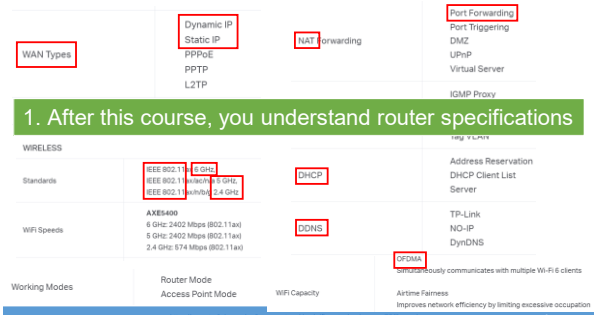
Computer Networks X_400487

Lecture 10

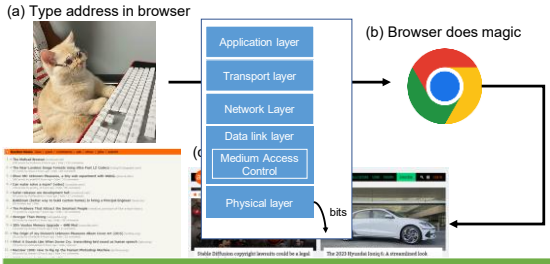
Course Recap

Lecturer: Jesse Donkervliet

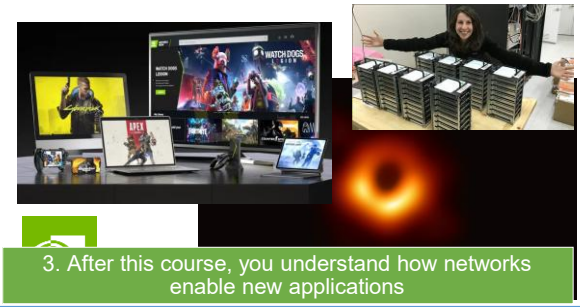


1. After this course, you understand router specifications

https://www.tp-link.com/en/home-networking/wifi-router/archer-axe75/#overview



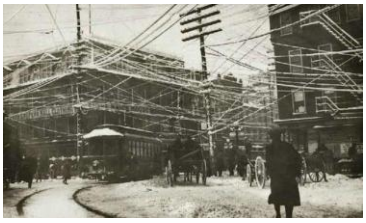
2. After this course, you understand browser magic

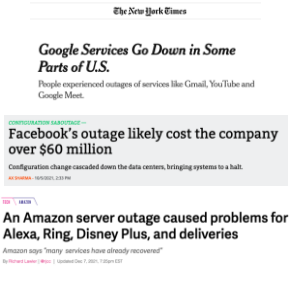


3. After this course, you understand how networks enable new applications

Image source: Nvidia, NASA, https://www.pbs.org/newshour/science/katie-bouman-hardly-knew-what-a-black-hole-was-her-algorithm-helped-us-see-one

Early telephone system





Further reading on Facebook outage:

1. https://blog.cloudflare.com/october-2021-facebook-outage/
2. https://engineering.fb.com/2021/10/05/networking-traffic/outage-details/

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TODAY'S AGENDA

1. ~~Intro~~
2. Content recap & exercises
3. Game demos
4. Wrap-up

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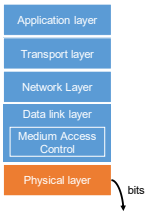
Responsibilities of the Physical Layer

1. Translating between bits/symbols and signals
2. (Static) channel allocation

Important properties:
1. Bit rate
2. Delay
3. Storage capacity
4. Error rate



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Nyquist & Shannon's theorems

Nyquist's theorem

Computing the maximum data rate for a *noiseless* channel.

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

R - maximum data rate
B - bandwidth
V - number of signal levels

Shannon's theorem

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

$R = B \times \log_2(1 + S/N)$

Signal to noise ratio (SNR) is expressed in decibel.

