Content Delivery Strategies

CS249i

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- Liz will post OH on Edstem (virtual and in-person)

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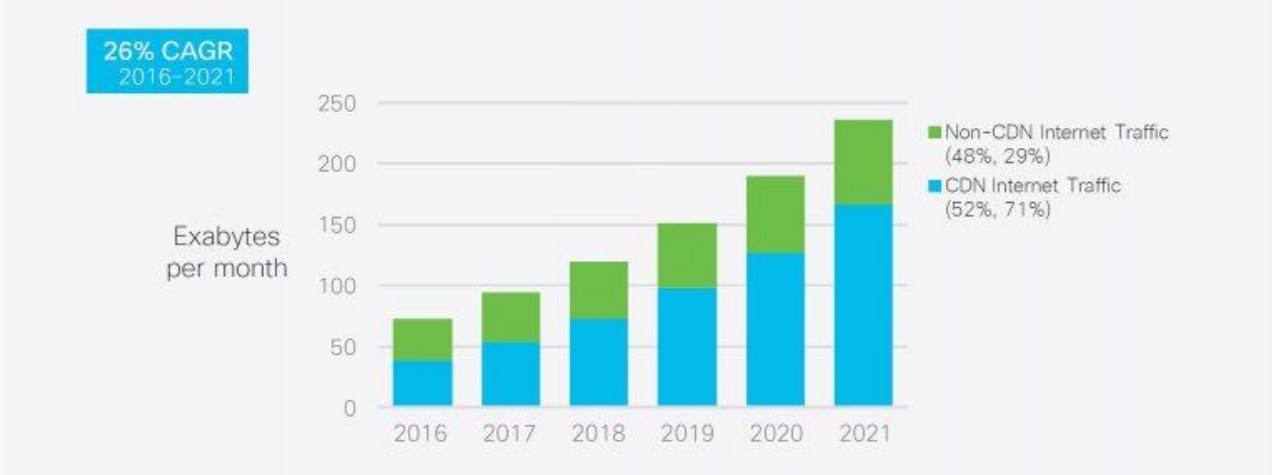
- Cisco estimates that 71% of Internet traffic traverses a content delivery network (CDN).
  - CDN's are how and *why* **The Modern Internet** works.
  - Content delivery is what Google, Amazon, Microsoft, Netflix, Cloudflare, Facebook, etc. all do.



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- Cisco estimates that 71% of Internet traffic traverses a content delivery network (CDN).
  - CDN's are how and *why* **The Modern Internet** works.
  - Content delivery is at the core of Google, Amazon, Microsoft, Netflix, Cloudflare, Facebook, etc. businesses and they are constantly working to improve content delivery.

- Creating content delivery strategies is a very interesting systems/networking problem
  - Many papers at top-tier systems and networking conferences (NSDI, OSDI, IMC)

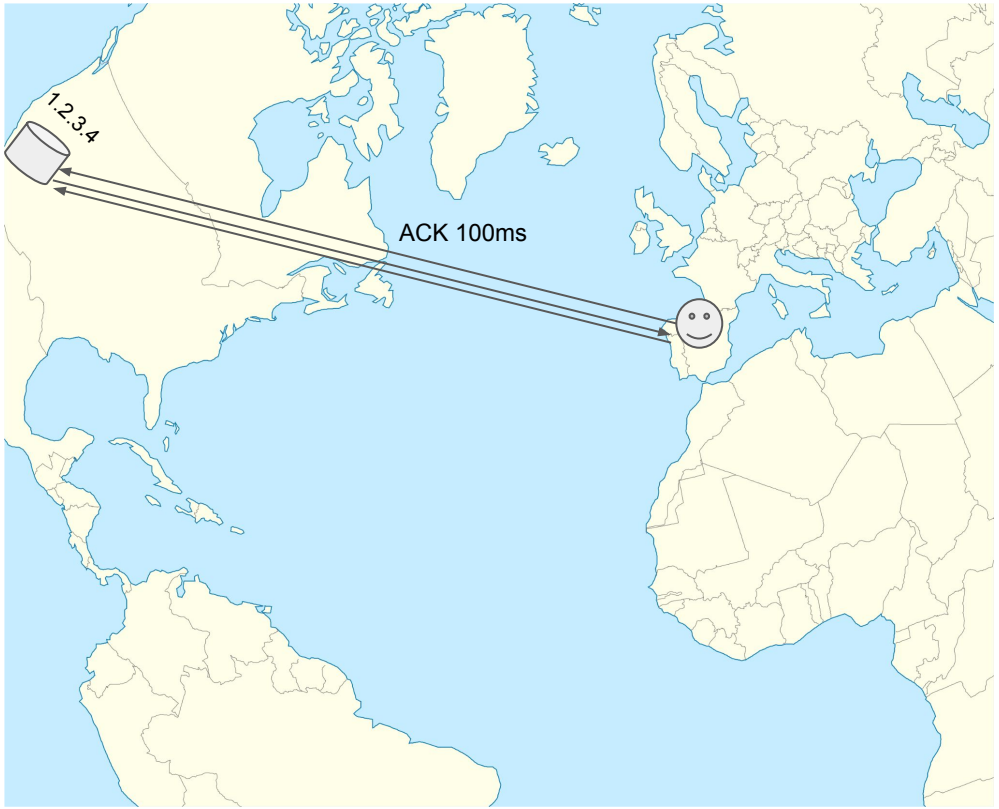
What does a world without a content delivery strategy look like?

Unicast

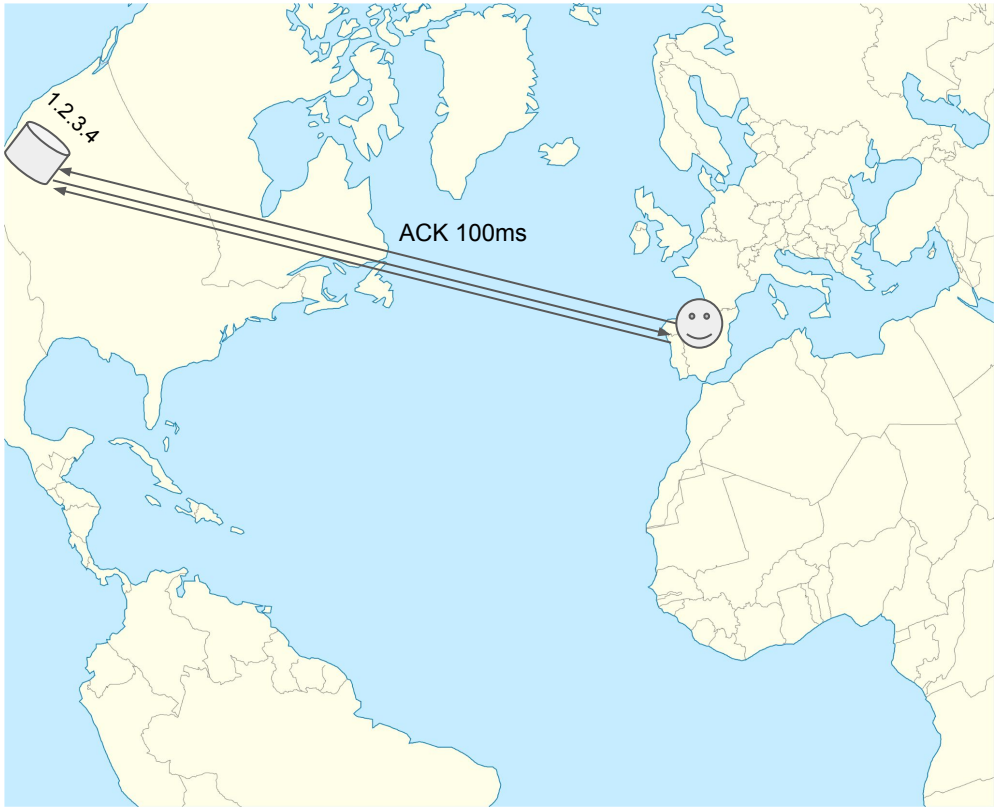
Unicast

Unicast

Unicast



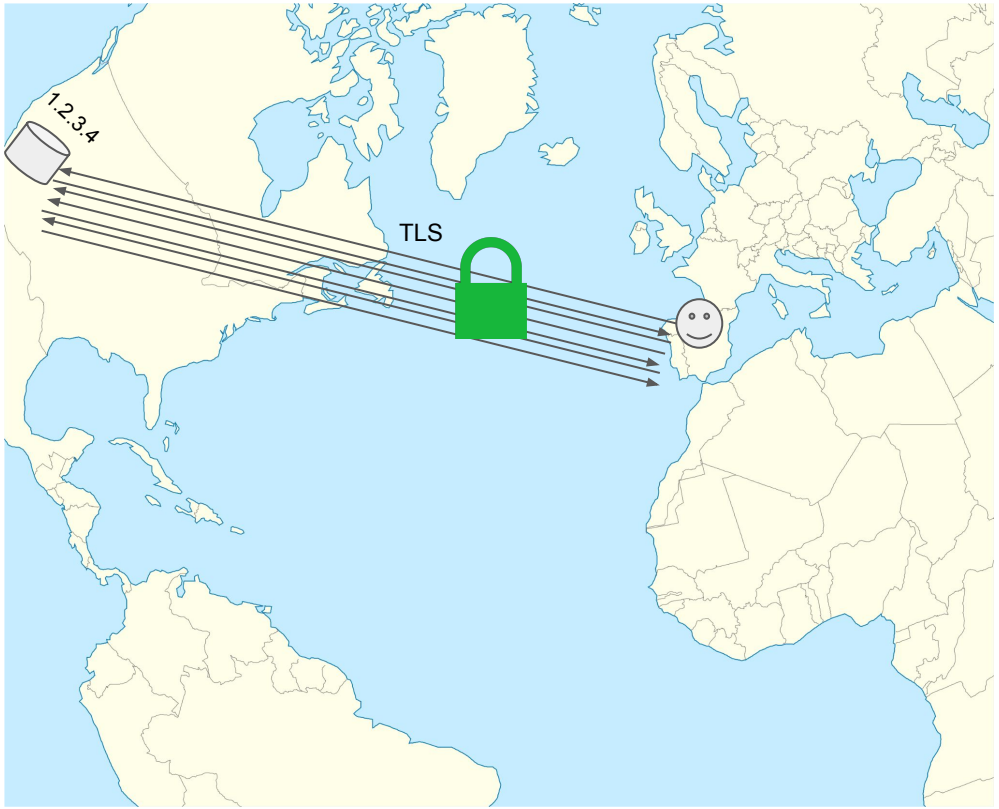
Unicast



TCP Handshake Time:

100ms *3 = 300ms

Unicast is too expensive



TCP Handshake Time:

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TCP + TLS Handshake Time:

100ms *3 + 100ms *4 = 700 ms

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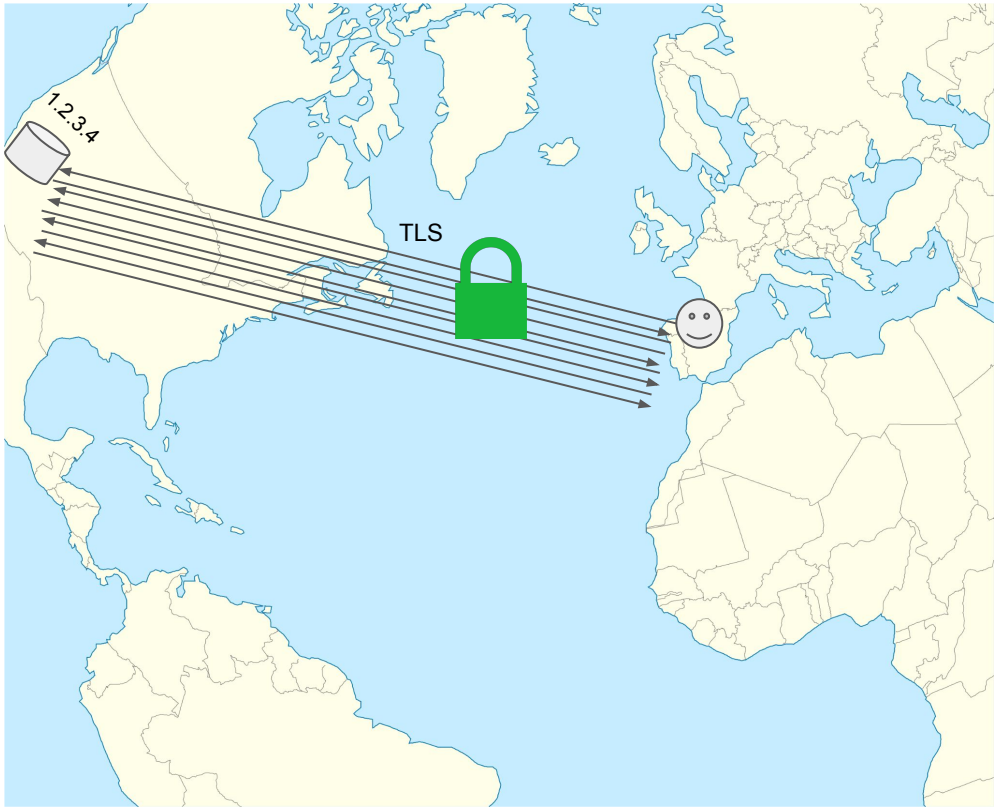

TCP Handshake Time:

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TCP + TLS Handshake Time:

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TCP + TLS + Content Time:

100ms *3 + 100ms *4 + 100ms * 2 = 900 ms

Speed Matters for Google Web Search

Jake Brutlag
Google, Inc.
June 22, 2009

Tens of Millions!

