Network Layer

application	Firefox, `ping`, ...
transport	TCP, UDP, ...
network	IP
link	ethernet, WiFi, ...
physical	electrons, photons, ...

Network Layer

application	Firefox, `ping`, ...
transport	TCP, UDP, ...
network	**IP**
link	ethernet, WiFi, ...
physical	electrons, photons, ...

Routing

Routing
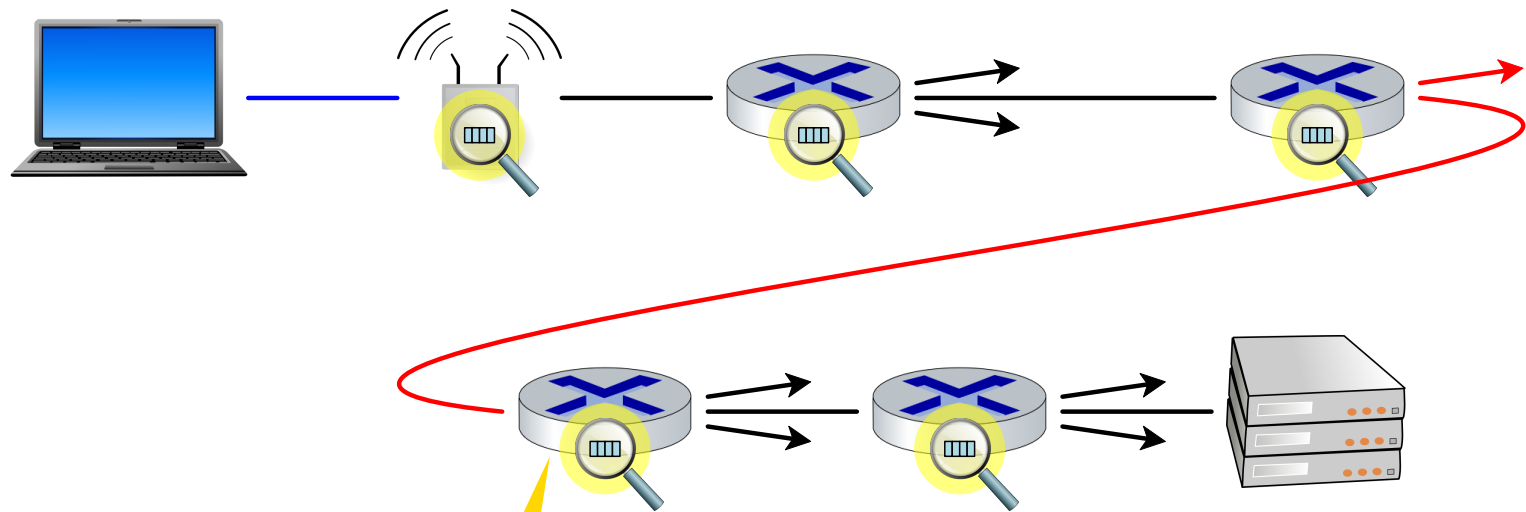

IP header
dest: 155.98.70.1
...
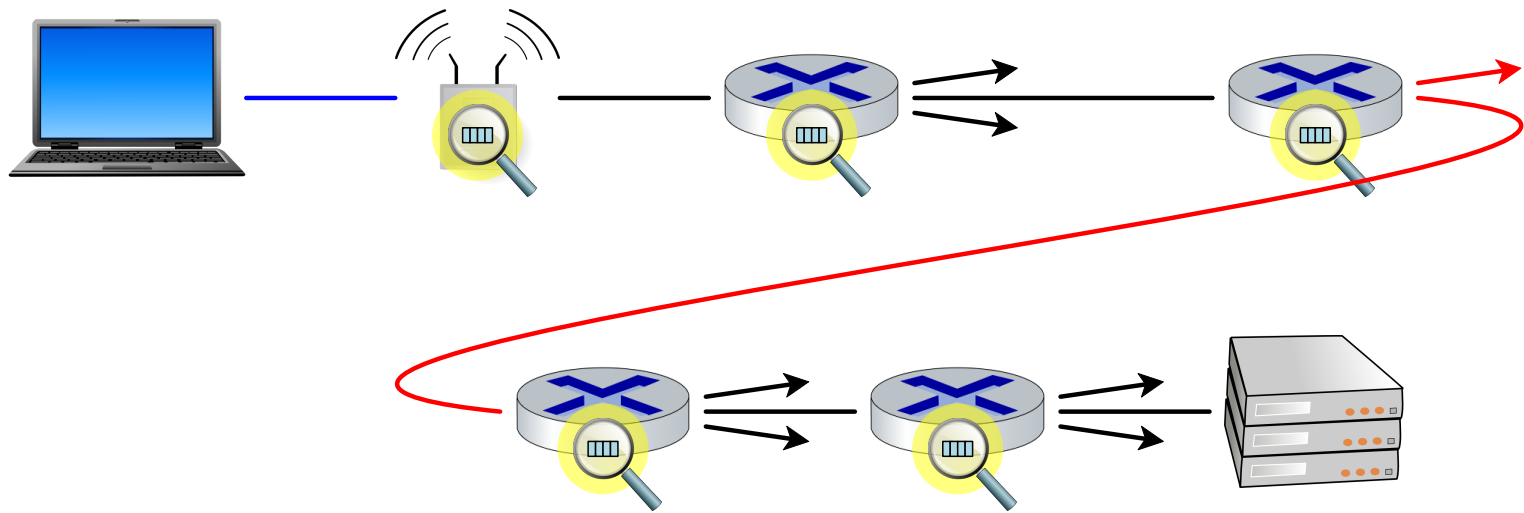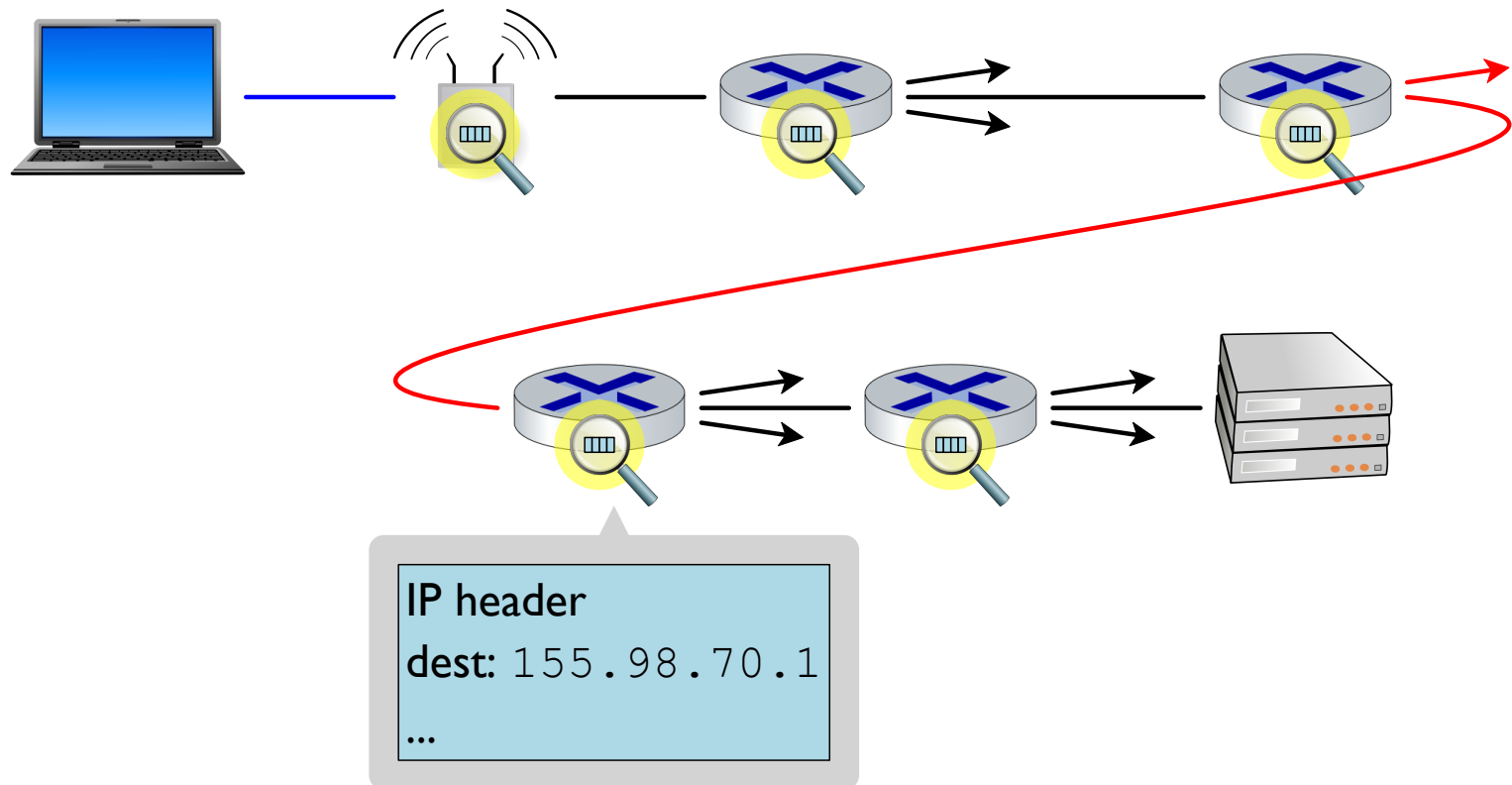
Routing

