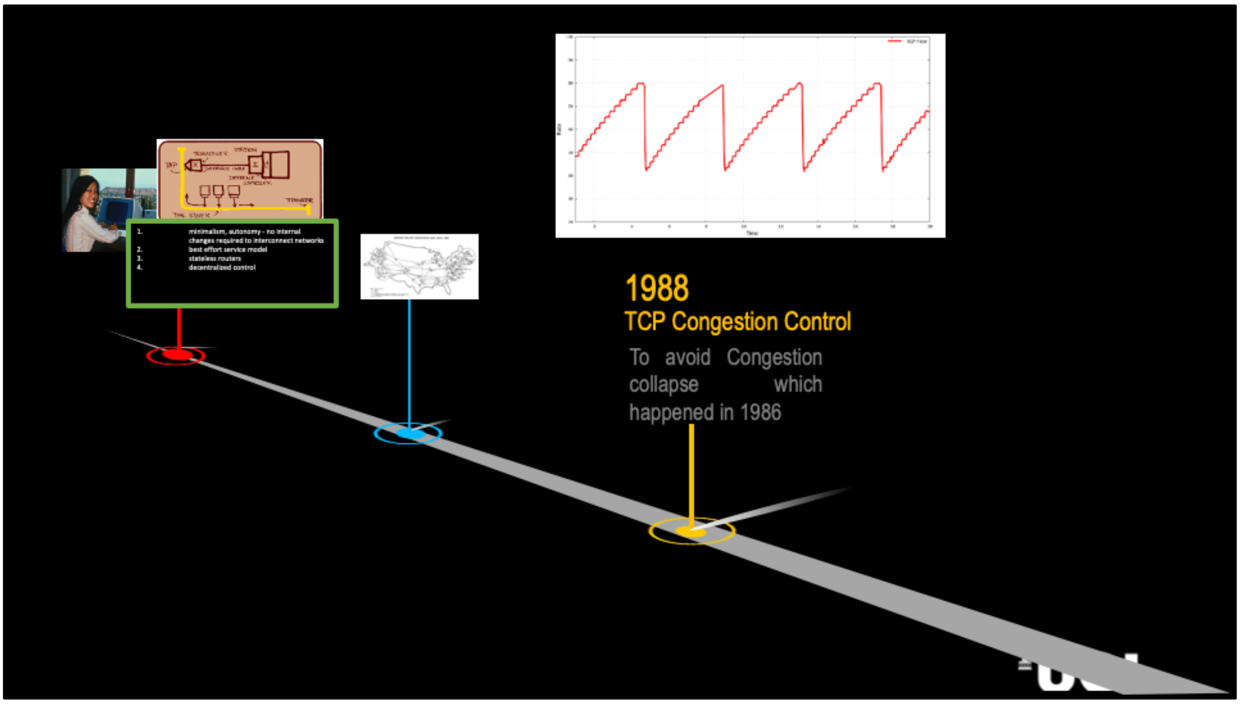


1973: Metcalfe's PhD thesis proposes Ethernet



1974: Cerf and Kahn - architecture for interconnecting networks
1974 - First node outside the USA in UCL


ARPANET/MILNET GEOGRAPHIC MAP, APRIL 1984
1. minimalism, autonomy - no internal changes required to interconnect networks
2. best effort service model
3. stateless routers
4. decentralized control
1983
TCP/IP and DNS



1. minimalism, autonomy - no internal changes required to interconnect networks
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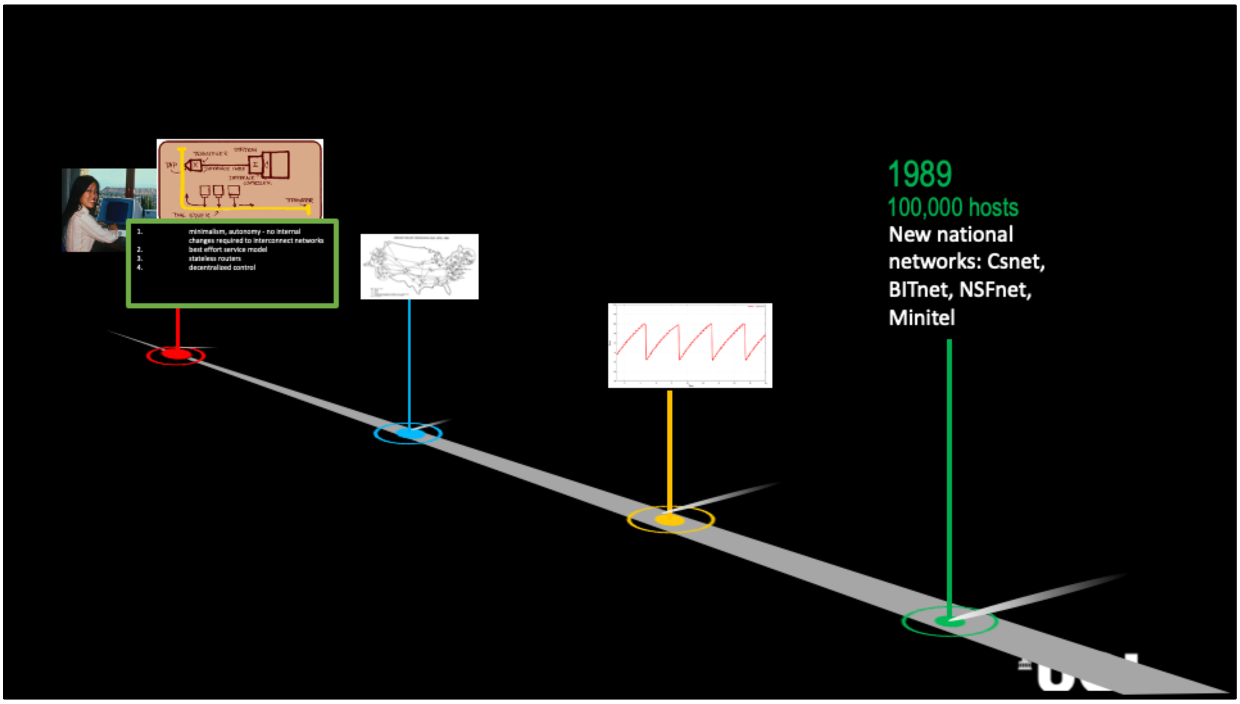
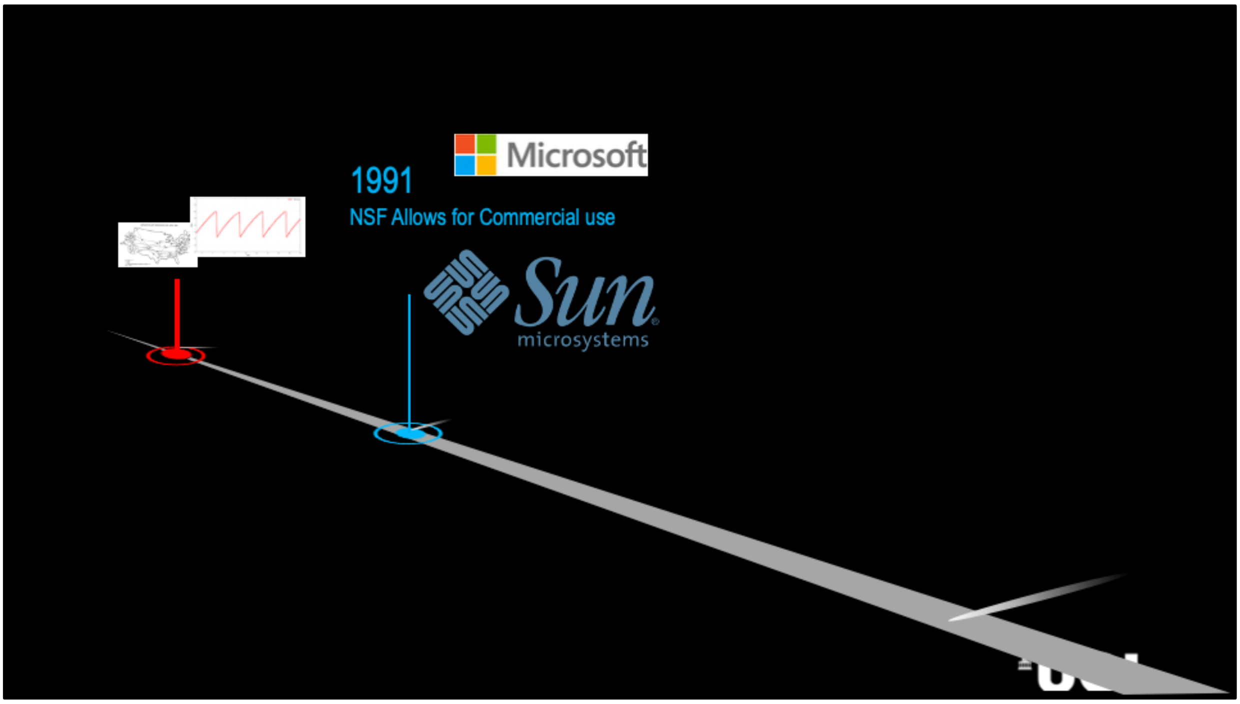
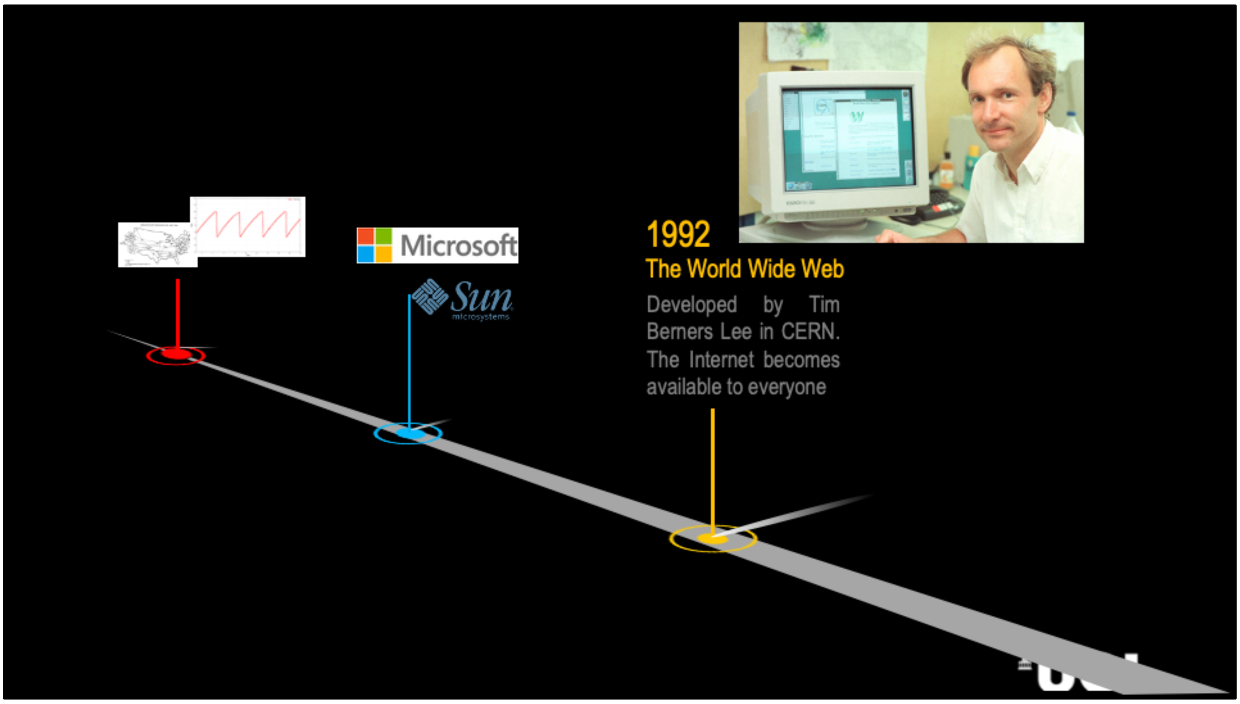
1988
TCP Congestion Control
To avoid Congestion collapse which happened in 1986

