The Evolving Architecture of the Web

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CLOUDFLARE

Head of Cryptography

CFSSL
Universal SSL
Keyless SSL
Privacy Pass
Geo Key Manager

Recently
Standards work
TLS 1.3

Competing Goals

make browsing more

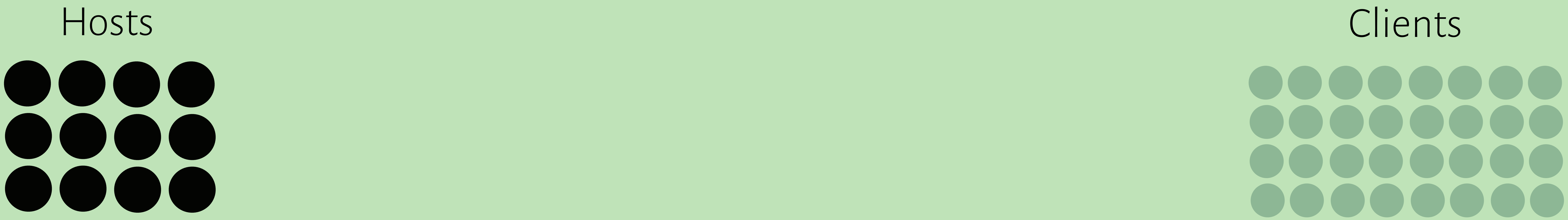
private

performant

HTTP
DNS

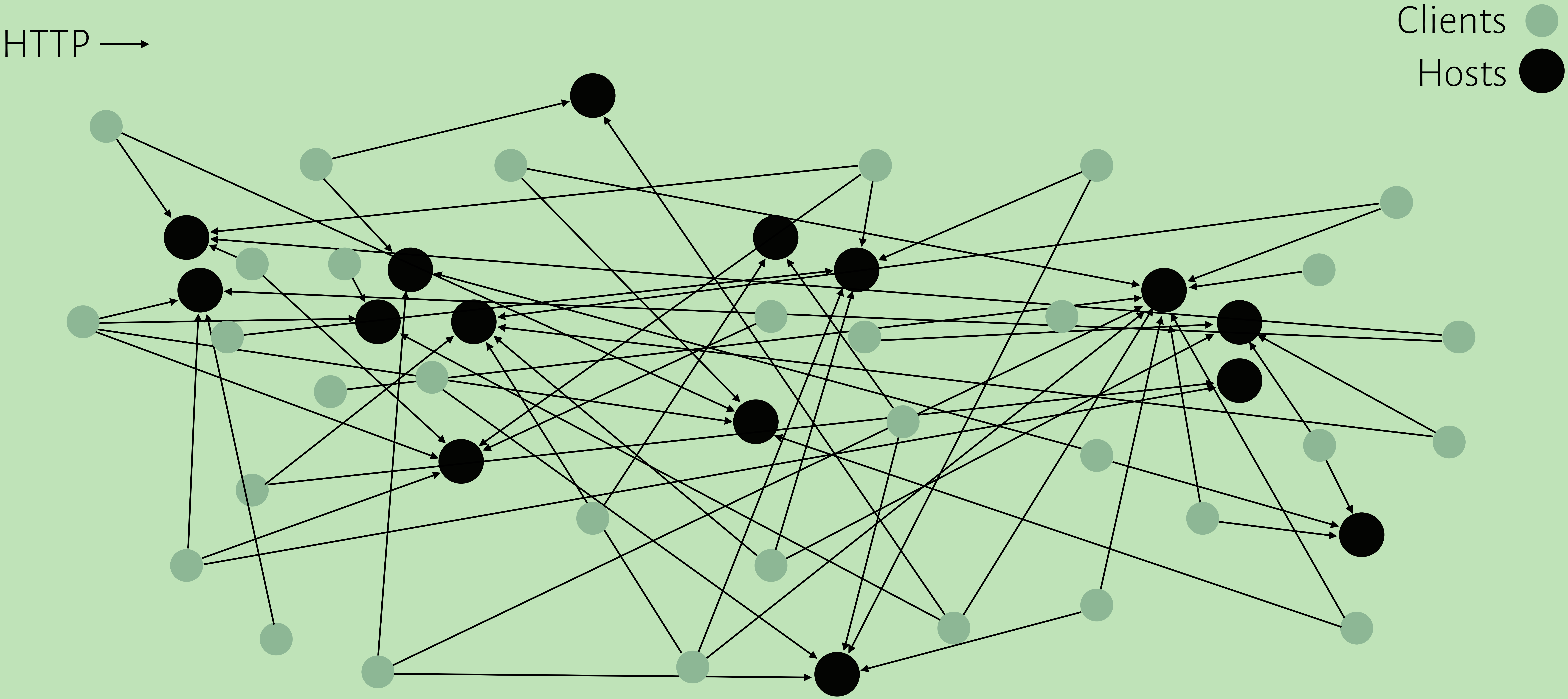
HTTP

DNS



Hosts

Clients



Geographically Centralized
Administratively Diverse

One IP per Hostname

HTTP →

What a network observer can see

Unique Client IP

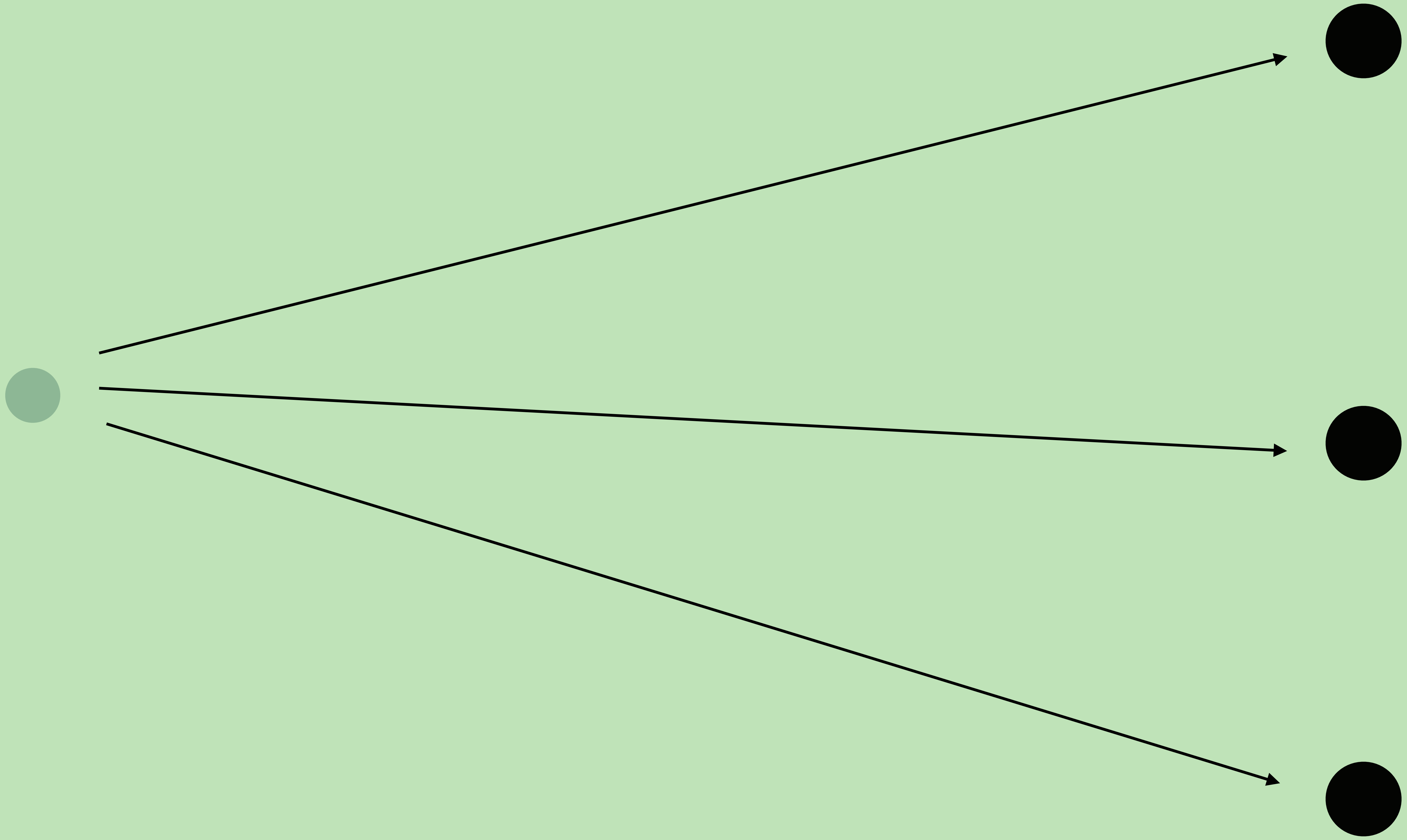
Unique Server IP

Server URL

Website content

Clients ●

Hosts ●



	Anonymity set
Client IP	**1**
Server IP	**1**

IPv4

4.3 Billion Addresses

Not enough for every user

HTTP ⟶

What a network observer can see

Client Proxy IP

Unique Server IP

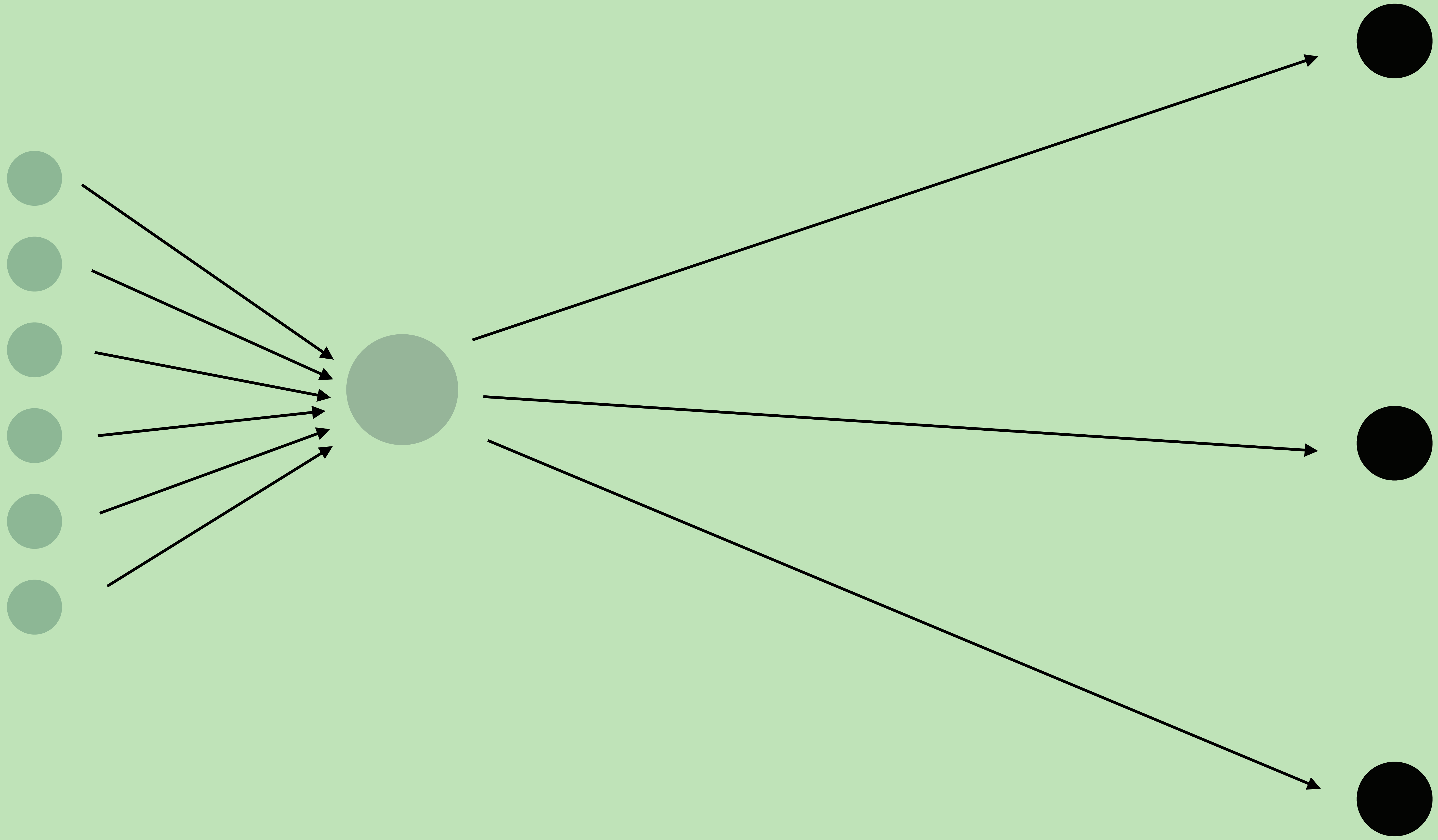
Server URL

Website content

Clients ●

Hosts ●

Proxy ●



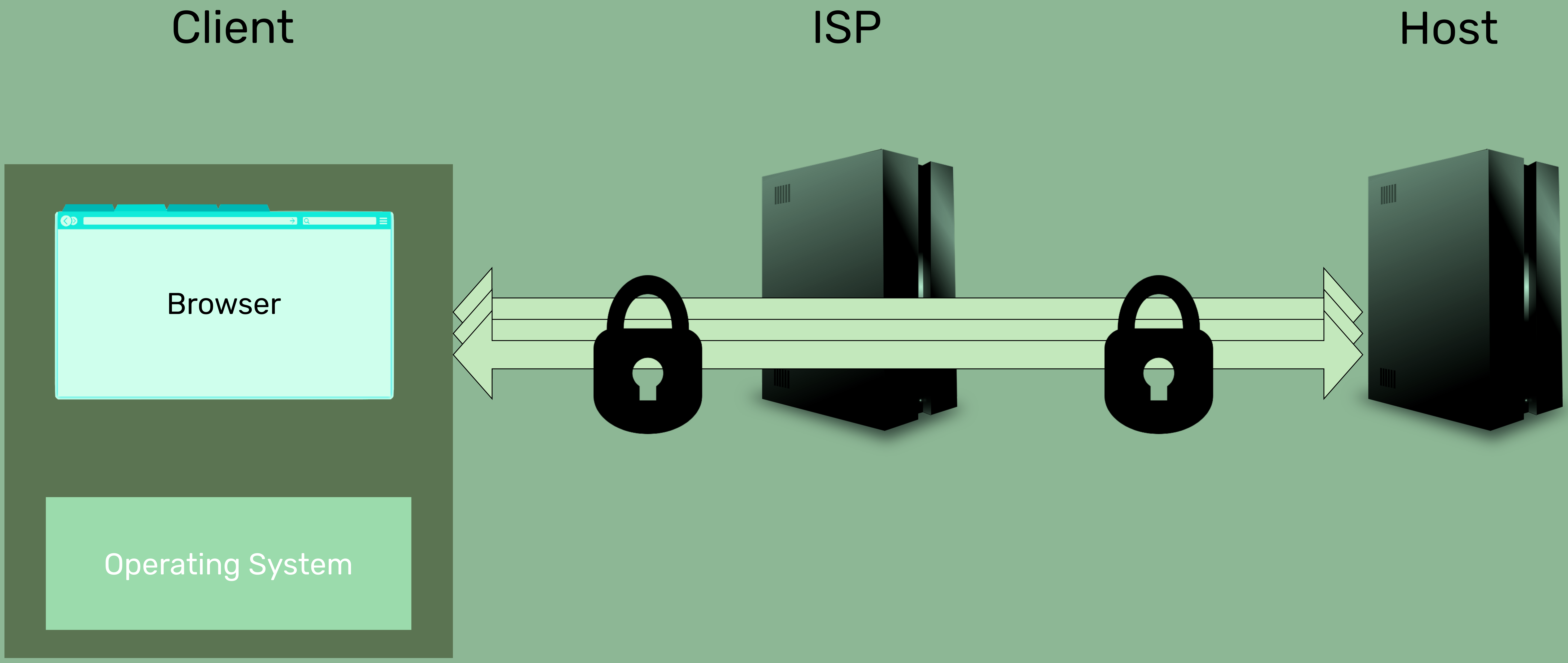
	Latency Cost
Tor	**3 round-the-world**
VPN	**1 round-the-world**
Carrier NAT	**Small**