400ms ↑ load time ↓ 0.74% in searches

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Internal goal of < 1 second response time

A world with a content delivery strategy

Taking advantage of edges

- Edge/ PoP (“Point of Presence”): server(s) located relatively near the client in order to help the client obtain the requested content

Taking advantage of edges

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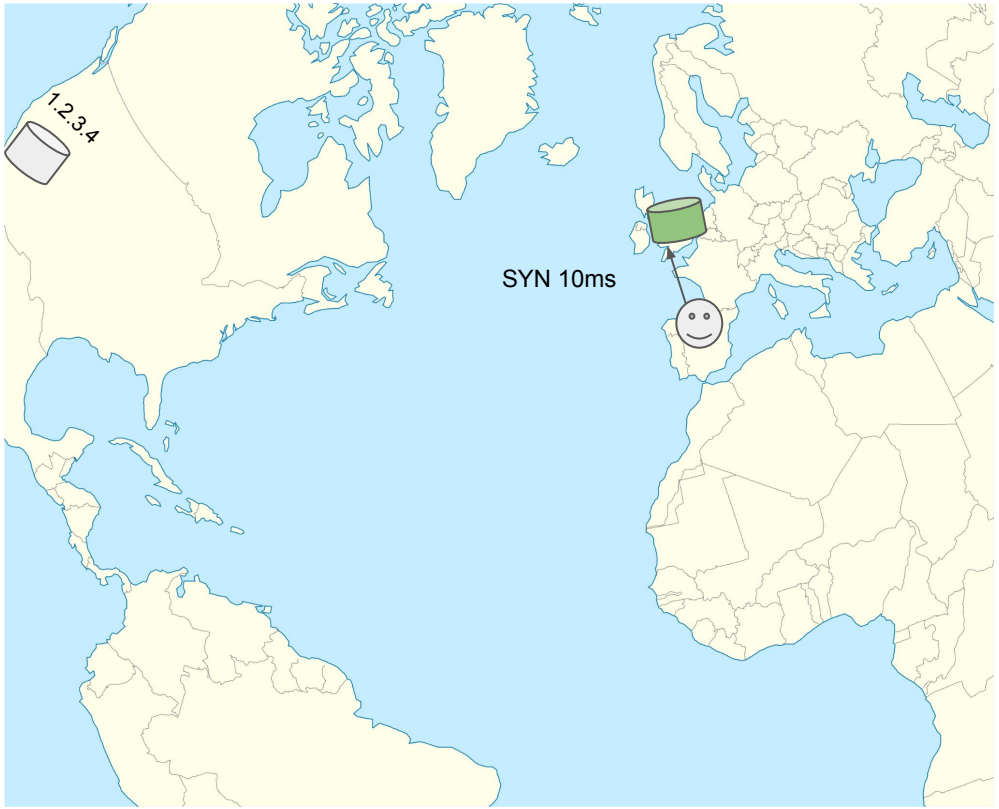

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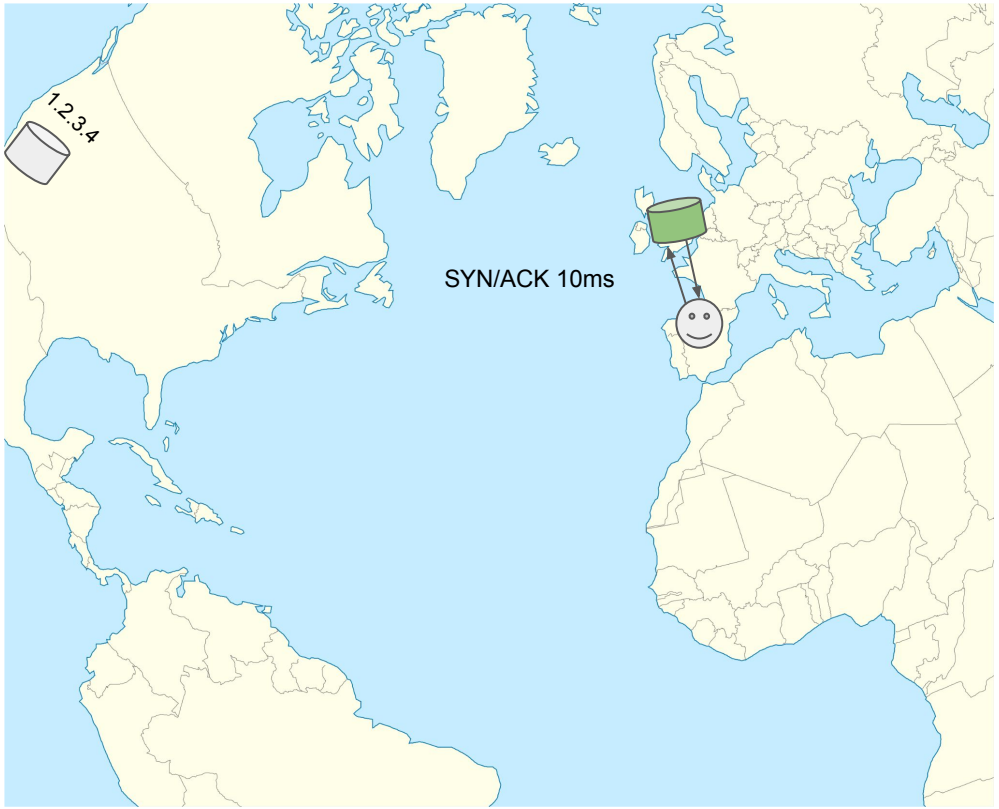


Taking advantage of edges

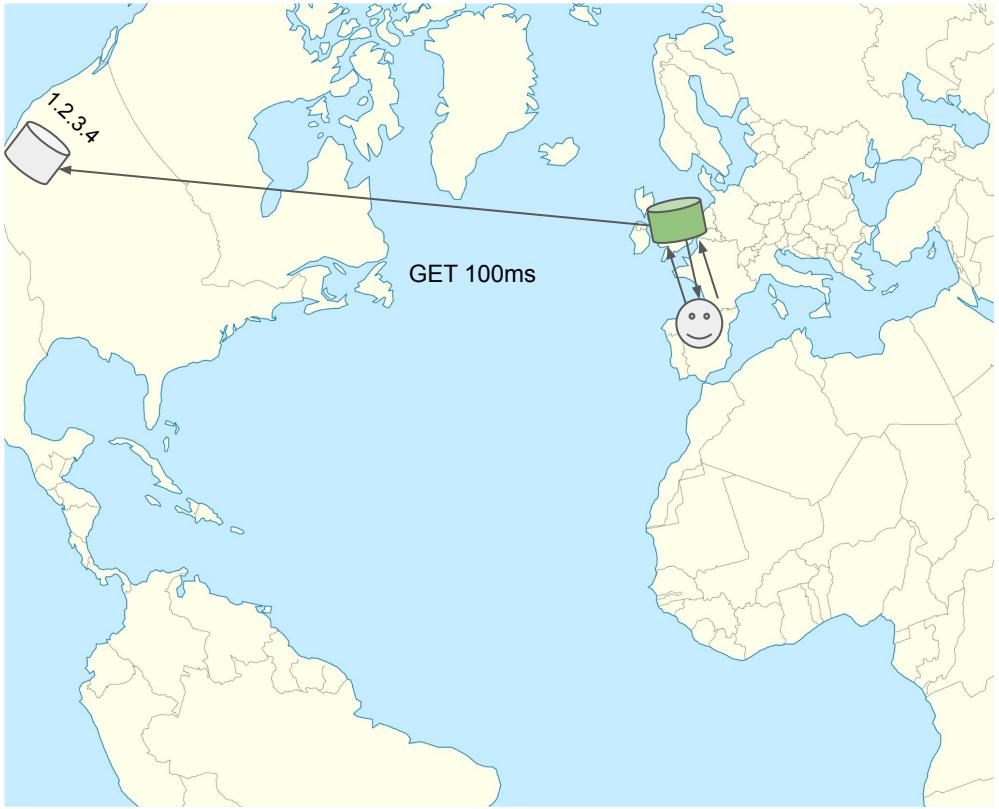
TCP Handshake Time:

10ms *3 = 30ms

TCP + TLS Handshake Time:

10ms *3 + 10ms *4 = 70 ms

Taking advantage of edges



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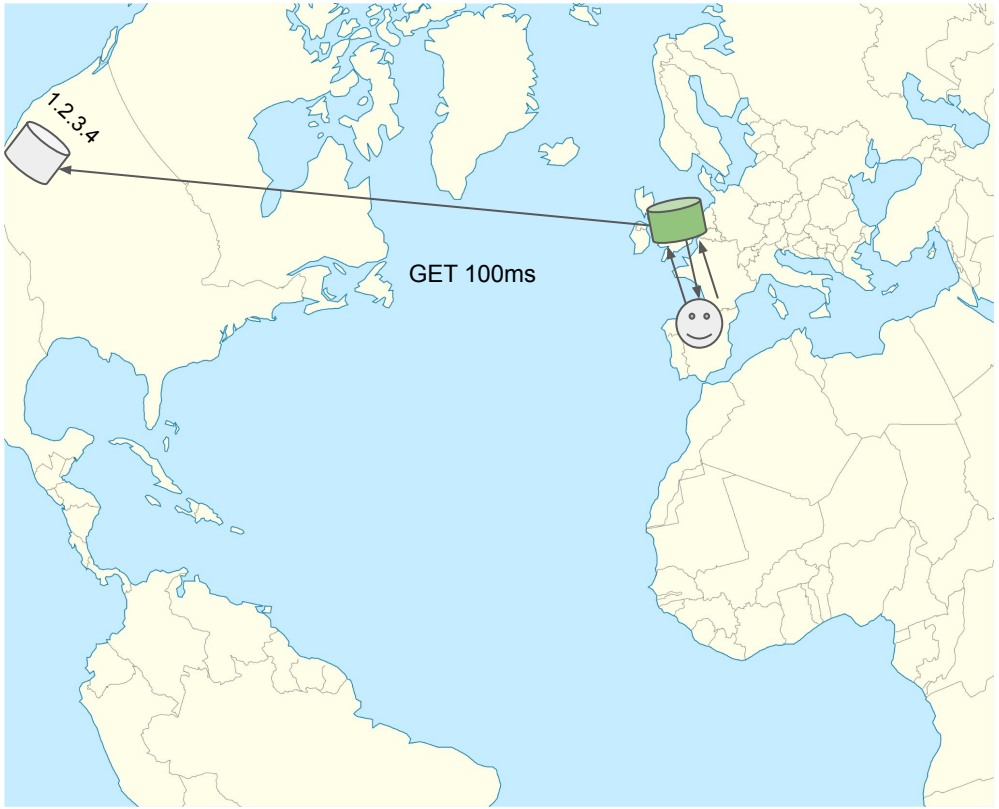
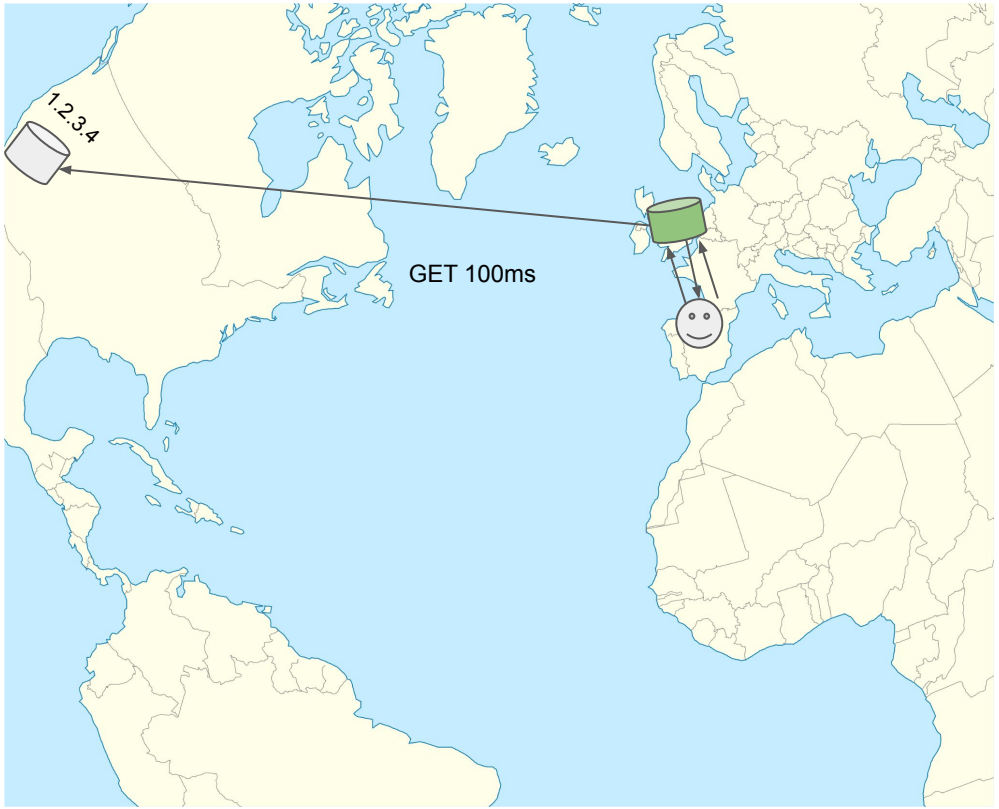


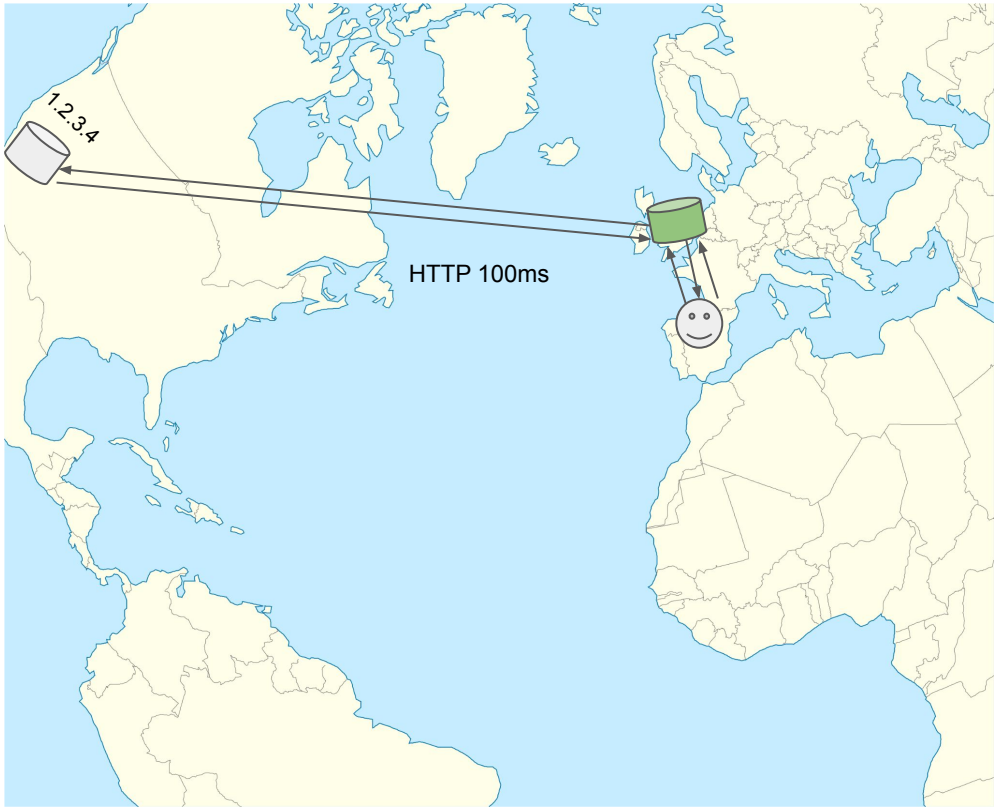
Why does the client not need to wait for the edge to establish a TCP/TLS connection?