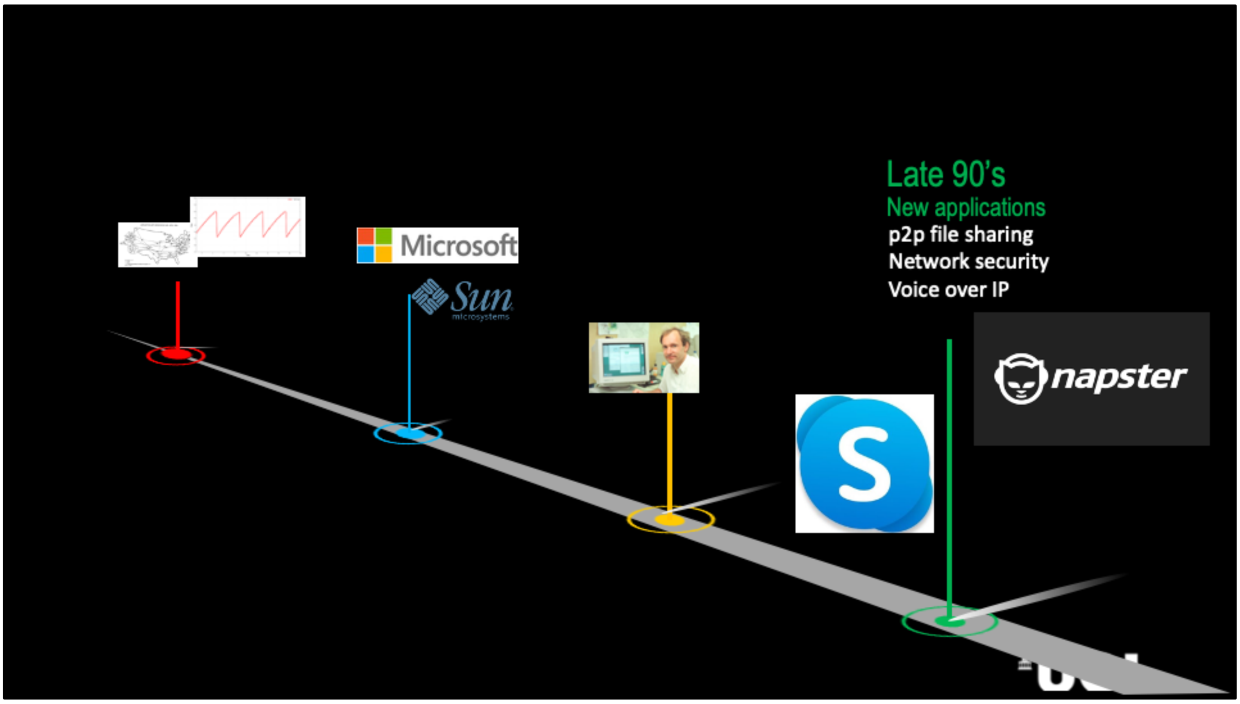

1. minimalism, autonomy - no internal changes required to interconnect networks
2. best effort service model
3. stateless routers
4. decentralized control
1989
100,000 hosts
New national networks: Csnet, BITnet, NSFnet, Minitel