	Anonymity set
Client	**k**
Server	**1**

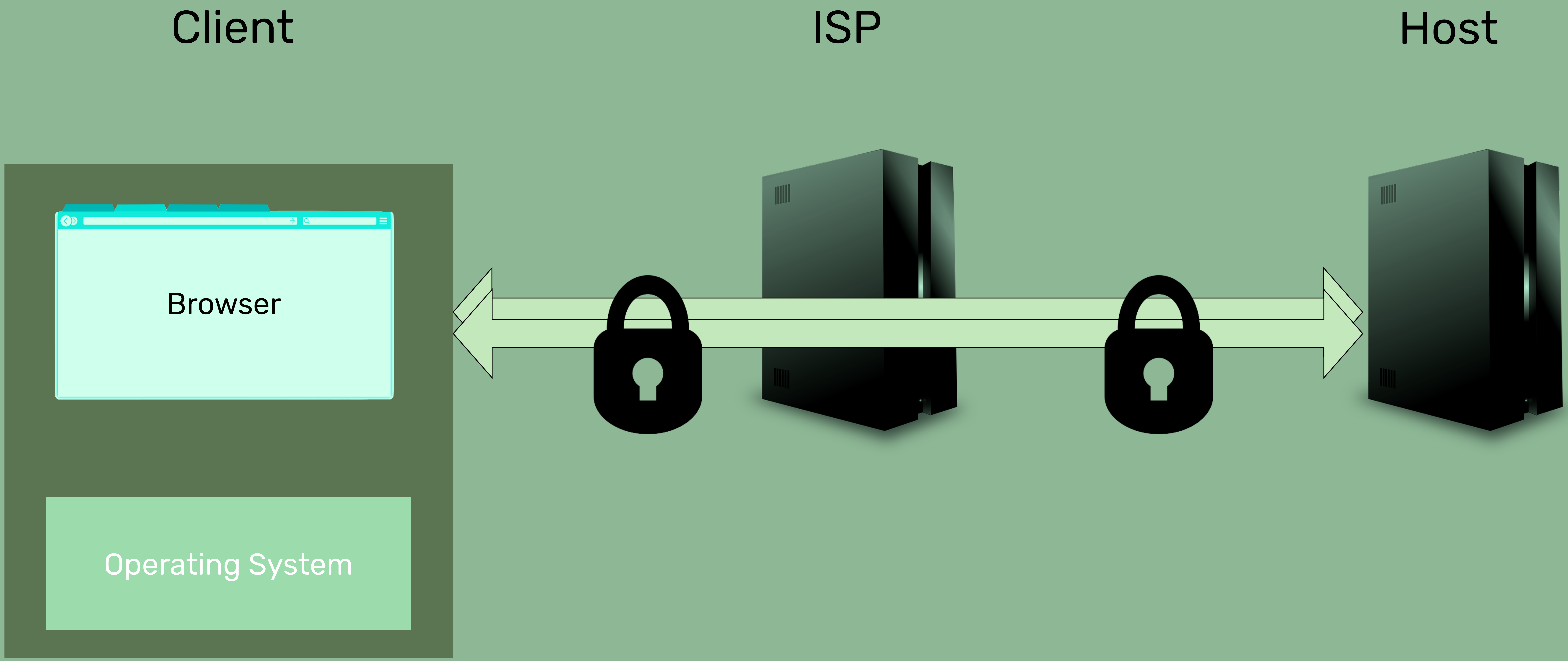
New Trends

ENCRYPT THE WEB

HTTPS



TLS 1.2



TLS 1.3: coming soon

HTTP ⟶ HTTPS ⟶

What a network observer can see

Clients ●

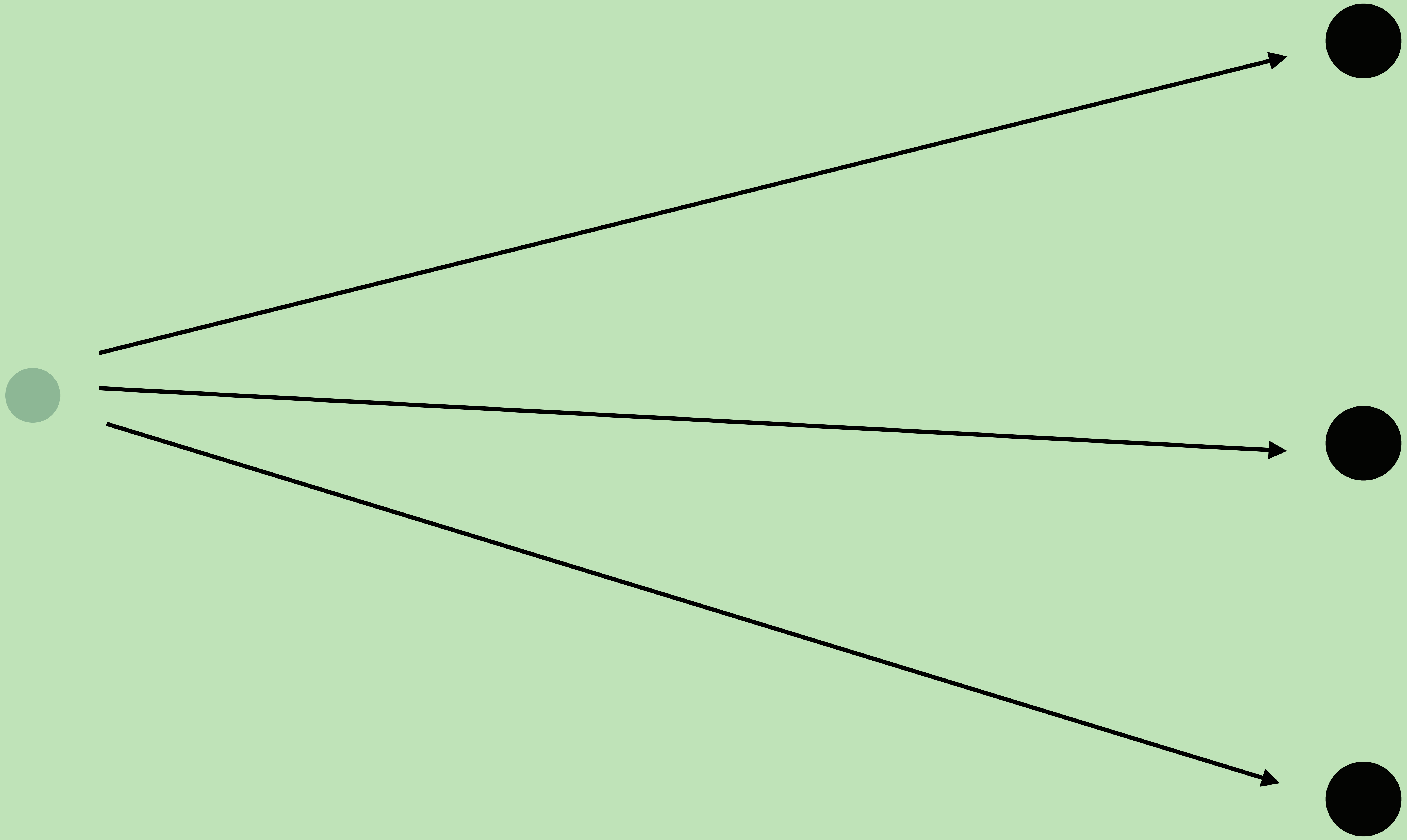
Hosts ●

Unique Client IP

Unique Server IP

~~Server URL~~

~~Website content~~

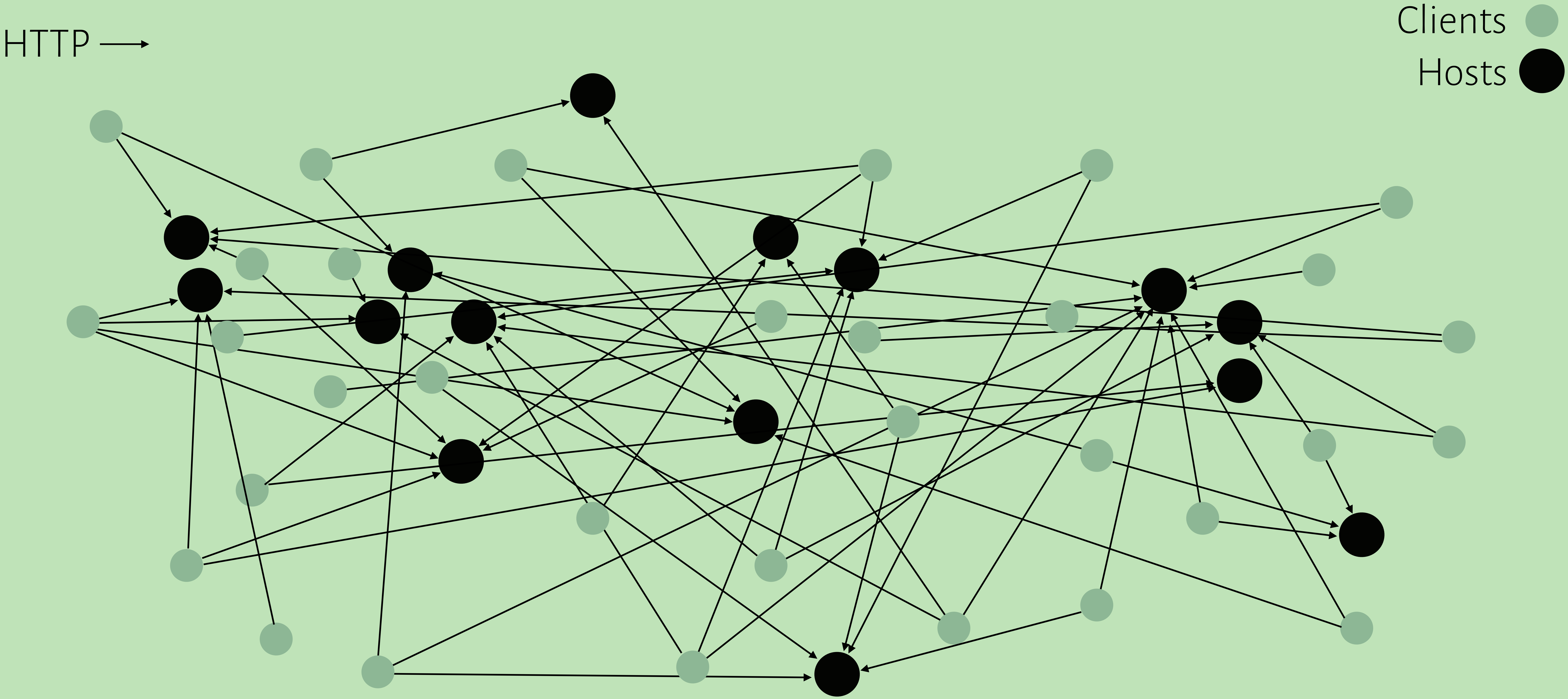


	Anonymity set
Client	**1**
Server	**1**

IPv4

4.3 Billion Addresses

Not enough for every website



Geographically Centralized

Administratively Diverse

One IP per Hostname

HTTP → HTTPS →

Clients ●

Hosts ●

Shared Hosts ●

More Geographically Centralized

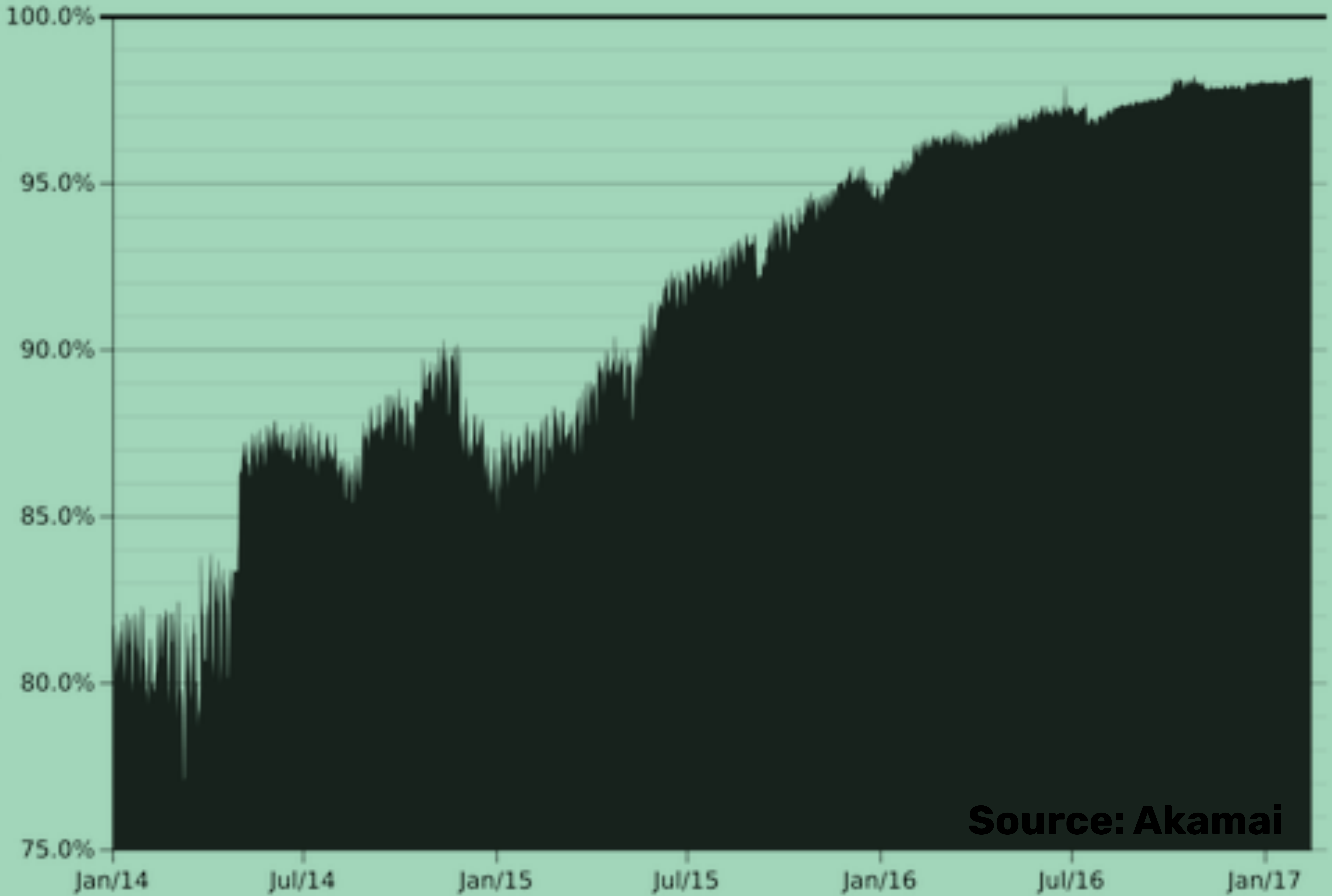
More Administratively Centralized

Multiple Hostname per IPs

SNI

Virtual Hosting

Send the hostname to the server so it can choose the certificate



Source: Akamai

HTTP → HTTPS →

What a network observer can see

Client Unique IP

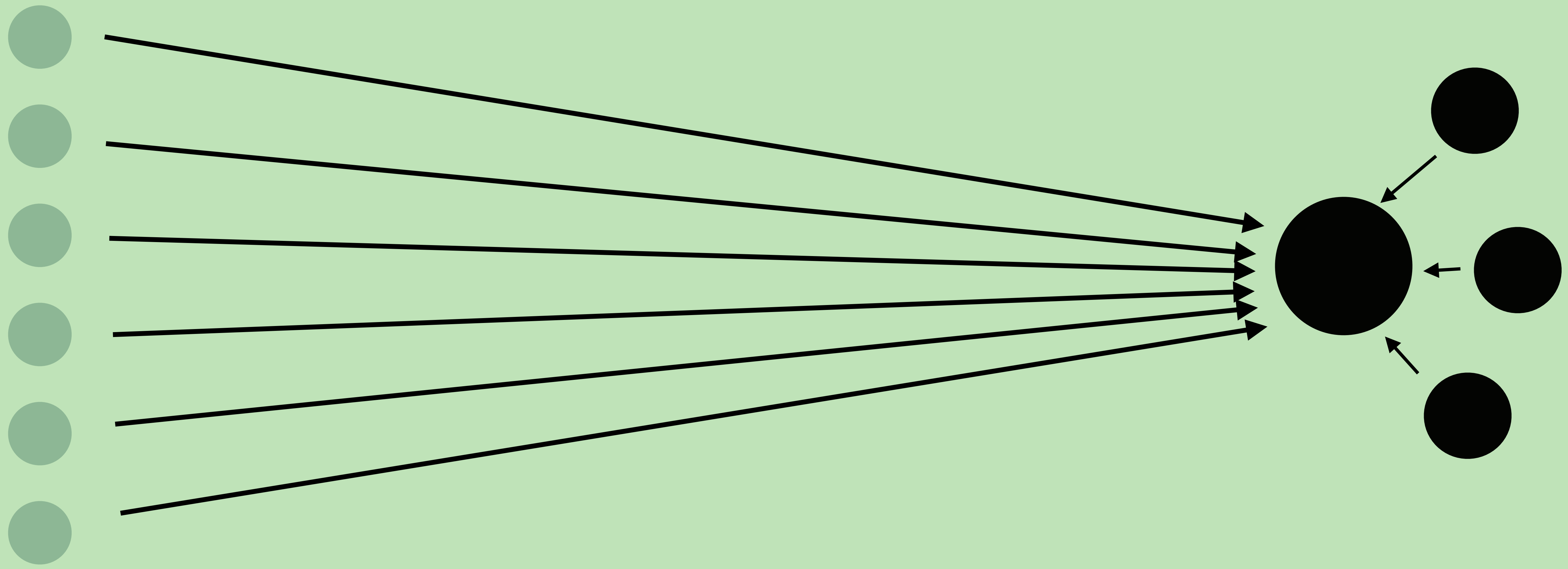
Shared Server IP

Hostname

Clients ●

Hosts ●

Shared Hosts ●



	Anonymity set
Client	**1**
Server (Shared IP+Hostname)	**1**

Internet Scans and IPv6

Privacy Evolves

Certificate Transparency

Wildcard certificates

Edge Services

Edge Services

- Websites and are delegating to globally distributed parties
- Authorized to terminate TLS
- Reduced Latency
- Improved DDoS resilience
- Anycast to reduce number of IPs needed

