Computer Networks X_400487

Lecture 10

Course Recap

Lecturer: Jesse Donkervliet

1. After this course, you understand router specifications

WAN Types	Dynamic IP Static IP PPPoE PPTP L2TP

NAT Forwarding	Port Forwarding Port Triggering DMZ UPnP Virtual Server
	IGMP Proxy ... Tag VLAN
DHCP	Address Reservation DHCP Client List Server
DDNS	TP-Link NO-IP DynDNS

WIRELESS

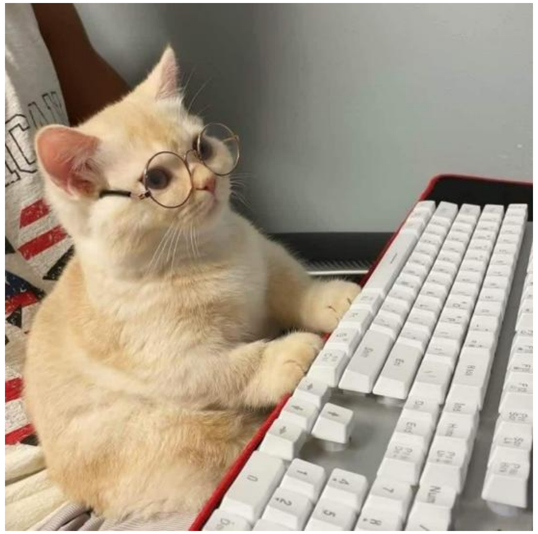
Standards	IEEE 802.11ax 6 GHz, IEEE 802.11ax/ac/n/a 5 GHz, IEEE 802.11ax/n/b/g 2.4 GHz
WiFi Speeds	**AXE5400** 6 GHz: 2402 Mbps (802.11ax) 5 GHz: 2402 Mbps (802.11ax) 2.4 GHz: 574 Mbps (802.11ax)

Working Modes	Router Mode Access Point Mode

WiFi Capacity	OFDMA Simultaneously communicates with multiple Wi-Fi 6 clients Airtime Fairness Improves network efficiency by limiting excessive occupation

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

(a) Type address in browser

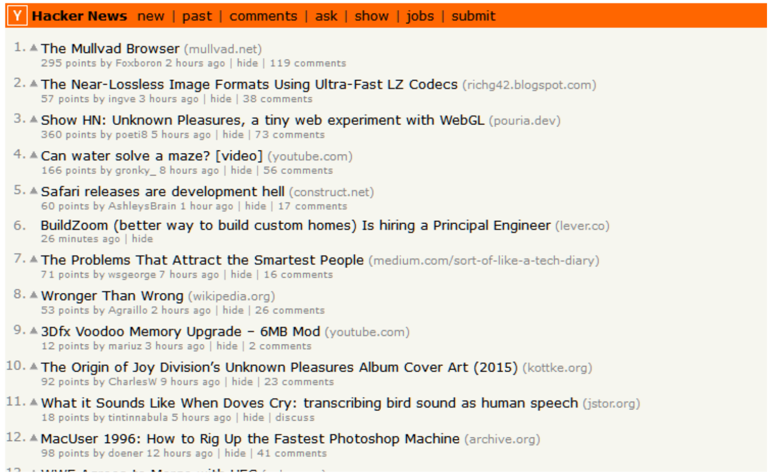


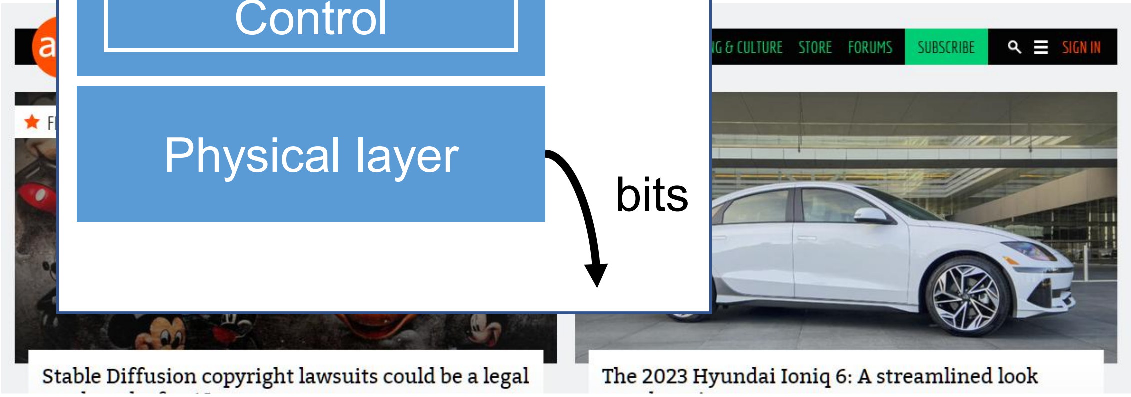
(b) Browser does magic

- Application layer
- Transport layer
- Network Layer
- Data link layer
  - Medium Access Control
- Physical layer

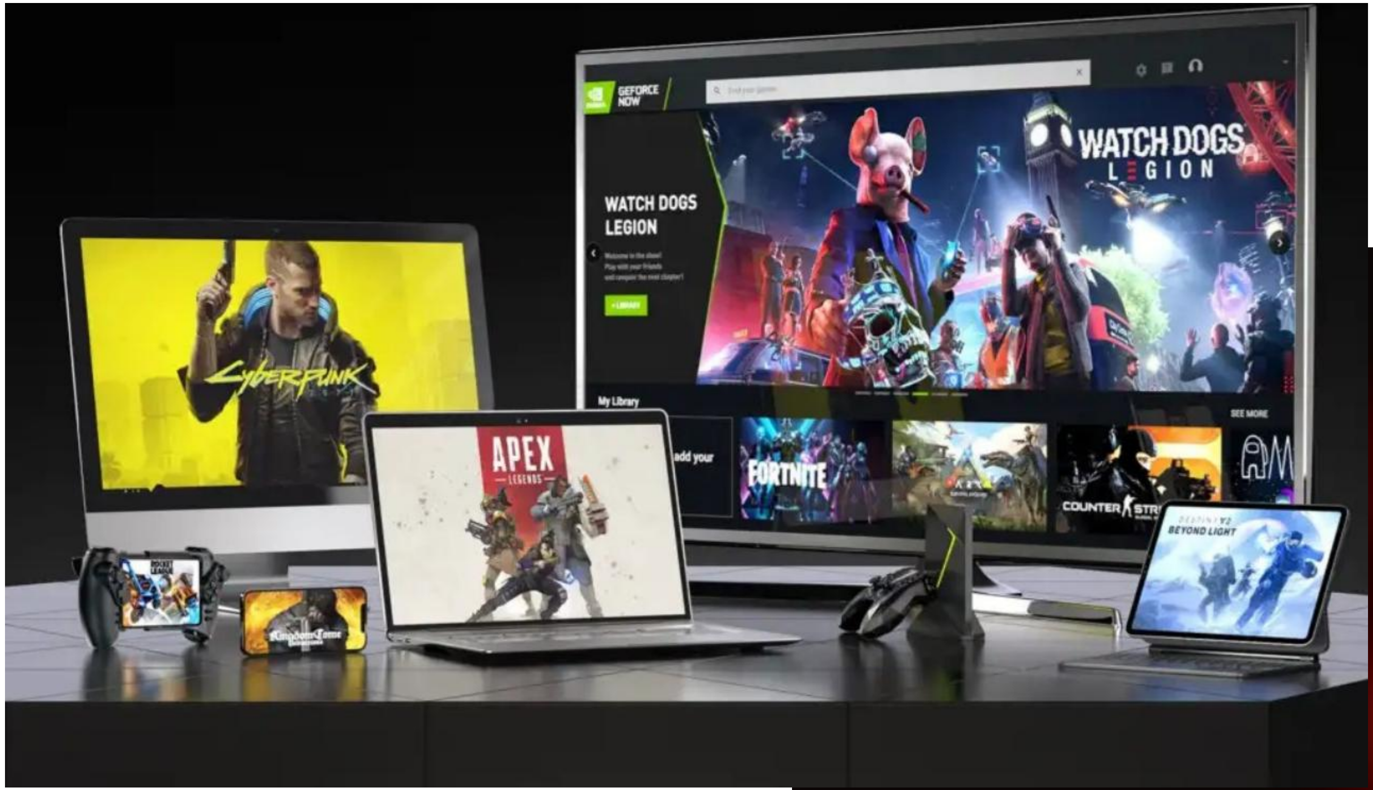
bits

(c





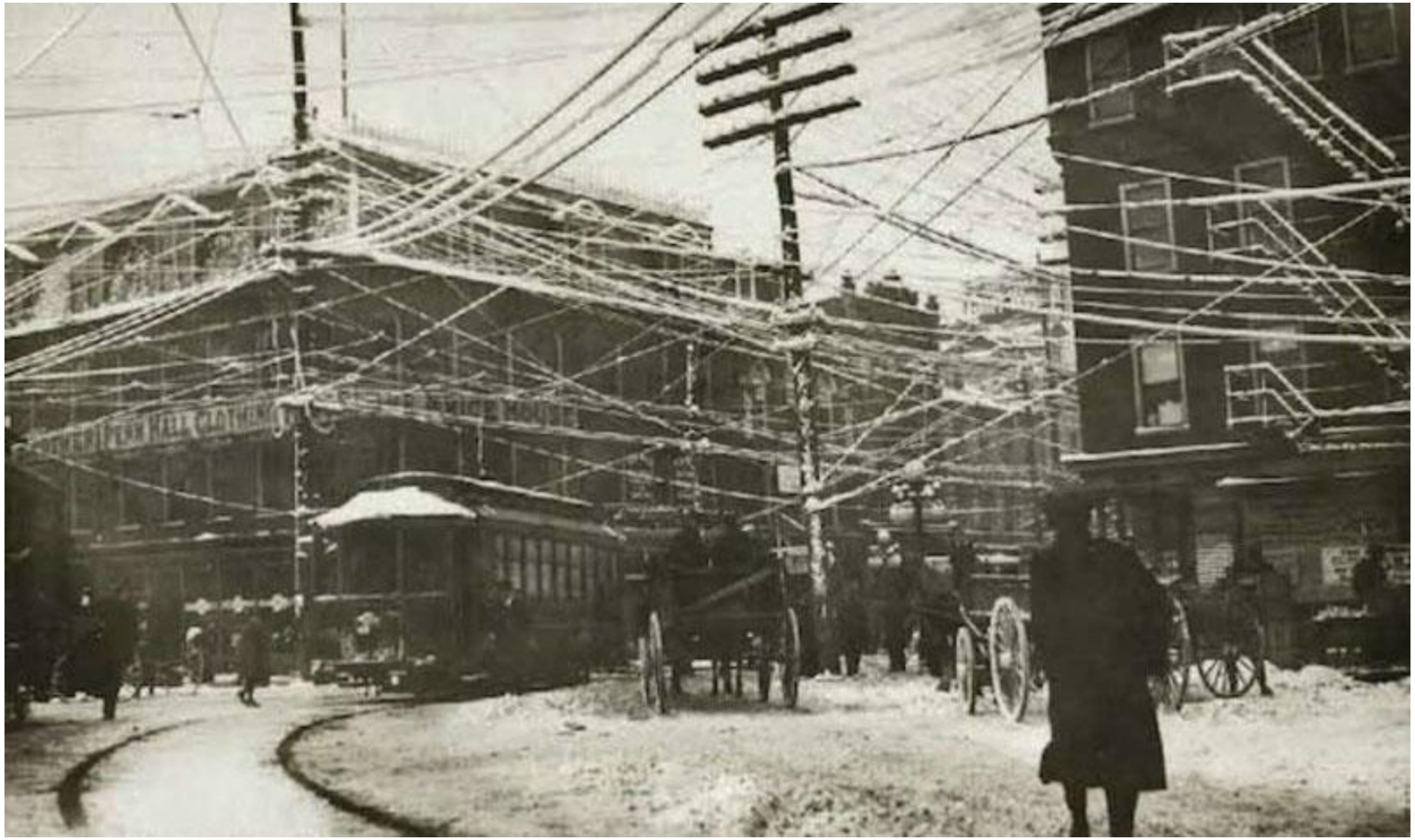
2. After this course, you understand browser magic



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



The New York Times

Google Services Go Down in Some Parts of U.S.

People experienced outages of services like Gmail, YouTube and Google Meet.