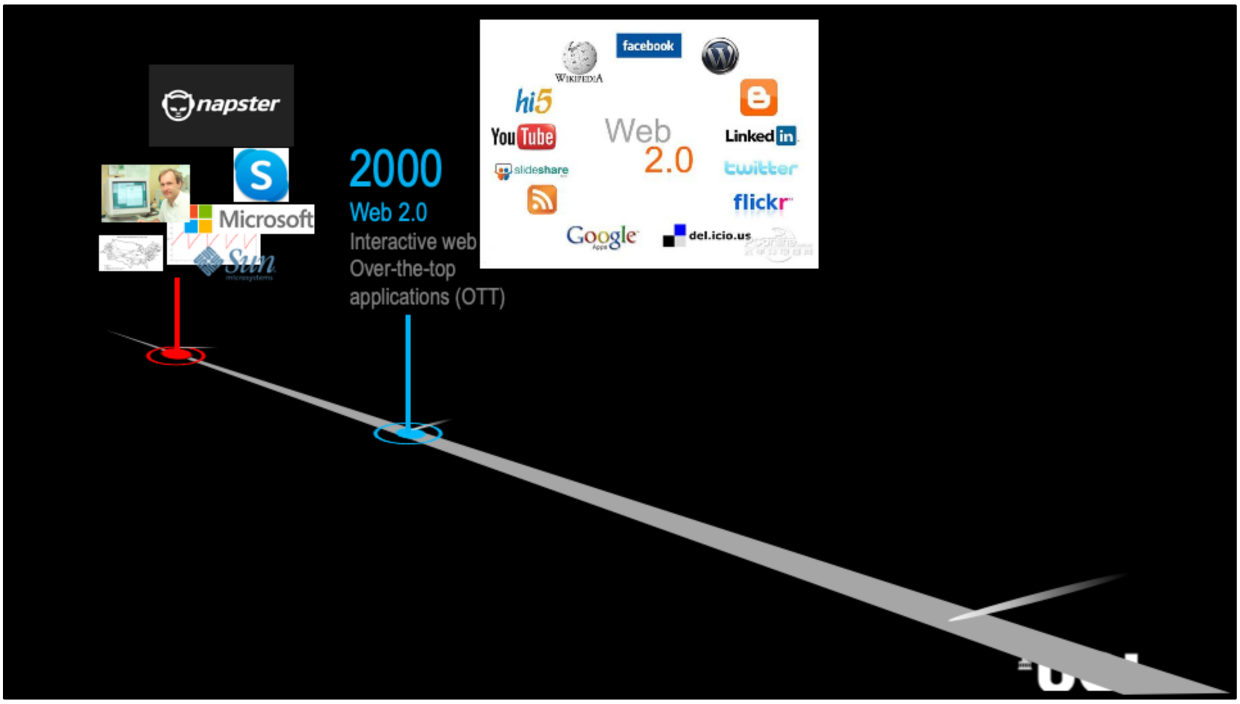
1991: NSF Allows commercial use



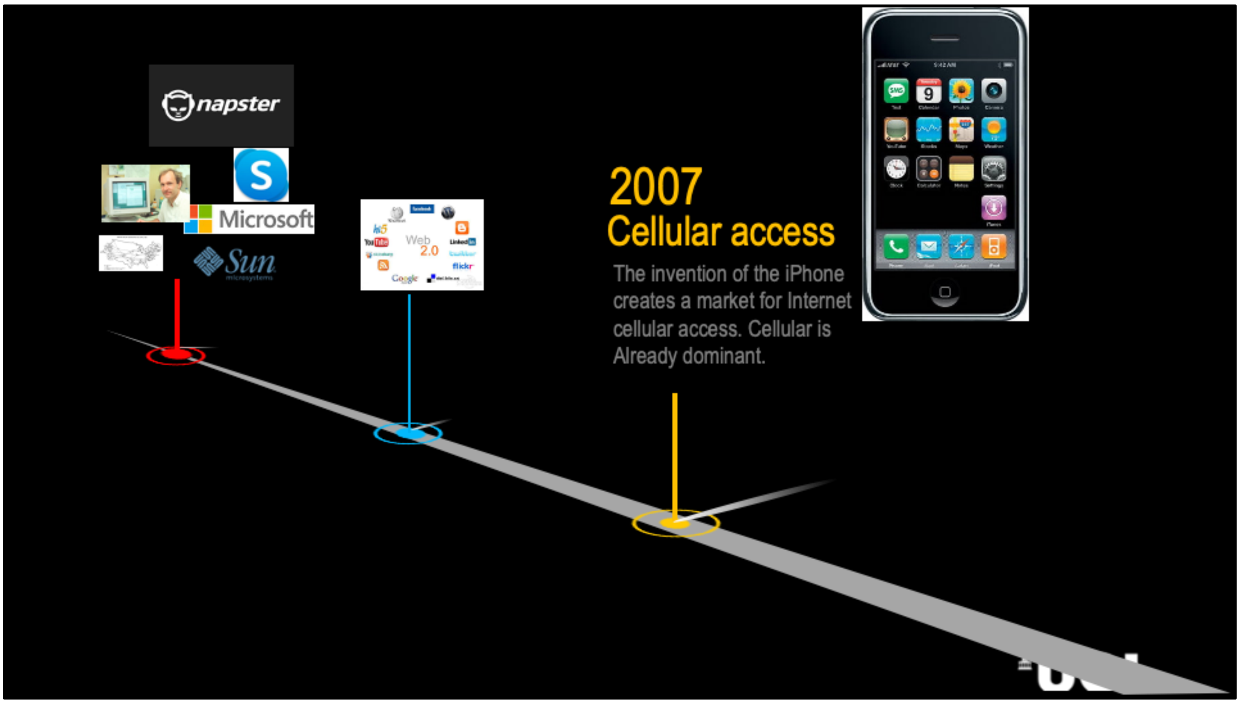
1993: The Word wide Web



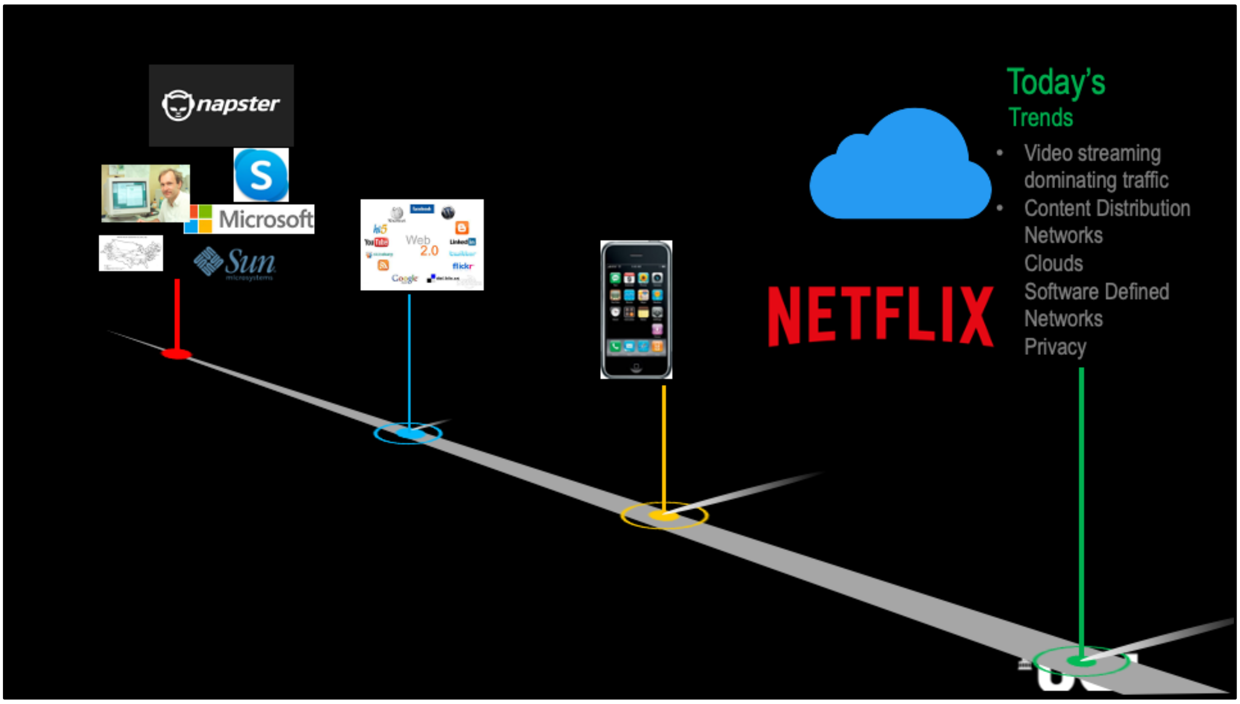
Late 90's|: P2P file sharing
Network Security
Voice over IP



2000's: javascript, interactive web
Over the Top Applications (OTT)



From 2007:Cellular Access. already dominant



Video streaming dominating the percentage of traffic
Content Distribution Networks (CDNs)
Clouds
Software Defined Networks
Privacy

Internet Access Statistics

WORLD INTERNET USAGE AND POPULATION STATISTICS 2020 Year-Q2 Estimates						
World Regions	Population (2020 Est.)	Population % of World	Internet Users 30 June 2020	Penetration Rate (% Pop.)	Growth 2000-2020	Internet World %
Africa	1,340,598,447	17.2 %	566,138,772	42.2 %	12,441 %	11.7 %
Asia	4,294,516,659	55.1 %	2,525,033,874	58.8 %	2,109 %	52.2 %
Europe	834,995,197	10.7 %	727,848,547	87.2 %	592 %	15.1 %
Latin America / Caribbean	654,287,232	8.4 %	467,817,332	71.5 %	2,489 %	9.7 %
Middle East	260,991,690	3.3 %	184,856,813	70.8 %	5,527 %	3.8 %
North America	368,869,647	4.7 %	332,908,868	90.3 %	208 %	6.9 %
Oceania / Australia	42,690,838	0.5 %	28,917,600	67.7 %	279 %	0.6 %
WORLD TOTAL	7,796,949,710	100.0 %	4,833,521,806	62.0 %	1,239 %	100.0 %

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

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Design Principles

Internet design philosophy

- End-to-end argument: Important functions (error control, encryption, delivery acknowledgement, etc) should be implemented by the end systems
- Fate Sharing: If one puts functionality in the end system, then that functionality only breaks if the end system breaks which would make the communication useless anyway.