HTTP ⟶ HTTPS⟶

Clients ●

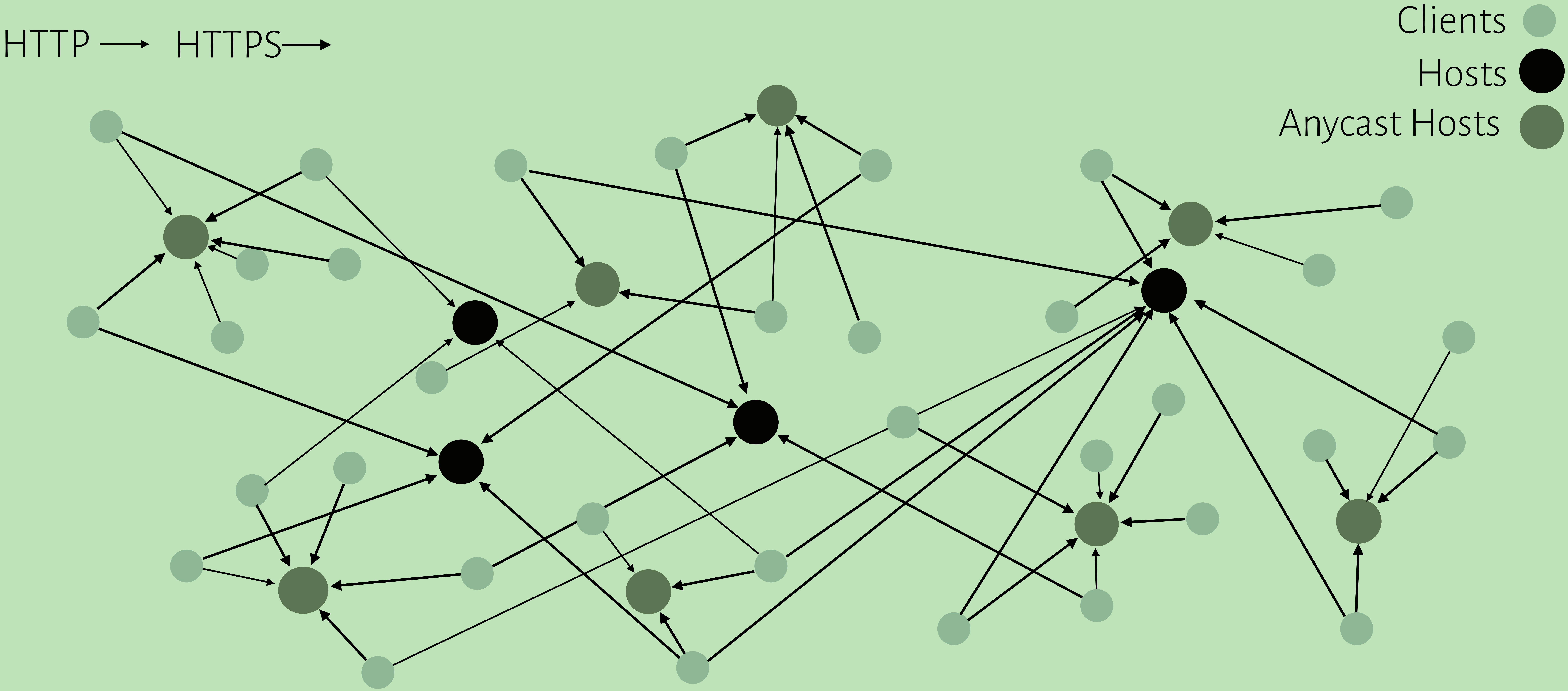
Hosts ●

Shared Hosts ●

More Geographically Centralized

More Administratively Centralized

Multiple IPs per Hostname



HTTP ⟶ HTTPS ⟶

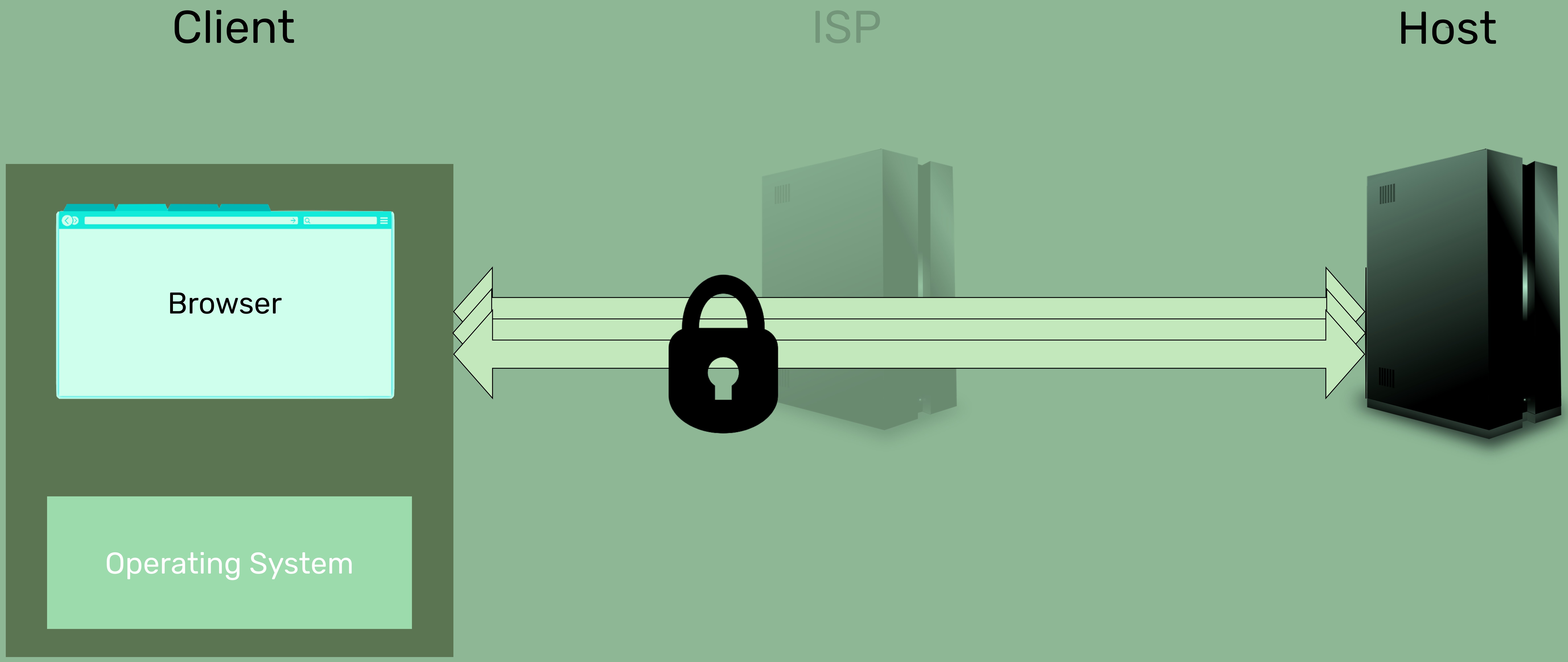
Clients ●

Hosts ●

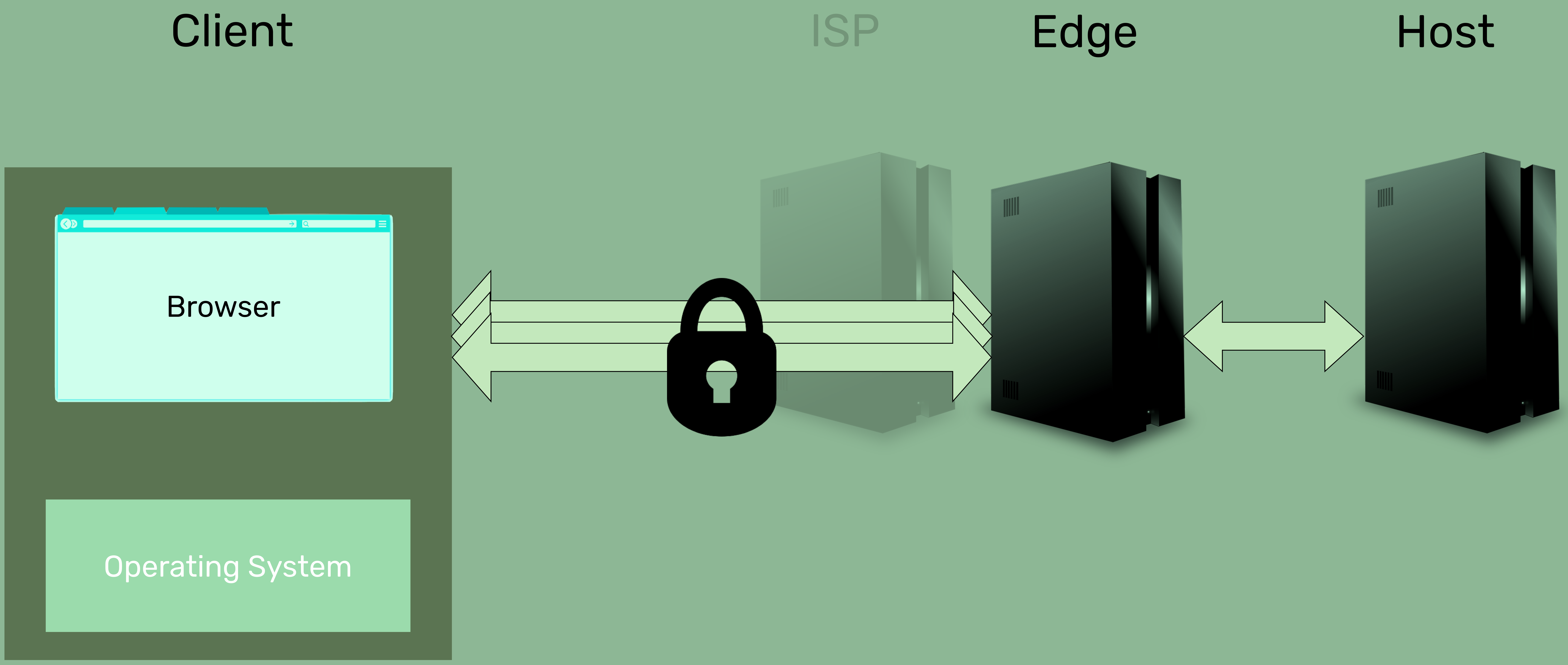
Anycast Hosts ●

Geographically Distributed
Administratively Centralized

Multiple IPs per Hostname



HTTPS

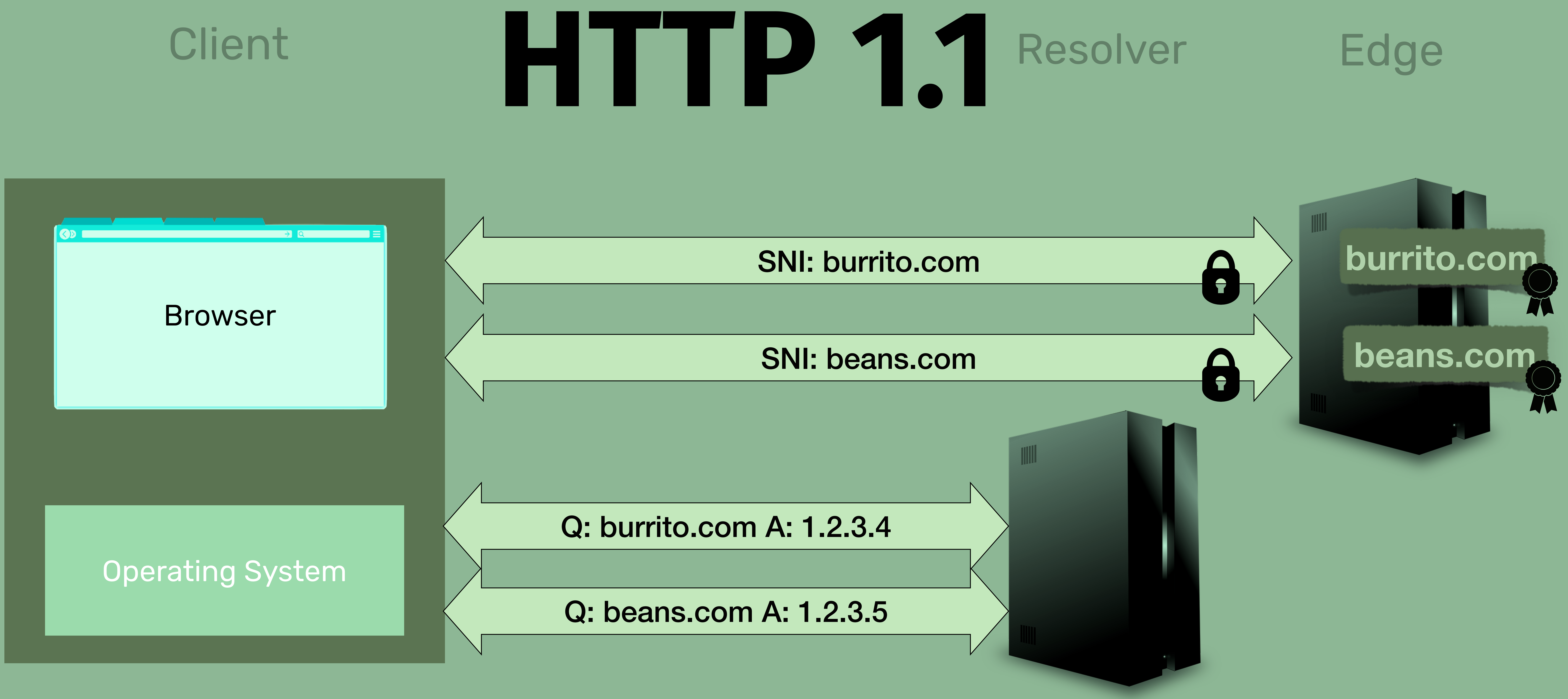


HTTPS

Questions

Can we improve ***privacy***?
Can we improve ***latency***?
Can we improve ***both***???

HTTP 1.1



Client

Resolver

Edge

Browser

Operating System

SNI: burrito.com

SNI: beans.com

Q: burrito.com A: 1.2.3.4

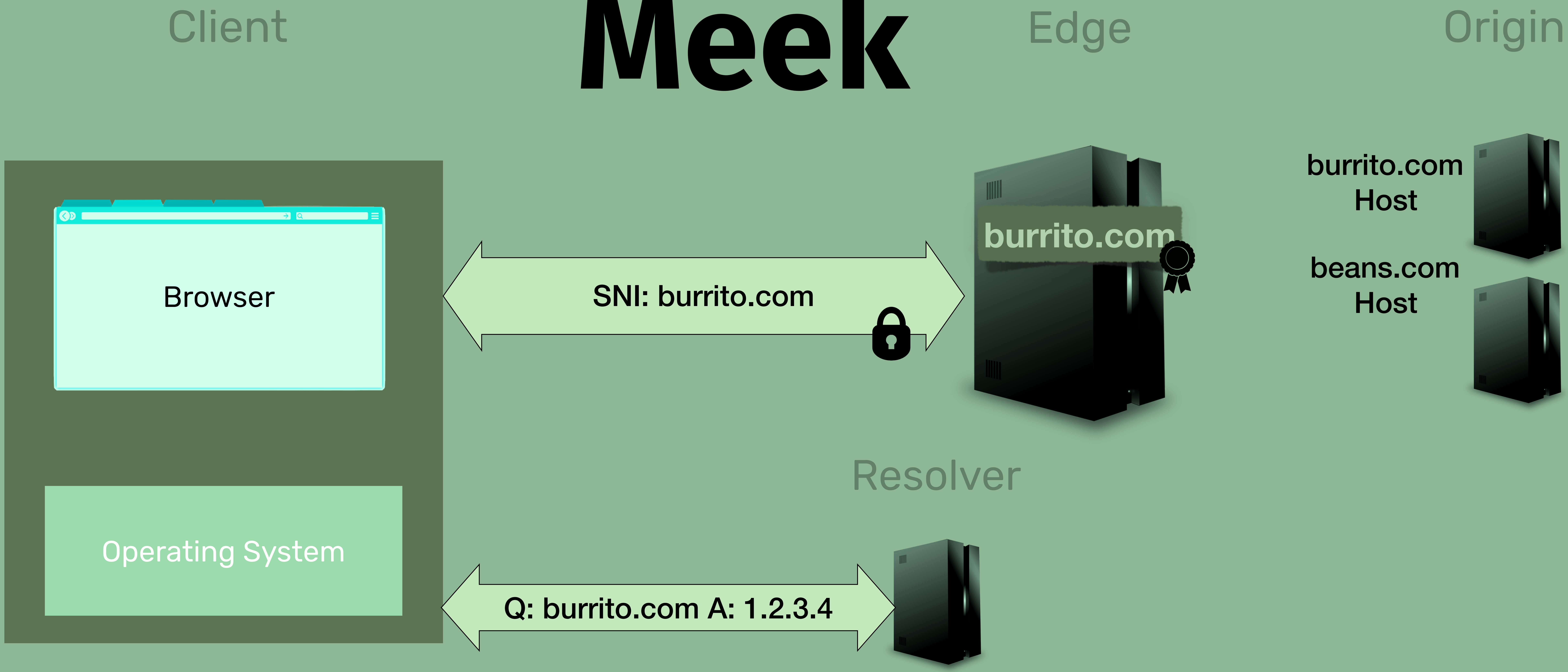
Q: beans.com A: 1.2.3.5

burrito.com

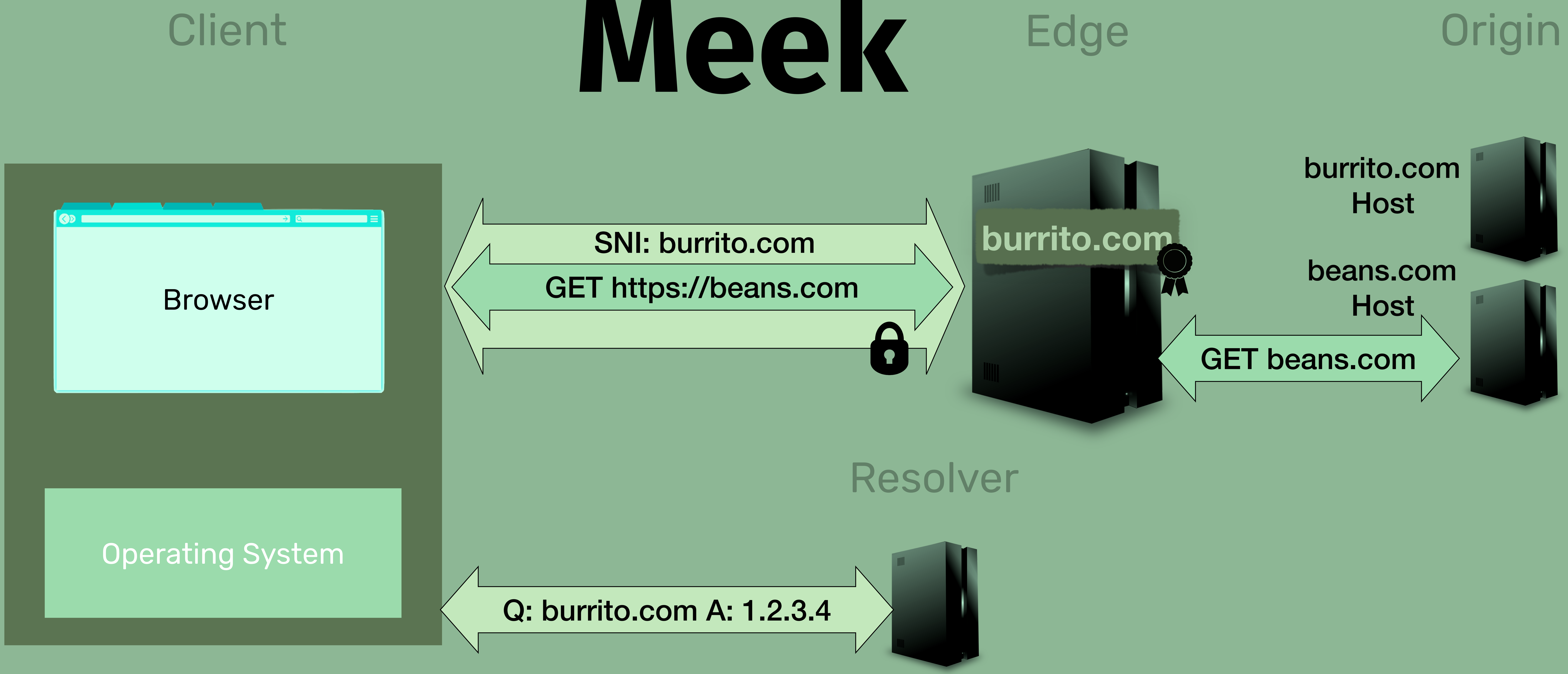
beans.com

Safety in Numbers

Meek


Client
Edge
Origin
Browser
SNI: burrito.com
burrito.com
burrito.com
Host
beans.com
Host
Resolver
Operating System
Q: burrito.com A: 1.2.3.4