CONFIGURATION SABOUTAGE —

Facebook's outage likely cost the company over $60 million

Configuration change cascaded down the data centers, bringing systems to a halt.

AX SHARMA - 10/5/2021, 2:33 PM

TECH AMAZON

An Amazon server outage caused problems for Alexa, Ring, Disney Plus, and deliveries

Amazon says "many services have already recovered"

By Richard Lawler | @rjcc | Updated Dec 7, 2021, 7:25pm EST

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/

YouTube

DigiD

nrc

twitch

bol.com

9 2
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D2L

Rabobank

ING

canvas

Bb
Blackboard

TODAY'S AGENDA

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

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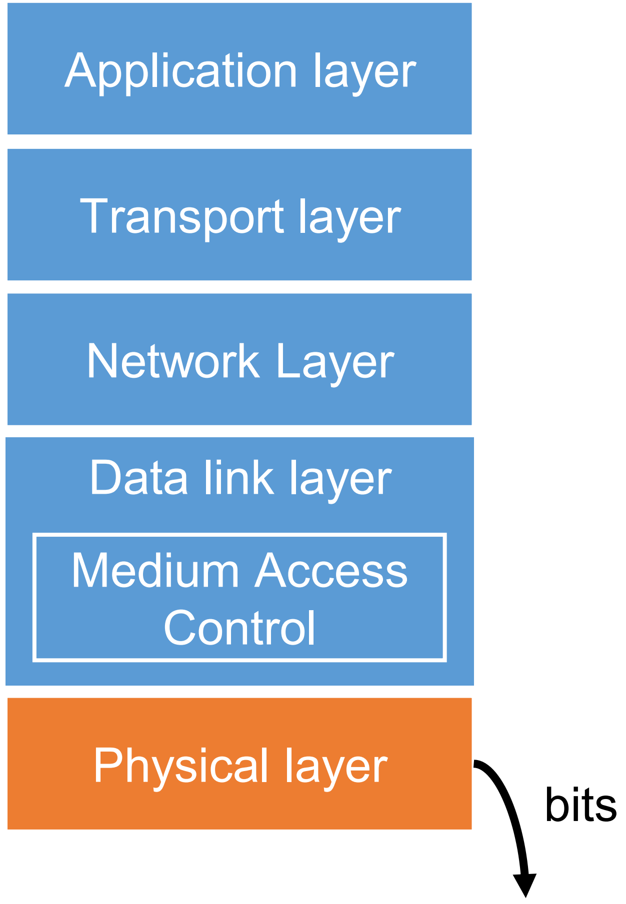
Responsibilities of the Physical Layer

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

Important properties:

1. Bit rate
2. Delay
3. Storage capacity
4. Error rate



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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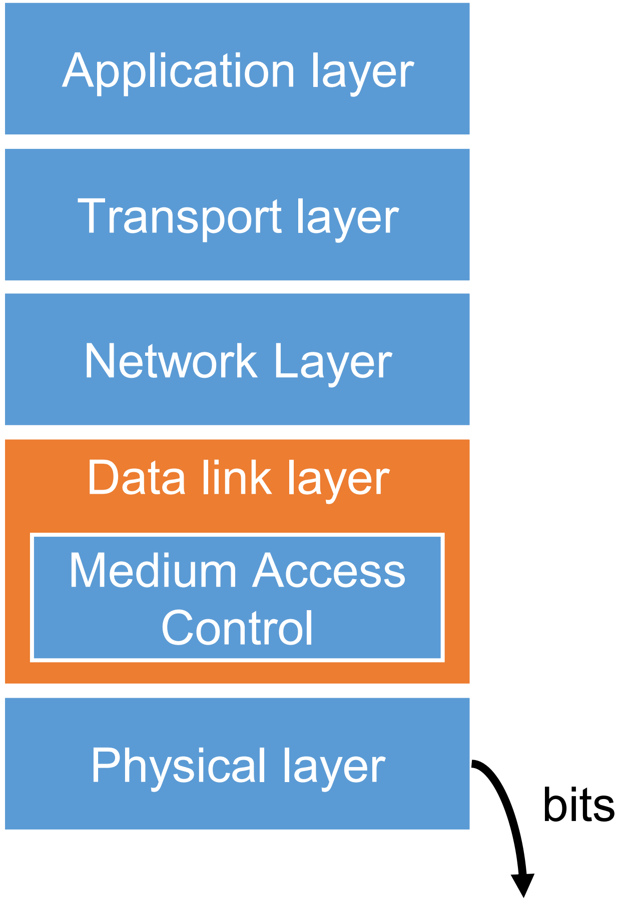
Responsibilities of the Data Link Layer

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



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: 11010101 0000

generator: 10011

$x^4 + x + 1$

```
   1001 1010000
   10011
         10000
         10011
          0011
```

Modulo 2 arithmetic.
No carries/borrows

Q: Consequences for implementation?

Message: 11010101, CRC: 0011,
Codeword: 11010101 0011

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

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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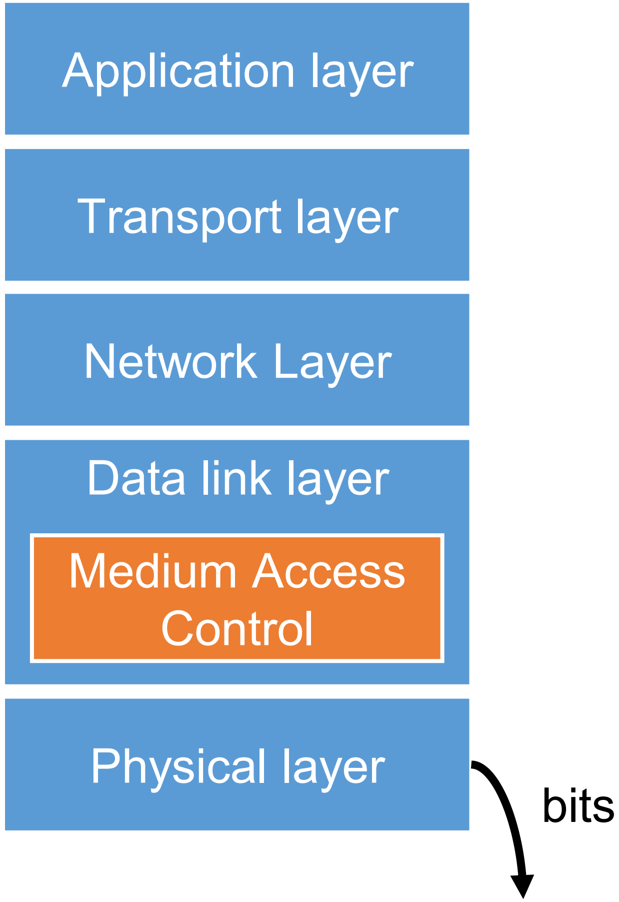
Responsibilities of the MAC Layer

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

Important properties:

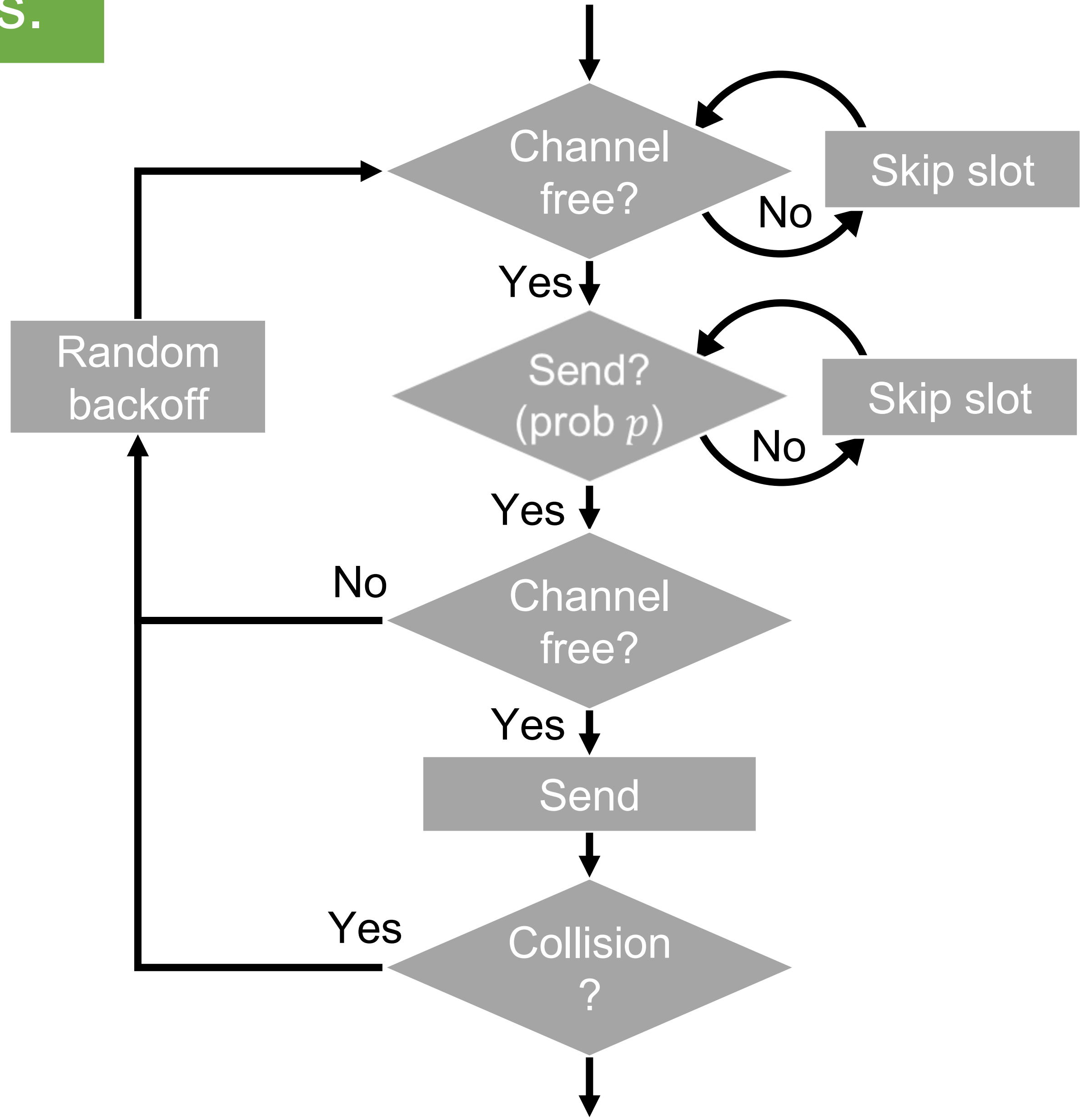
1. Bandwidth efficiency as function of #stations

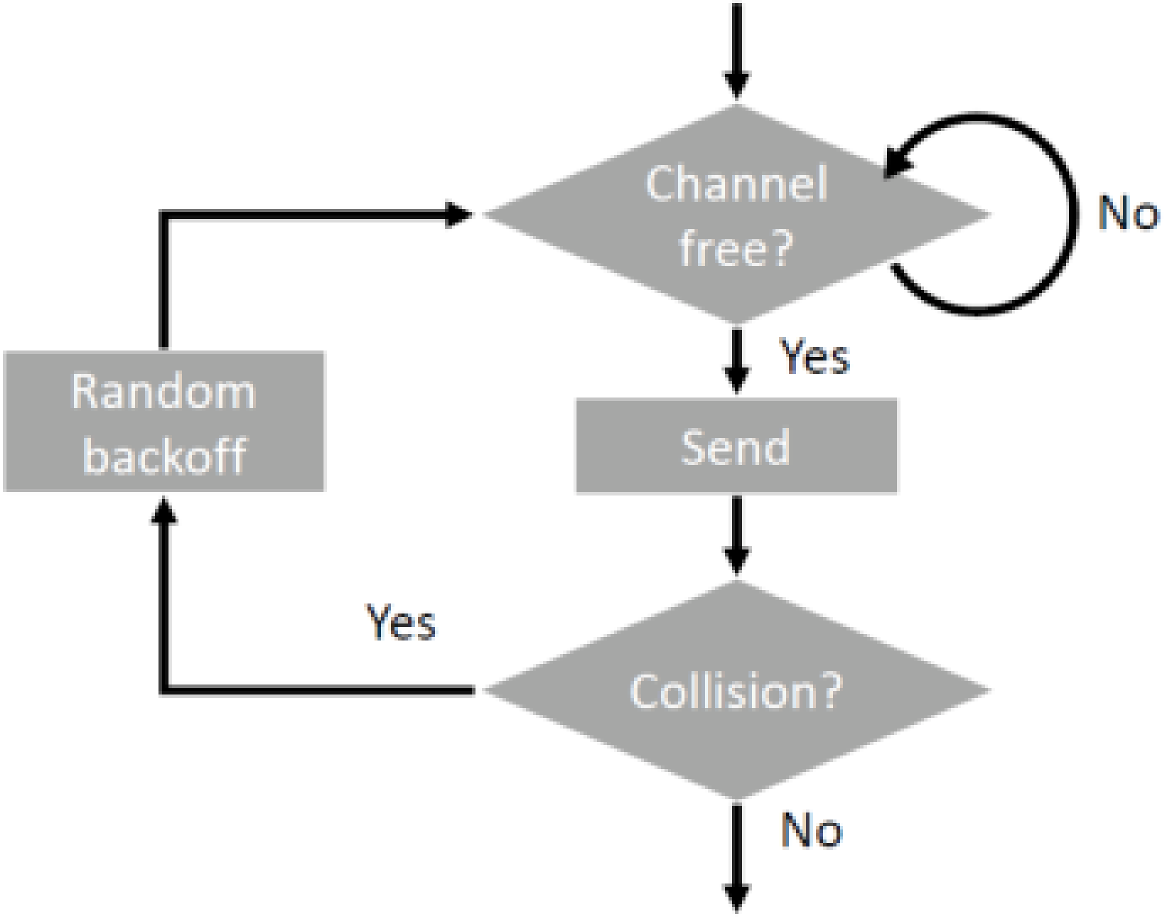


Applies to *slotted* channels.