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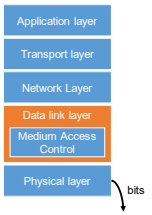
Responsibilities of the Data Link Layer

1. Framing
2. Flow control
3. Error control

Important properties:

1. Bandwidth efficiency
   - Sliding window size
   - Code rate
2. Number/types of errors reliably detected



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Cyclic Redundancy Check Example

Sender adds CRC

$1 \times x^4 + 0 \times x^3 + 0 \times x^2 + 1 \times x^1 + 1 \times x^0$

message: 110101010000

generator: 10011

$x^4 + x + 1$

```
 100110101000
 10011
  10000
  10011
   0011
```

Message: 11010101, CRC: 0011,
Codeword: 11010100011

Modulo 2 arithmetic. No carries/borrows

Q: Consequences for implementation?

$\frac{110101010011}{10011} = 0$

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Hamming codes - an example

Use bit-locations that are a power of 2 as check bits. Use the remaining positions for the message.

message: 1 101 0101

codeword: __1_101_0101

positions: 123456789…

1. Expand all bit locations into powers of two.
2. Decide the value of each check bit in position 2^i by calculating the parity function over all bits that have 2^i in their expansion.

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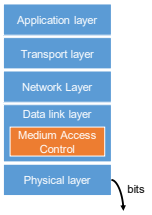
Responsibilities of the MAC Layer

1. (Dynamic) channel allocation
2. Collision detection/avoidance
3. Quality of Service

Important properties:

1. Bandwidth efficiency as function of #stations



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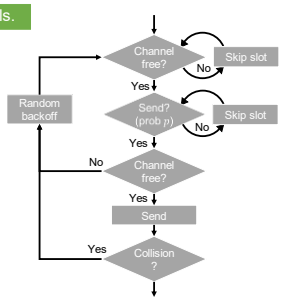
Applies to *slotted* channels.

p-persistent *Carrier Sense Multiple Access* (CSMA)

Keeps waiting. Sends frame with probability p.



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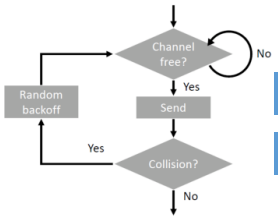

Q: Which protocol is this?

A: 1-persistent CSMA

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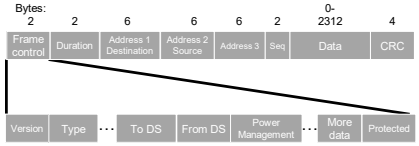
802.11 frame



Ethernet frame

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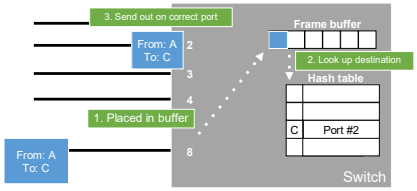
Ethernet switch

Q: Advantages of switches?



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The Network Layer

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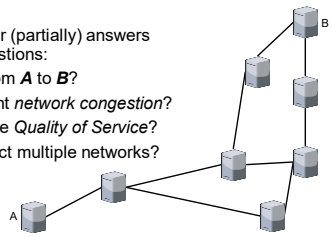
The Network Layer

Lowest layer concerned with end-to-end delivery.

The network layer (partially) answers the following questions:

1. How to get from ***A*** to ***B***?
2. How to prevent *network congestion*?
3. How to provide *Quality of Service*?
4. How to connect multiple networks?



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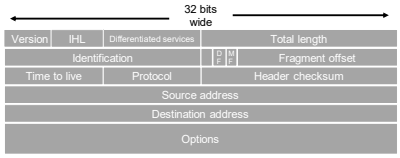
IP version 4

Q: What is the maximum size of an IP packet?

Q: If IHL field has value 6, how long is the IP packet header?

Frame header: 20-60 bytes (Options 0-40 bytes)



Check the book for the detailed view!

Routing tables

You want to know for every address, on which link to forward the packet. For this we use a routing table.

Routing table for C.

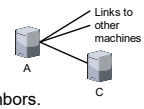
We are directly connected to A

We are station C

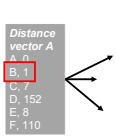
To	Distance	Line
A	7	A
B	59	A
C	0	-
D	75	E
E	1	E
F	103	E

If packet should go to D, minimum distance is 75. Forward to E.