Meek



Client

Edge

Origin

Browser

Operating System

SNI: burrito.com

GET https://beans.com

burrito.com

burrito.com
Host

beans.com
Host

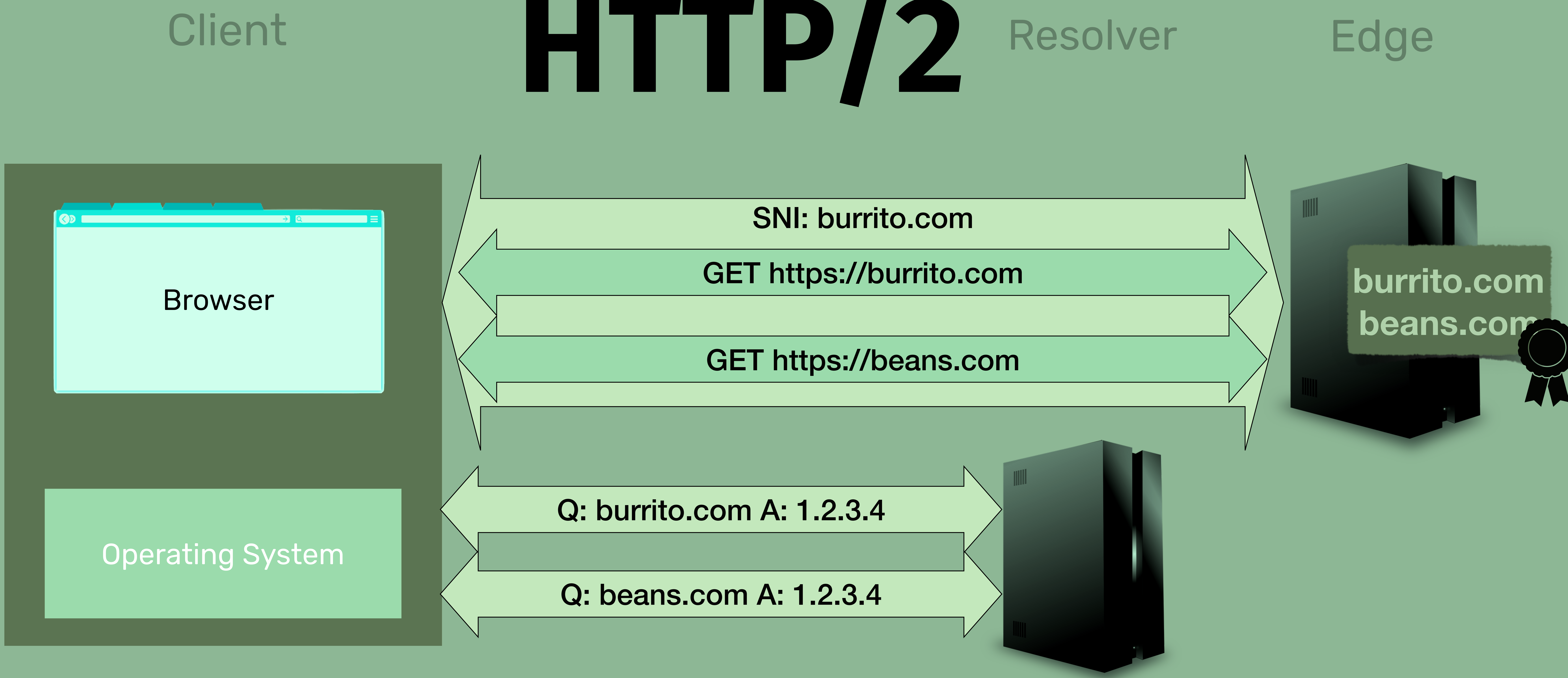
GET beans.com

Resolver

Q: burrito.com A: 1.2.3.4

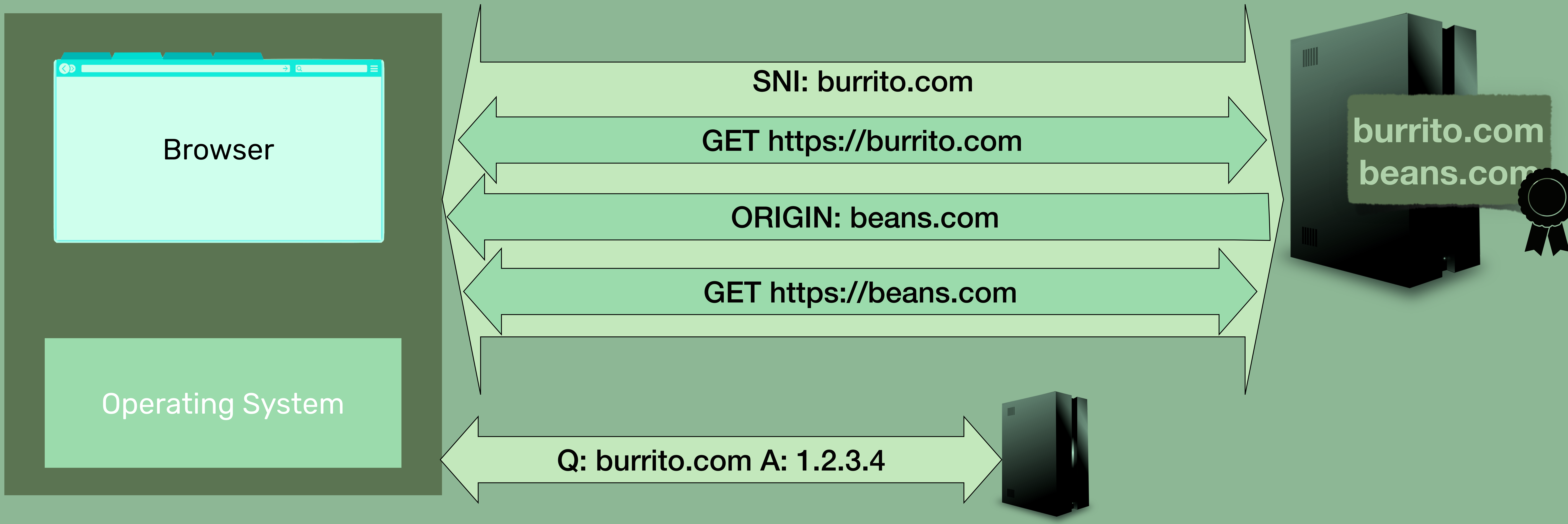
Mismatch: SNI, Host, SAN

HTTP/2



Connection Coalescing

HTTP/2



Client

Resolver

Edge

Browser

Operating System

SNI: burrito.com

GET https://burrito.com

ORIGIN: beans.com

GET https://beans.com

Q: burrito.com A: 1.2.3.4

burrito.com
beans.com

ORIGIN Frame

What a network observer can see

HTTP ⟶ HTTPS ⟶

Clients ●

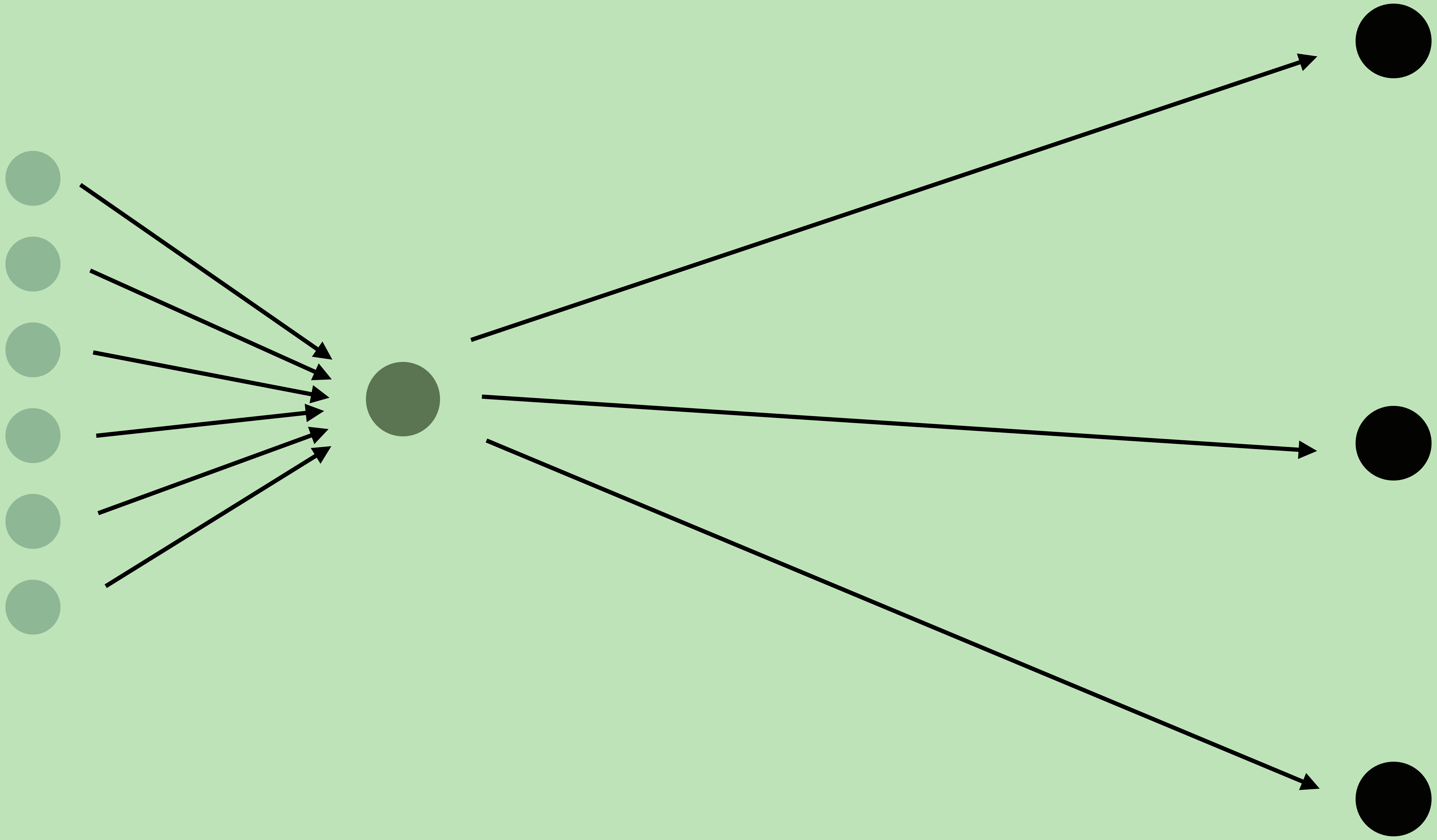
Hosts ●

Anycast Hosts ●

Client Unique IP

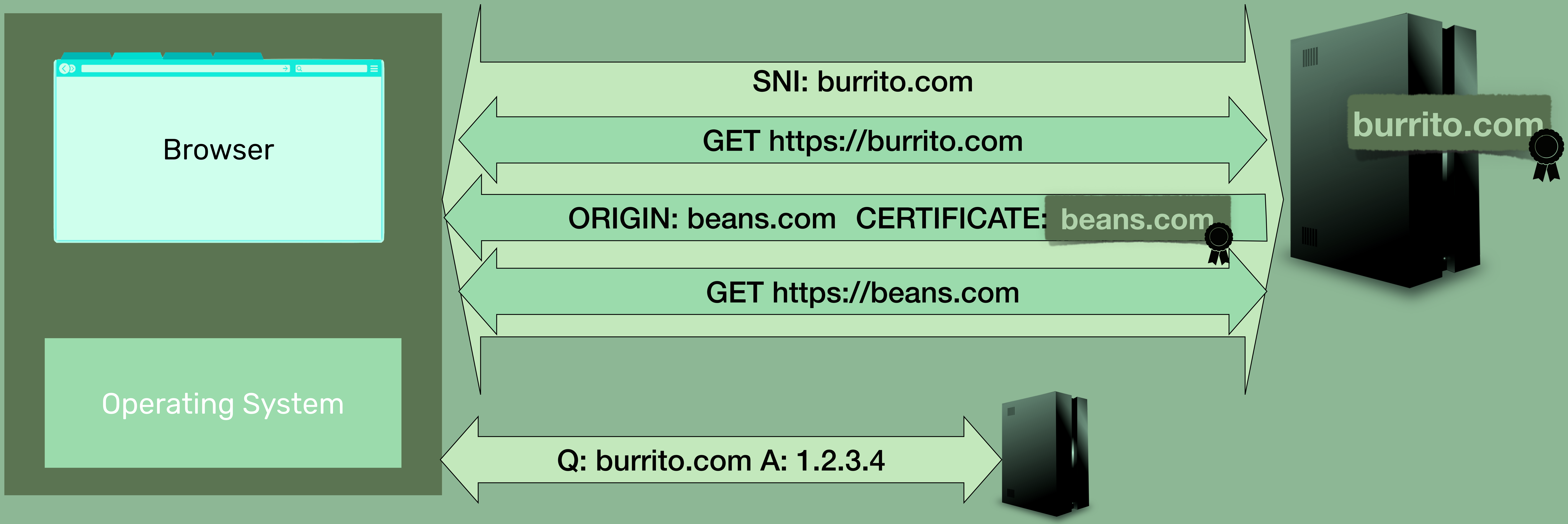
Shared Server IP

First Hostname

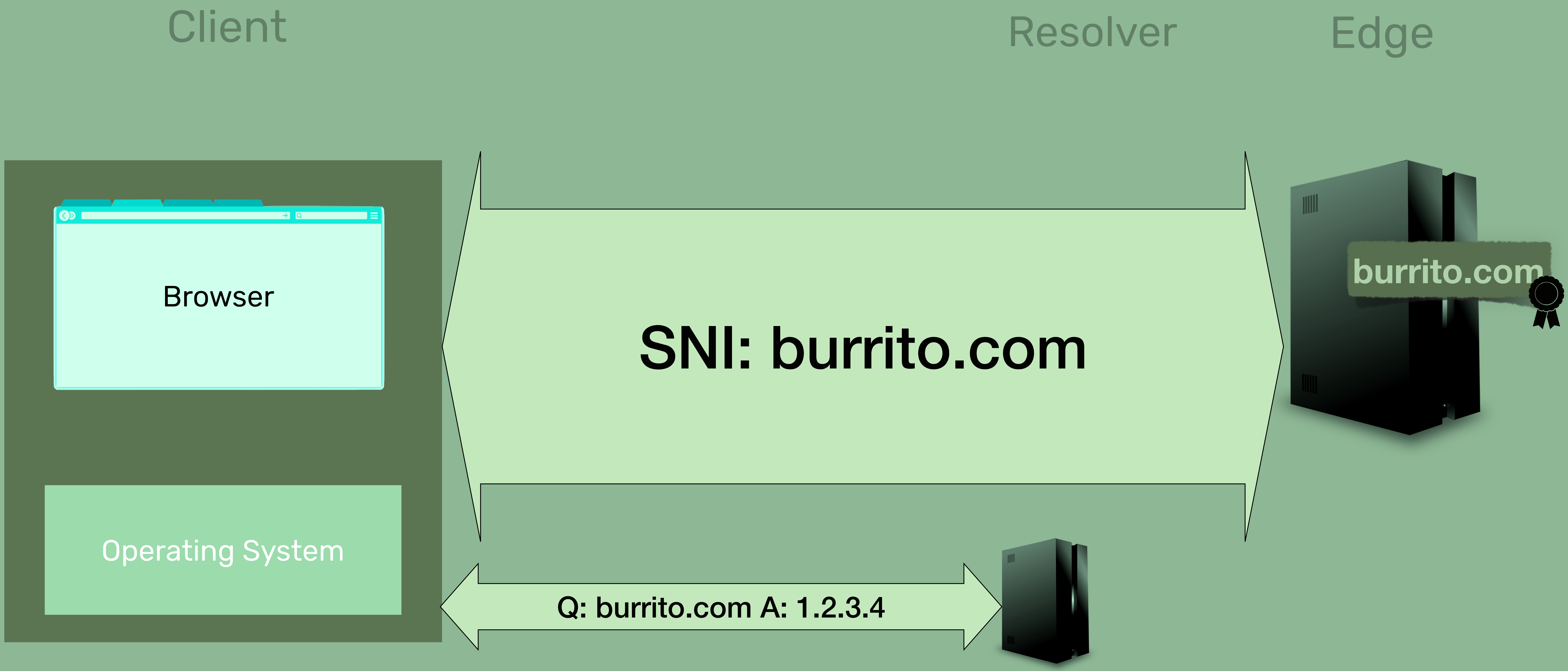


	Anonymity set
Client	**1**
Server (Shared IP+Certificate)	**~20**

HTTP/2



CERTIFICATE Frame


Client
Resolver
Edge
Browser
Operating System
SNI: burrito.com
burrito.com
Q: burrito.com A: 1.2.3.4