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

Keeps waiting. Sends frame with probability p.





Q: Which protocol is this?

A: 1-persistent CSMA

802.11 frame

Bytes:							
2	2	6	6	6	2	0-2312	4
Frame control	Duration	Address 1 Destination	Address 2 Source	Address 3	Seq	Data	CRC

Frame control:

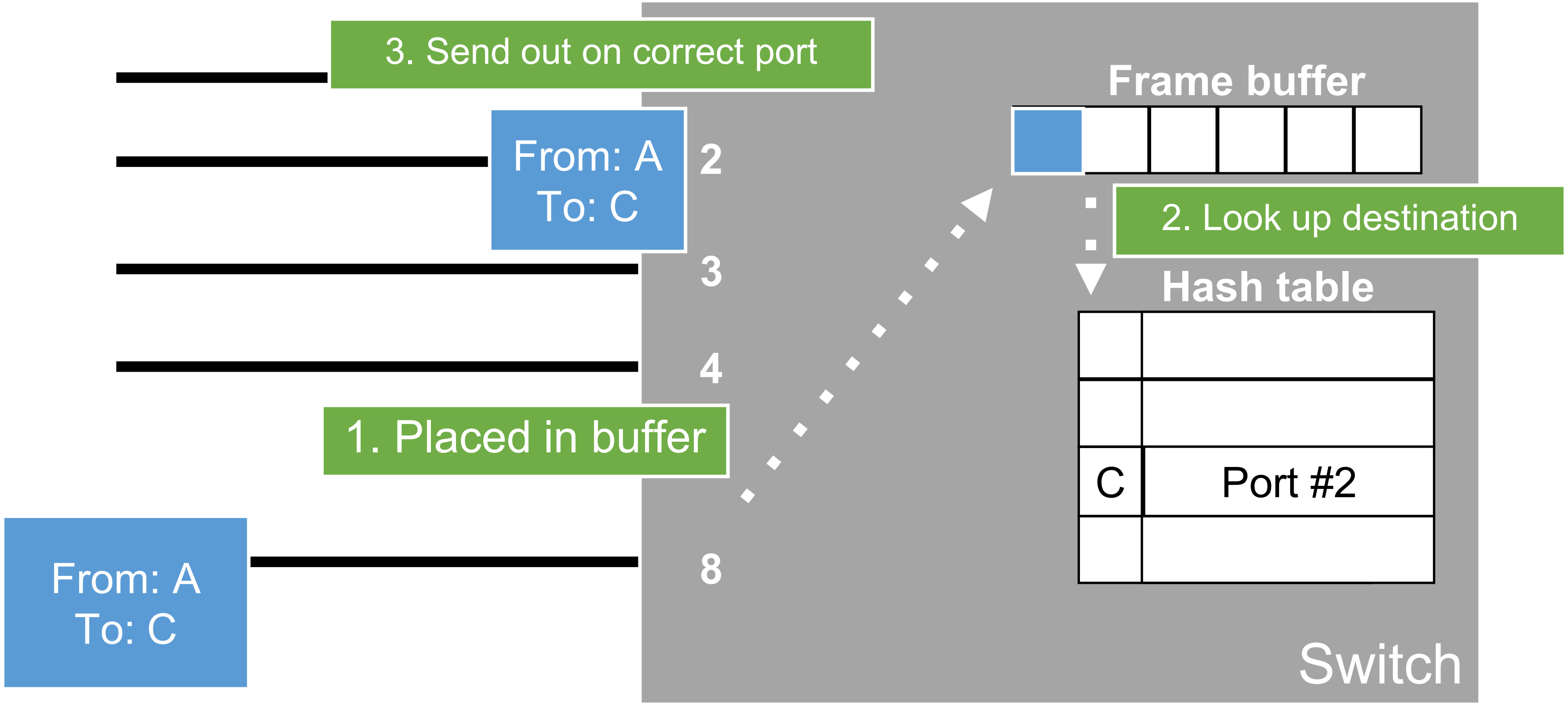
Version	Type	…	To DS	From DS	Power Management	…	More data	Protected

Ethernet frame

	Preamble	Destination address	Source address	T/L	Data	P	CRC
Bytes:	8	6	6	2	0-1500	0-46	4

Ethernet switch

Q: Advantages of switches?



The Network Layer

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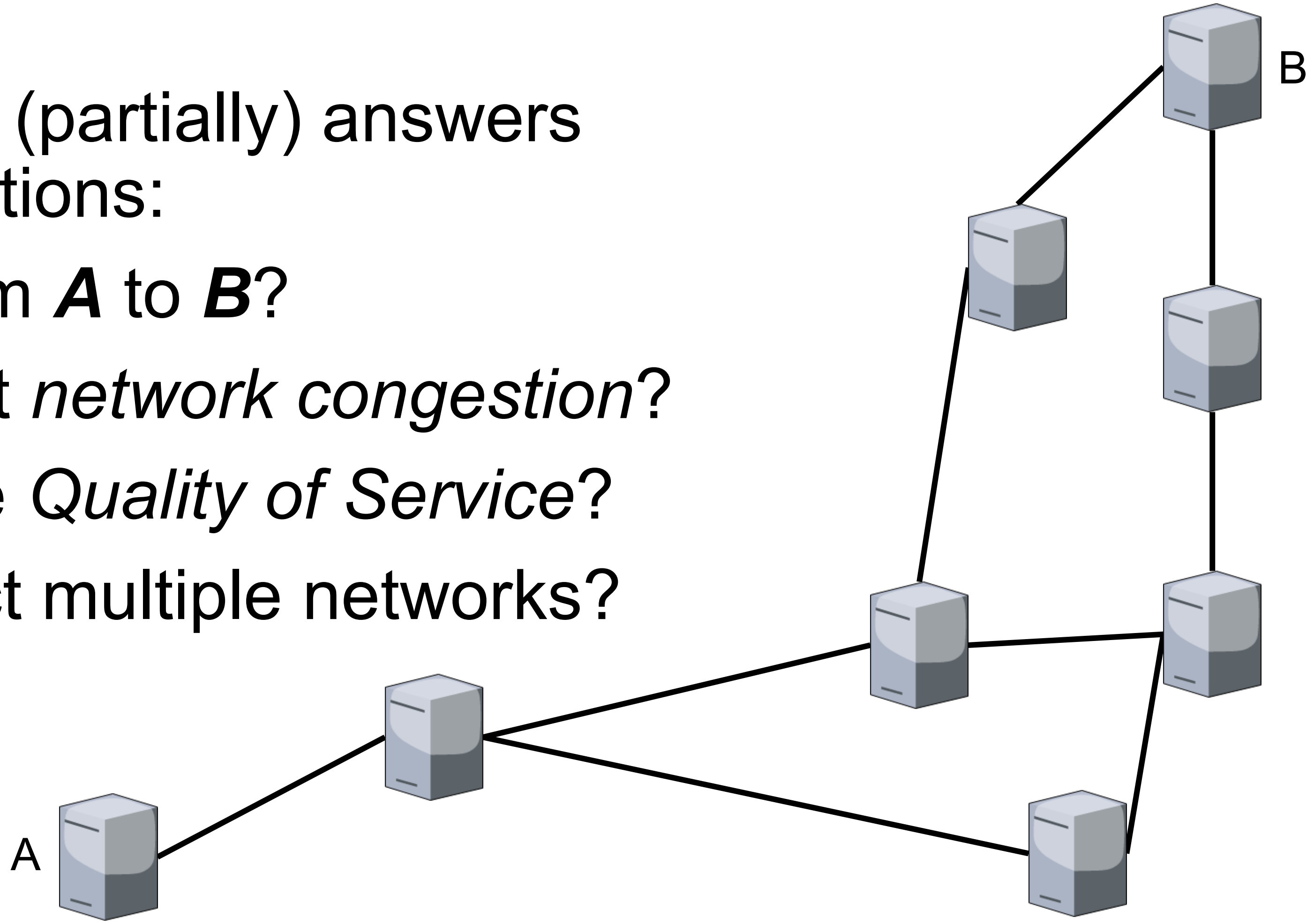
The Network Layer

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?

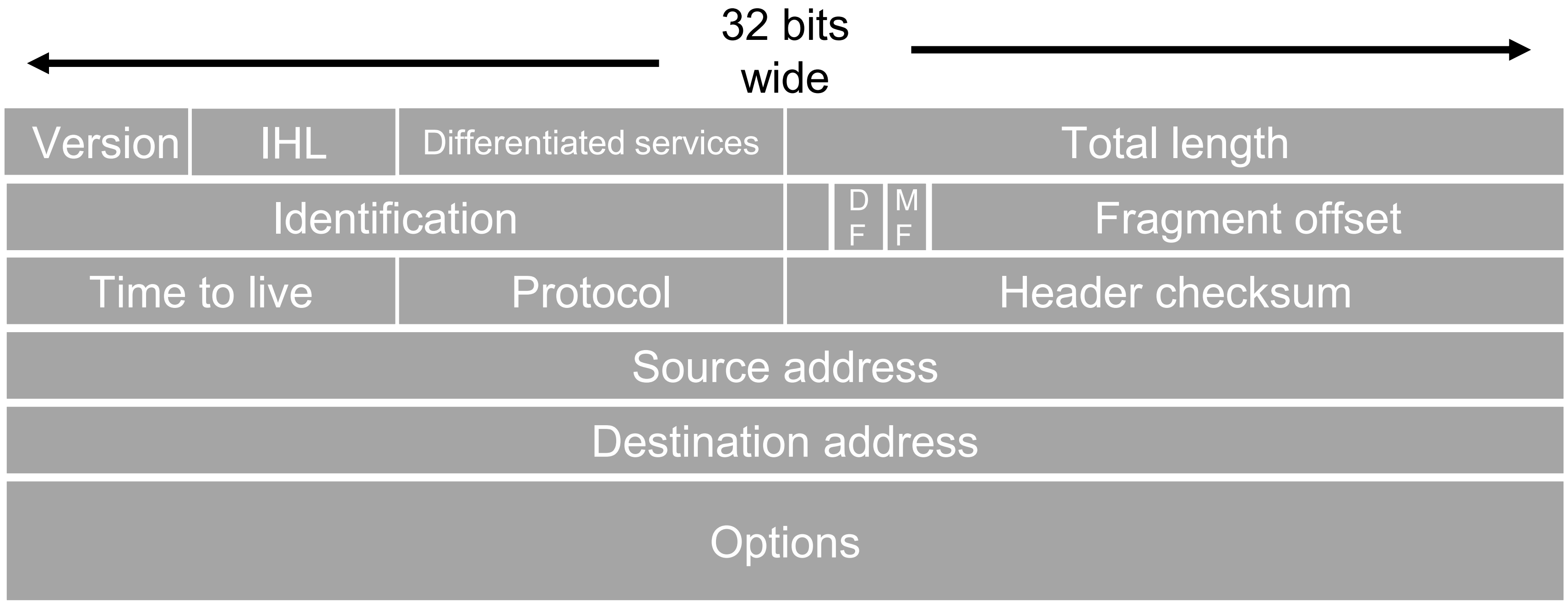


IP version 4

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.