Distance vector routing



1. Send your *distance vector* to your neighbors.
2. You use incoming *distance vectors* from your neighbor to construct a *routing table*.



Routing table for C.

To	Distance	Line
A	7	A
B	8	A
C	0	
D	75	
E	1	
F	103	

Q: What can go wrong when using this algorithm?

Routing algorithms can calculate routes to prefixes, instead of to every individual address

Internet Protocol Prefixes and Subnets

Vrije Universiteit given a *prefix*. E.g., all IP addresses that match ***37.60.x.y***.

16 bits used by network

Address starts with 37.60? If yes, route to VU.

Example address: 37.60.194.64.

00100101.00111100.11000010.01000000

Network | Host

Prefixes handed out by single organization: ICANN

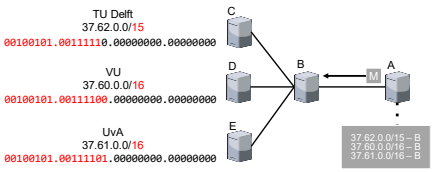
Organizations can further subdivide their prefix to create *subnets*

Prefix: 37.60.0.0/16

Subnet mask:

11111111.11111111.00000000.00000000

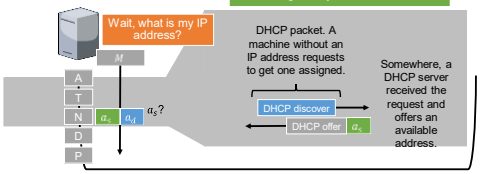
Internet Protocol - CIDR Classless InterDomain Routing



Dynamic Host Configuration Protocol (DHCP)

MAC addresses are built into NICs. But network addresses are not.

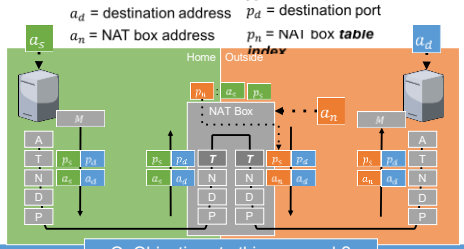
Used to configure other settings such as: ***DNS name servers***, addresses of default gateway, time servers, etc.



Q: How to send DHCP offer back to machine without an address?

Network Address Translation (NAT)

a_s = source address
a_d = destination address
a_n = NAT box address
p_s = source port
p_d = destination port
p_n = NAT box **table index**



Q: Objections to this approach?

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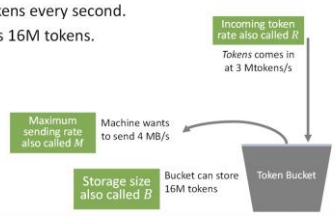
Traffic shaping
Token bucket example

Maximum *burst duration* is $\frac{B}{M-R}$ seconds

Bucket loses 1Mtokens every second.
Full bucket contains 16M tokens.



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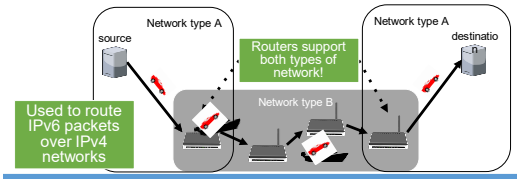
Tunneling

Q: How to route IPv6 traffic over IPv4 network?
A: [IPv6 hdr][IPv4 hdr][data]
B: [IPv4 hdr][IPv6 hdr][data]

If the ***source*** and ***destination*** networks use the same protocols, we can use ***tunneling***.



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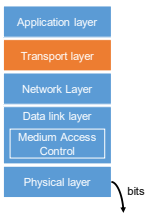
Responsibilities of the Transport Layer

1. Fair and dynamic bandwidth allocation
2. Prevent network congestion
3. Provide (reliable) network service to applications
4. Support Quality of Service



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The transport layer
Provided services

Runs only on the host and destination

Provides a ***reliable*** data stream over an ***unreliable*** network.
Provides communication between ***applications***.