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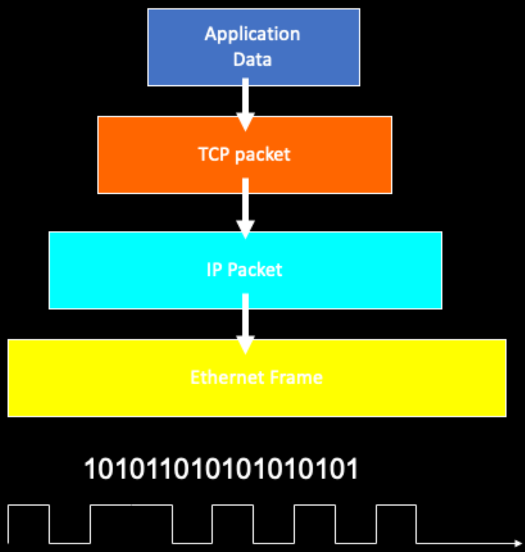
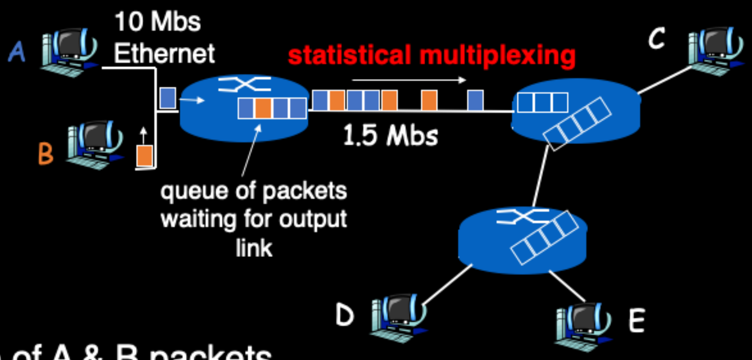
Russian Dolls

We are going to have lots of packets inside packets…for example:

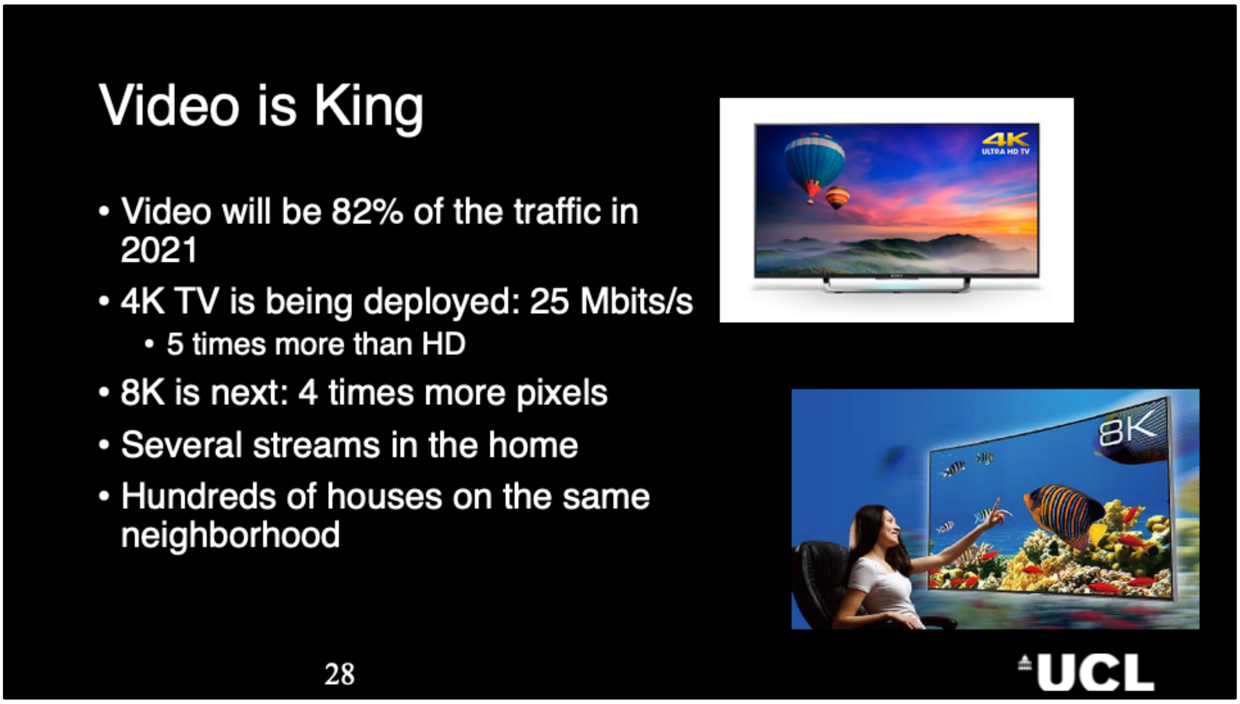


Packet Switching: Statistical Multiplexing



- Sequence of A & B packets does not have fixed pattern statistical multiplexing.

Future Applications



Percentage of traffic of video
HD->4K->8K->multi-user->multi-homes

Virtual Reality

- Revolution in Healthcare, Education and Entertainment
- Interactivity will demand very short latency ≈10ms

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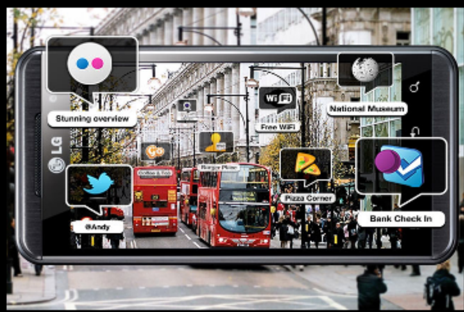
Augmented reality

- Image processing for precise superimposition
- Delay is even more crucial



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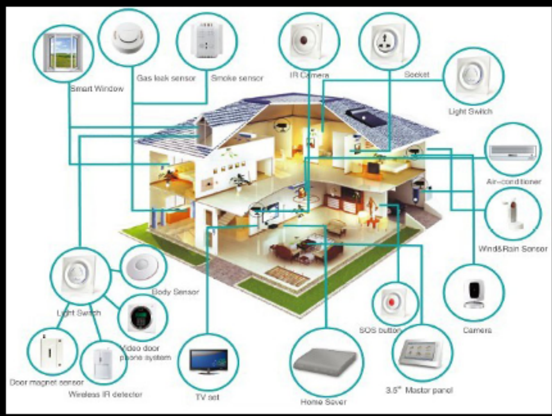
Holograms

- 3 orders of magnitude more data
- Interactivity
- Use cases in Education, Health, Entertainment
- Telepresence

The Smart Home

- Hundreds of data sensors, microphones, actuators
- Holograms/Virtual Reality for telepresence
- Privacy concern



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http://smarthomeenergy.co.uk/what-smart-home

You come out of the house; Mention need for extended vision; 10 million deliveries in London

Smart cities

- Vast majority of people will live in cities
- Thousands of applications
  - Environment
  - Transport
  - Retail
  - Logistics
  - Water and Electricity

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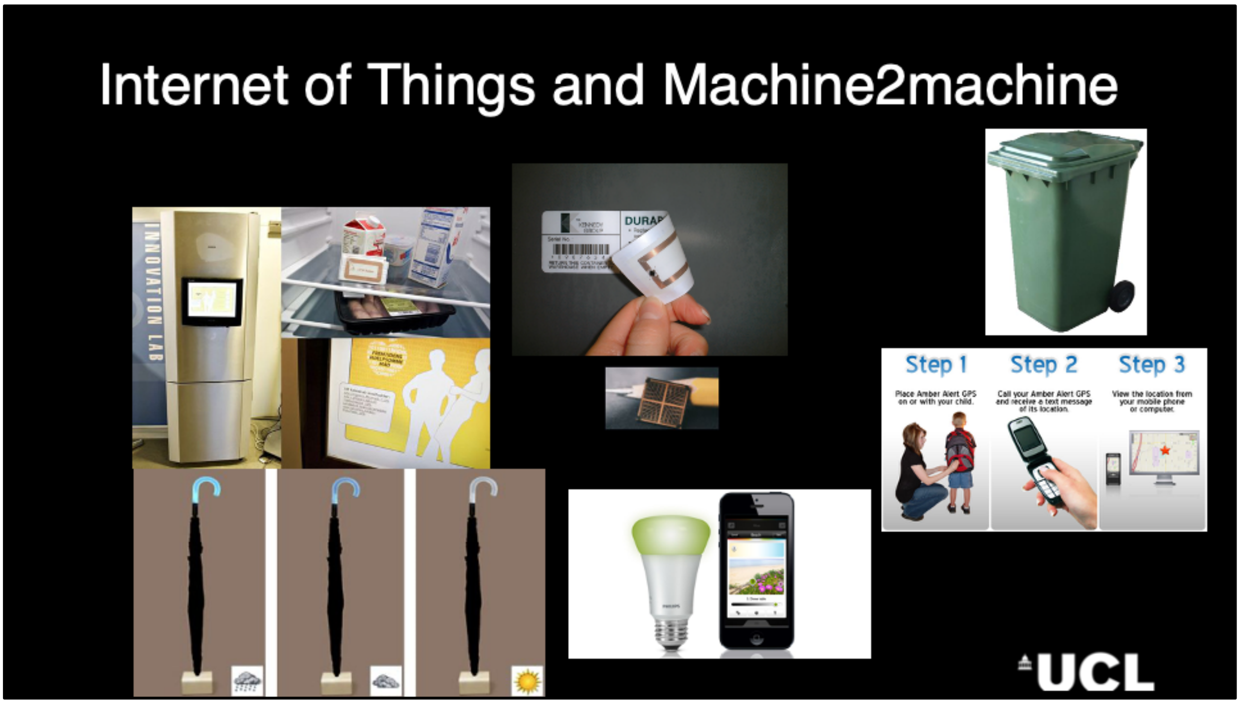
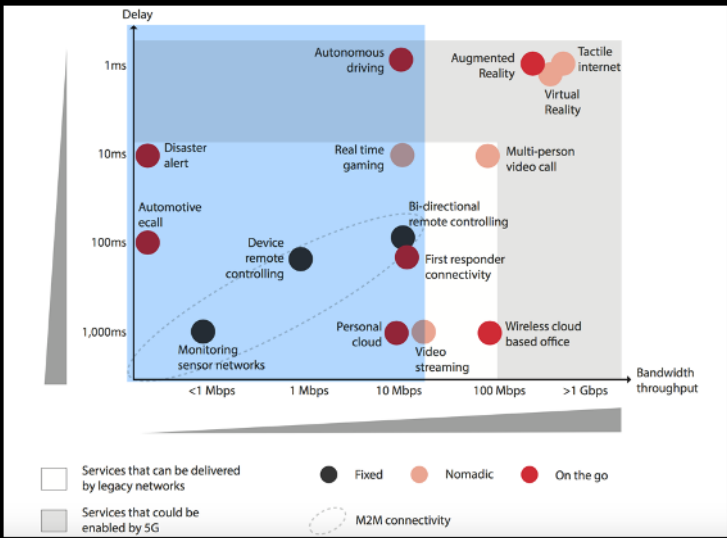