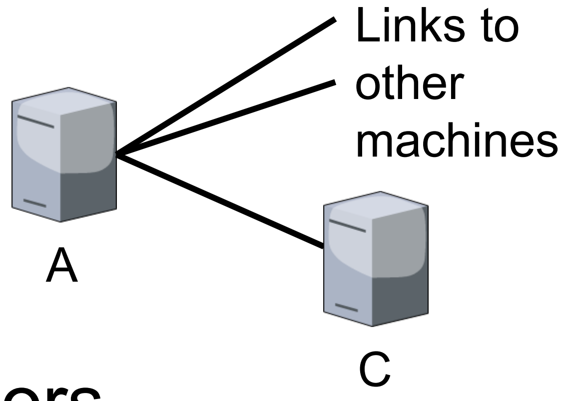
To	Distance	Line
A	7	A
B	59	A
C	0	-
D	75	E
E	1	E
F	103	E

We are directly connected to A

We are station C

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*.

Distance vector A
A, 0
B, 1
C, 7
D, 152
E, 8
F, 110

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*

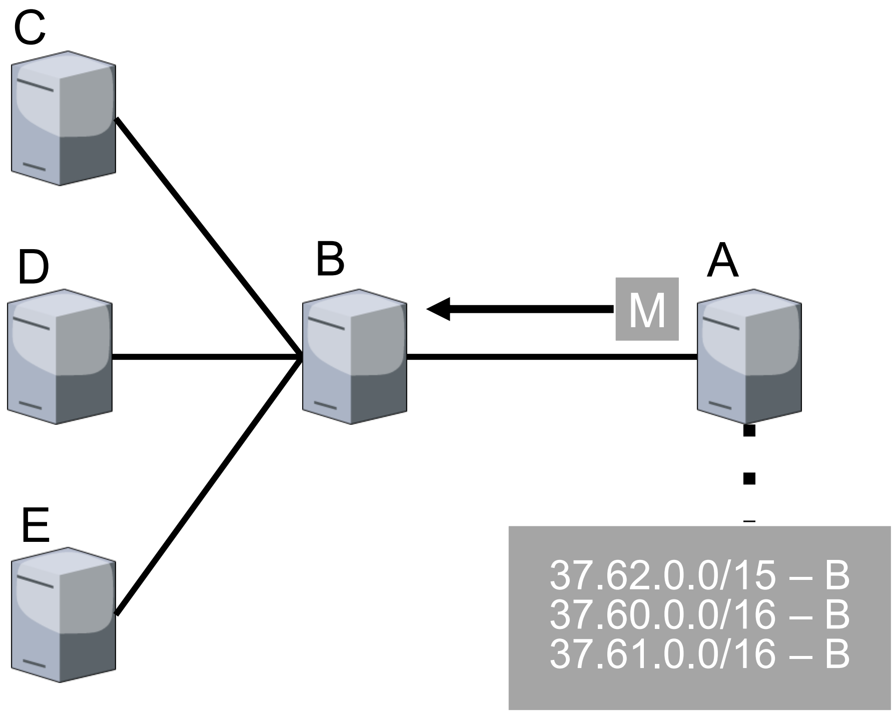
Prefix: 37.60.0.0/16
Subnet mask:
11111111.11111111.00000000.00000000

Internet Protocol - CIDR
Classless InterDomain Routing

TU Delft
37.62.0.0/15
00100101.00111110.00000000.00000000

VU
37.60.0.0/16
00100101.00111100.00000000.00000000

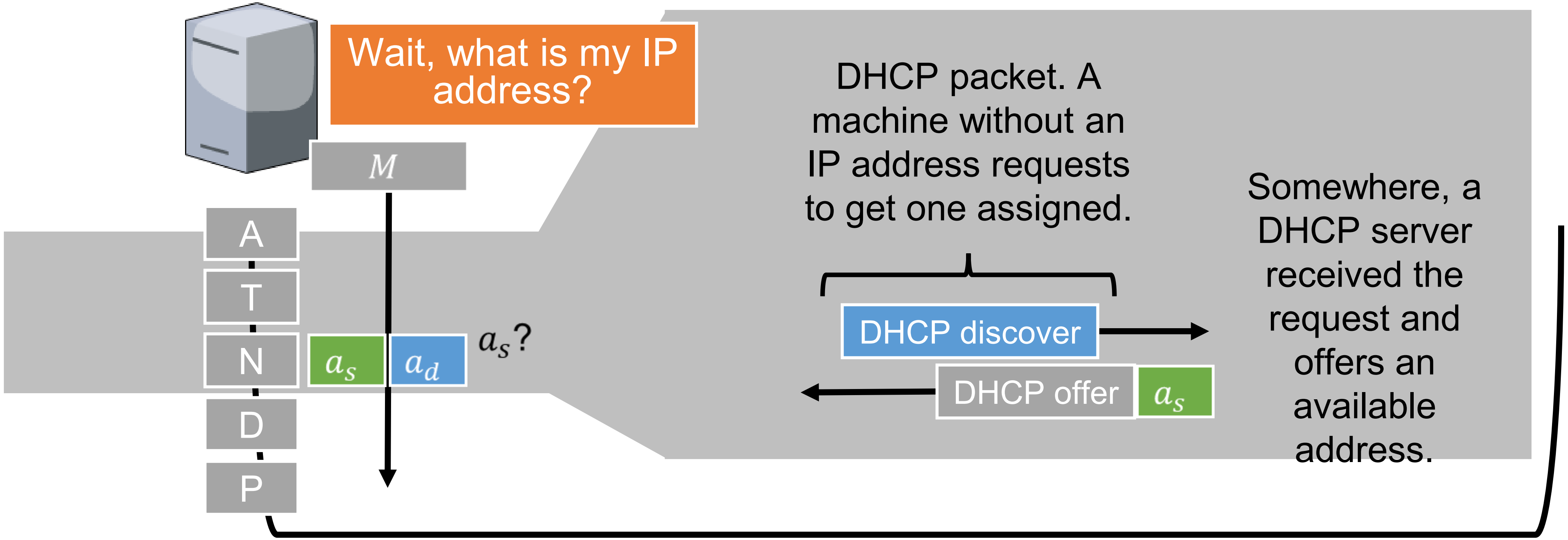
UvA
37.61.0.0/16
00100101.00111101.00000000.00000000



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.

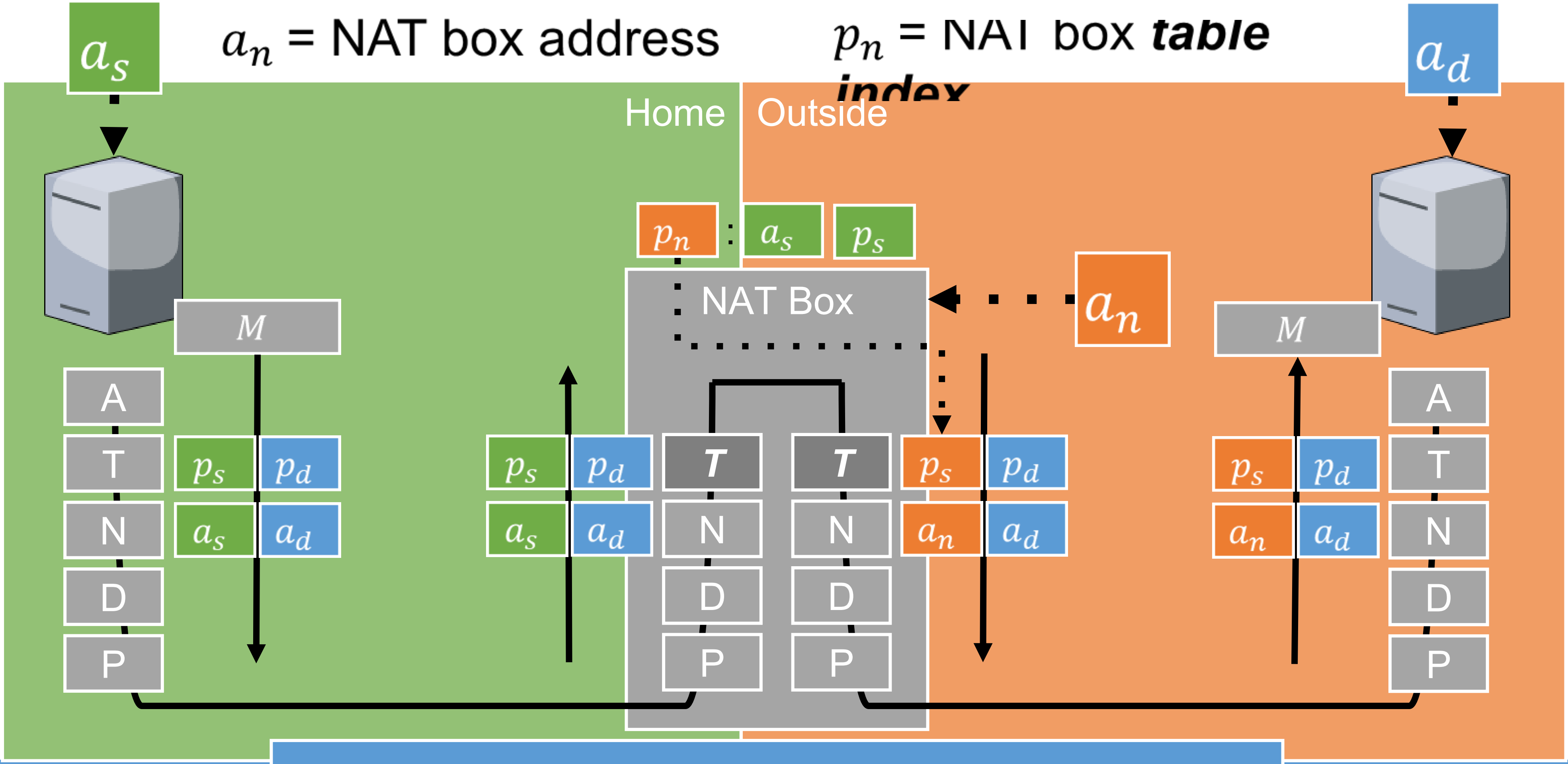


Q: How to send DHCP offer back to machine without an address?

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?

Traffic shaping
Token bucket example

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

Bucket loses 1Mtokens every second.

Full bucket contains 16M tokens.