End-to-End Argument

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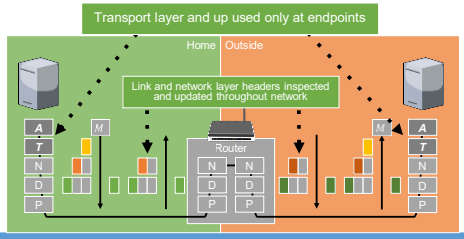
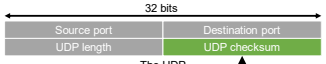
Transport layer only present at source and destination



User Datagram Protocol (UDP)

RFC 768

Very thin layer on top of IP. Header provides ***ports*** needed to connect to remote applications.



UDP does ***not*** do:

1. Flow control
2. Congestion control
3. Retransmissions

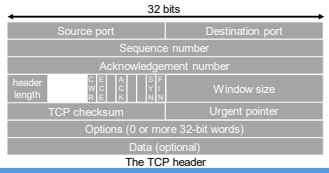
Q: Can you name a service that works well with UDP?

Transmission Control Protocol (TCP)

One of the most important protocols on the Internet

Provides a ***reliable end-to-end byte stream*** over an unreliable network

Header: 20-60 bytes (Options: 0-40 bytes)



Q: How to calculate total TCP segment size?

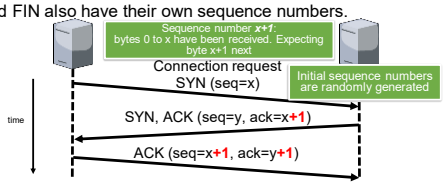
Q: When are packets with 0 data bytes used?

TCP connection establishment Three-way handshake

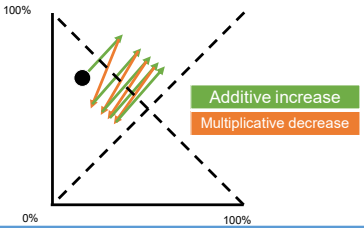
Uses timestamp option to improve performance on high-bandwidth networks

Every ***data byte*** has its own sequence number.*

*SYN and FIN also have their own sequence numbers.

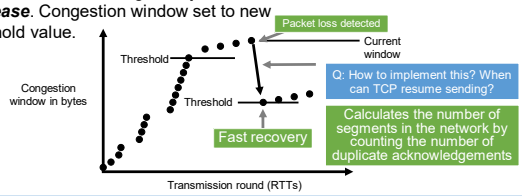


Additive increase Multiplicative decrease



TCP Reno (= TCP Tahoe + fast ***recovery***)

Threshold reduced using ***multiplicative decrease***. Congestion window set to new threshold value.



Q: How to implement this? When can TCP resume sending?

Calculates the number of segments in the network by counting the number of duplicate acknowledgements

Recap: Link Utilization

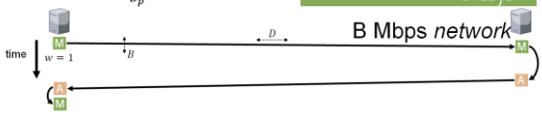
- Frame size (in bits/bytes): f
- Window size (in frames): w
- Bandwidth (max. data rate of physical channel): B_p
- Bandwidth (frames per second): B_f
- Propagation delay (in seconds): D

It takes $\frac{f}{B_p}$ seconds to send frame, $\frac{B_p}{f} = B_f$

It takes D s for the frame to arrive at the receiver, takes D s for the (0-bit) acknowledgment to come back at the sender

1 frame per $\frac{f}{B_p} + 2 \times D$ seconds

Link utilization= $\frac{w}{1+2B_f D}$



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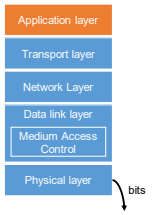
Responsibilities of the Application Layer

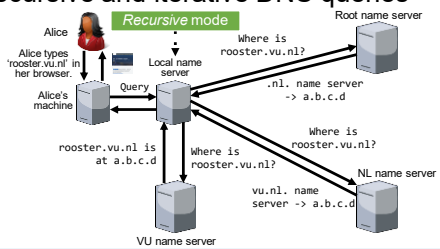
Provide applications that are (indirectly) useful to people

1. DNS
2. Mail and messaging
3. The Web
4. Multimedia applications
5. *Your future app here?*



Other name servers are in *iterative* mode

Recursive and iterative DNS queries



Base64 encoding

Q: How large is the overhead of base64 encoding?