Internet of Things and Machine2machine
Step 1
Place Amber Alert GPS on or with your child.
Step 2
Call your Amber Alert GPS and receive a text message of its location.
Step 3
View the location from your mobile phone or computer.

5G



- https://gsmaintelligence.com/research/?file=141208-5g.pdf&download

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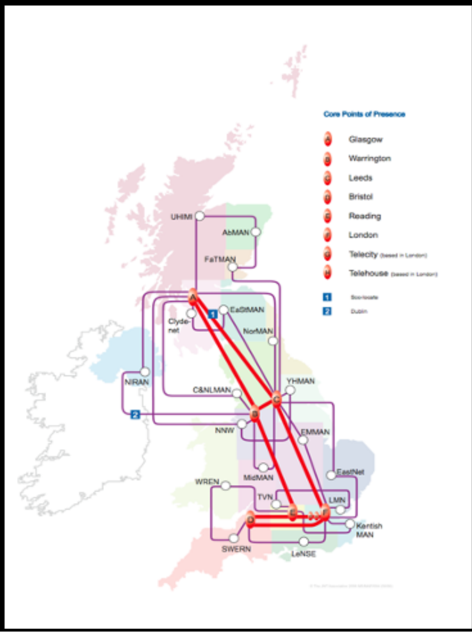
Examples of Networks

JANET



Core Points of Presence
Glasgow
Warrington
Leeds
Bristol
Reading
London
Telecity (based in London)
Telehouse (based in London)
Dublin
UHIMI
AbMAN
FaTMAN
EaStMAN
Clyde-net
NorMAN
NIRAN
C&NLMAN
YHMAN
NNW
EMMAN
EastNet
WREN
MidMAN
TVN
LMN
Kentish MAN
SWERN
LeNSE

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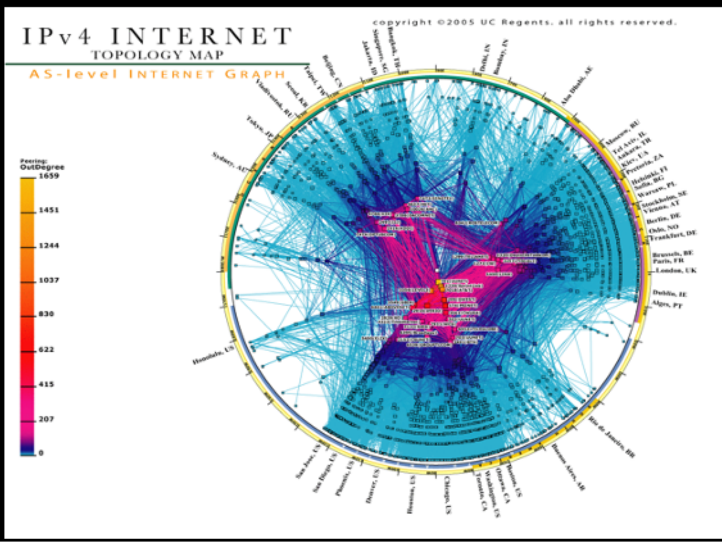
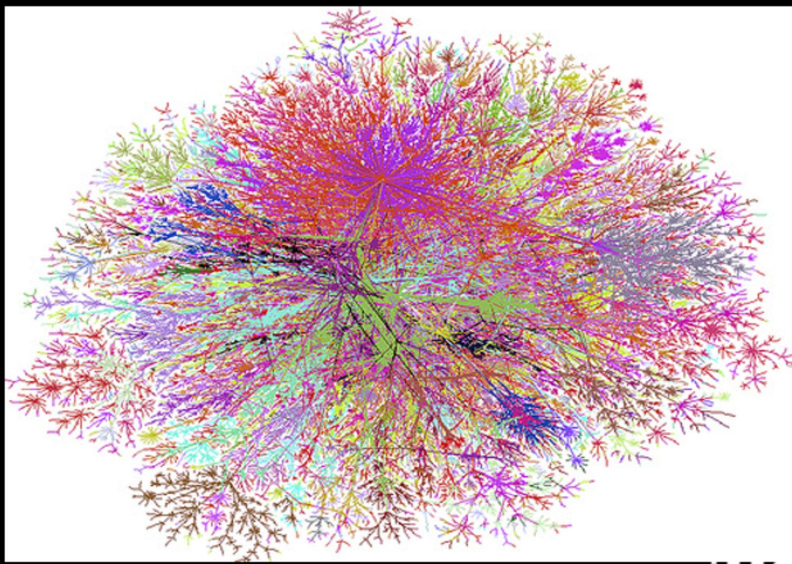
The Internet



The Internet



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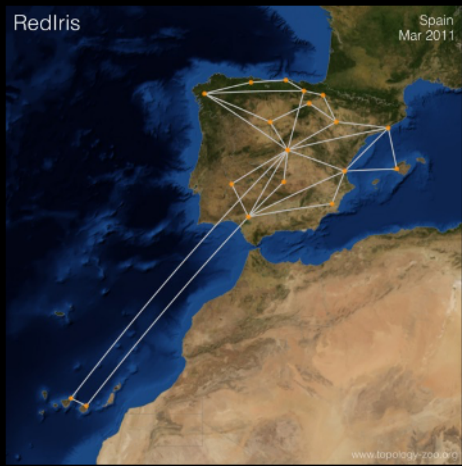
Topologies: http://www.topology-zoo.org



More Topologies

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Bell Canada
Canada, USA
<2005
www.topology-zoo.org


Carnet
Croatia
Aug 2010


CESNET
Czech Republic
Jun 2010


BTN
USA
<2005
www.topology-zoo.org

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Summary

- History
- Internet design principles
- Future applications
- Examples of Networks

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Computer Networks

Outline

- Types of Networks
- Types of Addressing
- Quality of Service metrics

LAN - Local Area Network

- Connects computers that are physically close together (< 1 mile).
  - high speed
  - multi-access
- Technologies:
  - Ethernet 10 Mbps, 100Mbps, 1Gbps
  - Token Ring 16 Mbps
  - FDDI 100 Mbps
- Data Center Networking

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WAN - Wide Area Network

- Connects computers that are physically far apart. “long-haul network”.
  - Higher Delay than a LAN. Faster speeds
  - Traditionally less reliable than a LAN.
  - Point-to-point
- Technologies:
  - Telephone lines
  - Satellite communications
  - SONET/SDH – ATM
  - Increasingly Ethernet

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MAN - Metropolitan Area Network

- Larger than a LAN and smaller than a WAN
- Campus-wide network (FDDI, DQDB, ATM)
- Interconnects LANs
- Technologies:
- coaxial cable
- Microwave
- optical

FDDI	Fiber Distributed Data Interface
DQDB	Distributed-Queue Dual-Bus
ATM	Asynchronous Transfer Mode

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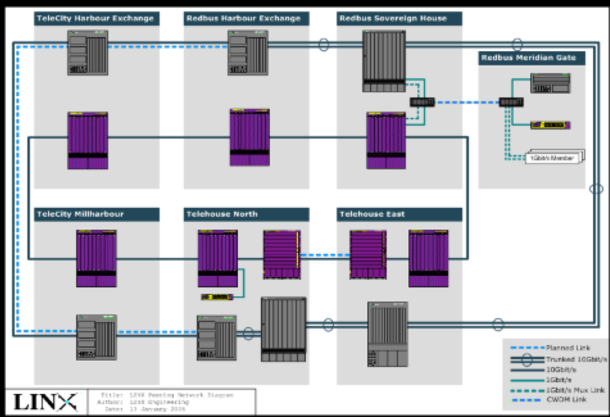
A big MAN: Linx, The London Internet eXchange point



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Another MAN: KentMan

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Home Networking

- New Challenges and Opportunities
- Access:
  - ADSL
  - Optical fibre
  - Wireless, Satellite
- Access inside the house
  - Wifi, Bluetooth, power cables
  - Wifi signal, wifi throughput, wifi leaking
  - Internet of things (wifi, zigbee)

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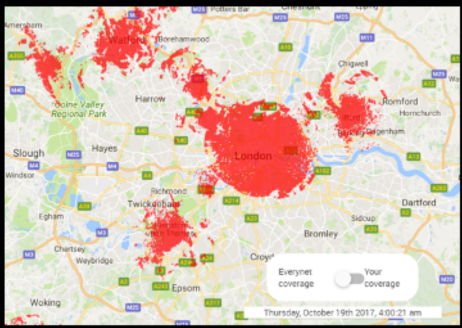
Low Power Networking: LORA and Narrowband IoT

- Long Distance
- 9v battery
- Up to 10 years
- Bytes per minute



Personal Area Networks

- A niche market but an important one
- Healthcare and the Internet of things
- Bluetooth dominates (but Wifi low energy may become relevant)
- Energy is critical !