Incoming token rate also called R

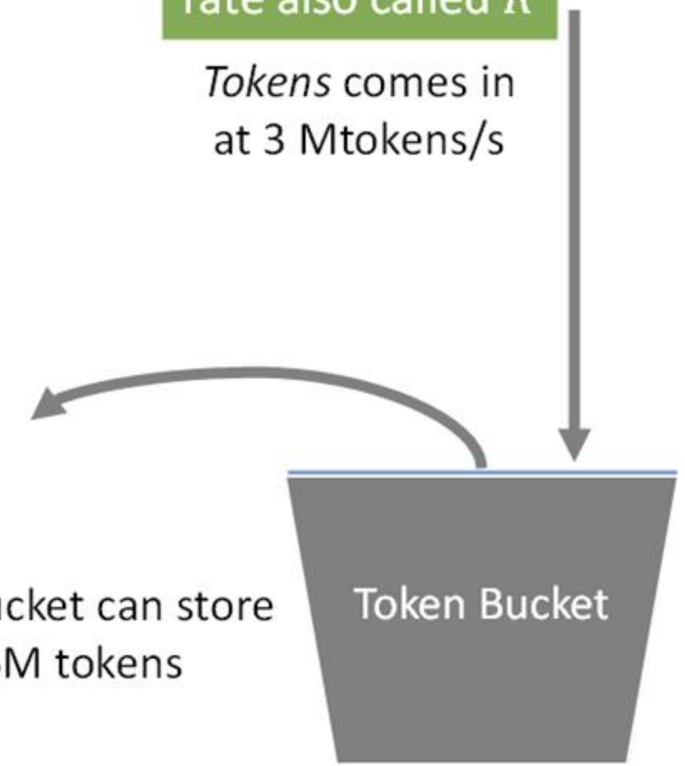
Tokens comes in at 3 Mtokens/s

Maximum sending rate also called M

Machine wants to send 4 MB/s

Storage size also called B

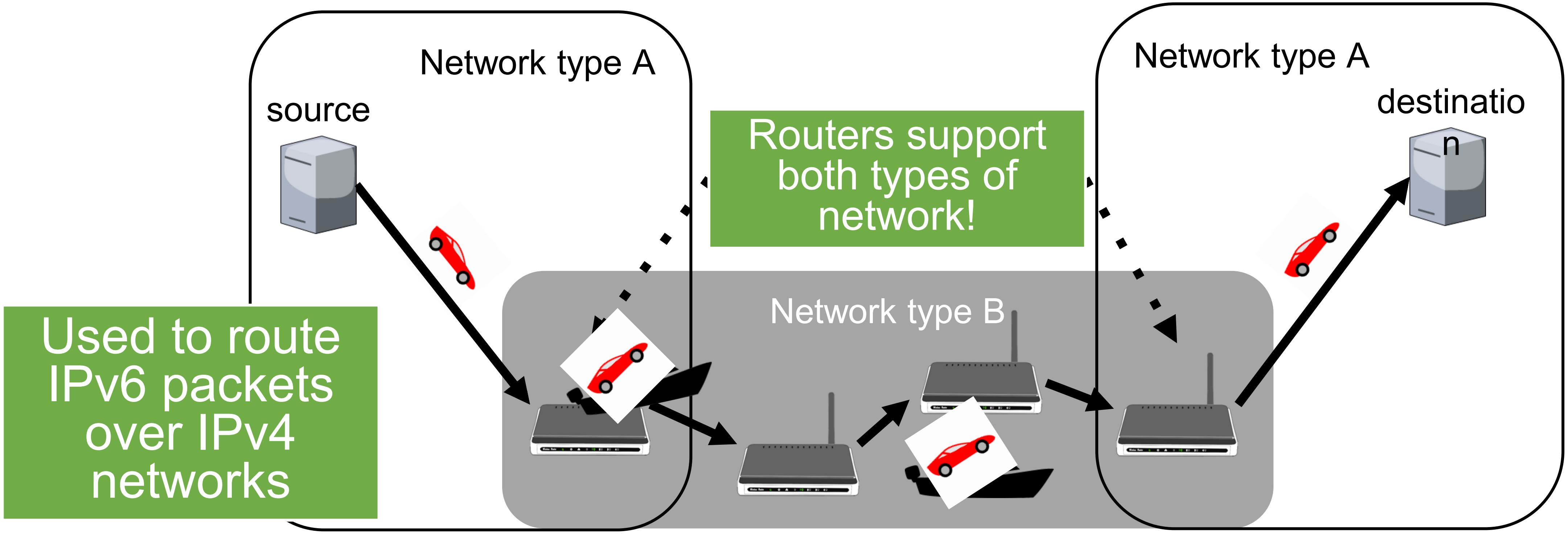
Bucket can store 16M tokens



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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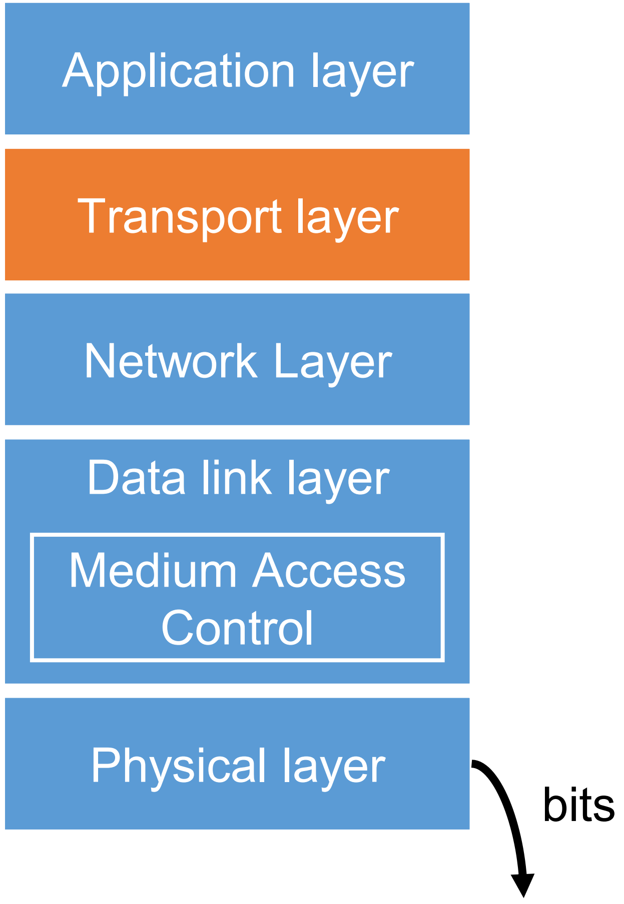
Responsibilities of the Transport Layer

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



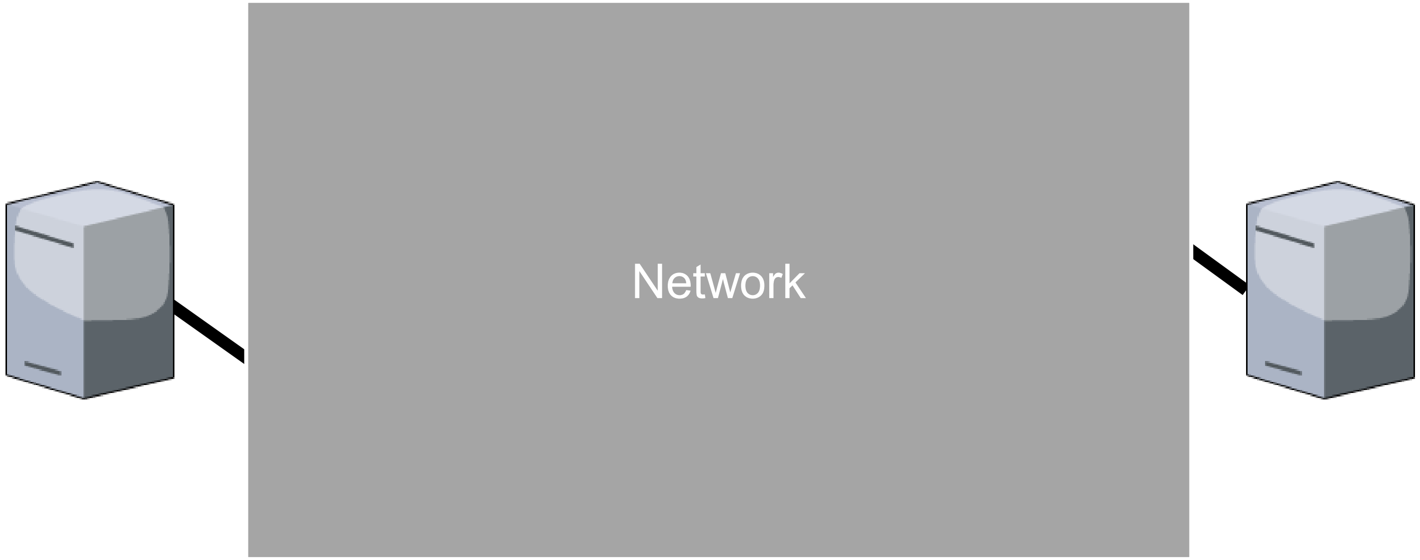
The transport layer Provided services

Runs only on the host and destination

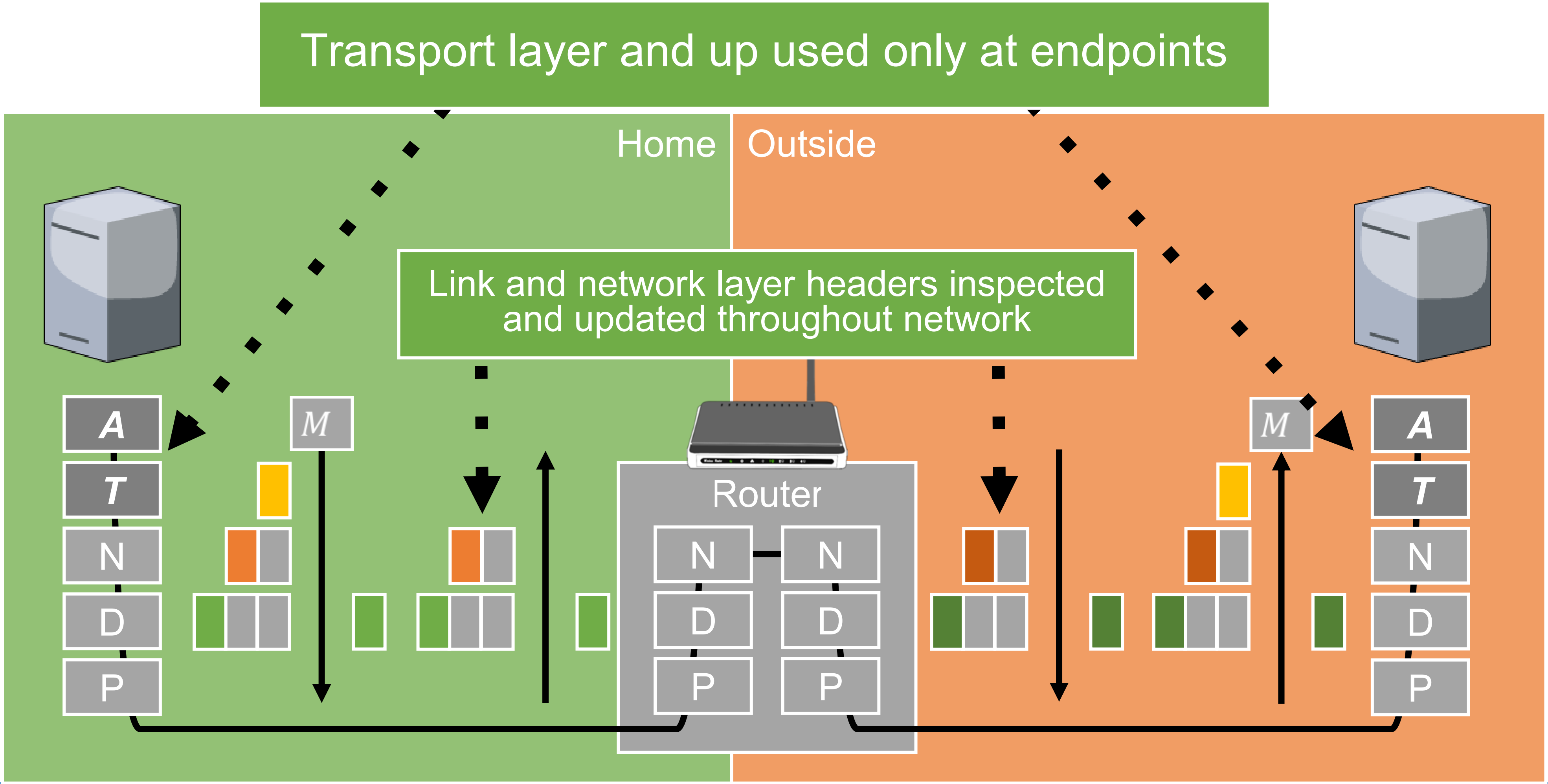
Provides a ***reliable*** data stream over an ***unreliable*** network.

Provides communication between ***applications***.

End-to-End Argument



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.

32 bits

Source port	Destination port
UDP length	UDP checksum

The UDP header

Includes fields from the IP header!

