Load Balancing

Practical Distributed Systems 2022: Lecture 3

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What is load balancing?

Process of distributing traffic among many servers capable of handling it

Two purposes:

- Scaling
- Availability

Two slightly different application contexts:

- Load balancing incoming traffic from clients to client-facing app server
- Load balancing traffic between app servers and other services inside the datacenter

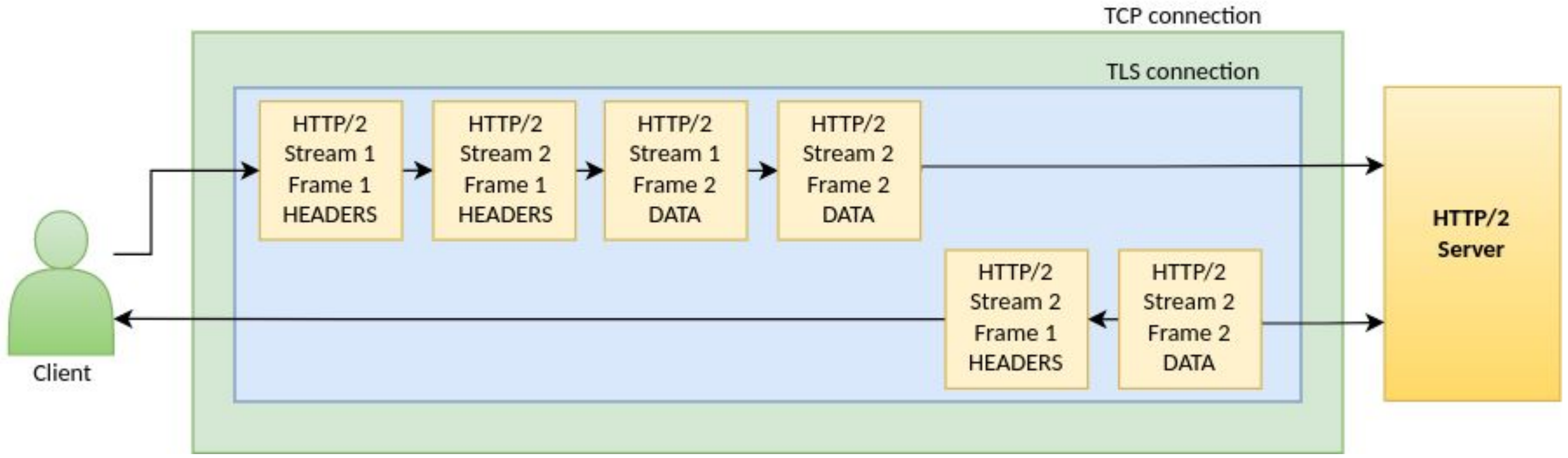
Review of common layer 7 protocols: HTTP/1.0

- New TCP connection for each request
- TCP connection is terminated after response has been received by the client
- Multiple TCP connections required for multiple requests to be in-flight

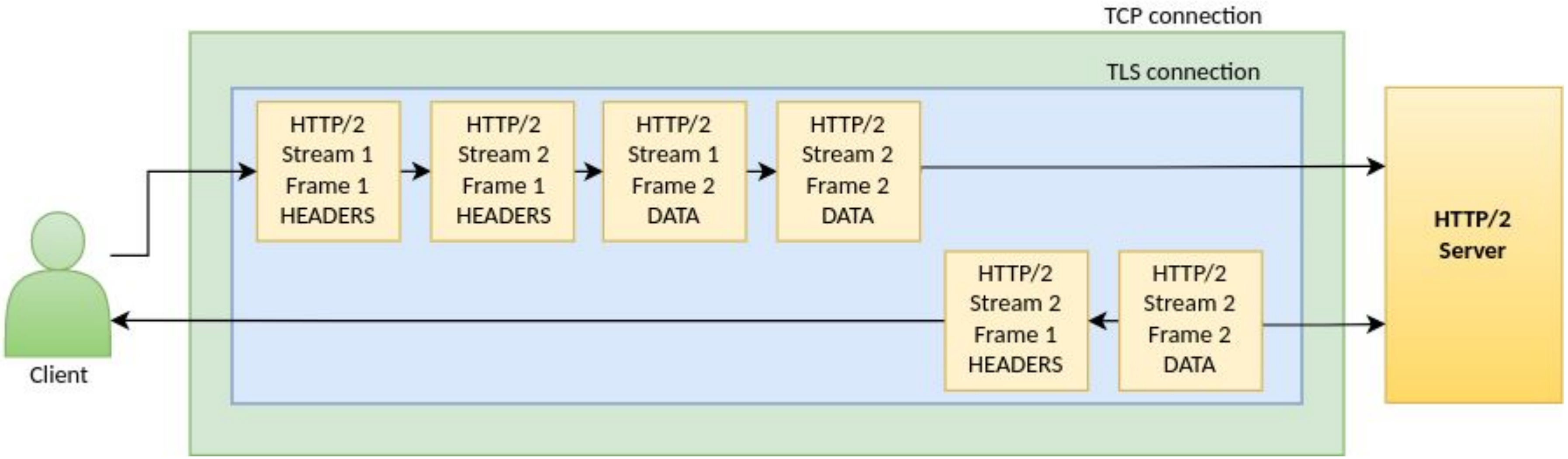
Review of common layer 7 protocols: HTTP/1.1