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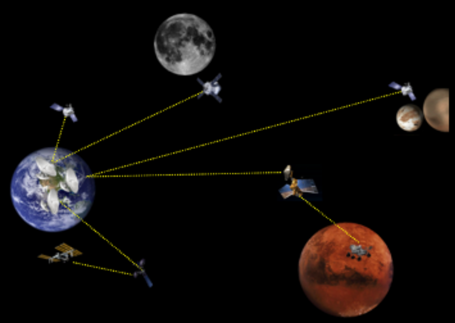
Space Networking: Interplanetary Internet

- To sustain life and travel to other planets
- Very high delay (e.g. Earth-Mars: 4 to 24 minutes)



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Addressing Methods

- Unicast: message sent to one destination
- Broadcast: message sent to all hosts in a network
- Multicast: message sent to all members of a group
- Anycast: message sent to closest member of a group

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Quality of Service Metrics
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Throughput

- Measured in bits per second (e.g 4 Mbits/s)
- Depends on:
  - Transmission rate of the links in the path
  - Packet loss
  - Packet delay
  - Application requirements

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Packet Loss

Caused by:

- Congestion in the network
- Active queuing policies
- Link Failures

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Delay

- Some applications require low end-to-end delay:
  - Voice: 150ms
  - Interactive services: 10ms
  - Financial services: each ms costs money
- Five components:
  - Propagation
  - Queueing
  - Processing (e.g. middleboxes)
  - Packetizations (increased by lower layers, e.g. DSL interleaving)
  - Transmission (data rate)

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Propagation Delay

- Dominated by speed of light on fibre (aprox 210,000 km/s (each 210km takes a millisecond)
- Increased by the fact that fibres do not follow straight lines

Queuing Delay

- Each link has a queue
- For lightly loaded links never more than 10 packets
- Overloaded links can have 100ms delay

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Processing delay

- Router, wireless points, end hosts take time to analyse the packets and determining what to do with them
- Routers need to check for error, determine next link, etc
- In normal conditions very small. But if data processing is involved can be a major source

Packetization delay

- Time to acquire the data to be sent
- Example: Voice to be encoded. If it's coded at 32 Kbps you have to wait 20ms to get 80 bytes
- Lower layers: ADSL interleaving, used to "shuffle" fragments to increase reliability. Adds about 5ms of delay

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Transmission delay

- Determined by data rate links
- Examples:
  - On 1Mbps link takes 10ms to send a 10000 bit packet
  - On 10Gbps takes 1μs, on 50Kbits/s, 200ms

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Summary

- Types of Networks
- Types of Addressing
- Types of Delay

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The OSI model

Outline

- Connection-Oriented vs connectionless
- Understand the need for Layering
- Know what each layer does
- OSI vs TCP/IP
- How to connect networks

Connection-Oriented Service

Connection-Oriented service uses *circuits*

- A single path is first established for each new connection.
  - call setup, call release
- The *network* guarantees that data are delivered in order.
- No loss or duplication.
- If anything goes wrong the connection is broken.
- It is possible to limit the number of connections.
- The network can guarantee bandwidth at connect time.
  - waste of bandwidth, if resources (channel) not used
- The network can refuse new connections
- Examples: Telephony (PSTN), cellular network, ISDN, ATM

Connectionless Service

Connectionless service uses *datagrams*

- Each datagram is independently routed.
- Each datagram includes the destination address.
- No guarantee that datagrams are delivered in order.
- No guarantee that datagrams are not lost or duplicated.
- Direct transmission of data, no call set-up
- Best-effort earnest attempt to deliver
- Resources shared, little waste of bandwidth
- If network overly utilized, further traffic is still allowed
- Examples: Postal Service, Ethernet, Internet Protocol (IP)

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CO versus CL Services

Pro connection-oriented

- Reliability, file transfer and terminal traffic main applications
- Faster forwarding, after call setup the path is constant
- Better to lock-out further calls, than to degrade service
- “Simple” Terminal Equipment, offload complexity to the core network

Pro connectionless

- Fault tolerant, if link fails other paths available
- Applications like voice and video can tolerate datagram loss
- Better suited to bursty traffic, link reservation is a waste
- Fair, better allow user access, not only some lucky users
- Efficient for client-server applications with hundreds of clients
- “Simple” core network

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Why Layering?

- Divide a task into separate functions and then define each piece independently (or nearly so).
- Establishing a well defined interface between layers makes porting easier. Decoupling.
- Major Advantages:
  - Code Reuse
  - Extensibility
  - Division of tasks. Each engineering implementing a layer does not need to know how the lower one is implemented

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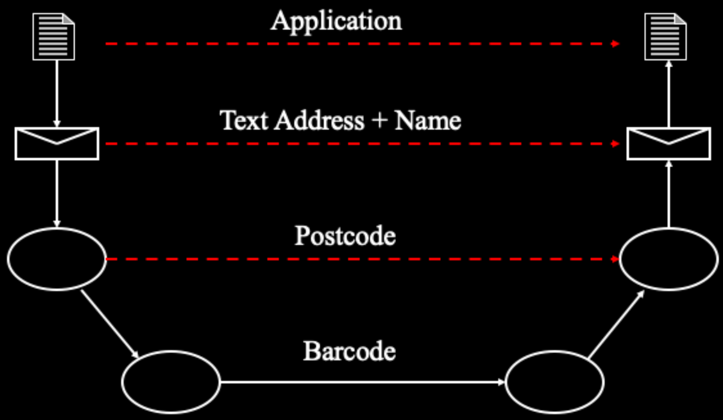
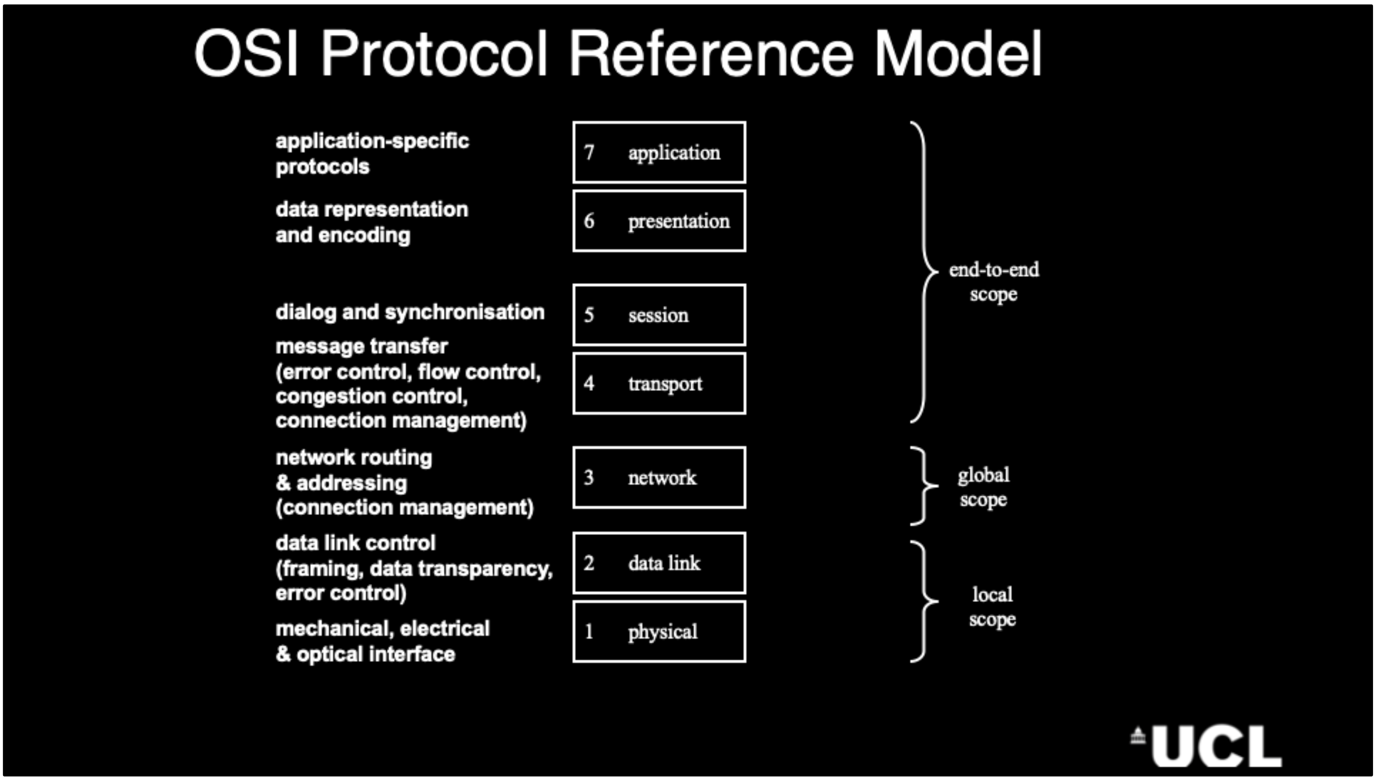
Layering Example: Royal Mail