What this changes

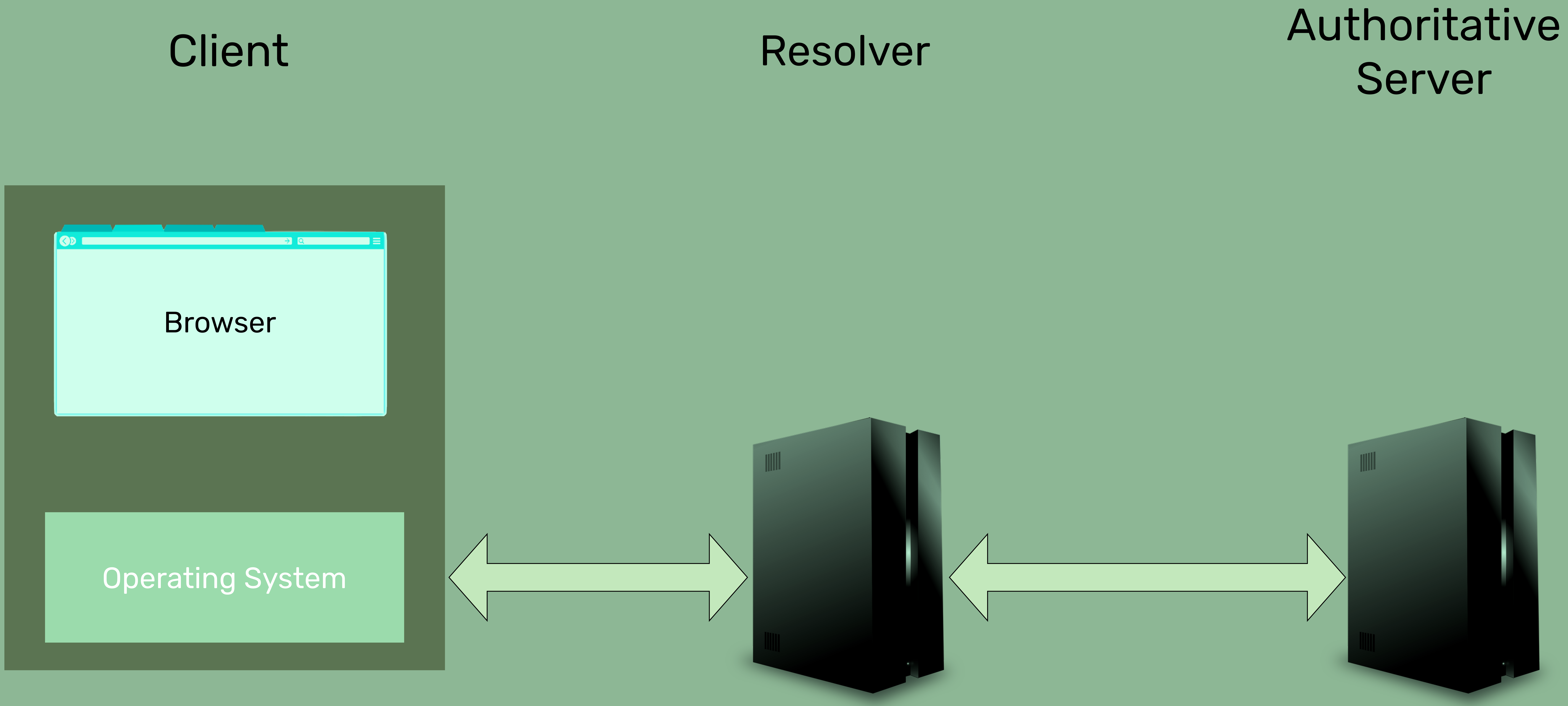
Having a certificate gives you routing authority

	Anonymity set
Client	**1**
Server (Shared IP+First Hostname)	**k**

k is the set of domains on certificates that can be obtained through “First Hostname”