UDP does ***not*** do:

1. Flow control
2. Congestion control
3. Retransmissions

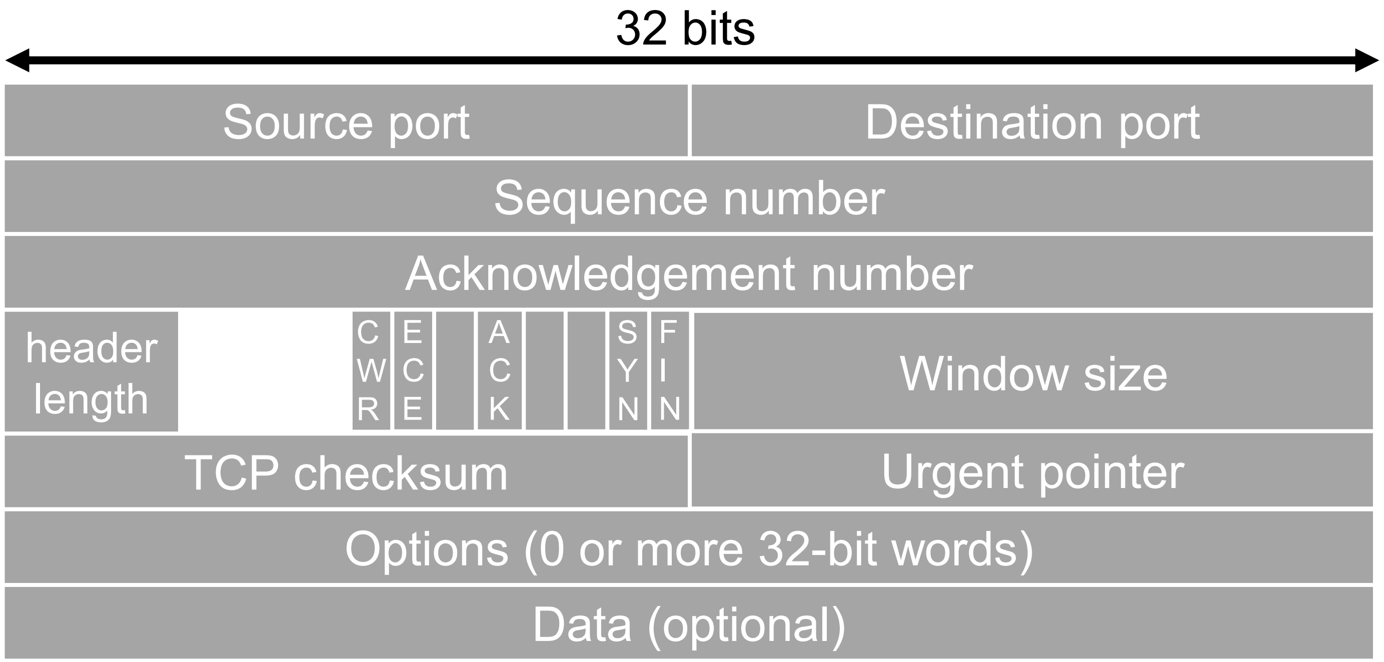
Q: Can you name a service that works well with UDP?

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)



The TCP header

Q: How to calculate total TCP segment size?

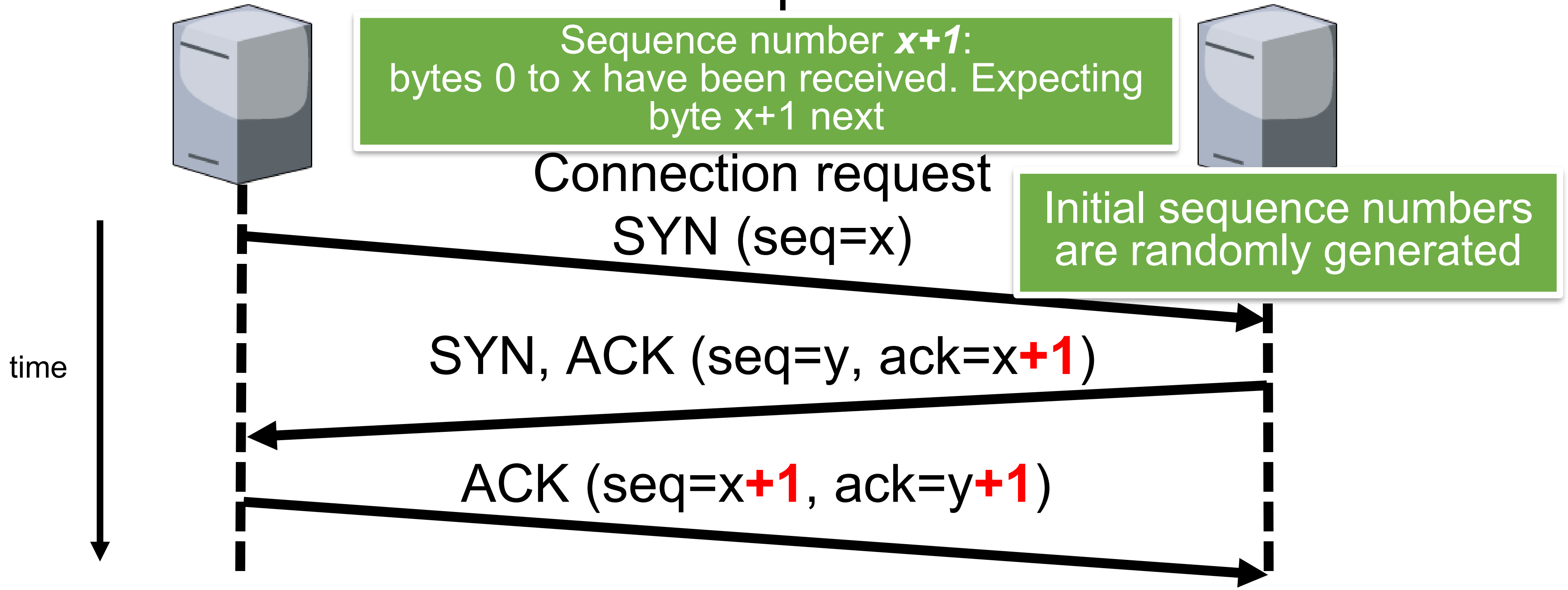
Q: When are packets with 0 data bytes used?

TCP connection establishment
Three-way handshake

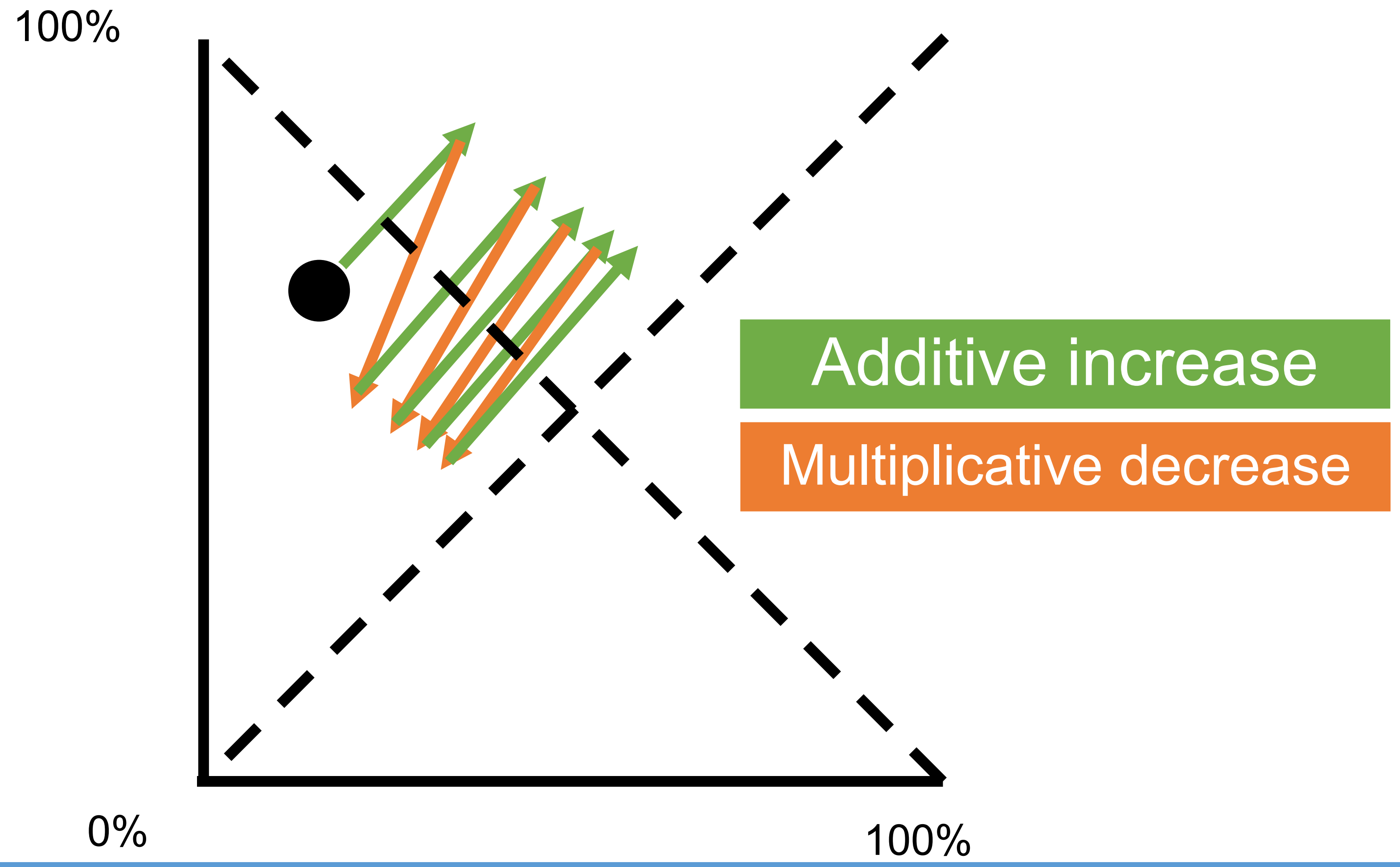
Uses timestamp option to improve performance on high-bandwidth networks

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

*SYN and FIN also have their own sequence numbers.