Taking advantage of edges



Edge can immediately send the GET request because it will have established a TCP connection before-hand and kept it alive.

Taking advantage of edges



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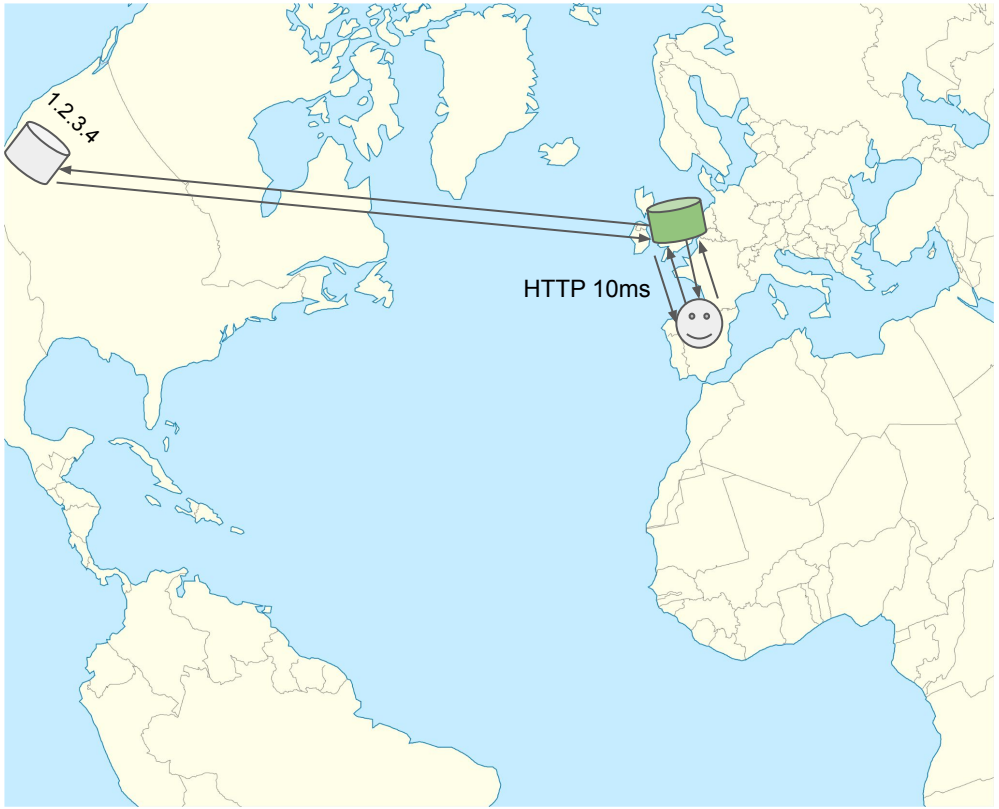


TCP Handshake Time:

10ms *3 = 30ms

TCP + TLS Handshake Time:

10ms *3 + 10ms *4 = 70 ms

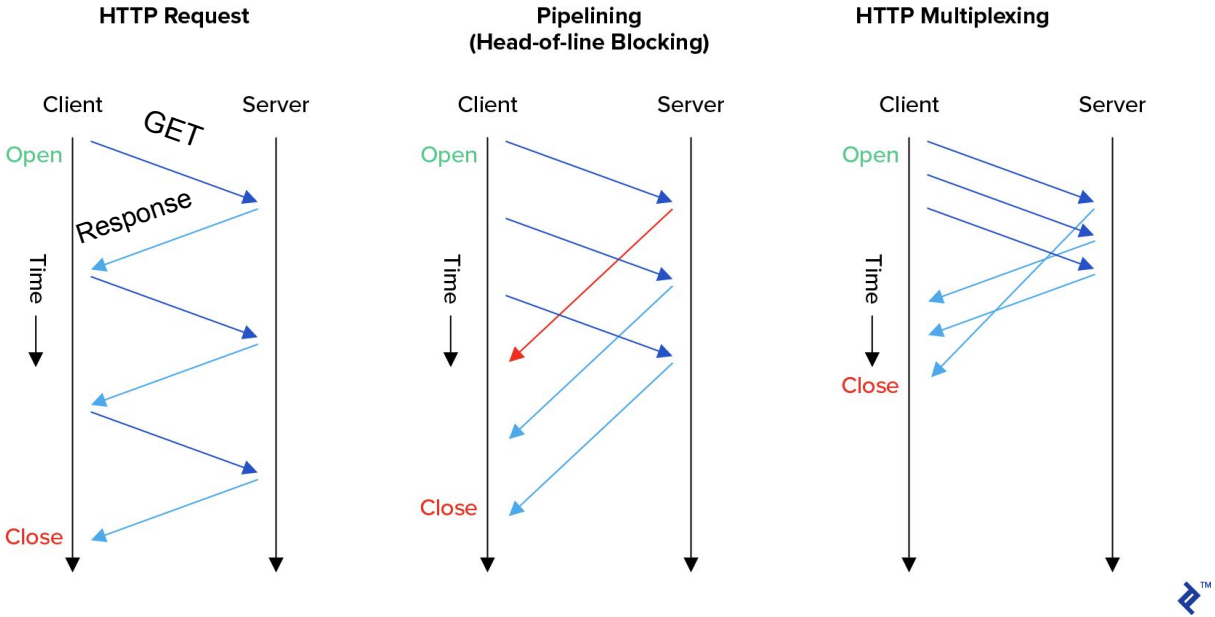
TCP + TLS + Content Time:

70ms + 2*100ms + 10ms = 280ms

>3x savings!

Protocols have evolved to help make proxying connection efficient at scale

HTTP/2 Multiplexing allows data requests to be sent in parallel and responses to be sent as soon as they are ready (non-blocking).



Edge does not need to wait for client A's HTTP response if client B's HTTP response is ready

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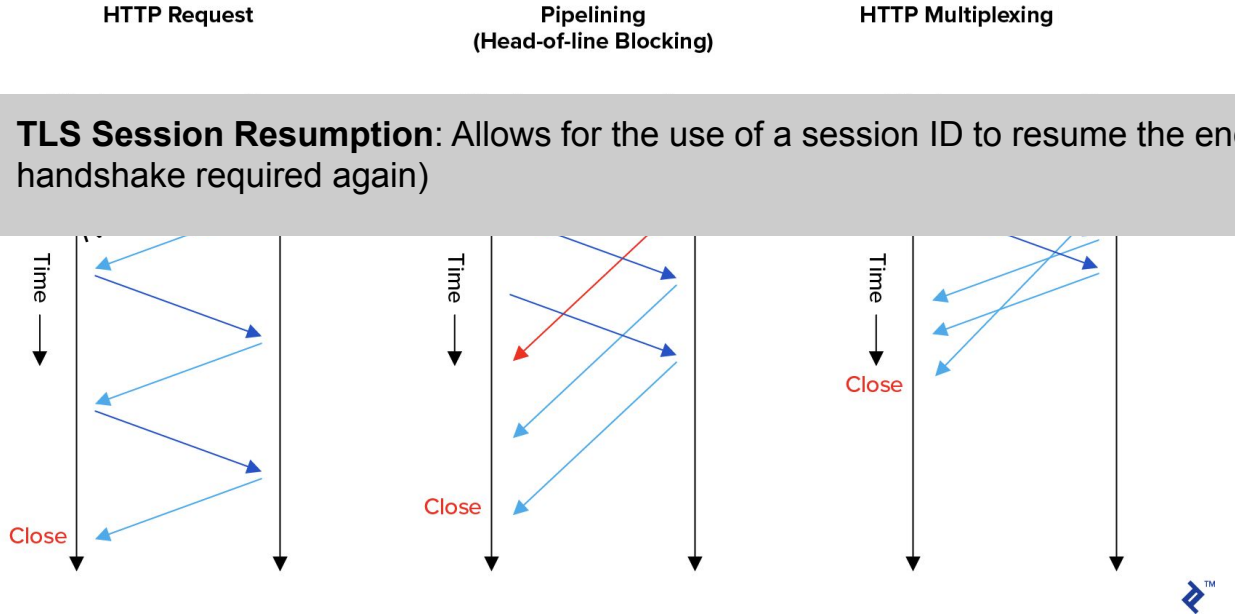
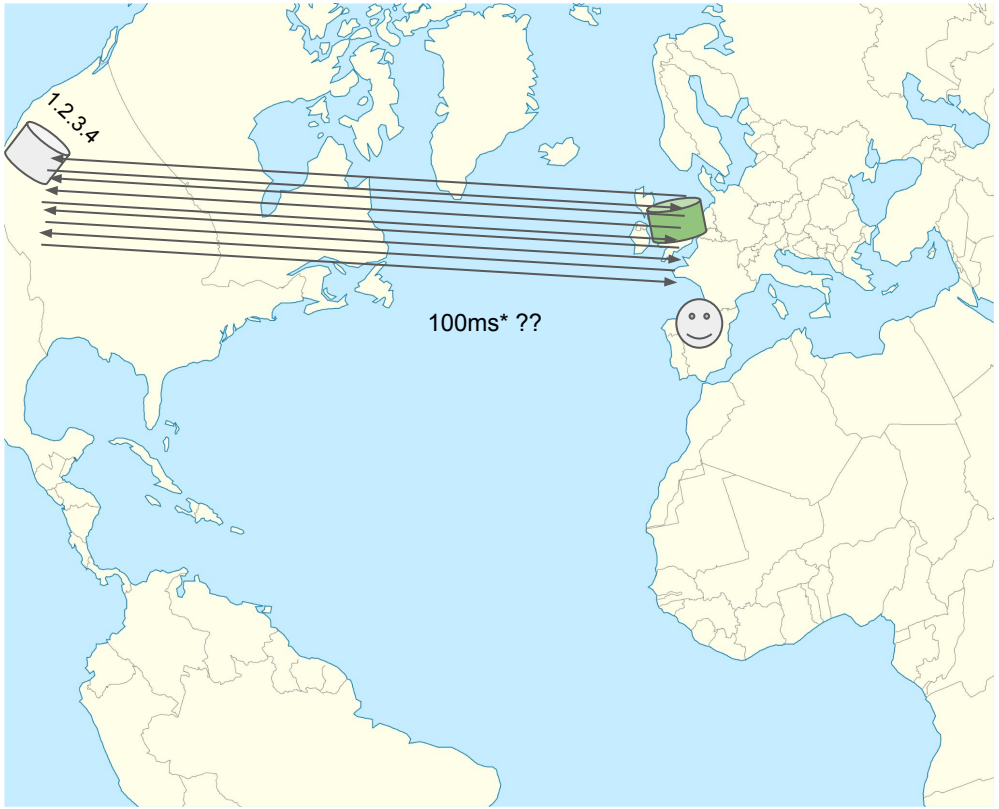


TLS Session Resumption: Allows for the use of a session ID to resume the encrypted session (i.e., no full TLS handshake required again)

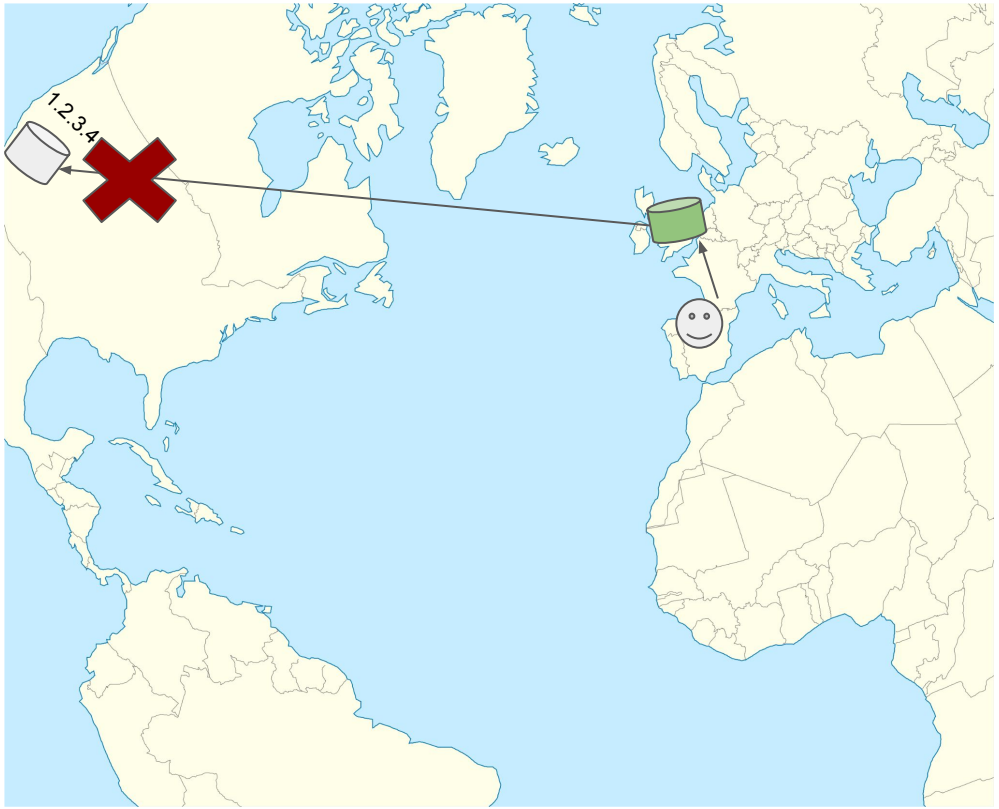
for client A's HTTP response if client B's HTTP response is ready