Meek-like circumvention protection

Only send the CERTIFICATE frame on certain resources



Client

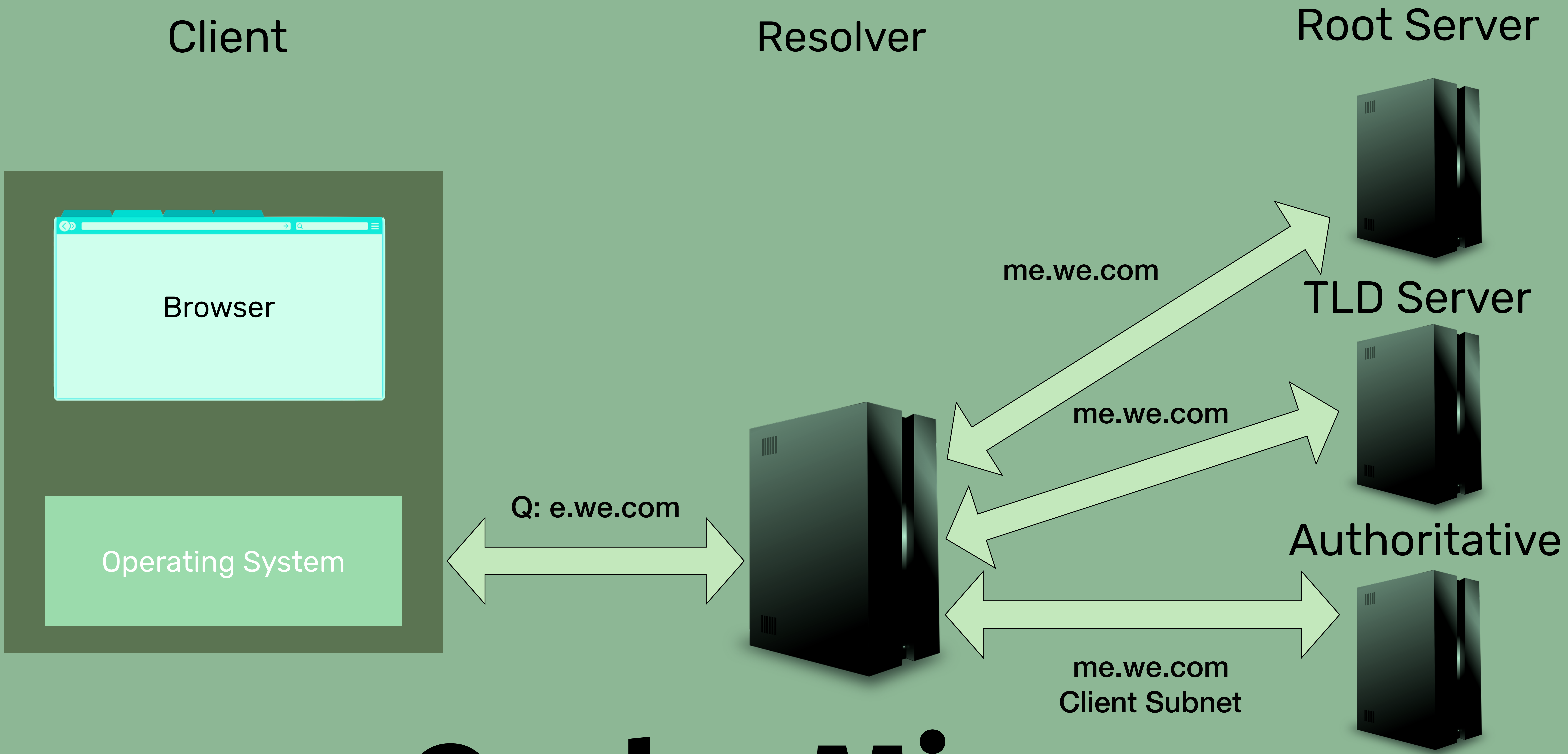
Browser

Operating System

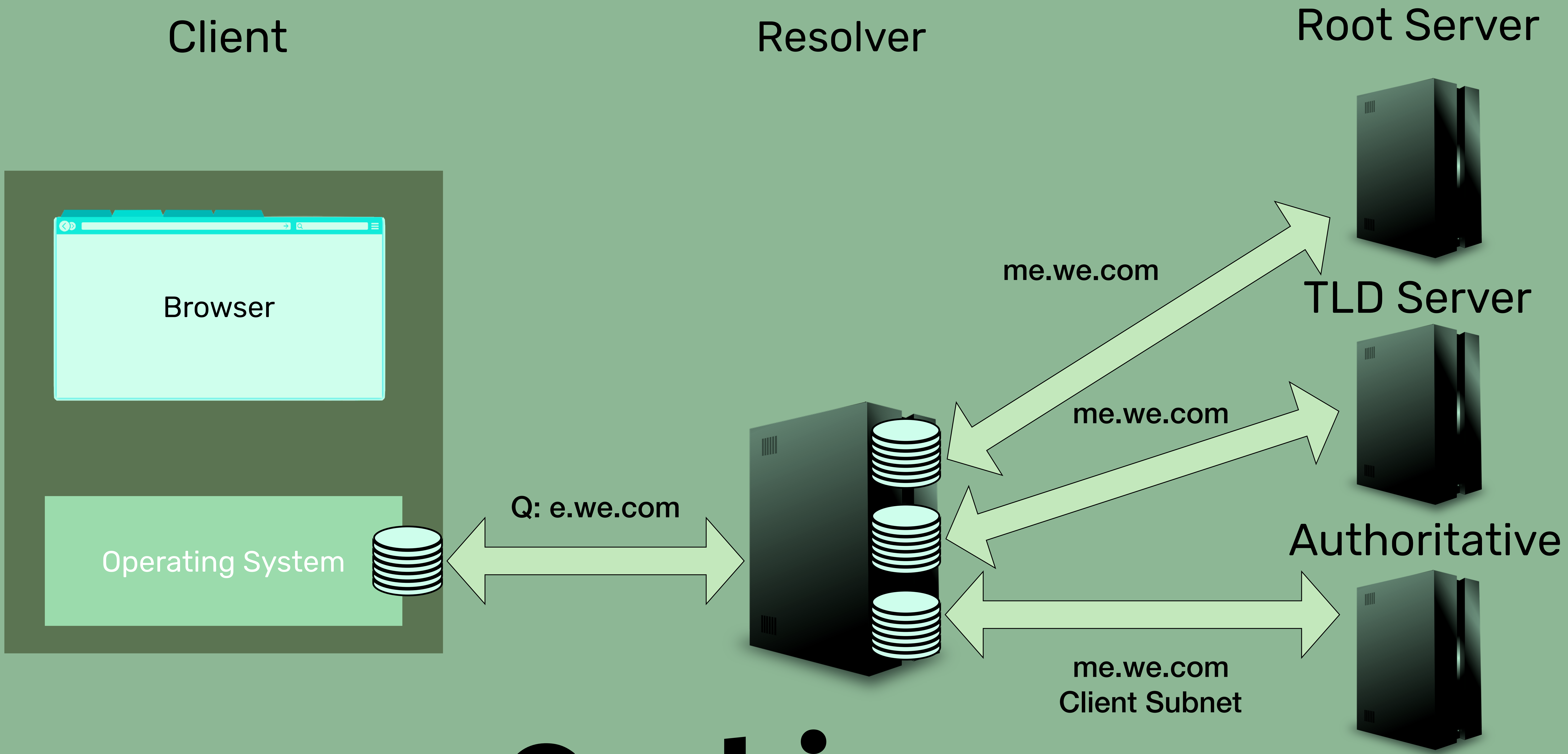
Resolver

Authoritative Server

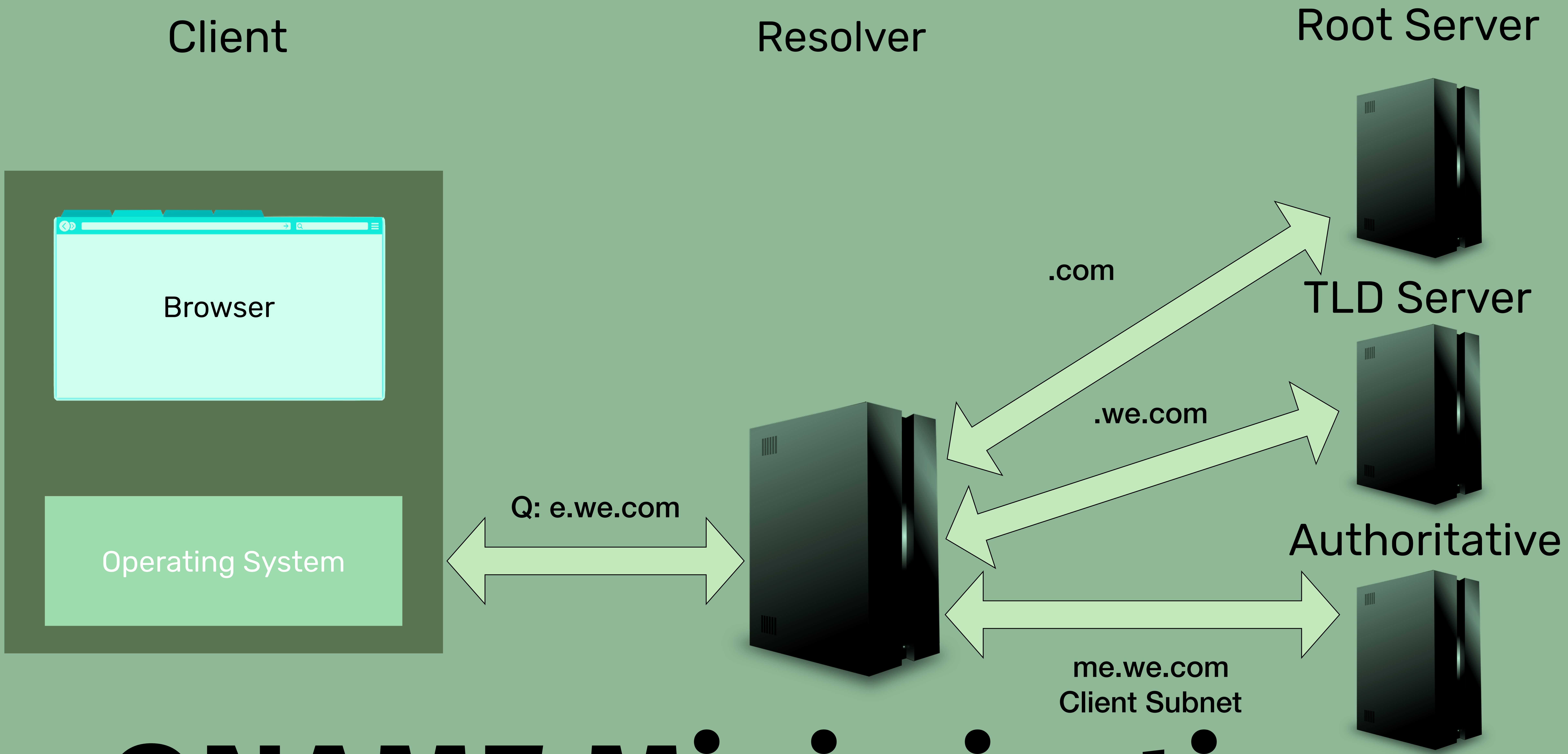
DNS


Client
Resolver
Root Server
Browser
me.we.com
TLD Server
me.we.com
Q: e.we.com
Operating System
Authoritative
me.we.com
Client Subnet

Cache Miss

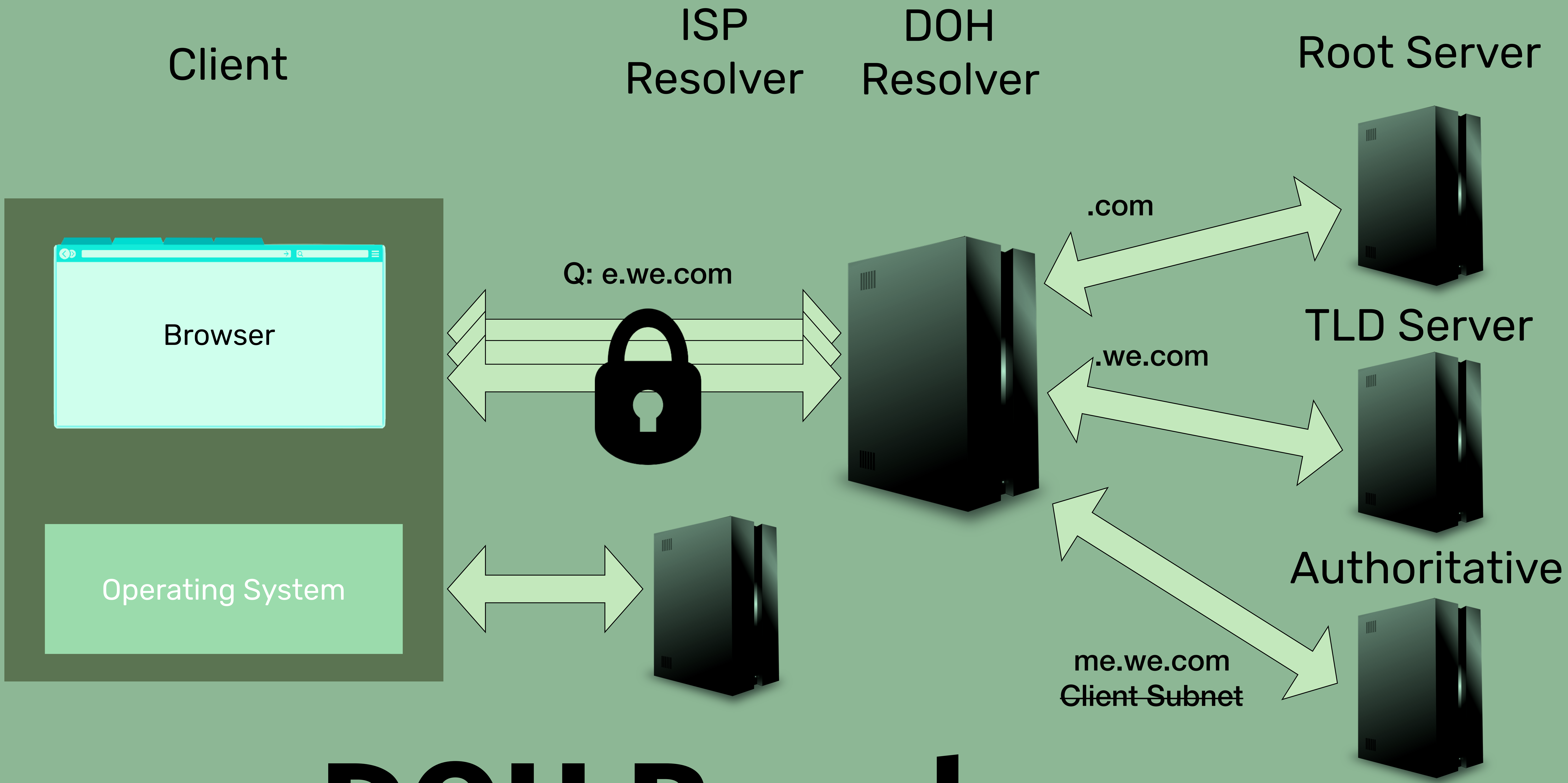

Client
Resolver
Root Server
TLD Server
Authoritative
Browser
Operating System
Q: e.we.com
me.we.com
me.we.com
me.we.com
Client Subnet