Used to convert binary data to and from ASCII.

Alphabet: `[A-Za-z0-9+/]`

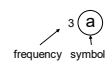
6 bits are translated into 1 character.

Q: What is the base64 encoding of `0xC0FFEE`?

	C	a	t
ASCII	01000011	01100001	01110100
Base64	010000	110110	000101	110100
	Q	2	F	0

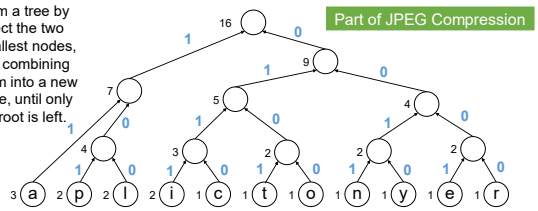
11 101 101 100 0111 0110 11 0101 0111 0100 0011 100 11 0010 0001 0000 (54 bits) "application layer"

Huffman Encoding

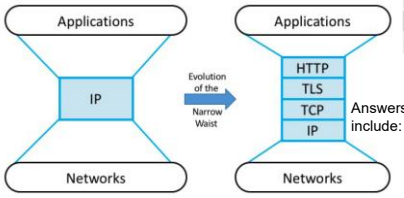


Form a tree by select the two smallest nodes, and combining them into a new node, until only the root is left.

Part of JPEG Compression



HTTP is the new "narrow waist"



E.g., REST

Method	Description
GET	Read a Web page
HEAD	Read a Web page's header
POST	Append to a Web page
PUT	Store a Web page

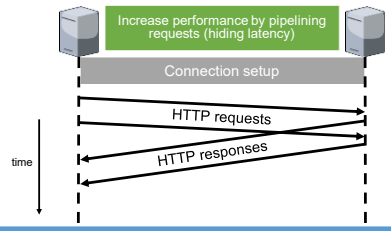
Q: Advantages over using TCP directly?

Answers include:

- Provides set of methods
- Provides security
- Provides *naming*

Source: Peterson, Larry L., and Bruce S. Davie. Computer networks: a systems approach. Elsevier, 2007.

HTTP
Pipelined requests



HTTP/3 (HTTP + ***QUIC***)

QUIC orders data per *stream* | RFC 9051

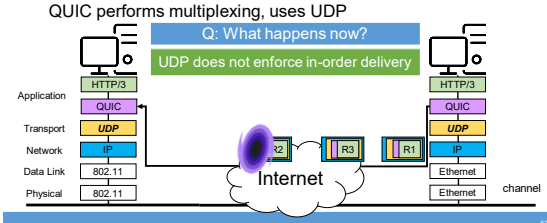
Each HTTP request can use a separate stream; within a stream, data is delivered in order; across streams no such guarantee is made

HTTP/3 uses the ***QUIC*** protocol

QUIC performs multiplexing, uses UDP

Q: What happens now?

UDP does not enforce in-order delivery



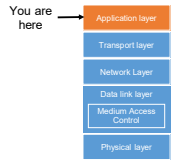
Milestone reached!

Creating large-scale distributed systems is difficult!

We can now ***start*** building applications and systems that communicate over a network!

Advanced courses unlocked:

1. Advanced Systems Programming
2. Advanced Computer Networks
3. Distributed systems
   (also requires Computer Organization and Operating Systems)



TODAY'S AGENDA

1. ~~Intro~~
2. ~~Content recap & exercises~~
3. Game demos
4. Wrap-up

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We hope you enjoyed the course and learned a lot!