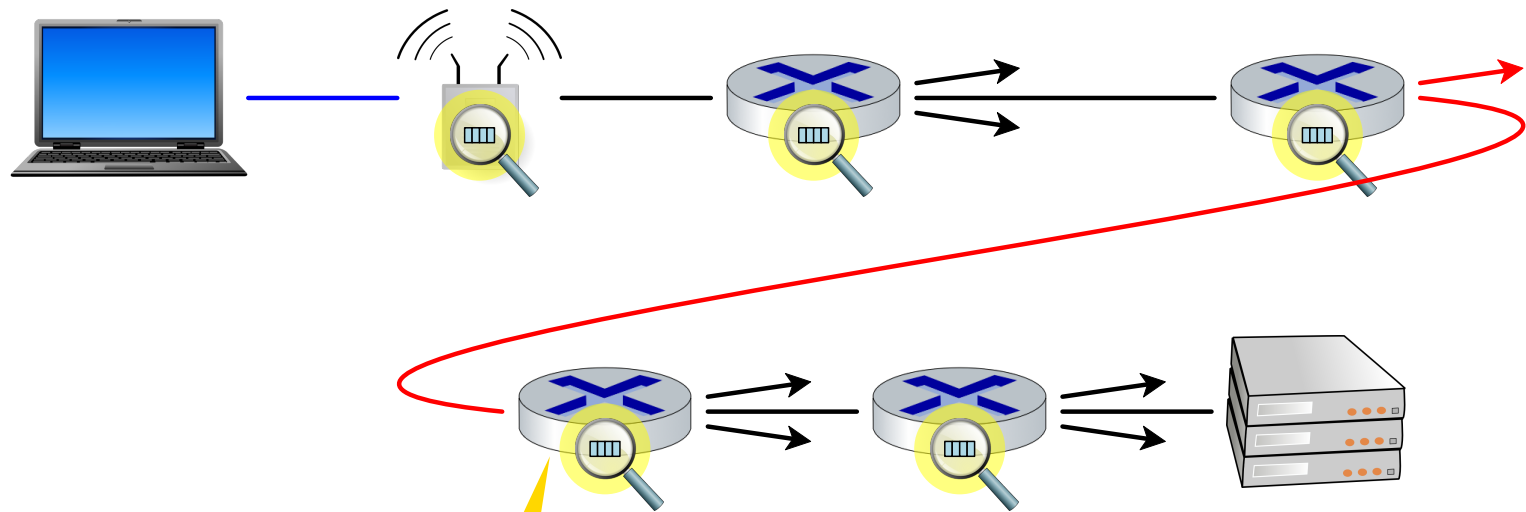Table mapping every address to an output link?

Routing

Table mapping every address to an output link?

That would be a ~4GB table

IP Name Structure

An IPv4 address is 32 bits

In hexadecimal form:

00000000   **to**   FFFFFFFF

IP Name Structure

An IPv4 address is 32 bits

In hexadecimal form:

      `00 00 00 00` **to** `FF FF FF FF`

In dotted-decimal form:

      `0.0.0.0` **to** `255.255.255.255`

IP Name Structure

Hosts that are physically close tend to have similar IP addresses

`thistle.cs.utah.edu`	`155.98.69.112`	my office
`shanghai.cs.utah.edu`	`155.98.69.200`	my office
`rains.cs.utah.edu`	`155.98.68.106`	my office
`thebes.cs.utah.edu`	`155.98.65.57`	KSoC
`memphis.cs.utah.edu`	`155.98.65.56`	KSoC
`www.utah.edu`	`155.98.186.21`	UofU
`www.cs.utah.edu`	`141.193.213.11`	Wordpress

Every `155.98.X.X` address is on campus here

`155.98.0.0/16`

IP Name Structure

Hosts that are physically close tend to have similar IP addresses

`thistle.cs.utah.edu`	`155.98.69.112`	my office
`shanghai.cs.utah.edu`	`155.98.69.200`	my office
`rains.cs.utah.edu`	`155.98.68.106`	my office
`thebes.cs.utah.edu`	`155.98.65.57`	KSoC
`memphis.cs.utah.edu`	`155.98.65.56`	KSoC
`www.utah.edu`	`155.98.186.21`	UofU
`www.cs.utah.edu`	`141.193.213.11`	Wordpress

Every `155.98.X.X` address is on campus here

IP prefix `155.98.0.0/16`

IP Name Structure

Hosts that are physically close tend to have similar IP addresses

`thistle.cs.utah.edu`	`155.98.69.112`	my office
`shanghai.cs.utah.edu`	`155.98.69.200`	my office
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`www.utah.edu`	`155.98.186.21`	UofU
`www.cs.utah.edu`	`141.193.213.11`	Wordpress

Every `155.98.X.X` address is on campus here

IP prefix `155.98.0.0/16` number of bits for prefix

IP Name Structure

Hosts that are physically close tend to have similar IP addresses

`thistle.cs.utah.edu`	`155.98.69.112`	my office
`shanghai.cs.utah.edu`	`155.98.69.200`	my office
`rains.cs.utah.edu`	`155.98.68.106`	my office
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`www.utah.edu`	`155.98.186.21`	UofU
`www.cs.utah.edu`	`141.193.213.11`	Wordpress

`155.98.68.X` or `155.98.69.X` ⇒ KSoC untrusted network

`155.98.68.0/23`

IP Name Structure

Hosts that are physically close tend to have similar IP addresses

`thistle.cs.utah.edu`	`155.98.69.112`	my office
`shanghai.cs.utah.edu`	`155.98.69.200`	my office
`rains.cs.utah.edu`	`155.98.68.106`	my office
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`www.cs.utah.edu`	`141.193.213.11`	Wordpress

The modern hierarchical organization of addresses is called

Classless Inter-Domain Routing (CIDR)