Even with a connection-proxy edge, content server is far away



Single content server is vulnerable

- Single point of service failure



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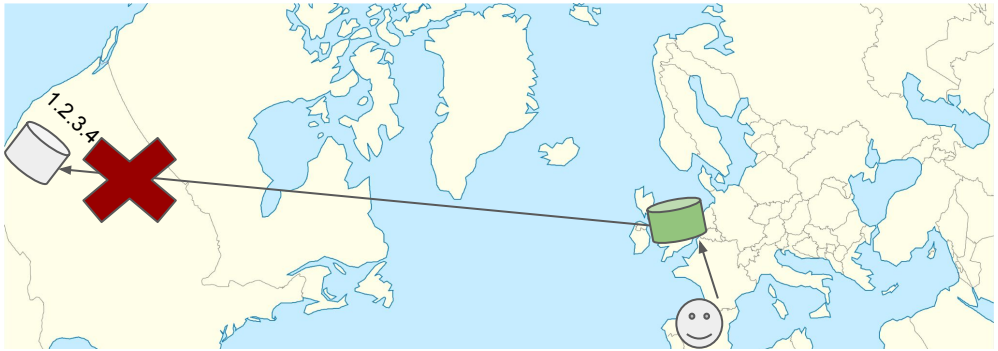
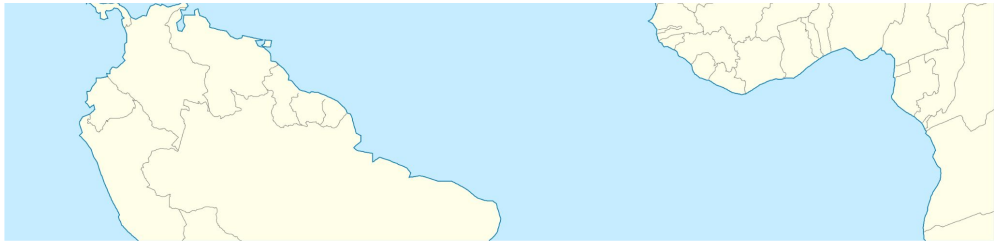
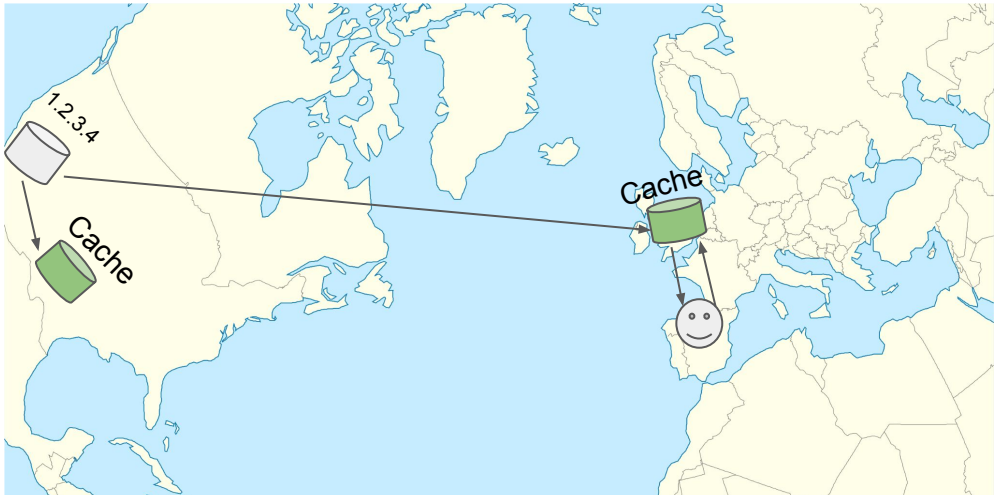


Ideally:

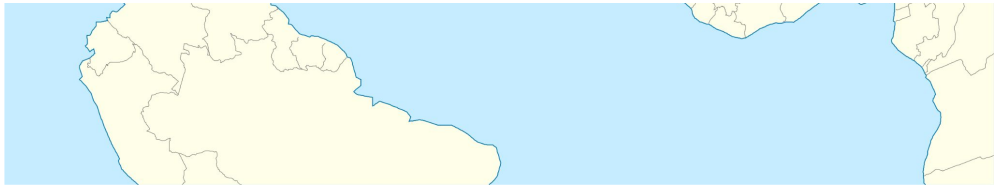
- Move content closer
- Have many content servers
- Have an edge close to the client



Options for moving content closer to user



- Cache popular static content in the edge



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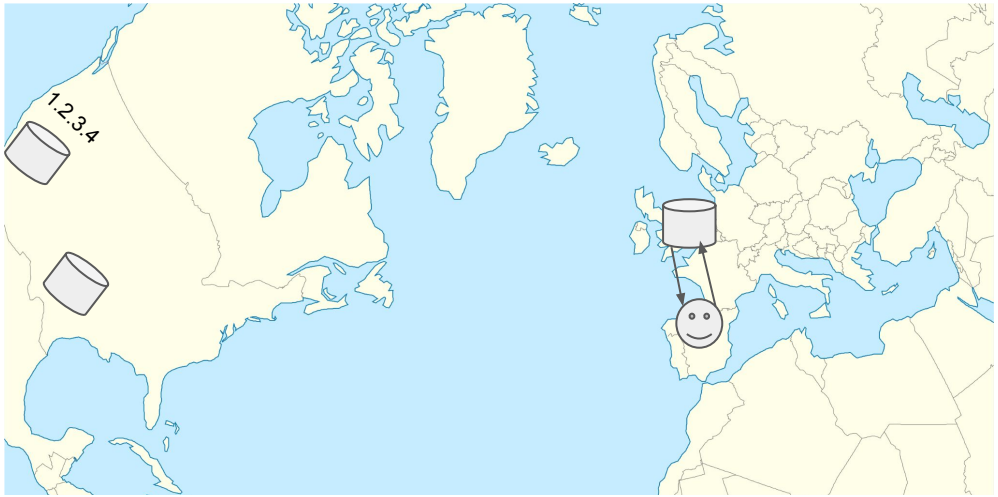
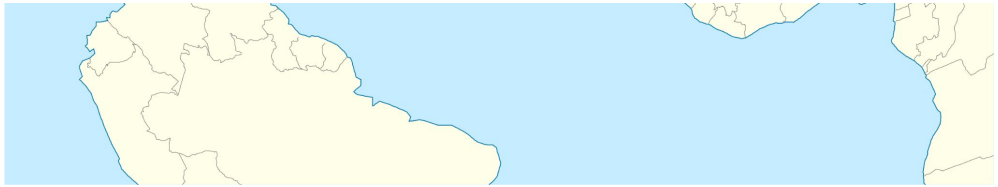


- Cache popular static content in the edge
- Make edge a replicated content server (better for dynamic content)



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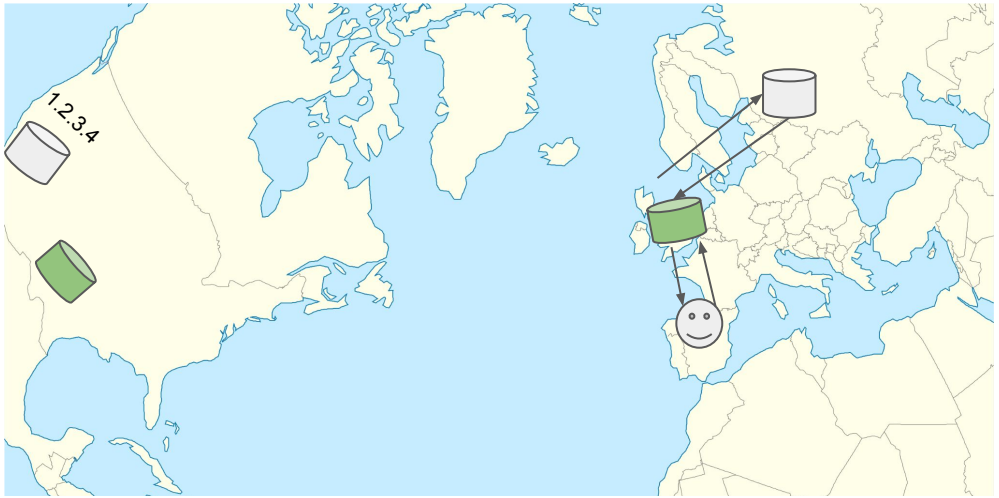
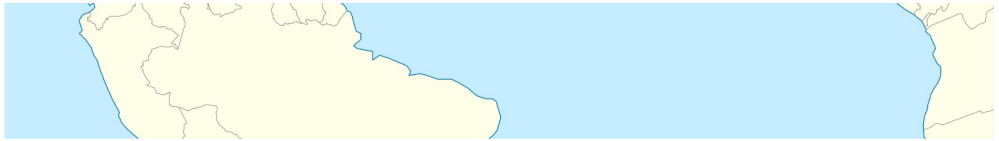


- Cache popular static content in the edge
- Make edge a replicated content server
- Some combination of both



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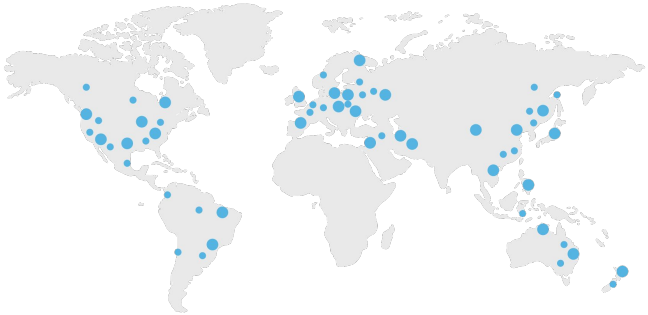
- **“Scattered” Strategy**: Prioritize physical distance to client
  - Many low/medium capacity PoPs



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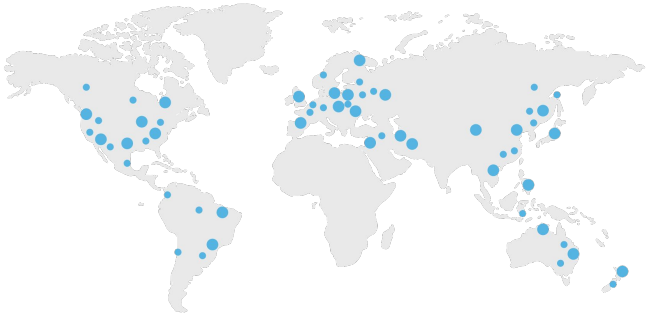

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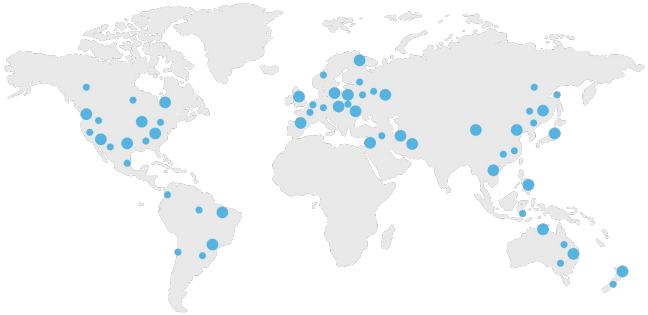

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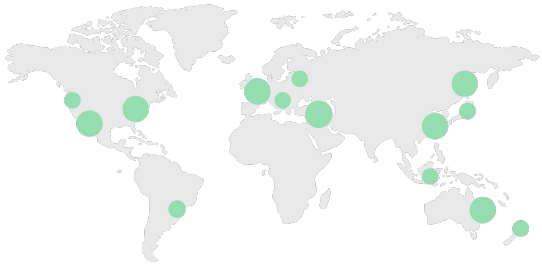
(-) Modern fiber cables makes distance less of a bottleneck

(-) Tough to maintain/update

“Copper-based transmissions currently max out at 40 Gbps, whereas fiber optics can carry data at close to the speed of light.”

Where should edge servers/ “PoPs” be located?