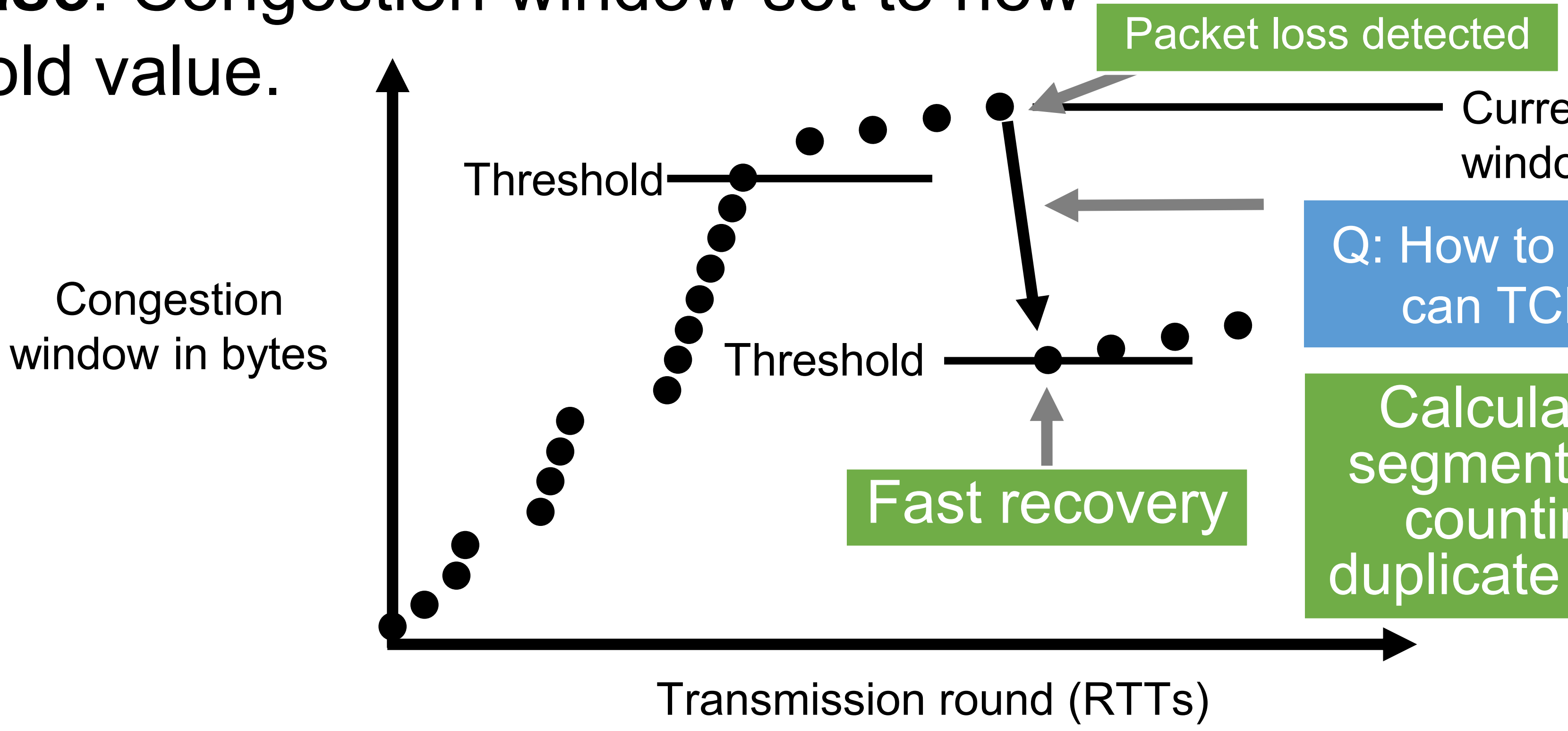


Additive increase
Multiplicative decrease



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

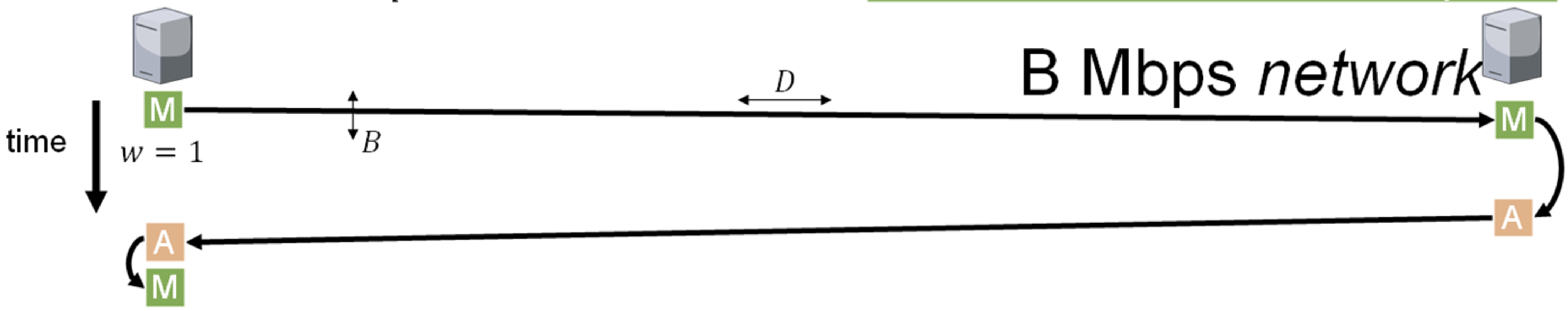
- Frame size (in bits/bytes): f
- Window size (in frames): w
- Bandwidth (max. data rate of physical channel): B_p
- Bandwidth (frames per second): B_f
- Propagation delay (in seconds): D

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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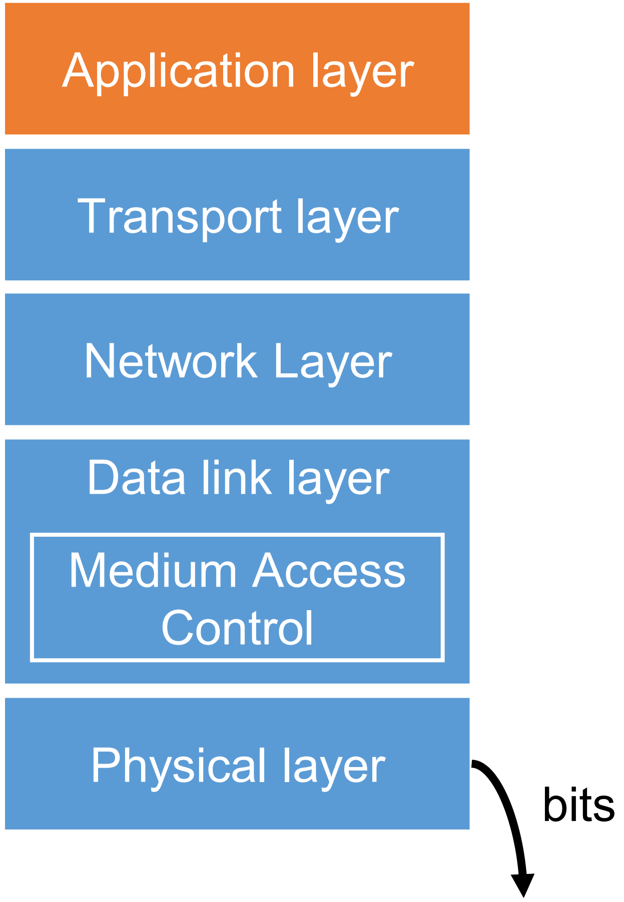
Responsibilities of the Application Layer

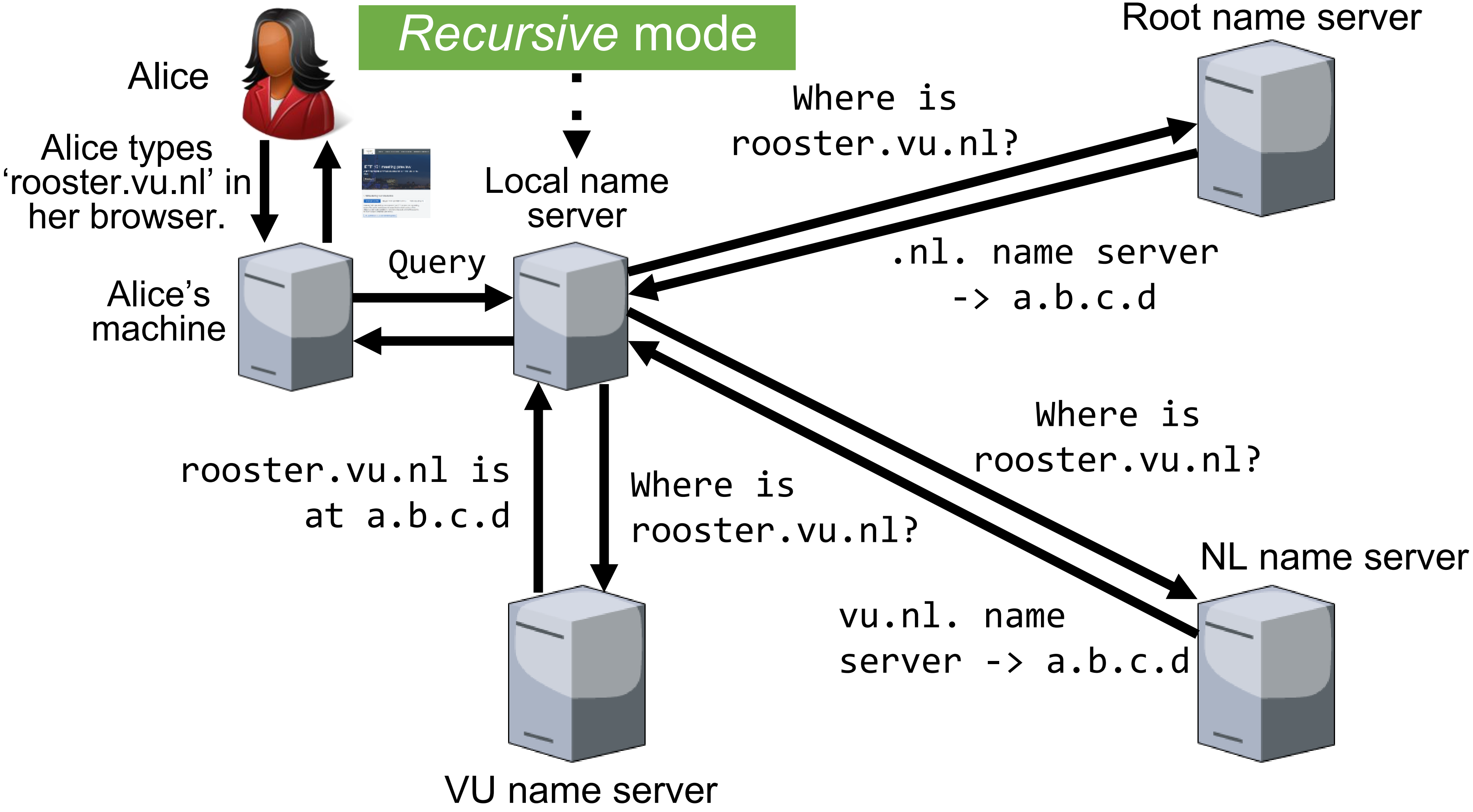
Provide applications that are (indirectly) useful to people

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`?

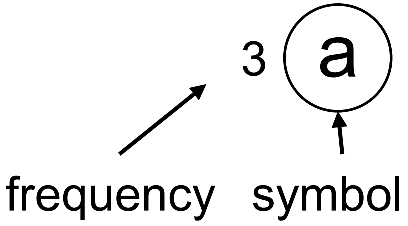
	C	a	t
ASCII	01000011	01100001	01110100

	Q	2	F	0
Base64	010000	110110	000101	110100

11 101 101 100 0111 0110 11 0101 0111 0100 0011 100 11 0010 0001 0000

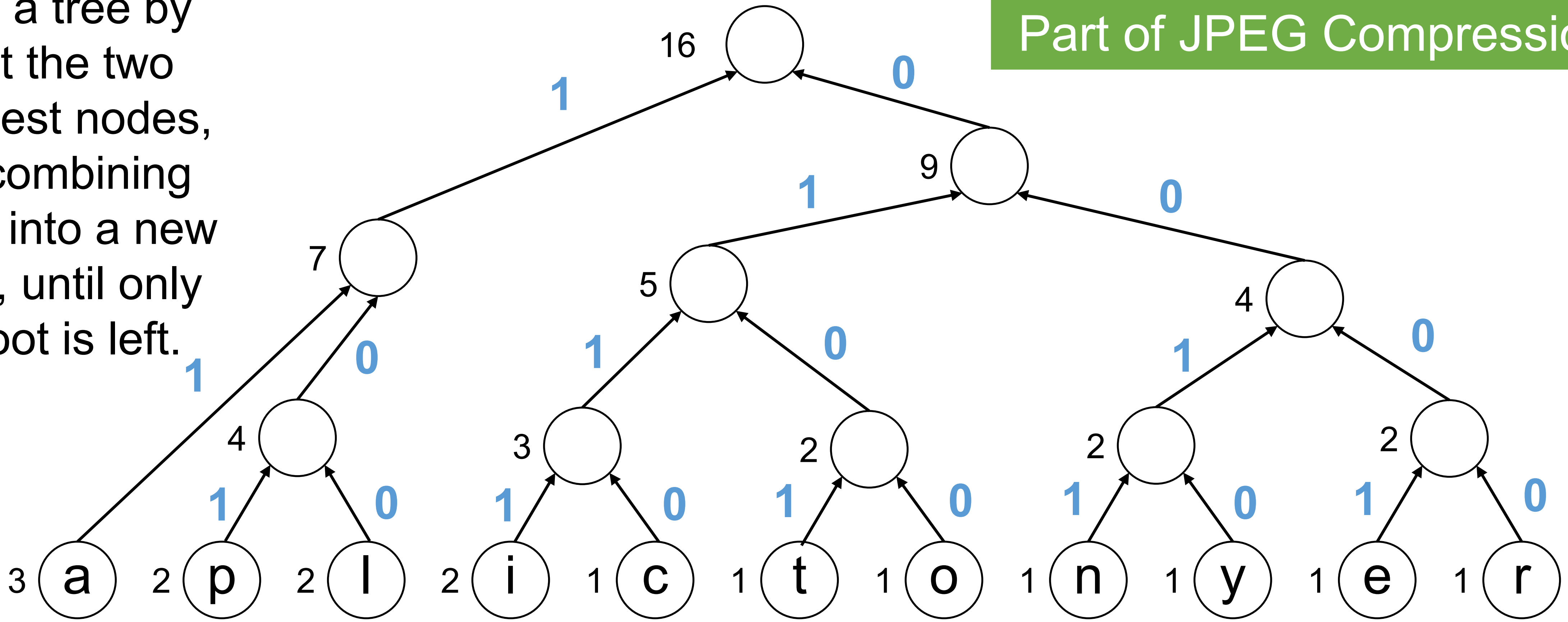
(54 bits) “application layer”