Addresses

Some address lookups to try:

```
$ dig lab1-1.eng.utah.edu

$ dig lab1-10.eng.utah.edu

$ dig www.apple.com

$ dig apple.com MX
```
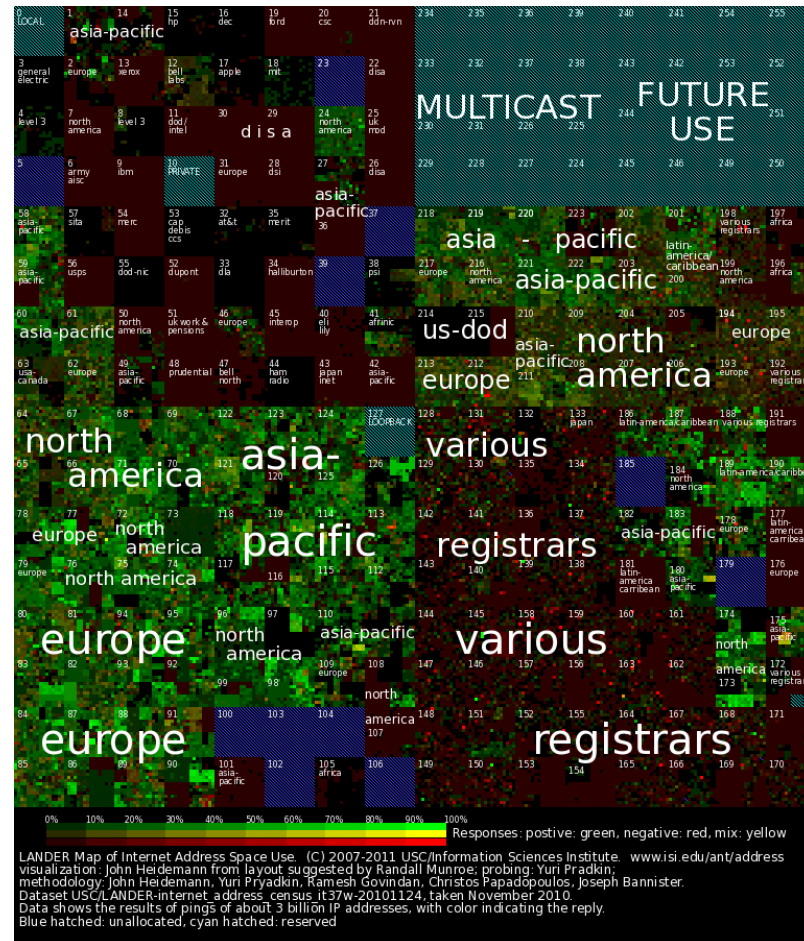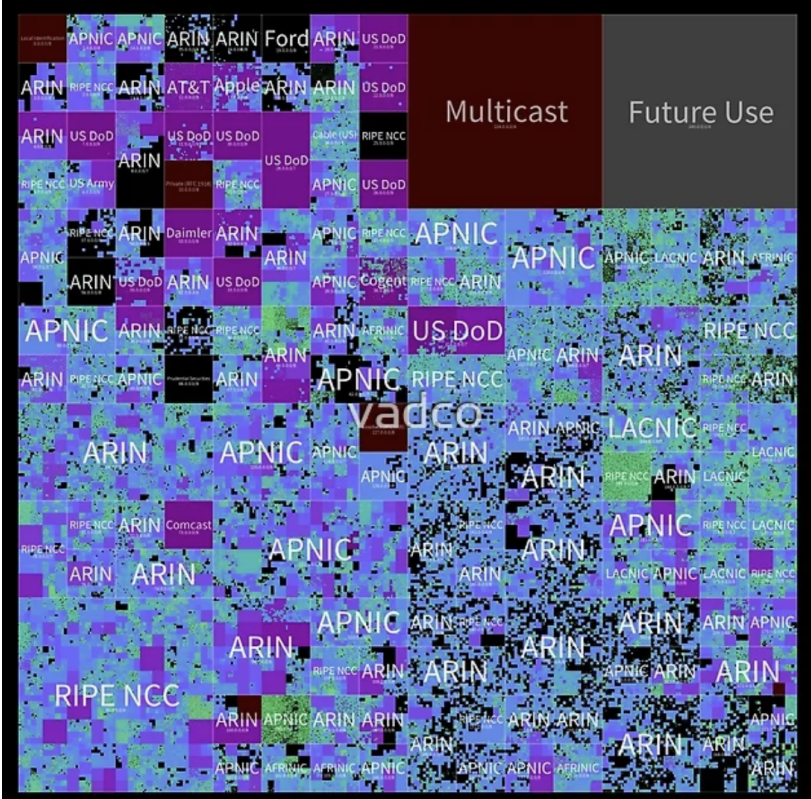
XKCD Map of the Internet 2006

`https://xkcd.com/195/`
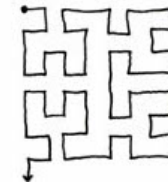
Map of the Internet 2010

Map of the Internet 2023

`https://www.redbubble.com/`

Map of the Internet 2023

See also
https://www.iana.org/numbers

https://www.redbubble.com/
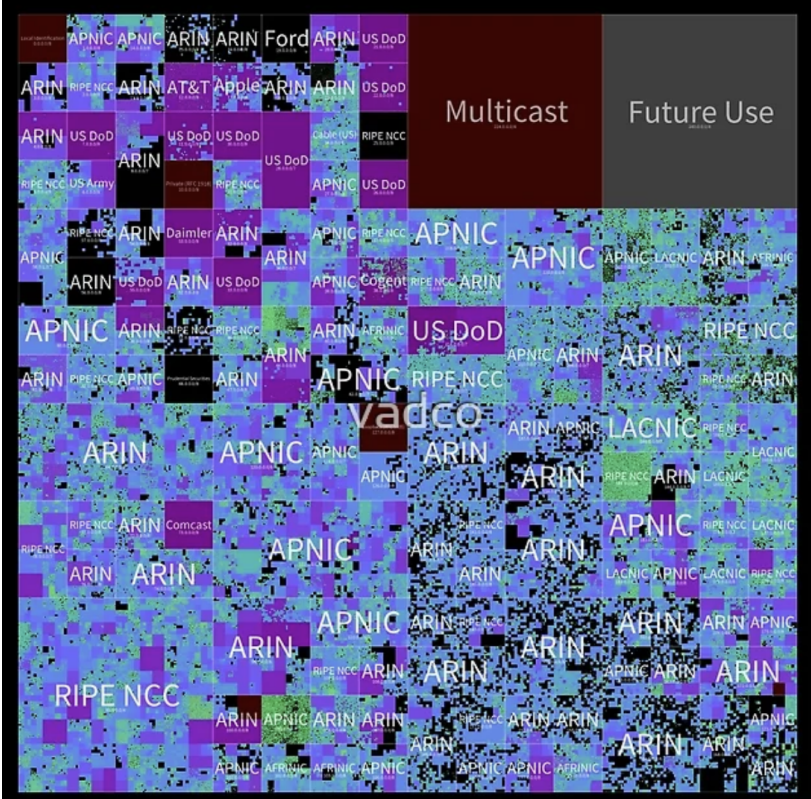
Map of the Internet 2023

One IP address
~ $50

https://www.redbubble.com/
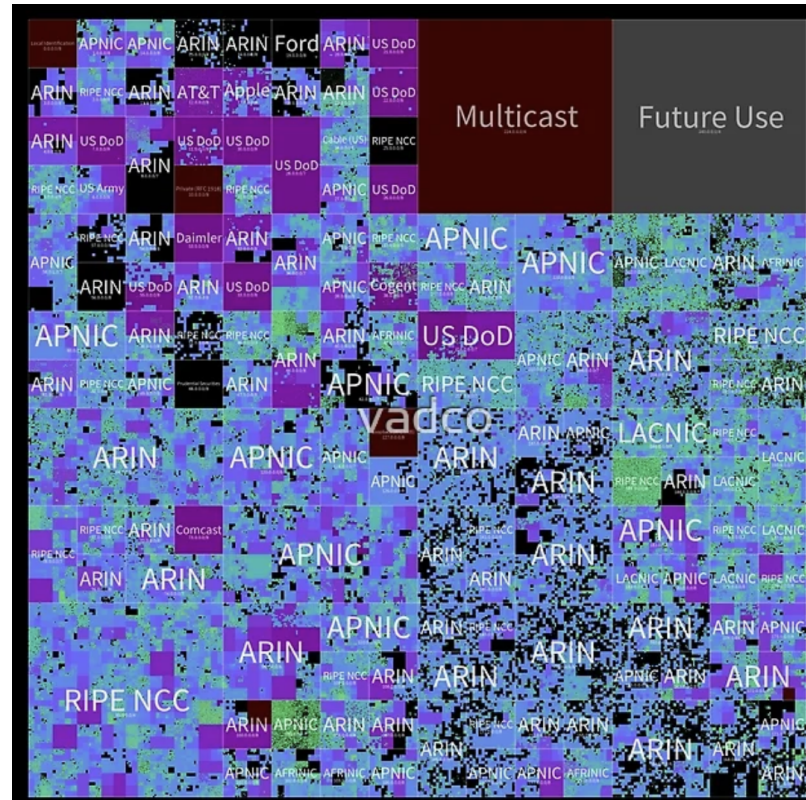
University of Utah AS17055