“Consolidated” Strategy: Prioritize fewer, but more powerful PoPs (data centers, IXPs)



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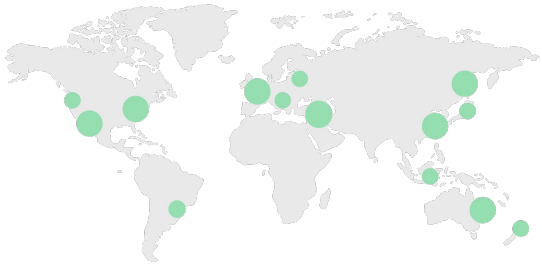

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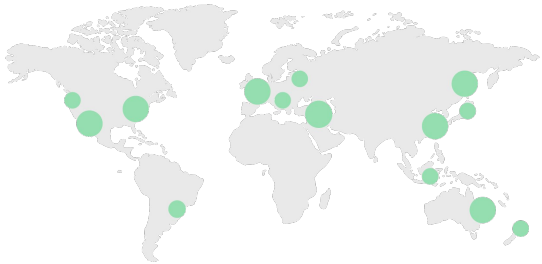

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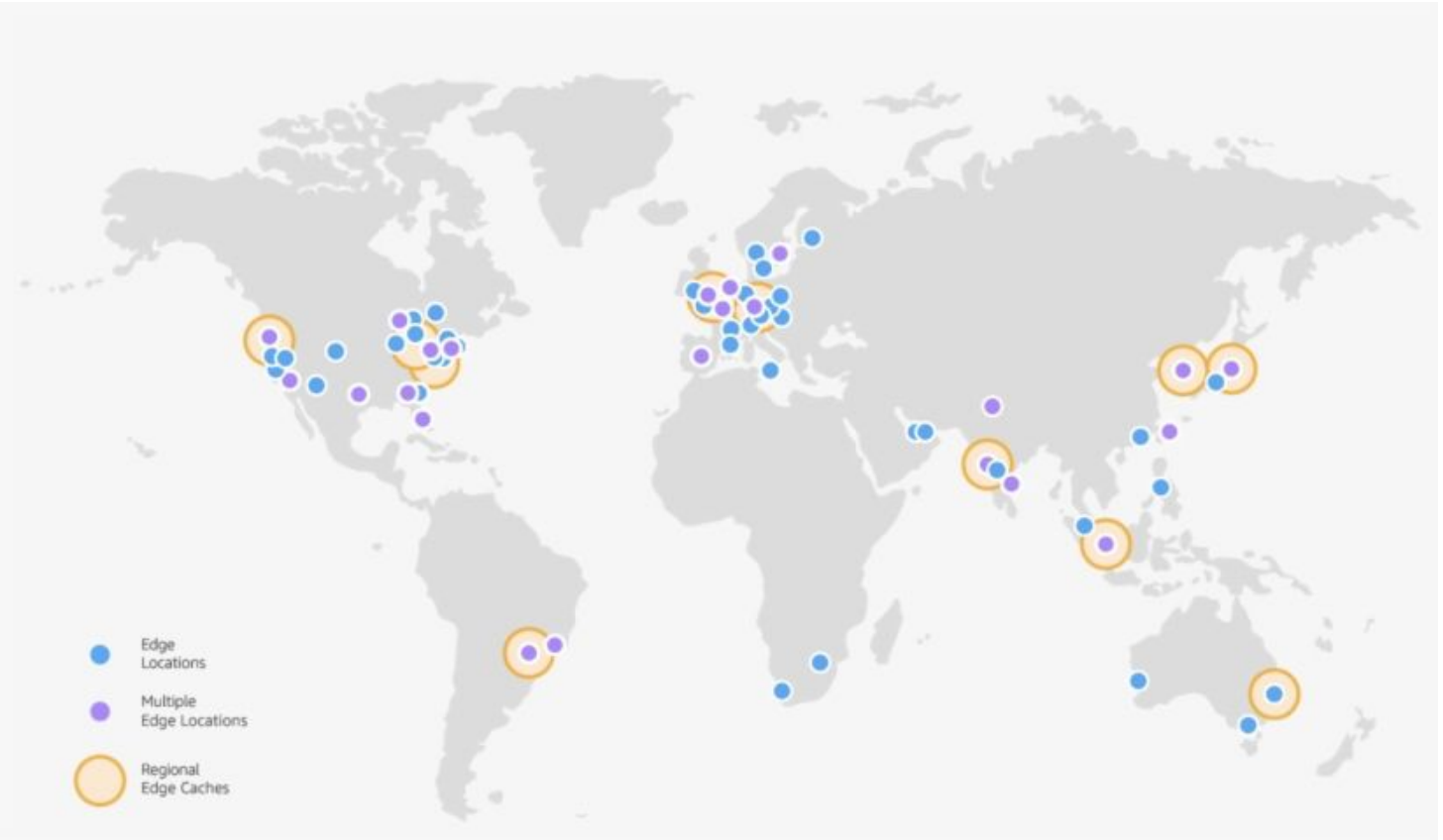
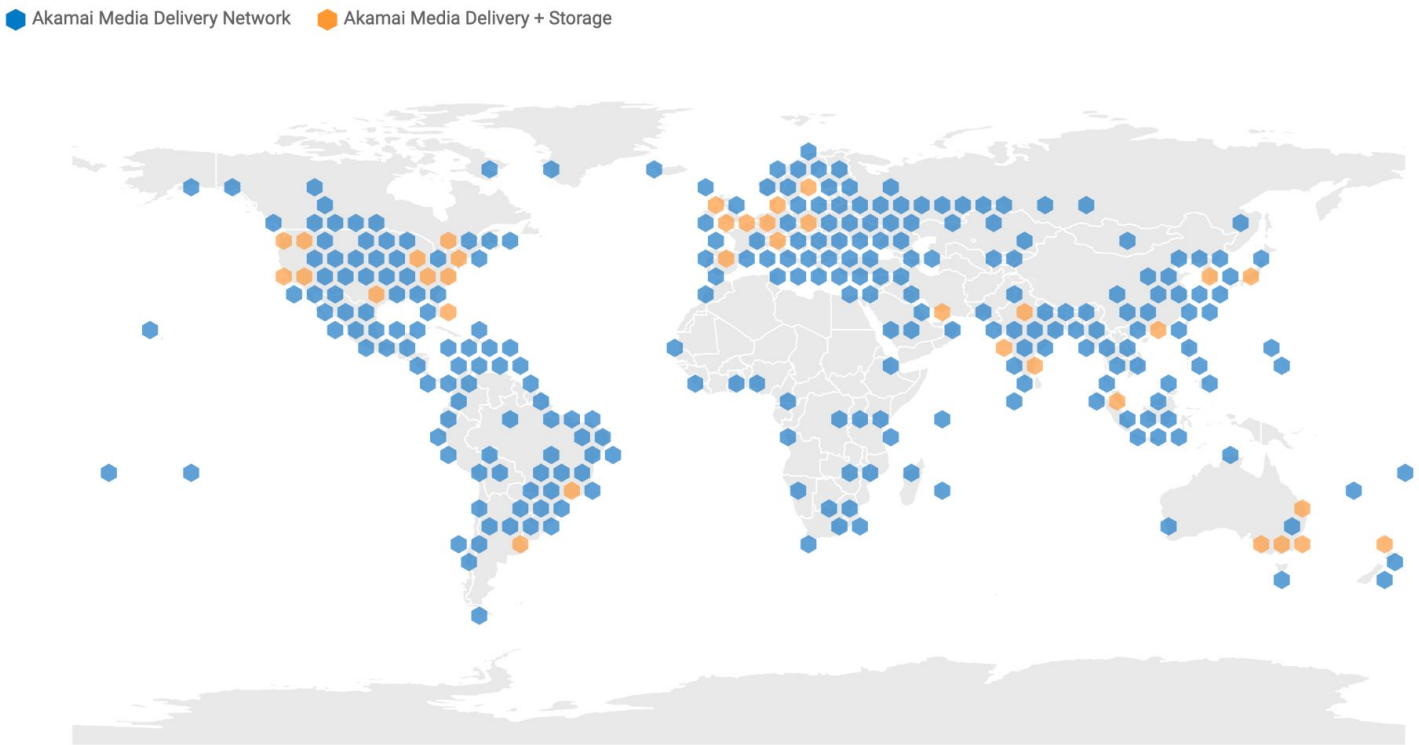
amazon cloudfront



https://aws.amazon.com/blogs/aws/200-amazon-cloudfront-points-of-presence-price-reduction/

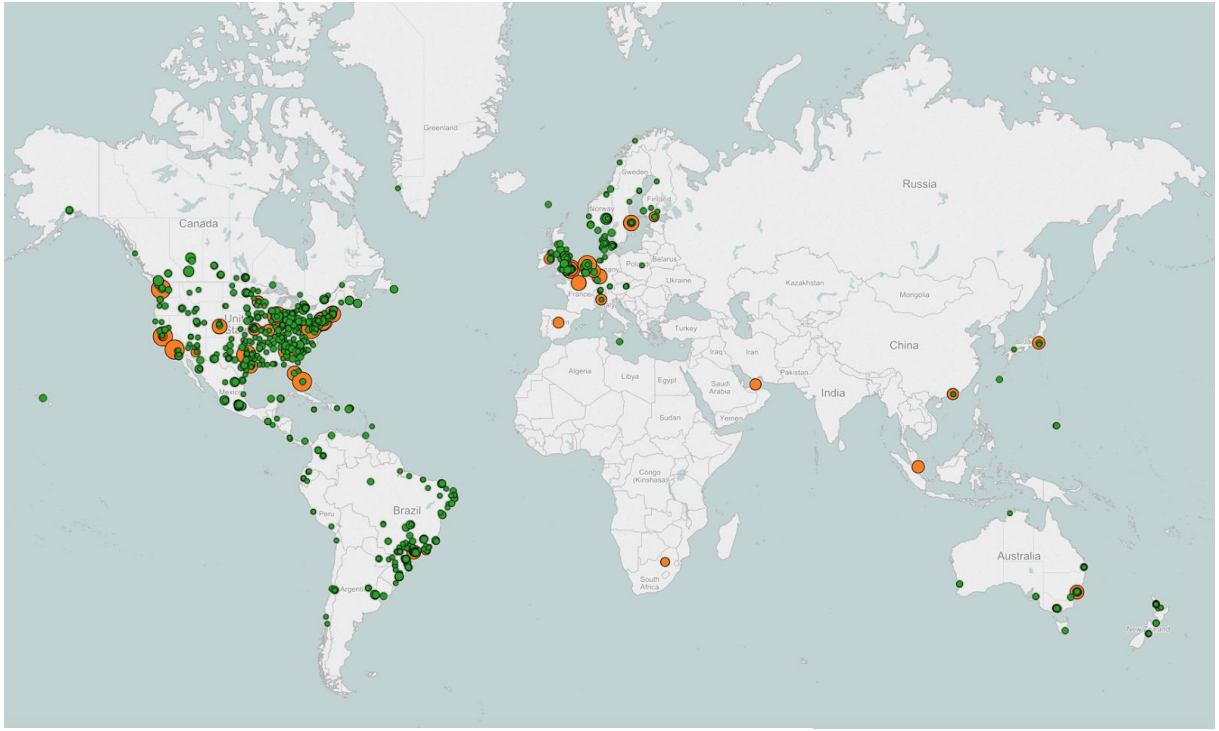
Akamai



https://www.akamai.com/visualizations/media-delivery-network-map

NETFLIX

Open Connect CDN



ISP Locations Internet Exchange Point (circles are sized by volume)

https://about.netflix.com/en/news/how-netflix-works-with-isps-around-the-globe-to-deliver-a-great-viewing-experience

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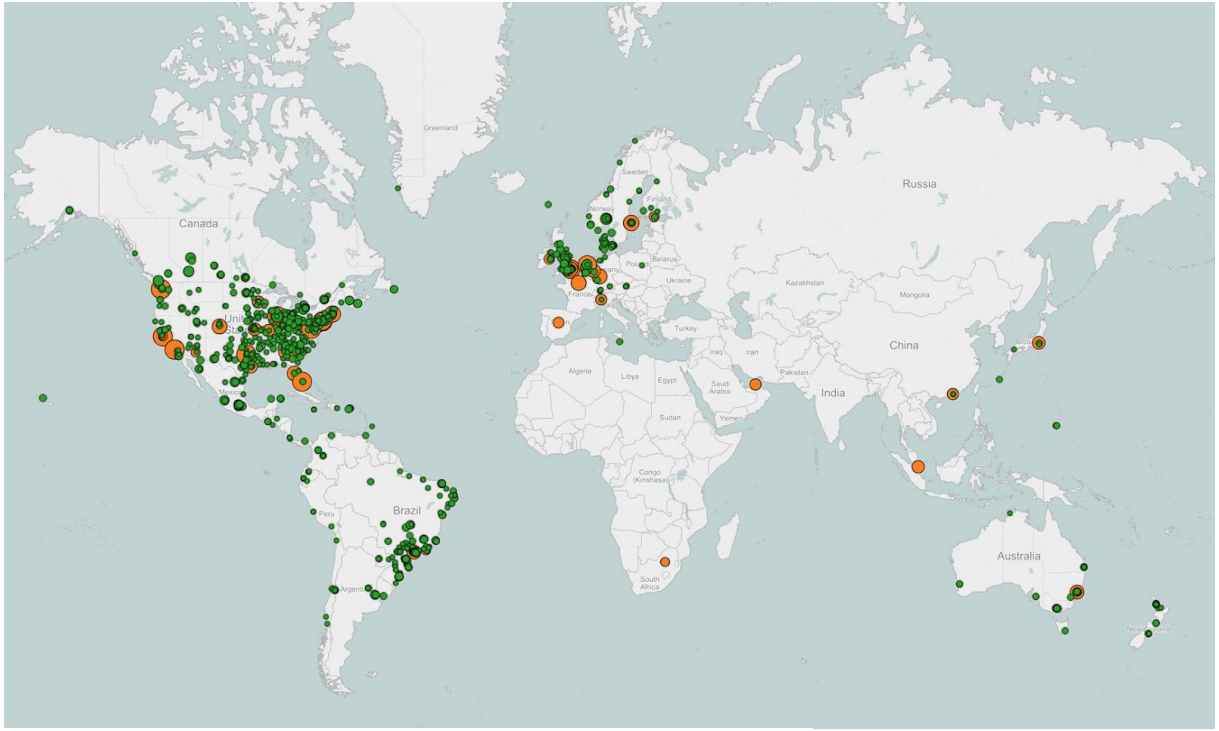

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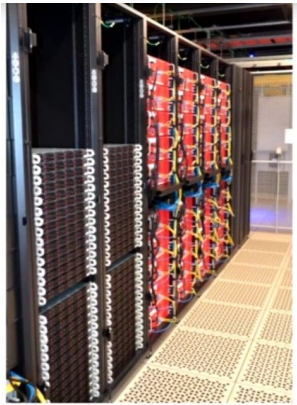


- Netflix does not run its own network! It convinces ISPs to put its own “Open Connect Appliances” in their data centers

https://about.netflix.com/en/news/how-netflix-works-with-isps-around-the-globe-to-deliver-a-great-viewing-experience

Why do ISPs participate in Netflix's Open Connect?