Huffman Encoding



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

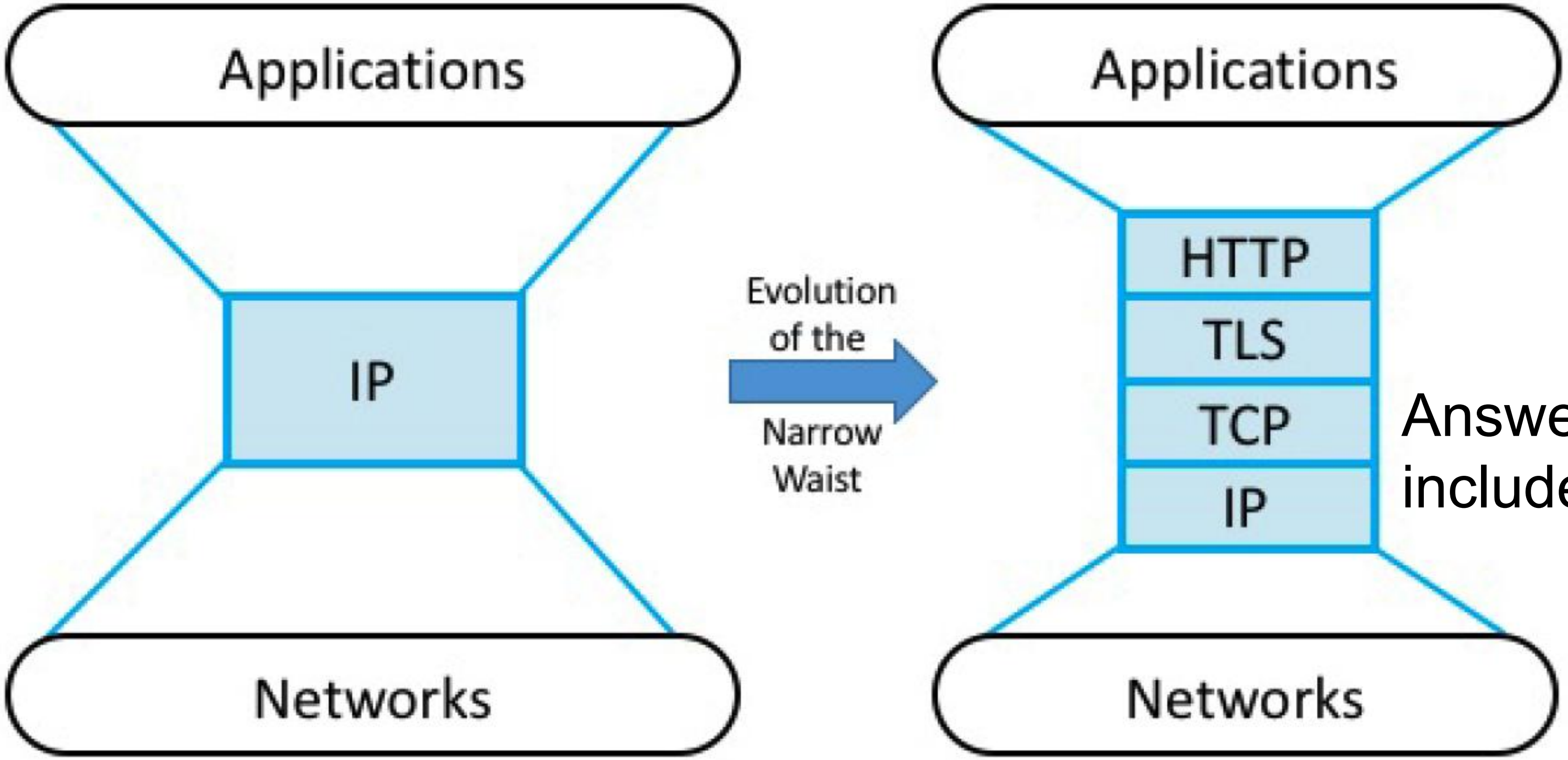
Part of JPEG Compression



E.g., REST

HTTP is the new “narrow waist”

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

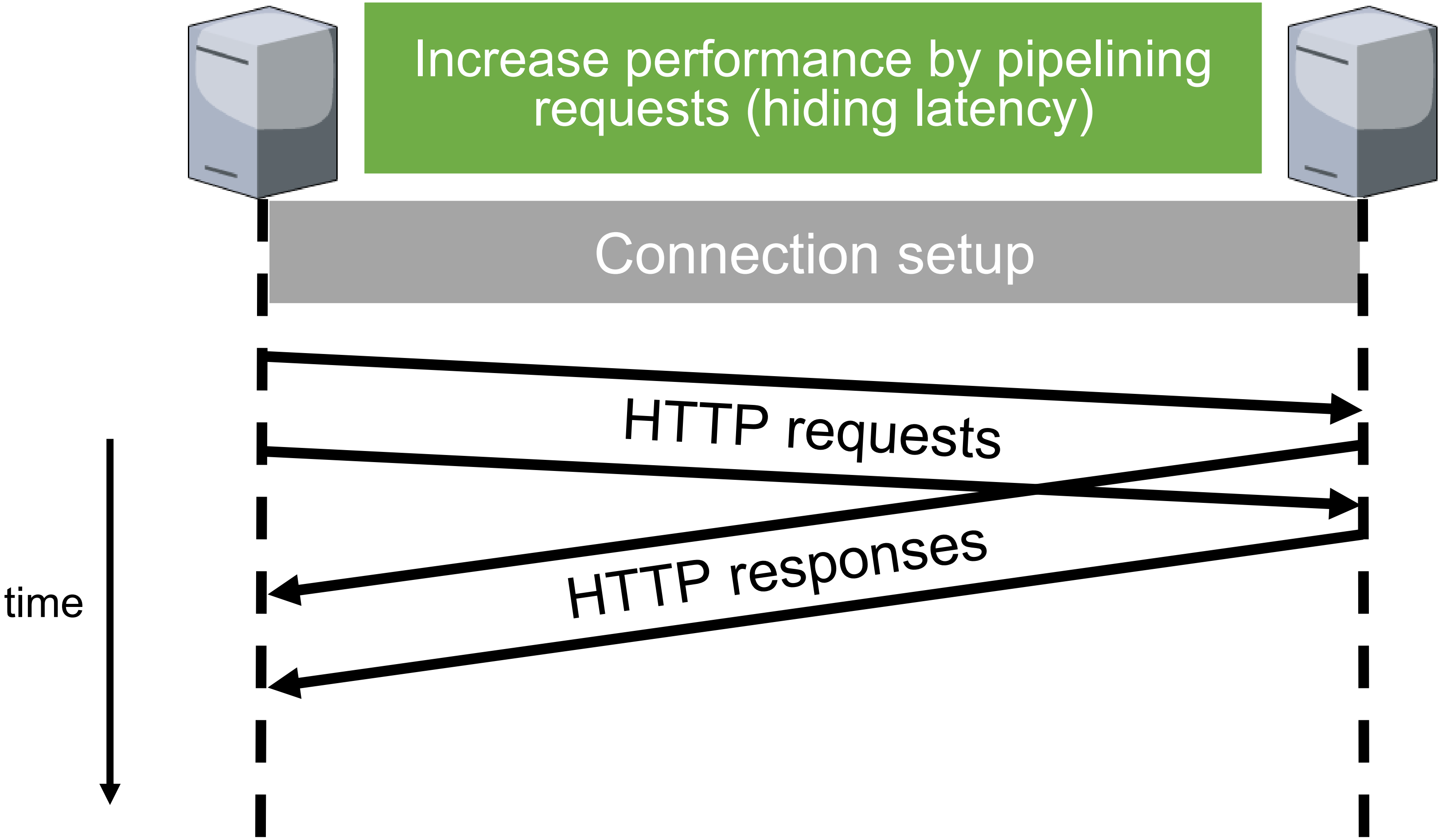


Q: Advantages over using TCP directly?

Answers include:

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

HTTP
Pipelined requests



QUIC orders data per *stream*

RFC 9051

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

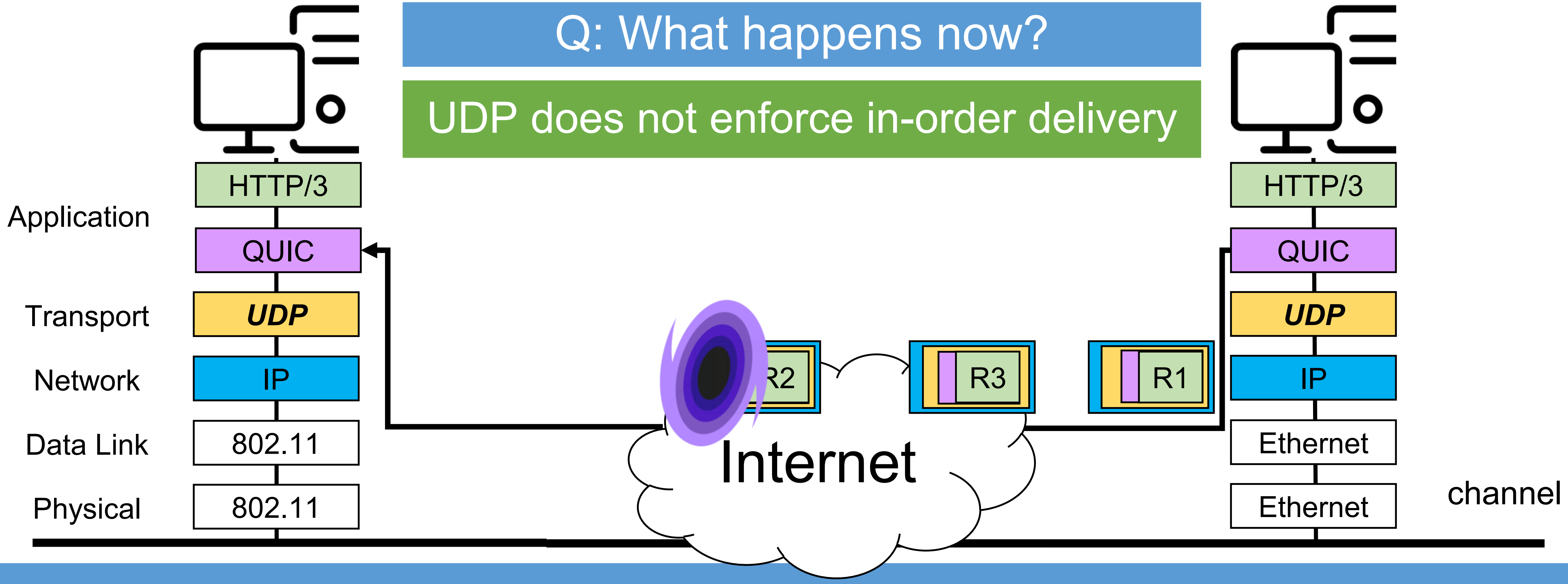
Each HTTP request can use a separate stream; within a stream, data is delivered in order; across streams no such guarantee is made

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

QUIC performs multiplexing, uses UDP

Q: What happens now?

UDP does not enforce in-order delivery



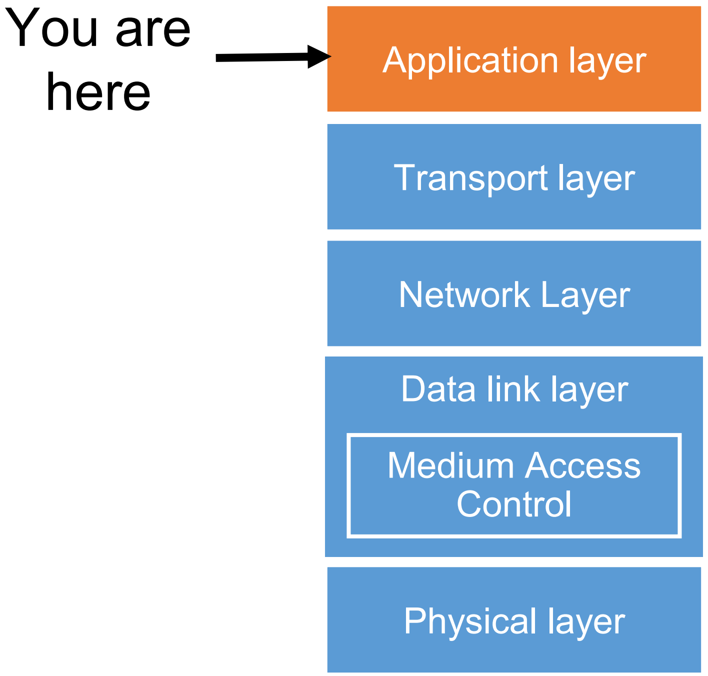
Milestone reached!

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)



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We hope you enjoyed the course and learned a lot!