IPv4:

128.110.0.0/16	65,536
128.110.100.0/24	256
128.110.152.0/22	1,024
128.110.156.0/24	256
128.110.216.0/21	2,048
128.110.96.0/22	1,024
155.100.0.0/16	65,536
155.101.0.0/16	65,536
155.101.66.0/24	256
155.97.0.0/16	65,536
155.98.0.0/16	65,536
155.98.32.0/20	4,096
155.99.0.0/16	65,536
155.99.144.0/24	256
192.5.12.0/24	256
198.60.30.0/23	512
199.104.93.0/24	256
204.99.128.0/24	256
204.99.160.0/20	4,096

https://ipinfo.io/AS17055

University of Utah AS17055

IPv6:

`2604:c340::/32`   79,228,162,514,264,337,593,543,950,336

Special Addresses

Local network use:

```
10.0.0.0/8

172.16.0.0/12

192.168.0.0/16
```

Loopback:

```
127.0.0.1
```

Subnet broadcast:

```
255.255.255.255
```

Special Addresses

Local network use:

    10.0.0.0/8

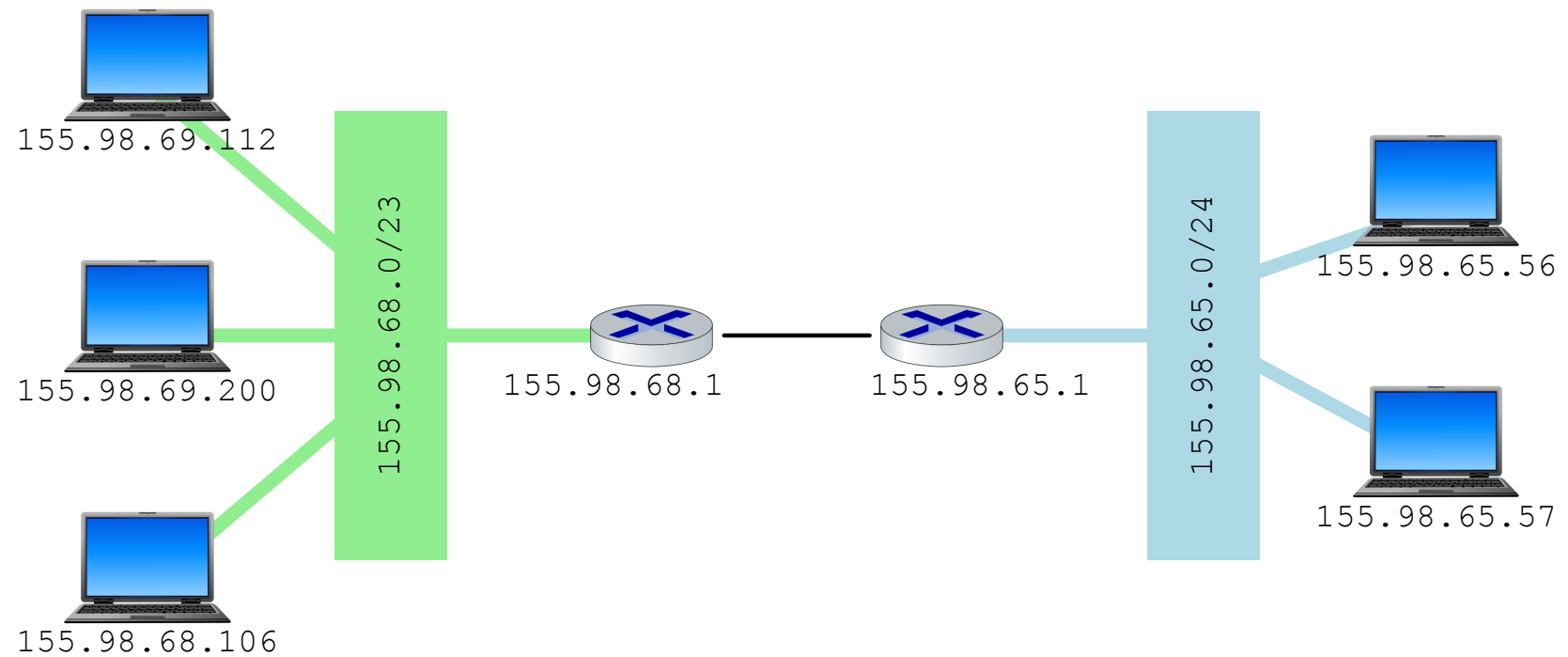   172.16.0.0/12

    192.168.0.0/16

Loopback:

    127.0.0.1

Usually also can use all 1 bits or all 0 bits after a prefix

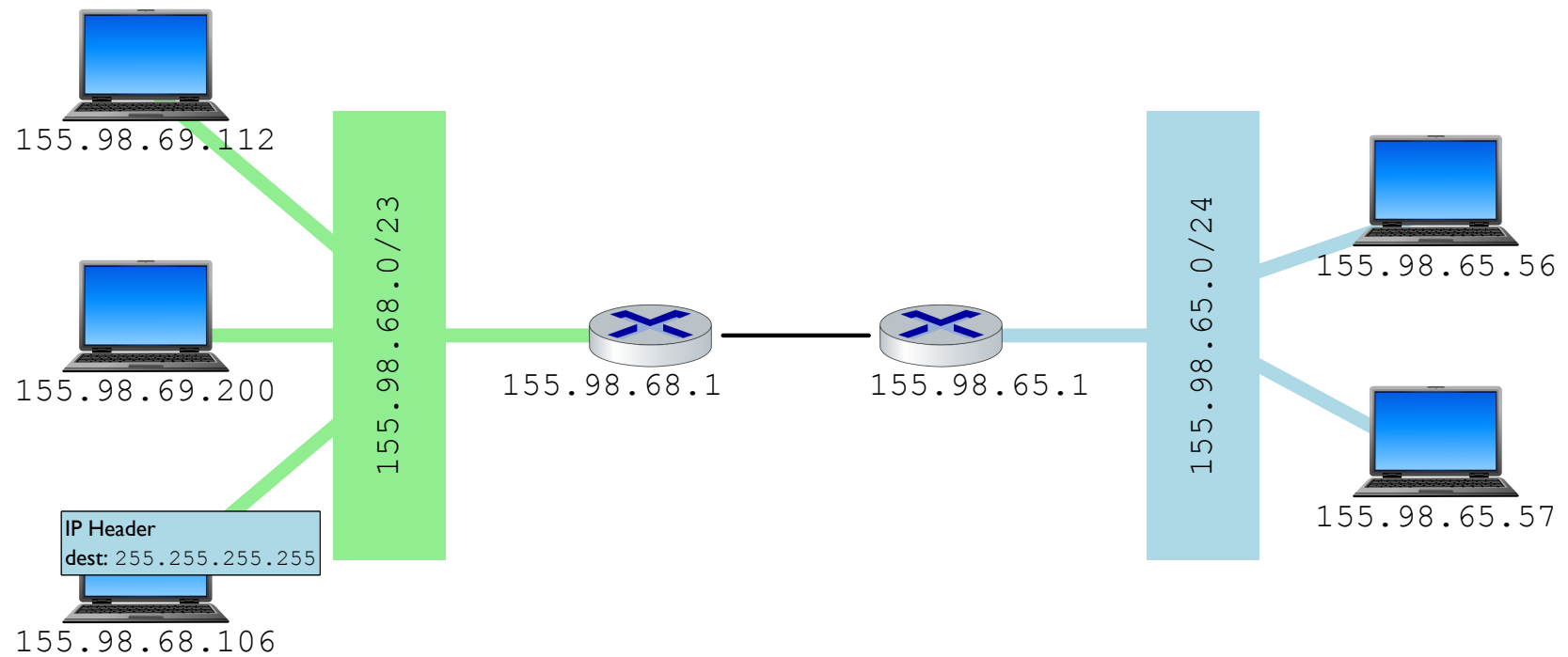Subnet broadcast:

    255.255.255.255

Subnets

A **subnet** can be small enough that every host sees every other

155.98.69.112

155.98.69.200

155.98.68.106

155.98.68.0/23

155.98.68.1

155.98.65.1

155.98.65.0/24

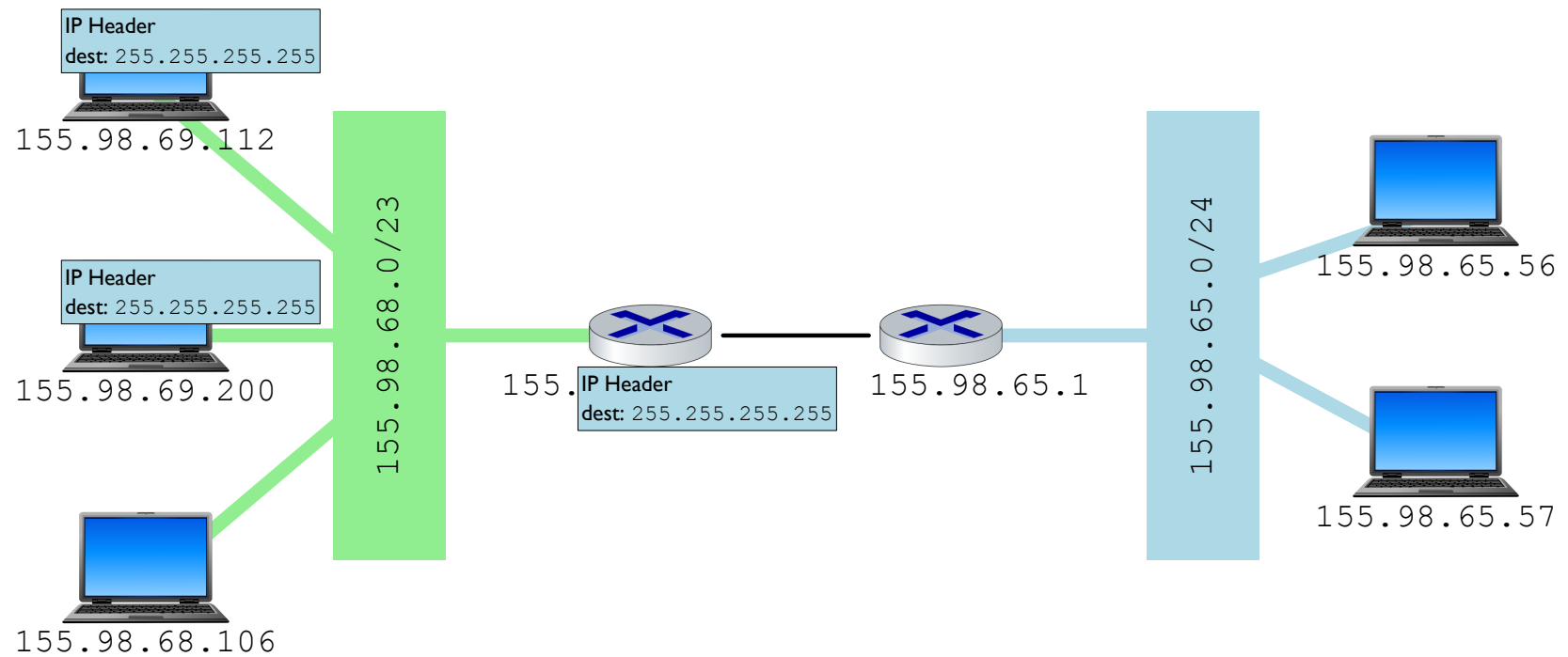155.98.65.56

155.98.65.57

Subnets

A **subnet** can be small enough that every host sees every other

Subnets

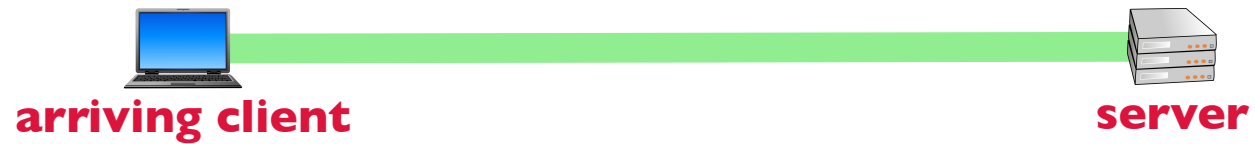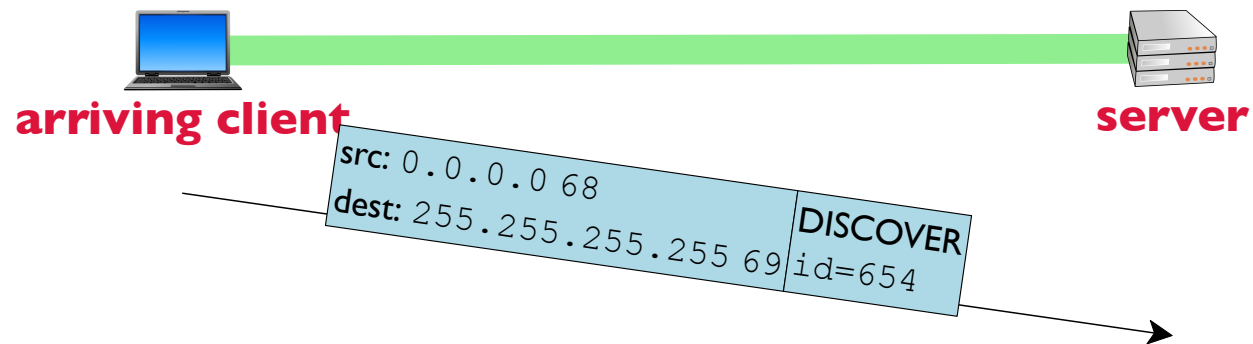A **subnet** can be small enough that every host sees every other