- Netflix promises to pre-position content during off-peak hours, in order to reduce burden on the Internet during peak hours. Thus, ISPs do not have to worry about building more network capacity.

A brief history of Netflix's infrastructure woes

1998: Netflix is born

2007: Netflix builds two datacenters. Netflix builds its own CDNs using 5 locations within the US

- Painful process: ordering equipment, installing, never large enough..always need more

2008: Netflix goes offline for three days due to their own infrastructure.

2008: Netflix moves to AWS (North Virginia, Portland Oregon, Dublin Ireland.) and has previously said they have no intention to operate out of more regions

2009: Netflix abandons building their own CDN, turn to Akamai, Limelight, Level 3

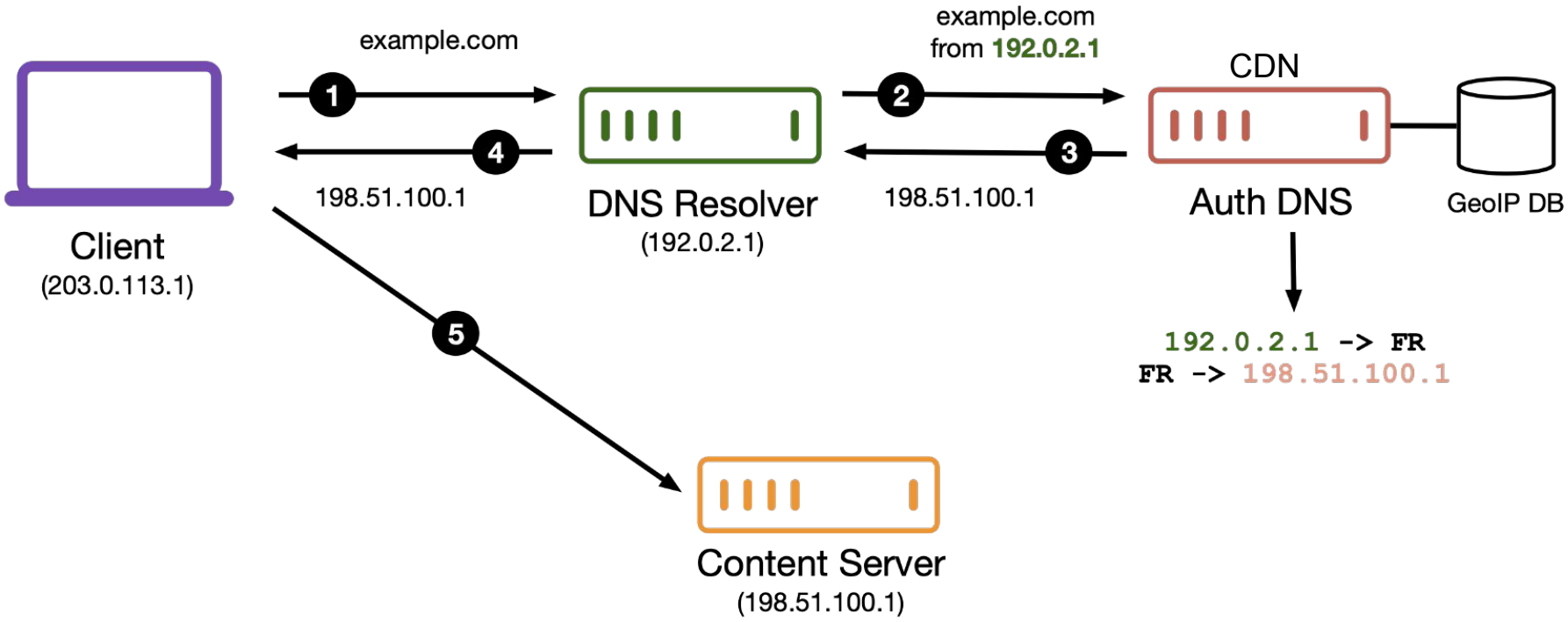
2011: Netflix decides they need a dedicated CDN to maximize network efficiency

2012: Netflix launches Open Connect (less expensive, better control, more scalable)

How does one choose the nearest PoP?

(1) (DNS routing, “Map the Internet”, Unicast) Approach

DNS uses the client resolver IP to return the edge/PoP IP that is closest to the client



(1) (DNS routing, “Map the Internet”, Unicast) Approach

Every edge/PoP is assigned its own unique IP address

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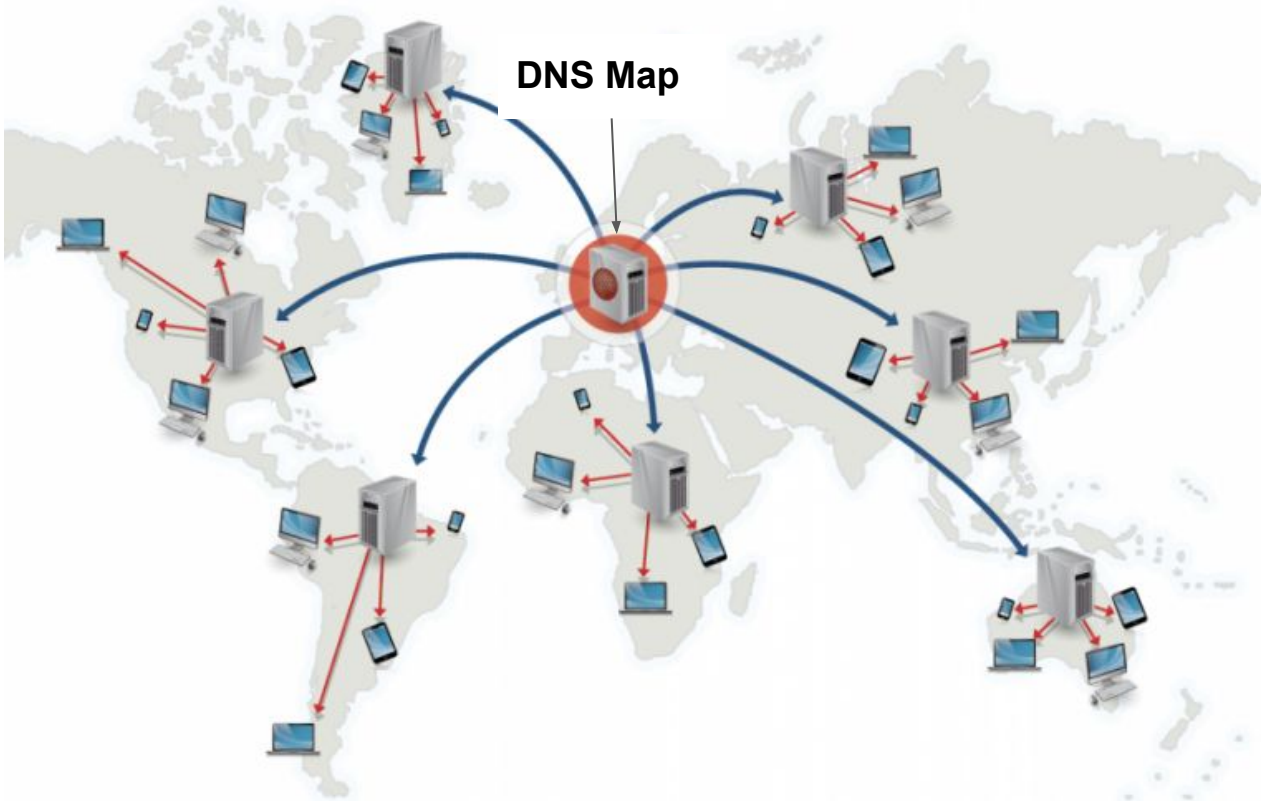
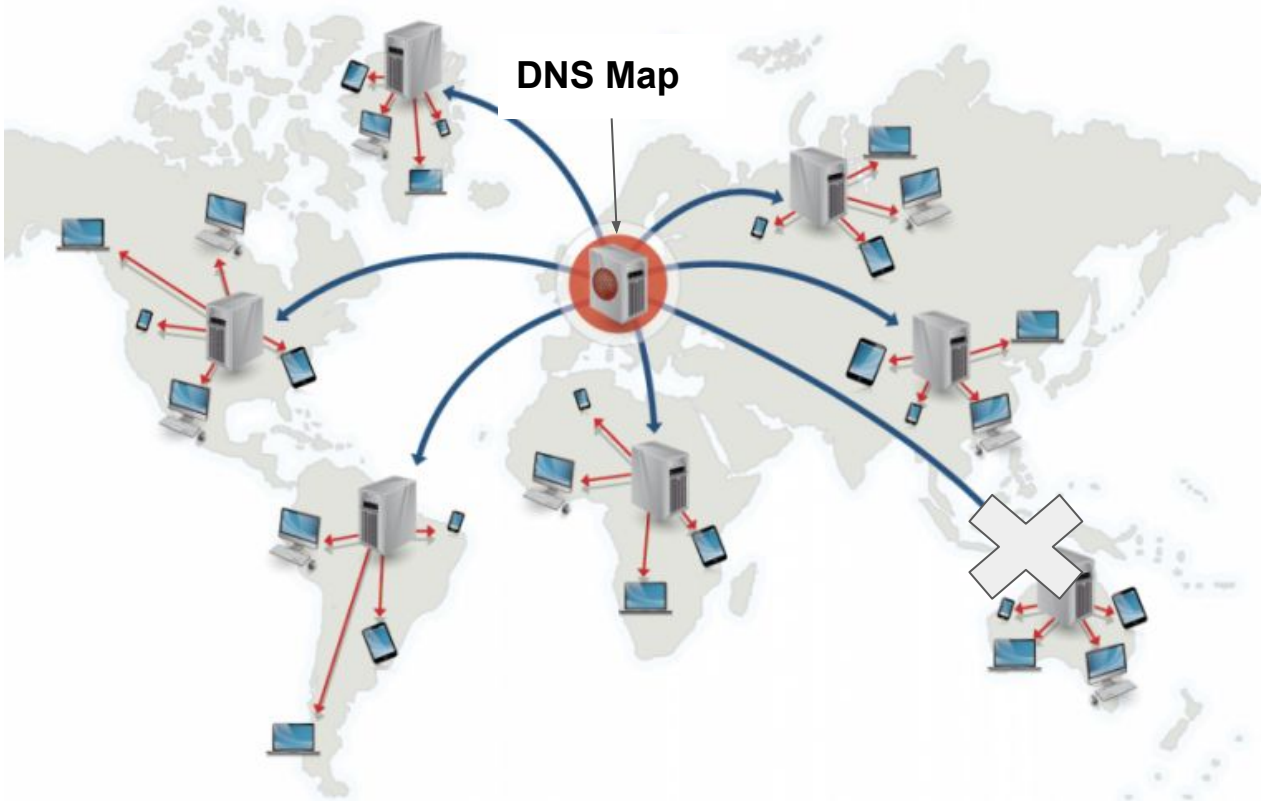


Upon failure of an edge/PoP, DNS must detect and re-route



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(+) direct control of which edge is chosen
(+) “real-time”* re-routing

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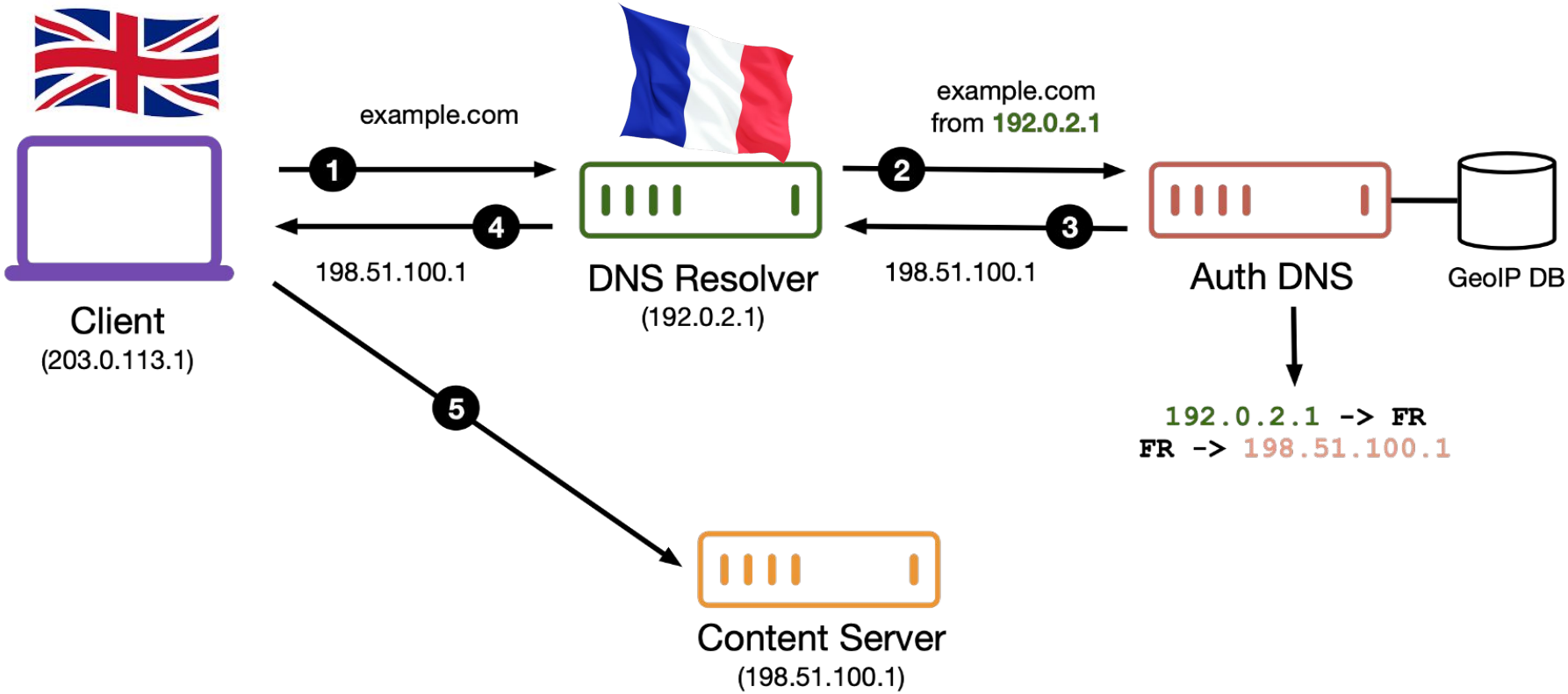
(+) direct control of which edge is chosen
(+) “real-time”* re-routing