The OSI Reference Model

- Parallel work to the Internet development
- Work started in 1970s
- Published first version in 1984 by ISO (International Standards organization
- Consists of two parts
  - Reference Model organizing networking functions in 7 layers
  - A set of specific protocols for each layer (never really deployed but with very interesting ideas)
- It was thought to be the ”serious” standard.


OSI Protocol Reference Model
application-specific protocols
data representation and encoding
dialog and synchronisation
message transfer (error control, flow control, congestion control, connection management)
network routing & addressing (connection management)
data link control (framing, data transparency, error control)
mechanical, electrical & optical interface
7 application
6 presentation
5 session
4 transport
3 network
2 data link
1 physical
end-to-end scope
global scope
local scope
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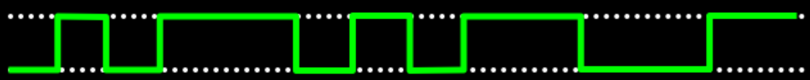
The 7 Layers

The Physical Layer

- Responsibility:
  - transmission of raw bits over a communication channel.
- Issues:
  - mechanical and electrical interfaces
  - time per bit
  - distances



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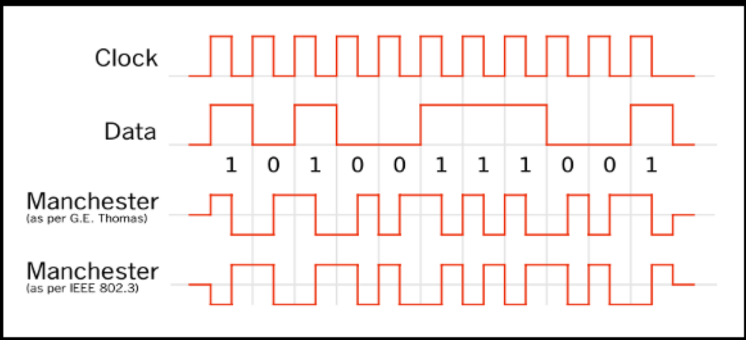
Manchester Code



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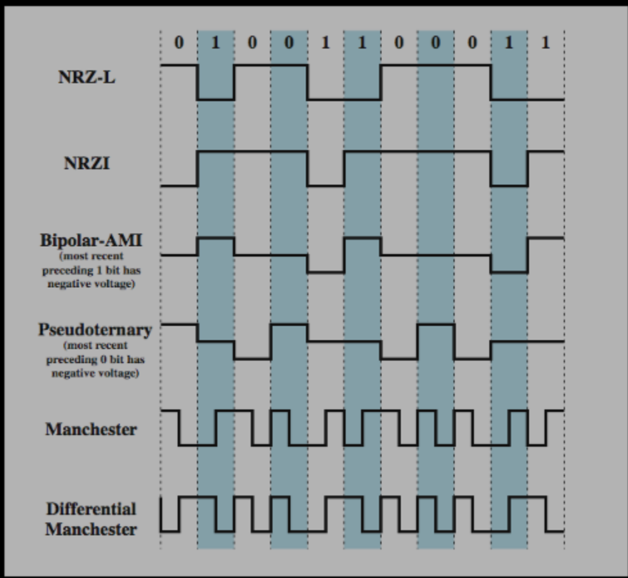
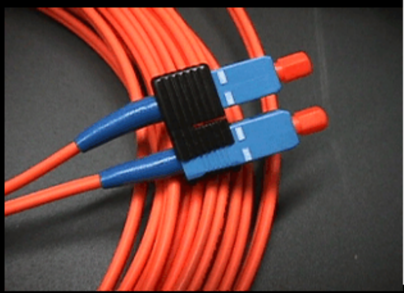
Other Digital Encoding Formats

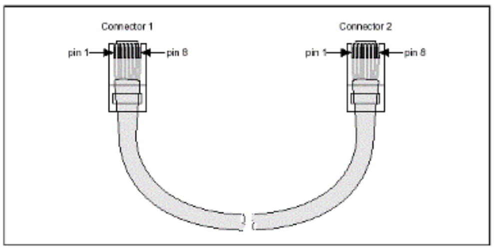


Cabling



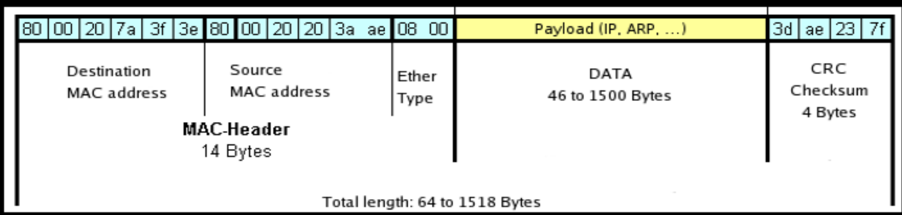
Ethernet Cable Wiring Connections

Pin	Connector 1	Connector 2 (Normal)	Connector 2 (Crossover)
1	white/orange	white/orange	white/green
2	orange	orange	green
3	white/green	white/green	white/orange
4	blue	blue	blue
5	white/blue	white/blue	white/blue
6	green	green	orange
7	white/brown	white/brown	white/brown
8	brown	brown	brown



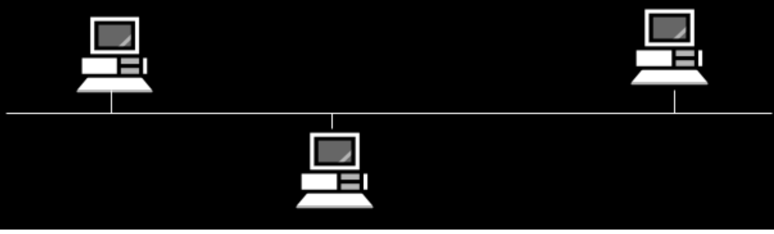
Ethernet Cable Pinouts

Data Link Layer: Ethernet Frame



CSMA/CD

- Ethernet uses a method called **Carrier Sense Multiple Access with collision Detection**
- In Ethernet networks the medium is shared
- Computers **sense** the medium to check if anybody is transmitting. If not, they start sending
- While sending they check if the wave is changed. If it does, than a **collision is detected**. The computer waits a random amount of time and then retransmits again.



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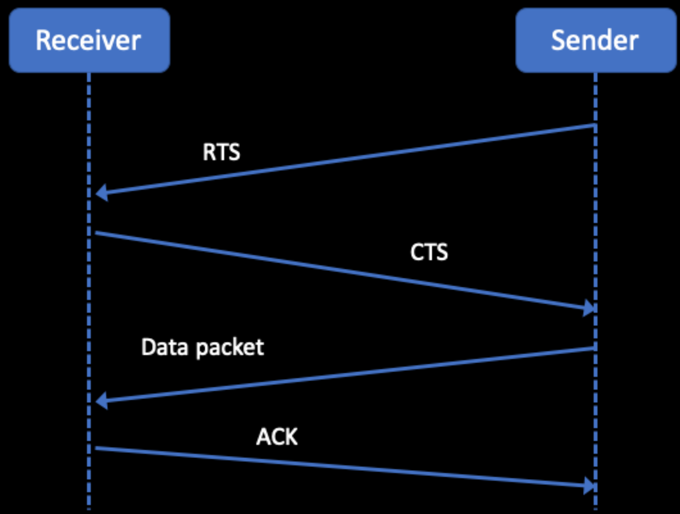
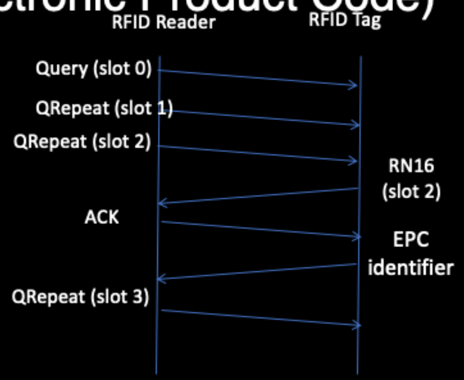
CSMA/CA ((used in Wi-Fi, 802.11)