DHCP

DHCP takes advantage of broadcast to configure a host

arriving client   **server**

DHCP

DHCP takes advantage of broadcast to configure a host

src: `0.0.0.0 68`
dest: `255.255.255.255 69` DISCOVER `id=654`

DHCP

DHCP takes advantage of broadcast to configure a host

arriving client   **server**

src: 0.0.0.0 68
dest: 255.255.255.255 69 | DISCOVER
id=654

OFFER
id=654
src: 223.1.2.5 69
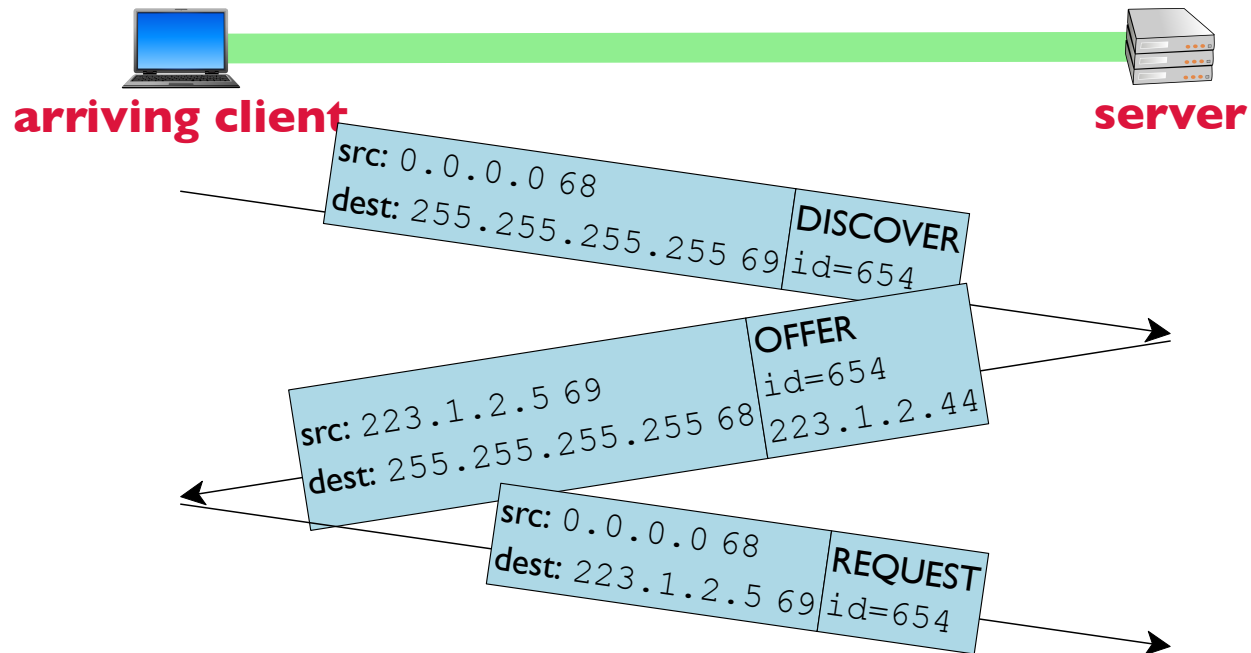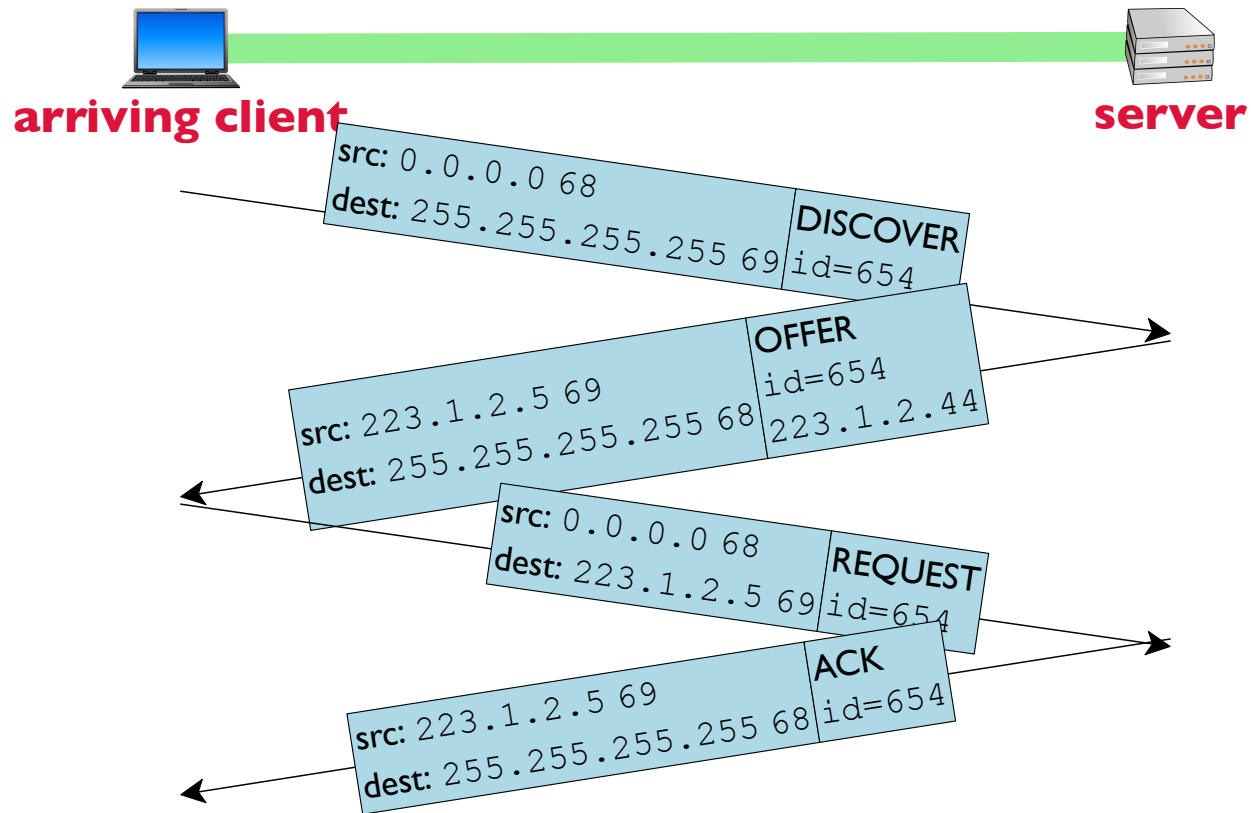dest: 255.255.255.255 68 | 223.1.2.44

DHCP

DHCP takes advantage of broadcast to configure a host

DHCP
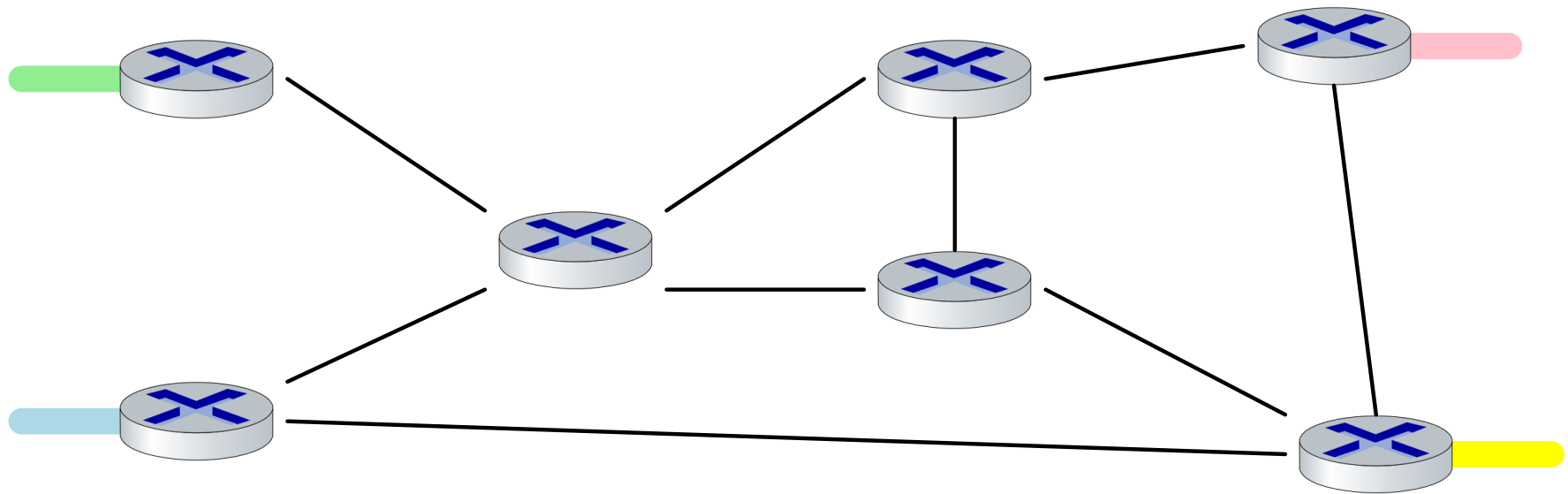
DHCP takes advantage of broadcast to configure a host