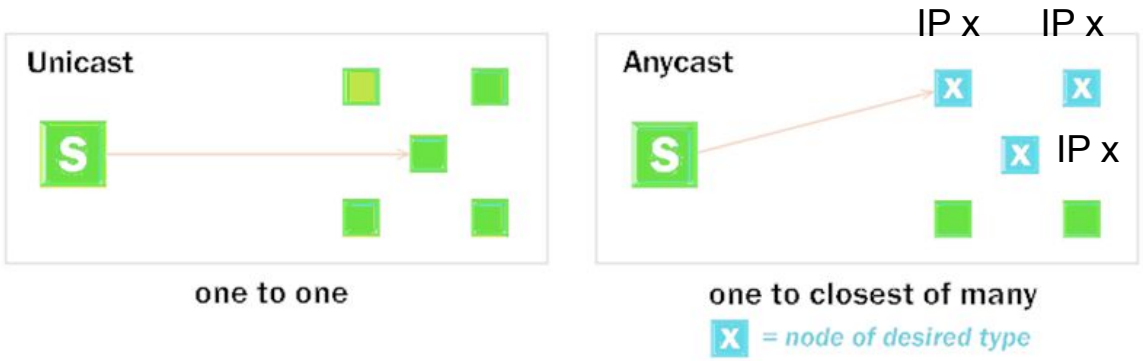
(-) Extra infrastructure/operations required
- “health” monitoring of edges/PoPs

(-) Availability requires short TTLs (increases the amount of DNS lookups..)
(-) DNS doesn’t always know where the client actually is (resolver location != client location) e.g., Google Public DNS and OpenDNS

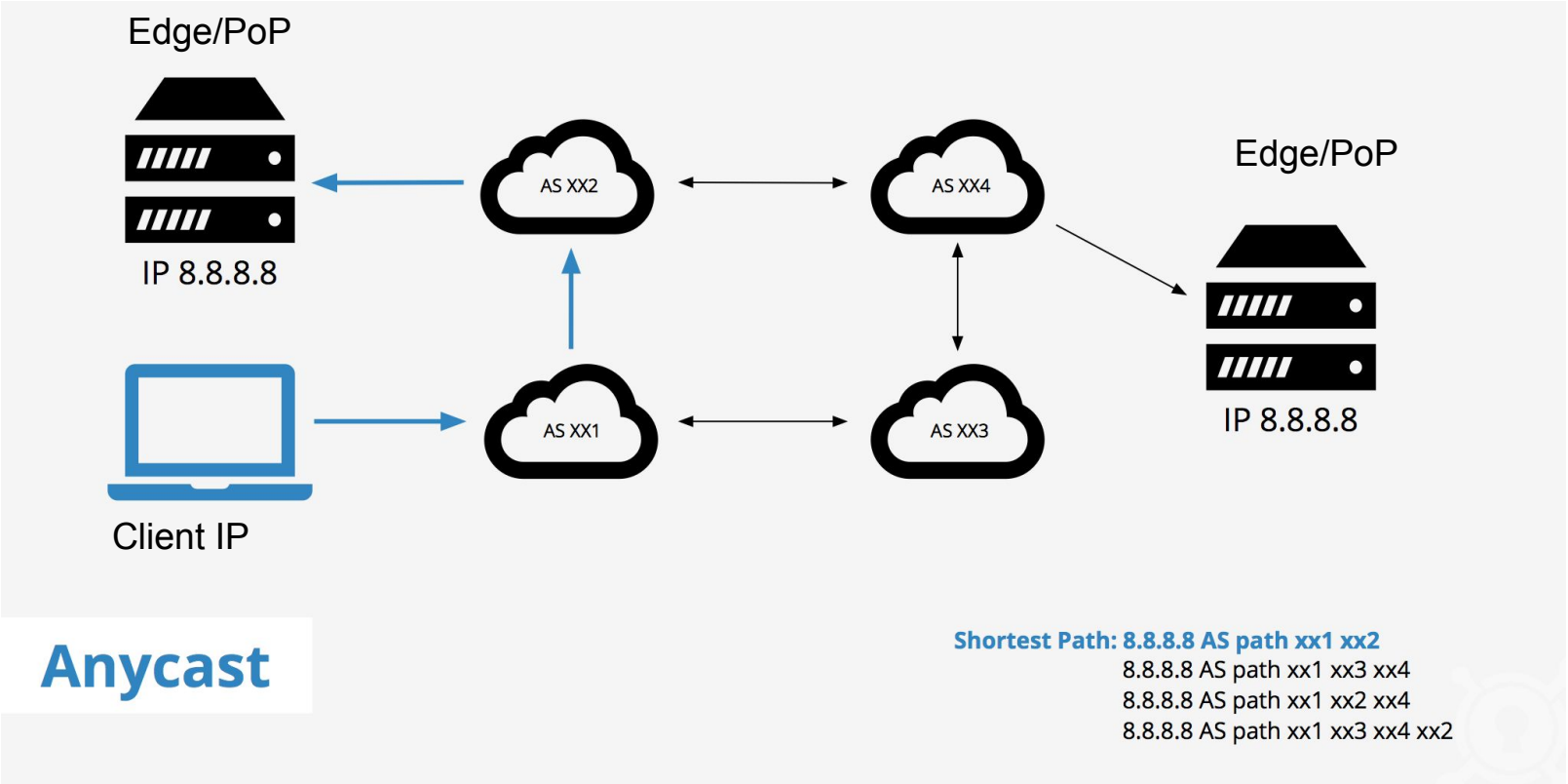
DNS doesn't always know where the client actually is



(2) Anycast routing approach



Anycast routing for CDNs



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(+) Naturally reactive to failures, thanks to BGP

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> **Global Thermonuclear War:** would be bad, but CloudFlare may continue to be able to route traffic to whatever portion of the Internet is left. As facilities

https://blog.cloudflare.com/cloudflares-architecture-eliminating-single-p/

Anycast routing for CDNs

(+) Clients choose the edge location; CDN does not need to guess

(+) Naturally reactive to failures, thanks to BGP

(-) Manipulating traffic can be slow: rely on BGP propagation

(-) BGP route flaps: TCP SYN and ACK can theoretically get diverted to different servers. Though route flap damping should take care of this.

Penalizes constant route changing
https://labs.ripe.net/author/clemens_mosig/route-flap-damping-in-the-wild/

Anycast routing for CDNs

(+) Clients choose the edge location; CDN does not need to guess

(+) Naturally reactive to failures, thanks to BGP

(-) Manipulating traffic can be slow: rely on BGP propagation

(-) BGP route flaps: TCP SYN and ACK can theoretically get diverted to different servers. Though route flap damping should take care of this.

(-) Have to predict which PoPs will likely receive the most traffic...predictions can change over time/ be wrong...but infrastructure is already there.

- Can create overload/ underload

FastRoute: A Scalable Load-Aware Anycast Routing Architecture for Modern CDNs

Ashley Flavel, Pradeepkumar Mani, David A. Maltz, and Nick Holt, *Microsoft;*
Jie Liu, *Microsoft Research;* Yingying Chen and Oleg Surmachev, *Microsoft*

https://www.usenix.org/conference/nsdi15/technical-sessions/presentation/flavel

FastRoute: How to handle anycast overload

System goal: To be able to re-route anycast traffic when an edge gets overloaded.

Solution design goal: Just as simple as anycast, but just enough control to re-route.

FastRoute: How to handle anycast overload

Microsoft

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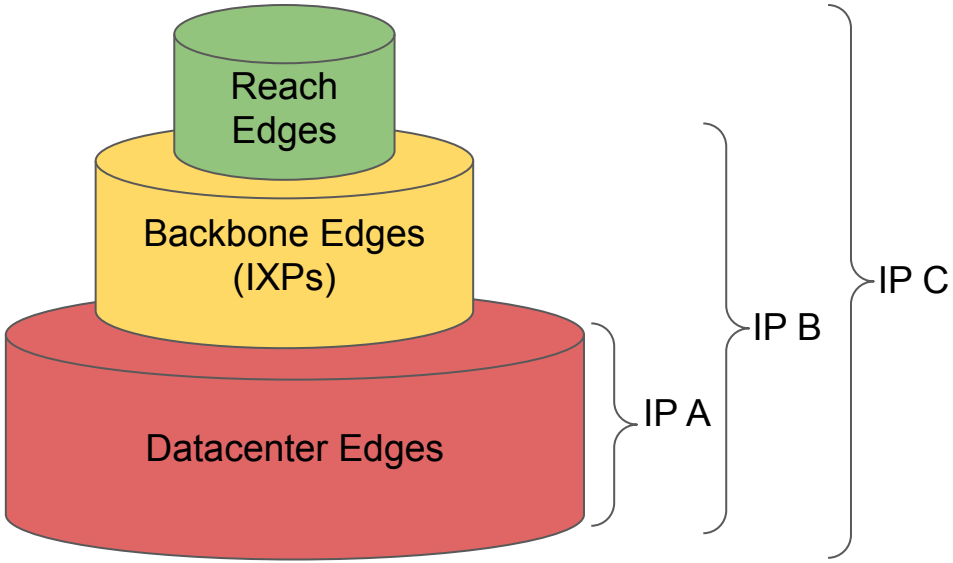

Anycast “layers”: b/c not all edges are created equal

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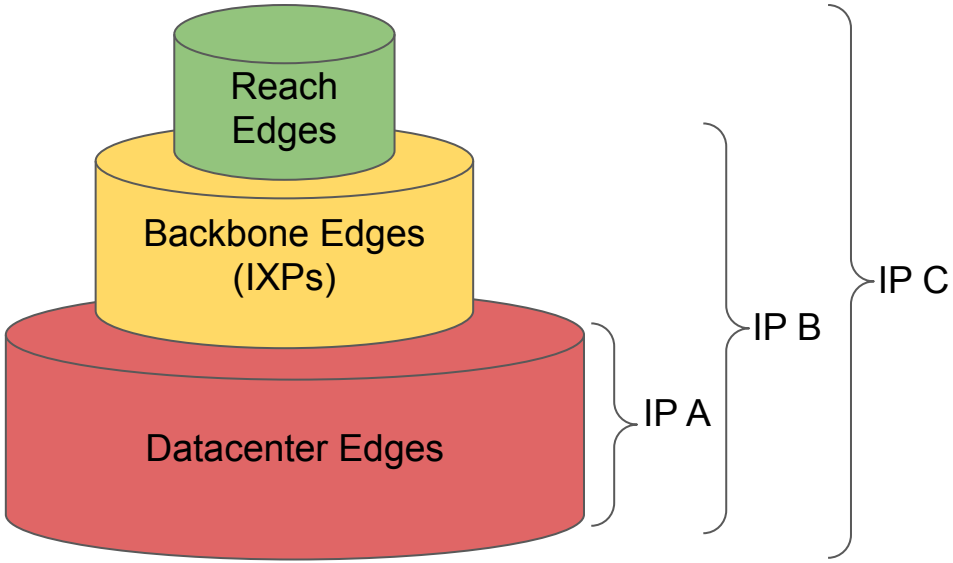
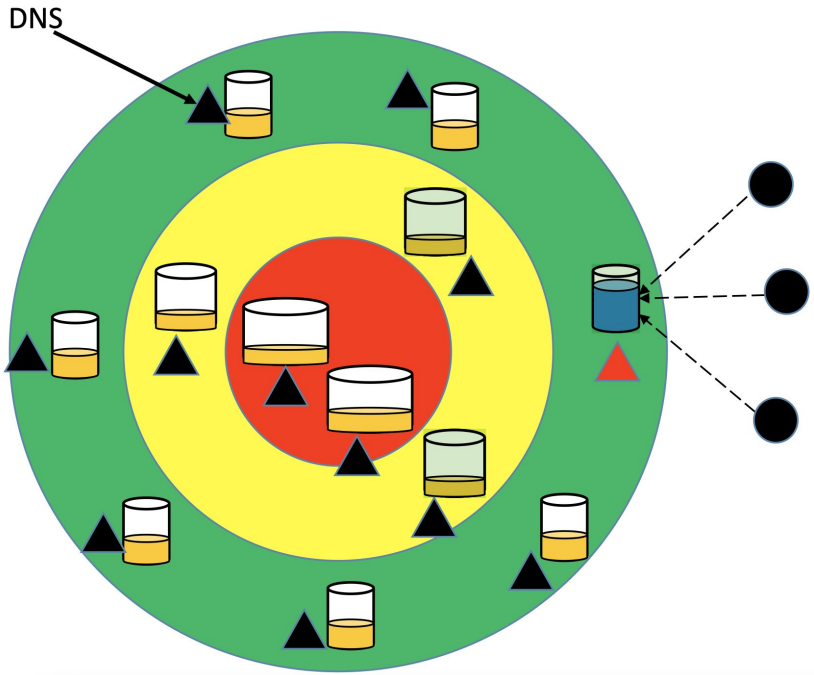


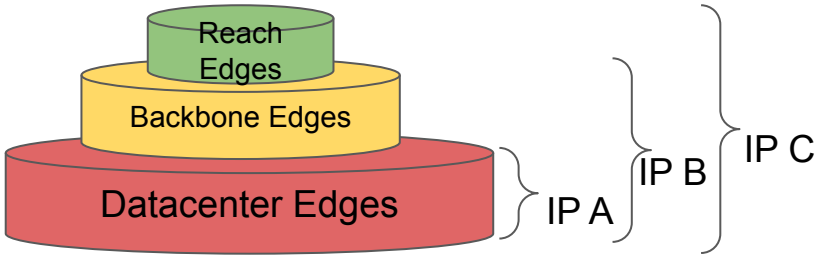
Anycast “layers”: b/c not all edges are created equal

Solution: DNS chooses which IP address layer to hand out to client. Then uses anycast to route to that group of nodes.