Caching



QNAME Minimization

DOH


Client

ISP Resolver

DOH Resolver

Root Server

Browser

Q: e.we.com

.com

TLD Server

.we.com

Operating System

Authoritative

me.we.com
~~Client Subnet~~

DOH Resolver

Latency

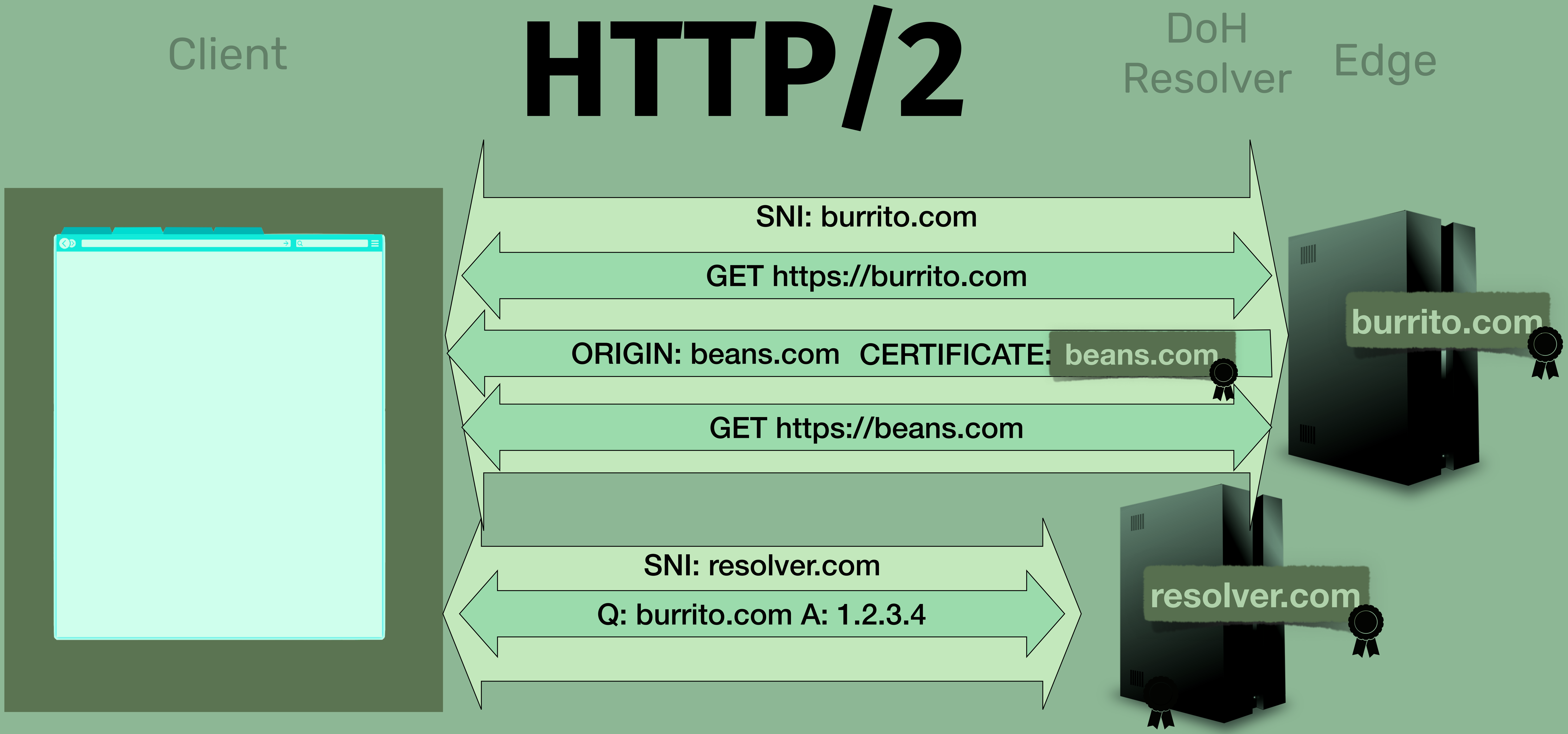
ISPs

Closer to user
Smaller cache
UDP

Edge DoH

Globally Distributed
TLS 1.3 0RTT

Challenges in the Enterprise



Client

HTTP/2

DoH Resolver

Edge

SNI: burrito.com

GET https://burrito.com

ORIGIN: beans.com CERTIFICATE: beans.com

GET https://beans.com

SNI: resolver.com

Q: burrito.com A: 1.2.3.4

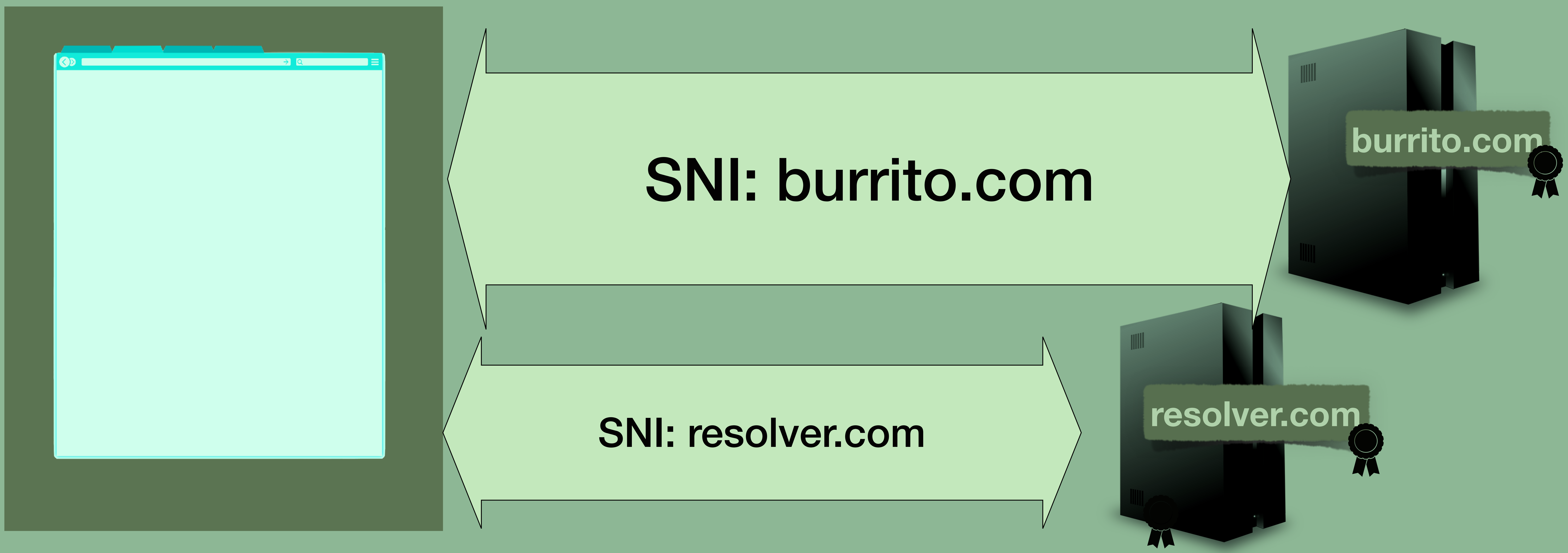
ORIGIN/CERT + DoH

HTTP/2

Client

DoH Resolver

Edge



SNI: burrito.com

SNI: resolver.com

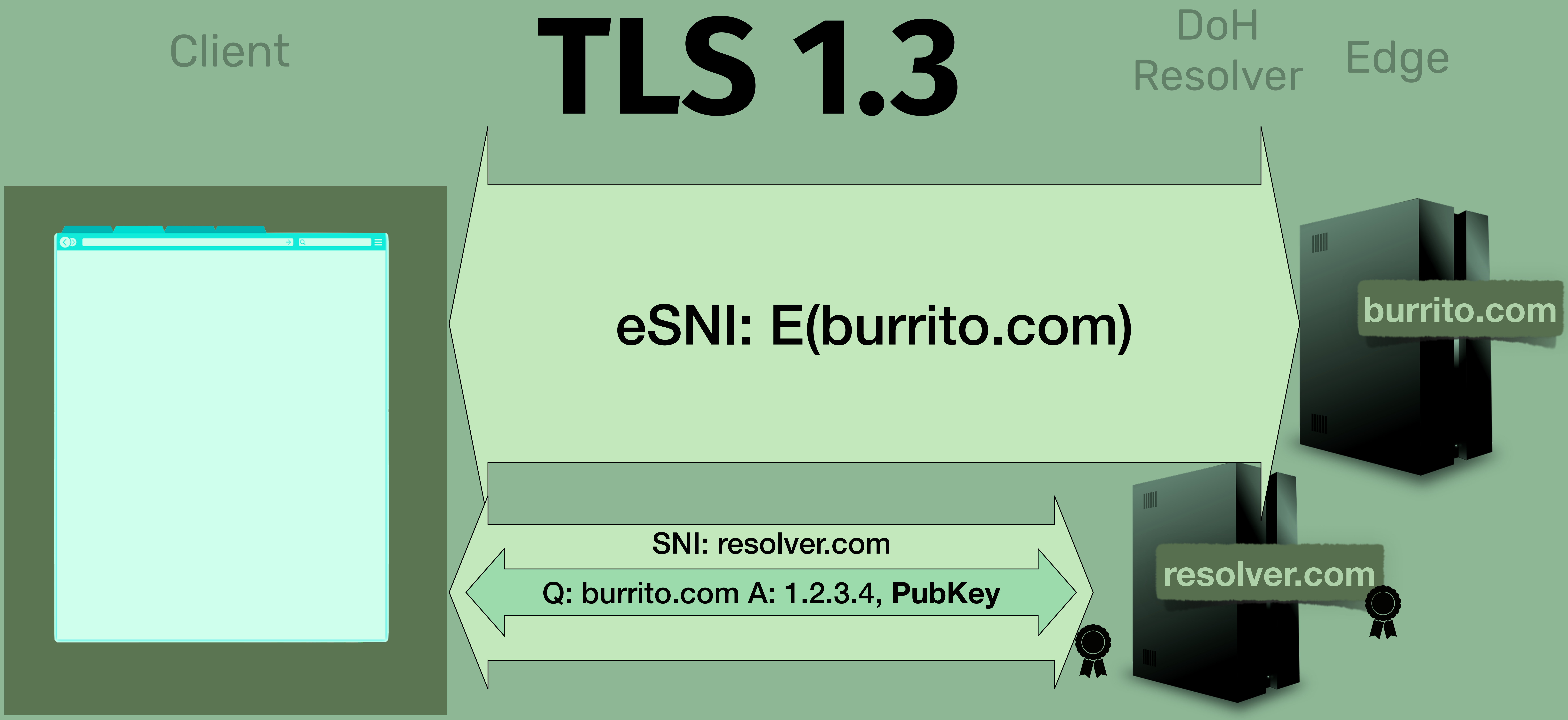
ORIGIN/CERT + DoH

SNI

Encryption

Encrypt SNI with client ephemeral key + server public key from DNS

TLS 1.3



O/C + DoH + eSNI

What a network observer can see

HTTP ⟶ HTTPS ⟶

Clients ●

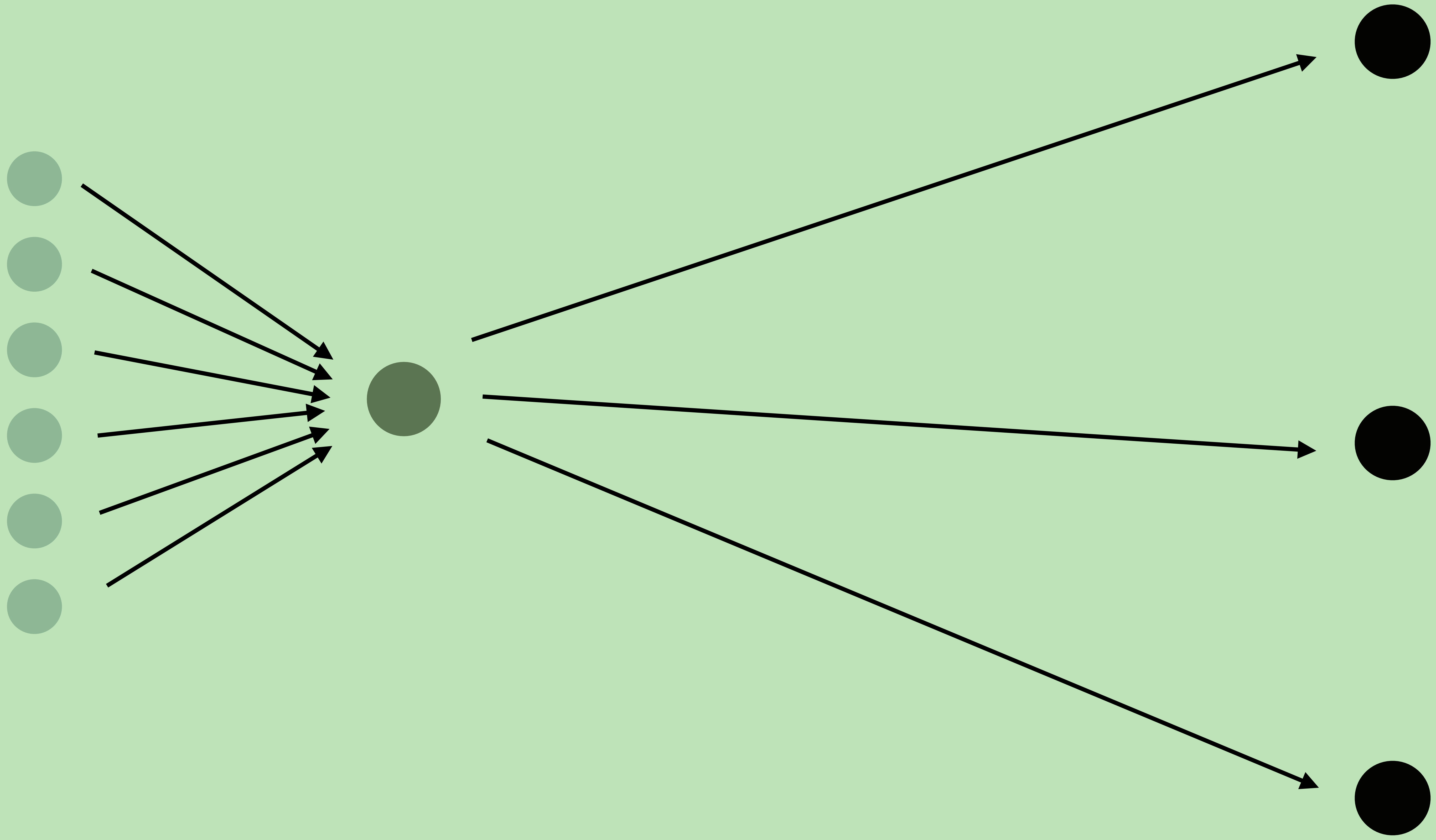
Hosts ●

Anycast Hosts ●

Client Unique IP

Shared Server IP

~~First Hostname (SNI)~~

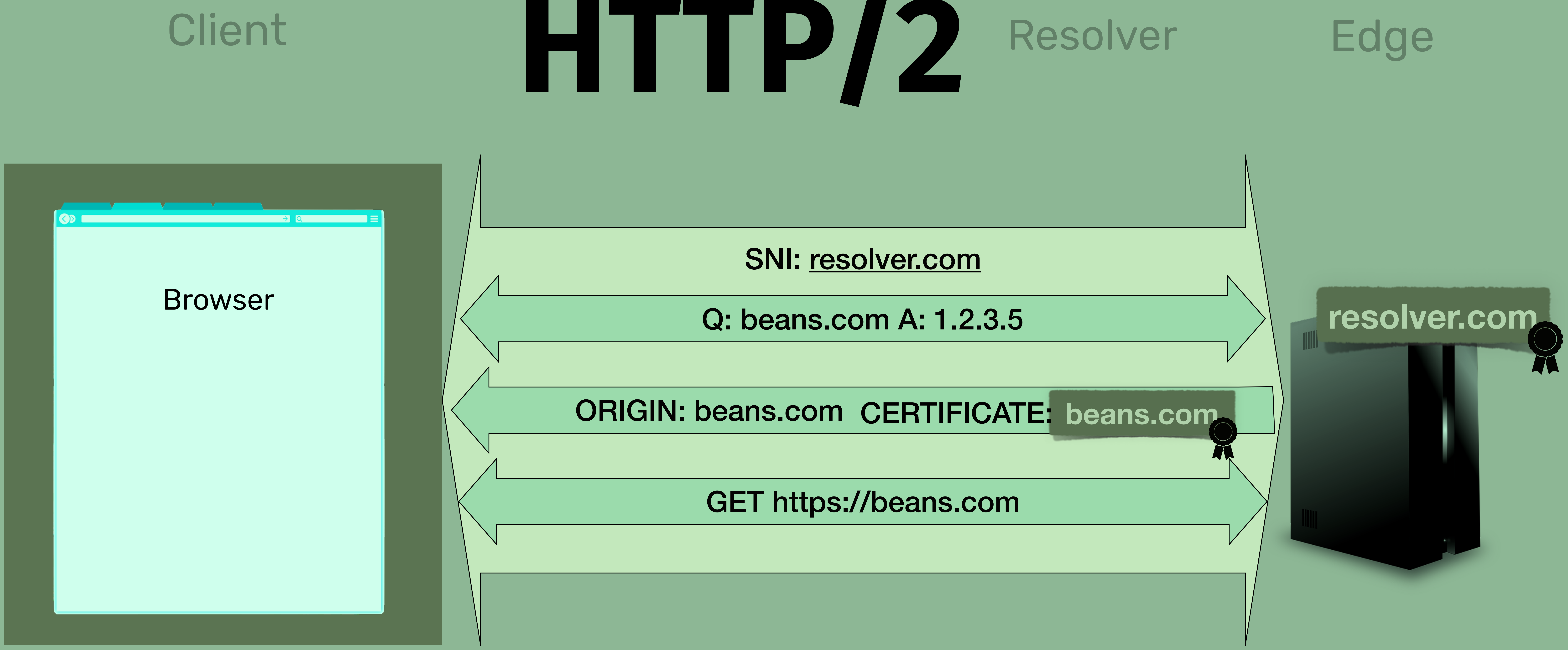


	Anonymity set
Client	**1**
Server	**K**

K is the set of domains that can be served on the IP

Caveat: If Server IP is static, then this give a hint about first hostname.

HTTP/2



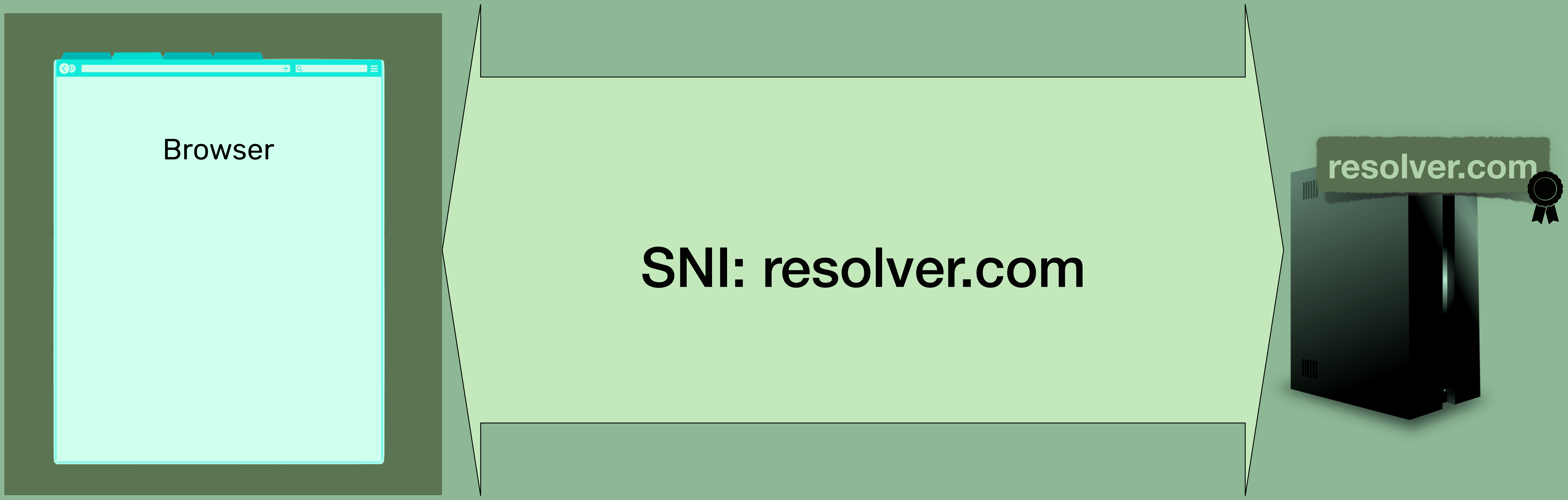
DOH “VPN”

HTTP/2

Client

Resolver

Edge



DOH “VPN”

	Anonymity set
Client IP	**1**
Server IP	**K**

K is the set of domains that can be served on the IP

No dynamic IP requirement

Where are we now?

ORIGIN implemented in Firefox

CERTIFICATE being standardized by IETF

DOH supported by Google DNS, 1.1.1.1

eSNI about to be submitted to IETF

ORIGIN

Privacy improvement limited by shared certs

Latency skip both DNS and HTTPS

Security certificate compromise risk

CERTIFICATE

Privacy hide any bean in any burrito

Latency extends origin benefits to any cert

Security exchange DNS for CT or OCSP stapling

DOH

Privacy first hop improvement

Latency depends on provider, TLS 1.3

Security security against attacks, allows passive DNS

eSNI

Privacy first domain privacy given dynamic IPs

Latency depends on DoH for reliability

Security risk of more MiTM

Open Questions

How much privacy does this actually give people?

Does this incentivize further consolidation?

Does increased performance and privacy outweigh the legitimate need for external visibility?

Website Fingerprinting

Removing explicit signals does not protect you from passive ones

Consolidation

Better performance when using a popular provider

Is visibility necessary?

Safety vs. Security

The Evolving Architecture of the Web

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