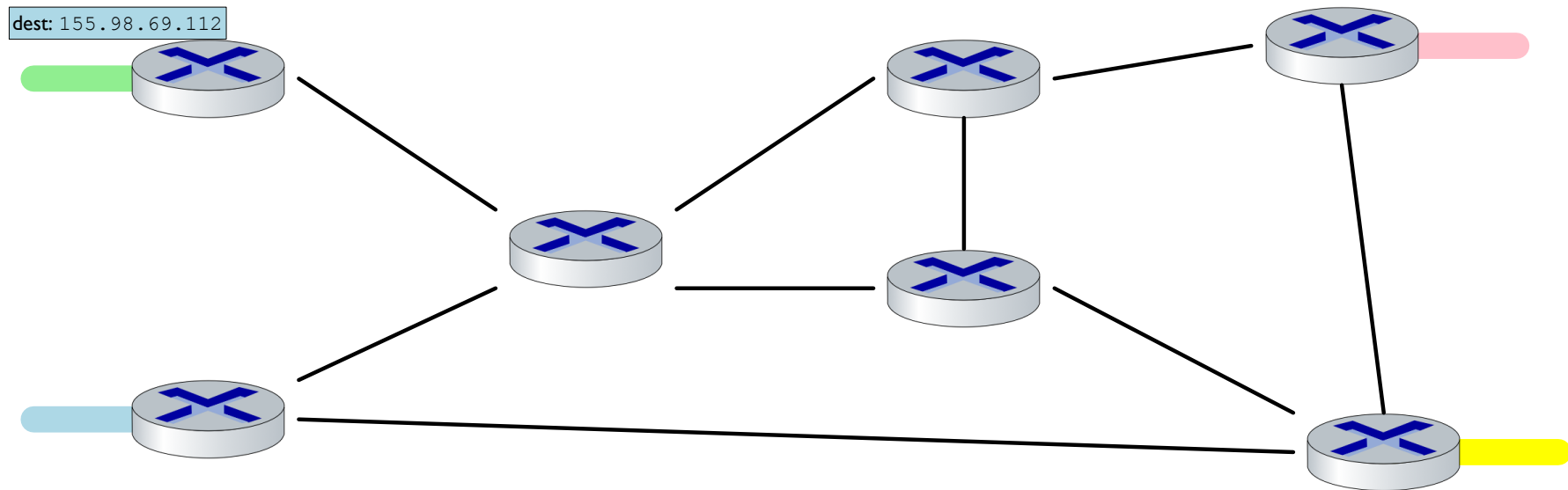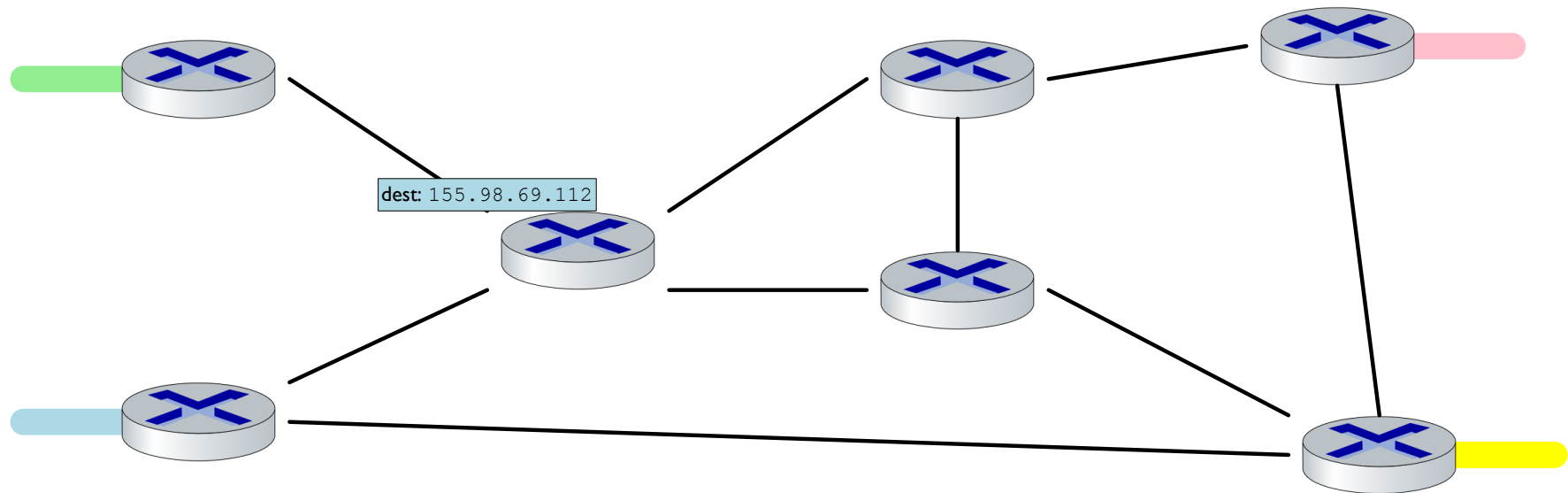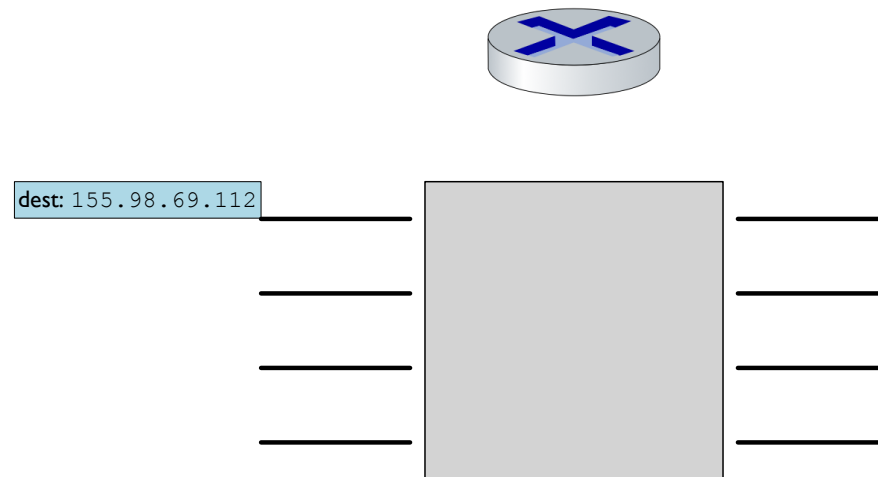**arriving client**   **server**