FastRoute: How to handle anycast overload

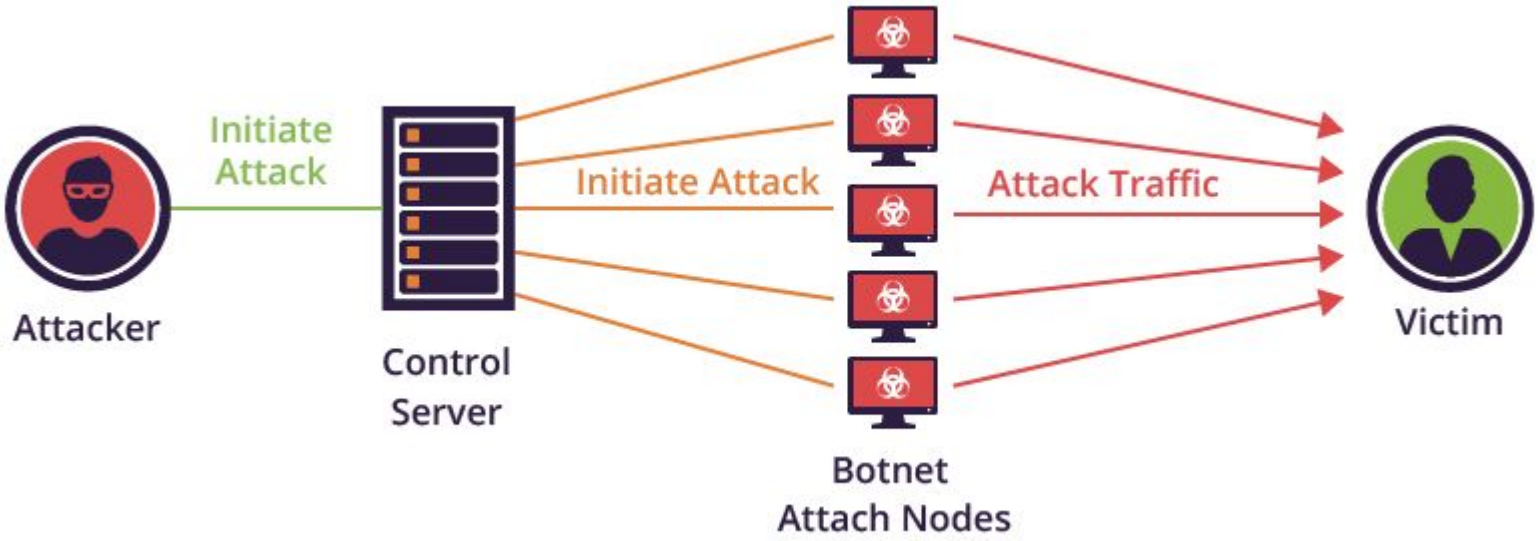


- DNS servers located in the same location as edges (e.g., reach edges) and they talk to each other.
- If DNS server detects that its neighboring edge is being overloaded, it starts handing out the IP address for the next layer of edges
- Still a decentralized approach!



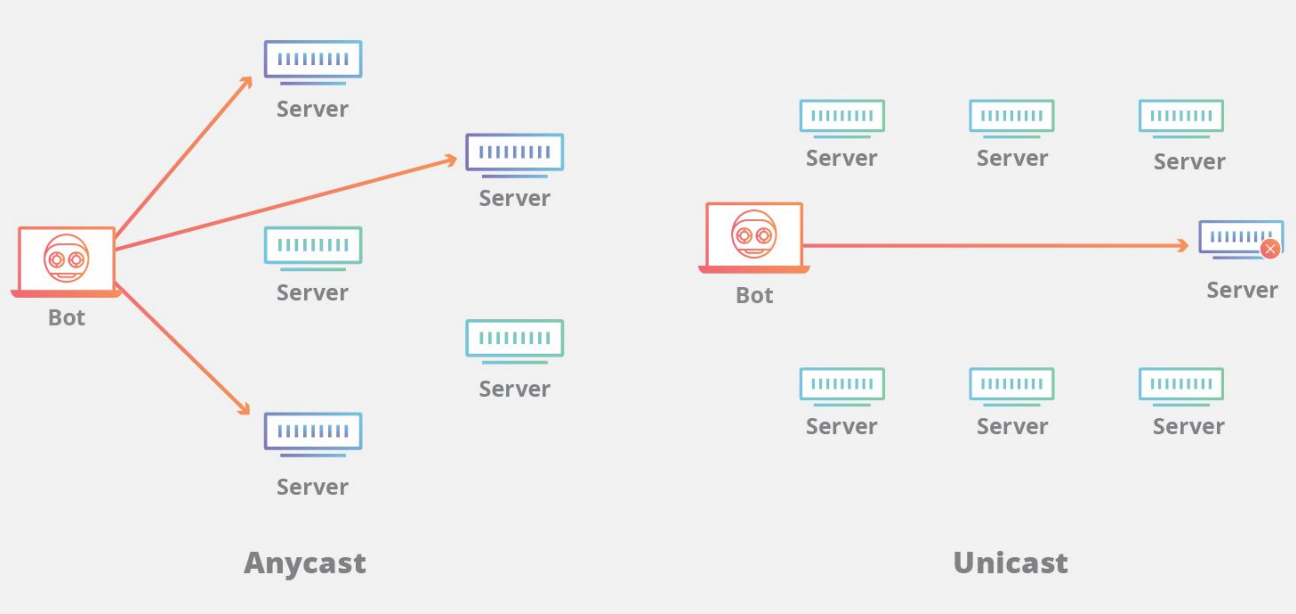
Anycast CDNs are perfect for mitigating DDoS attacks

DDoS attack: “Distributed Denial of Service”



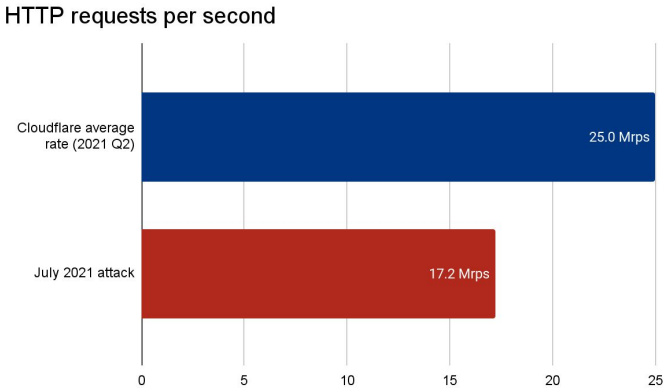
Botnets are often made up of IoT devices that are distributed all over the world

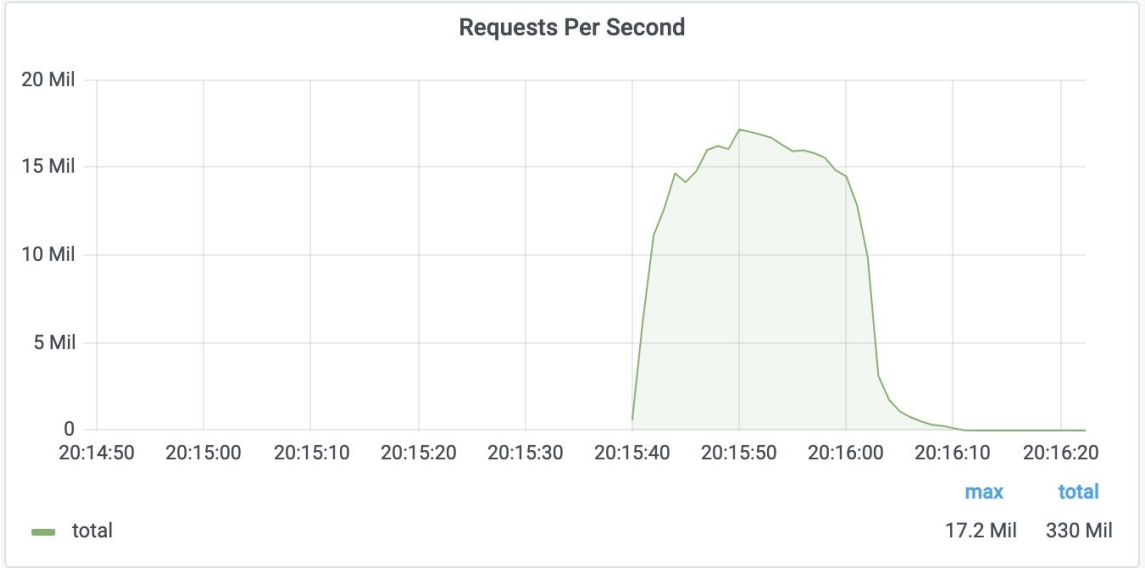
Anycast CDNs are perfect for mitigating DDoS attacks



Scattered bot traffic will be distributed amongst many servers, thereby mitigating the denial of service

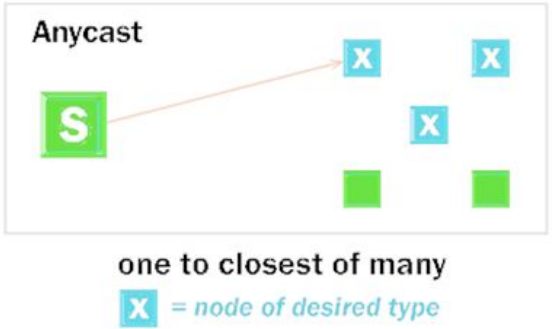
Cloudflare thwarts 17.2M rps DDoS attack — the largest ever reported (08/19/2021)





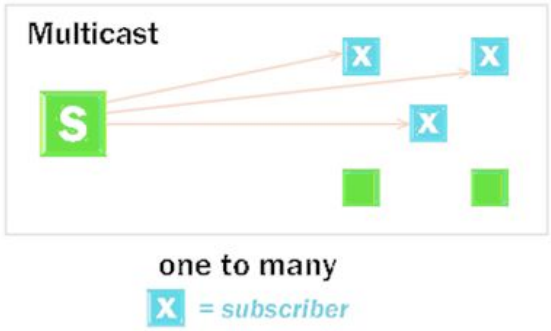
More strategic ways to deliver content

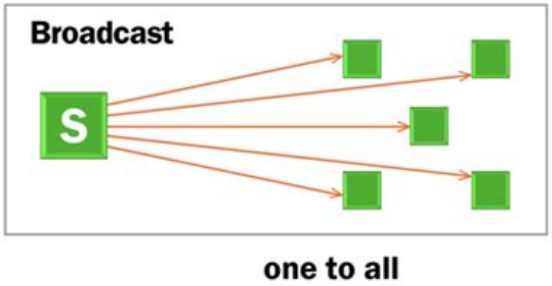
IP



BGP

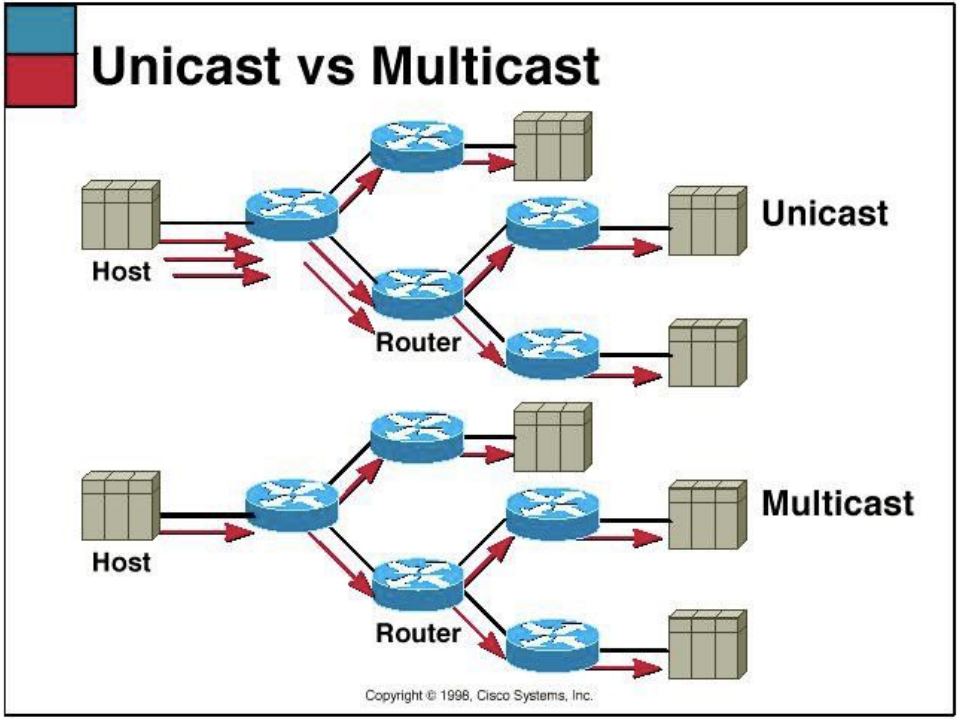
IP





IP

Multicast saves bandwidth between the host and the router



Questions?