UCL

Another example: EPC (Electronic Product Code)

- RFID reader (powered) and RFID tag (non powered)



4	1	2	1	2	2	1	4	5
Command 1000	DR	M	TR	Sel	Session	Target	Q	CRC

Physical parameters Tag selection

Error correction

- Networks are unreliable. Data link-layer can help here:
- Error correcting codes
  - Hamming codes
  - Binary convolutional codes
  - Reed-Salomon codes
  - Low-Density Parity Check codes
- Error detecting codes
  - Parity
  - Checksum
  - Cyclic Redundancy Code

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The Network Layer

- Responsibilities:
  - path selection between end-systems (routing).
  - subnet flow control.
  - fragmentation & reassembly
  - translation between different network types.
- Issues:
  - *packet* headers
  - virtual circuits

UCL

Non-IP network layer

- Historically there has been other network protocols: ATM, CLNP
- Other design choices include:
  - Admission control
  - Congestion control
- Reliability

The Transport Layer

Responsibilities:

- provides virtual end-to-end links between peer processes.
- end-to-end flow control / congestion control
- reliable communication

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The Session Layer

- Responsibilities:
  - Dialog Control (keep track of whose turn is it to transmit)
  - Token Management (preventing both parties from attempting the same critical operation simultaneously)
  - Synchronization (checkpointing long transmissions to allow time to pick up from where they left in the event of a crash and subsequent recovery

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The Session Layer

- In TCP/IP it does not exist formally. Many people identify some functions provided by some protocols as being part of **Session Layer**. Examples:
  - RTP and RTCP for video conferencing
  - Cookies for HTTP
  - SIP – Session Initiation Protocol
  - …
- Session layer functionality is usually implemented by the application itself

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The Presentation Layer

- Responsibilities:
  - data encryption
  - data compression
    - Lossless or lossy
  - data conversion
- Many protocol suites do not include a Presentation Layer.

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ASN.1 - Abstract Syntax Notation

```
FooProtocol DEFINITIONS ::= BEGIN

  FooQuestion ::= SEQUENCE {
    trackingNumber INTEGER,
    question       VisibleString
  }

  FooAnswer ::= SEQUENCE {
    questionNumber INTEGER,
    answer         BOOLEAN
  }

END
```

- Computers store data (integers, strings, floating point numbers) in different ways.
- ASN.1 allows for a common grammar
- Used in some TCP/IP protocols (e.g. RPC, SNMP)

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Encryption

- Uses cryptography
  - Symmetric
  - Asymmetric
- Allows for confidentiality and authentication
- Management of public keys is the hardest part

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The Application Layer

- Responsibilities:
  - anything not provided by any of the other layers
- Issues:
  - application level protocols
  - appropriate selection of “type of service”

Examples of Application Layer Protocols

- **HTTP** for the World Wide Web. This is the protocol used for web browsers to get web pages from web servers
- **SMTP**, **POP**, **IMAP** - to read and receive email
- Signaling Protocols like **SIP** for Voice over IP
- **Routing protocols** are Application level protocols that affect the Network Layer
- They are very easy to implement in any programming language

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Connecting Networks

- Repeater: physical layer
- Bridge: data link layer
- Router: network layer
- Gateway: network layer and above

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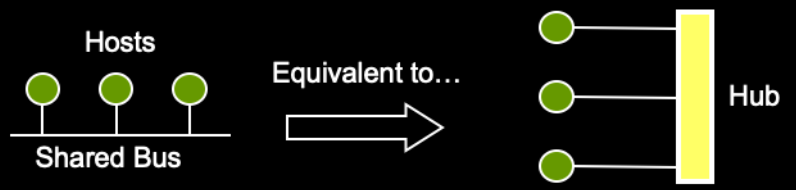
Repeater

- Copies bits from one part of the same network to another
- Does not look at any bits – regenerates them
- Allows the extension of a network beyond physical length limitations

Hub

- Star Topology – Multi-Access Device
- Regenerates Bits
- Multi-port device linking network segments*
- Copies all valid data to all ports
- Allows the extension of a network beyond physical length limitations



*

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Bridge

- Copies frames from one part of a network to another.
- Can operate selectively - does not copy all frames (must look at data-link headers). Provides isolation and so improves performance
- Extends the network beyond physical length limitations.

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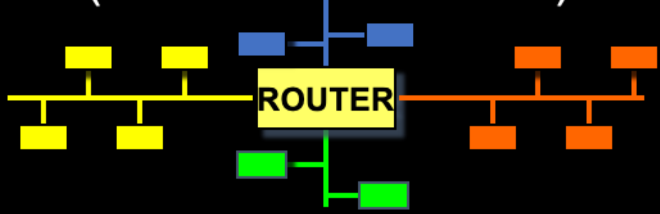
Router

- Transfers packets from one network to another.

- Makes decisions about what *route* a packet should take (looks at network headers).



Criticisms

OSI

- Bad timing (see next slide)
- Bad technology. Complex standard
- Bad implementations
- Bad politics

TCP/IP

- Does not distinguish clearly between service, interface and protocols
- Not easily exatendable. Lacks generality
- Link layer not well defined
- Many protocols have bad implementations

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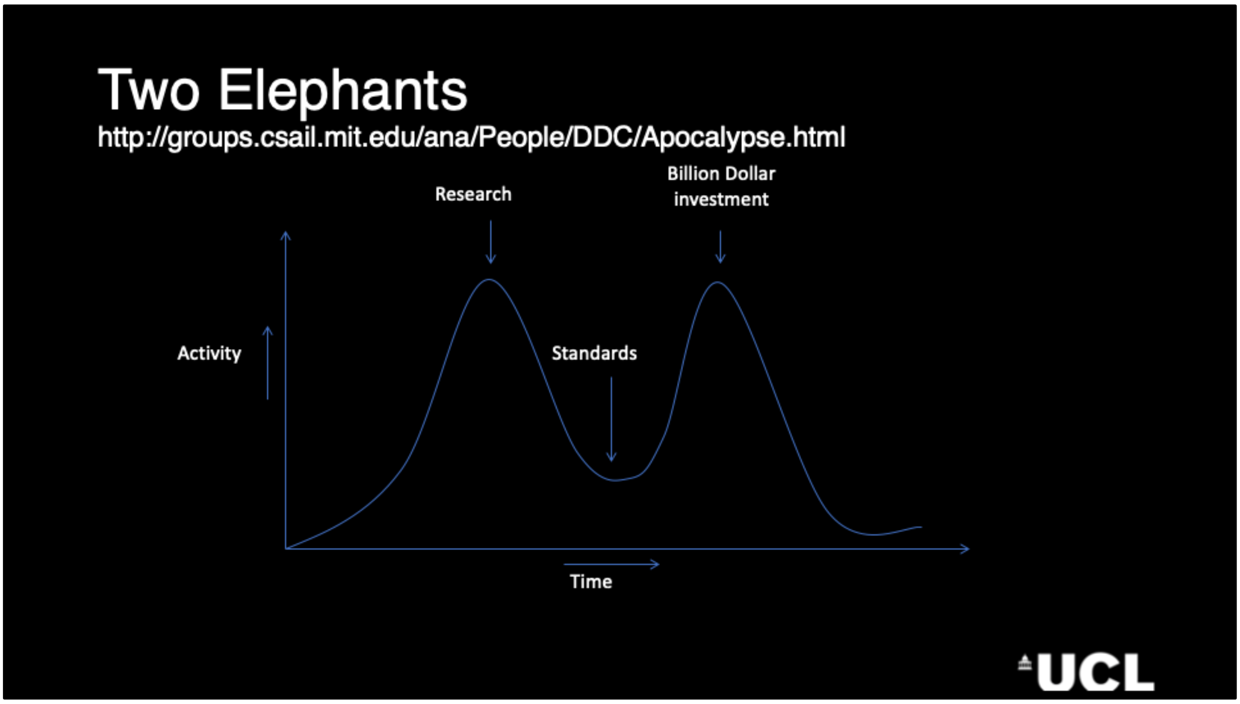
Two Elephants
http://groups.csail.mit.edu/ana/People/DDC/Apocalypse.html
Research
Billion Dollar investment
Activity
Standards
Time
UCL

Standard bodies

OSI/ISO/Telecoms

- ISO: 157 member countries
- IEEE
- ITU
- Wifi Alliance

Internet

- Internet Architecture Board
- IETF
- IRTF
- IANA: numbers (e.g. ports)
- W3C

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Summary

- Understand the need for Layering
- Know what each layer does
- OSI vs TCP/IP
- How to connect networks