src: `0.0.0.0 68`
dest: `255.255.255.255 69`
DISCOVER
`id=654`

OFFER
`id=654`
`223.1.2.44`
src: `223.1.2.5 69`
dest: `255.255.255.255 68`

src: `0.0.0.0 68`
dest: `223.1.2.5 69`
REQUEST
`id=654`

ACK
`id=654`
src: `223.1.2.5 69`
dest: `255.255.255.255 68`

Routing

Routing

dest: 155.98.69.112

56

Routing

dest: 155.98.69.112

Routing

Routing

dest: `155.98.69.112`

Routing

dest: 155.98.69.112

input ports

Routing

dest: 155.98.69.112

output ports

Routing

dest: 155.98.69.112

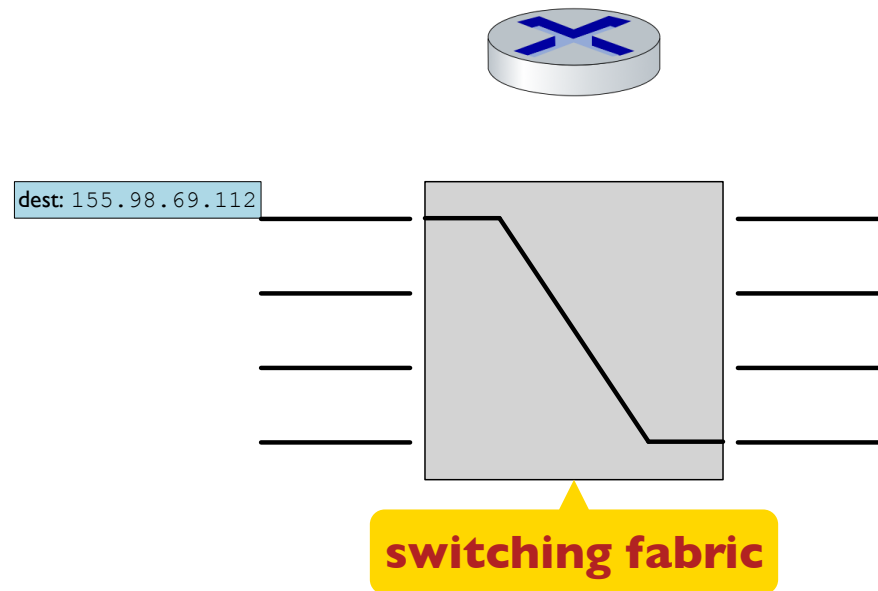**switching fabric**

Routing

dest: `155.98.69.112`

```
155.98.68.0/23  →  4
117.12.0.0/16   →  0
155.0.0.0/8     →  1
...
```
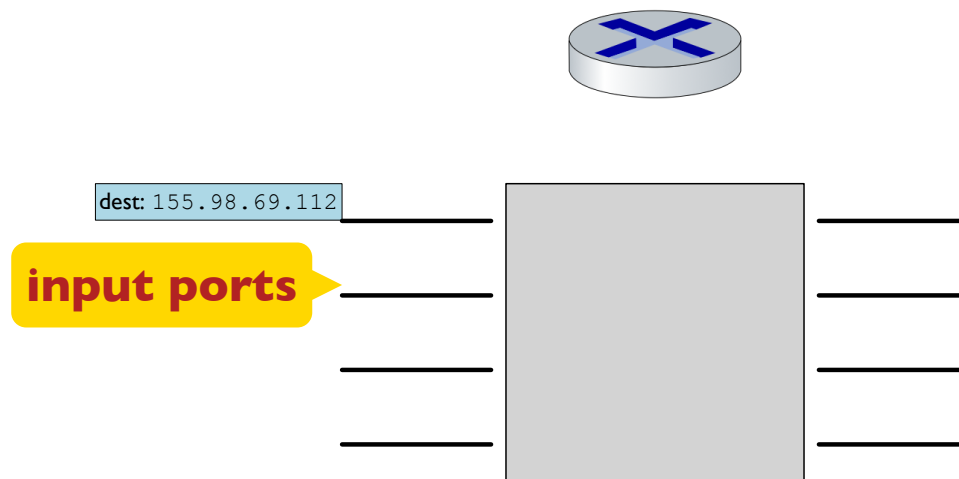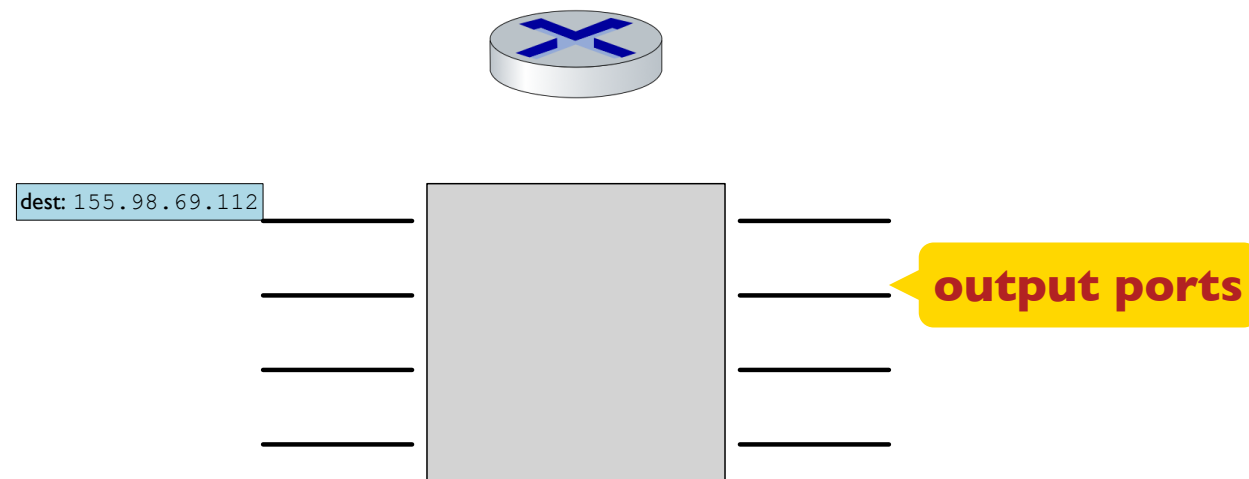
Routing

dest: `155.98.69.112`

Most specific rule applies

```
155.98.68.0/23   →   4
117.12.0.0/16    →   0
155.0.0.0/8      →   1
...
```

Routing

dest: 155.98.69.112

May queue packets
May use priority queue
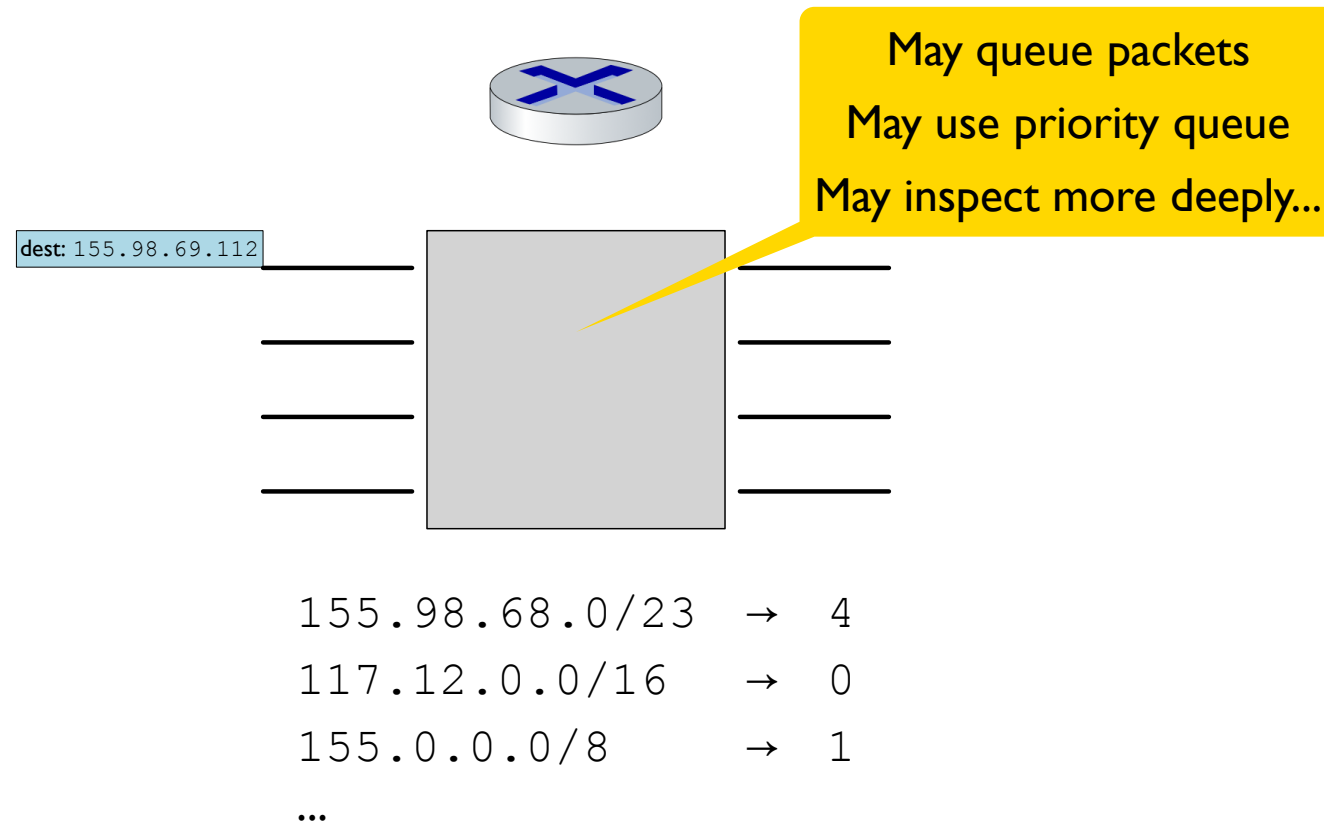May inspect more deeply...

```
155.98.68.0/23  →  4
117.12.0.0/16   →  0
155.0.0.0/8     →  1
...
```

Routing

dest: 155.98.69.112

Prefix-based rules make a **forwarding table**

```
155.98.68.0/23  →  4
117.12.0.0/16   →  0
155.0.0.0/8     →  1
...
```

Routing

dest: 155.98.69.112

155.98.68.0/23 → 4
117.12.0.0/16 → 0
155.0.0.0/8 → 1
...

Prefix-based rules make a **forwarding table**

More general rules, which might take into account transport-level fields, make a **flow table**

Routing

dest: 155.98.69.112

Prefix-based rules make a
forwarding table

155.98.68.0/23	→	4
117.12.0.0/16	→	0
155.0.0.0/8	→	1

More general rules, which
might take into account
transport-level fields, make a
flow table

software-defined networking (SDN)

Summary

The network layer routes packets based on destination address

...mostly

CIDR directs packets based on an address **prefix**

- a prefix identifies a **subnet**

- a router typically uses a prefix-based **forwarding table**