- TCP connection is opened for first request
- TCP connection can stay open after the response has been received by the client
- TCP connection can be reused for second/thrid request but only if no in-flight request uses it already
- Multiple TCP connections still required for multiple requests to be in-flight

Review of common layer 7 protocols: HTTP/2.0


TCP connection
TLS connection
HTTP/2 Stream 1 Frame 1 HEADERS
HTTP/2 Stream 2 Frame 1 HEADERS
HTTP/2 Stream 1 Frame 2 DATA
HTTP/2 Stream 2 Frame 2 DATA
HTTP/2 Stream 2 Frame 1 HEADERS
HTTP/2 Stream 2 Frame 2 DATA
HTTP/2 Server
Client

Review of common layer 7 protocols: GRPC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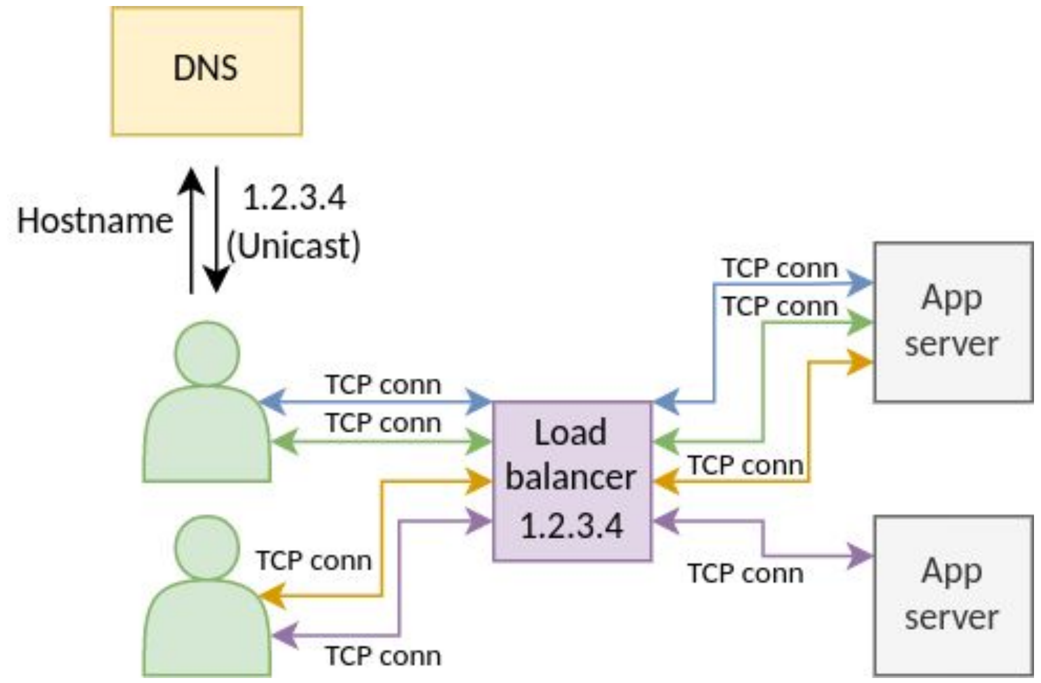
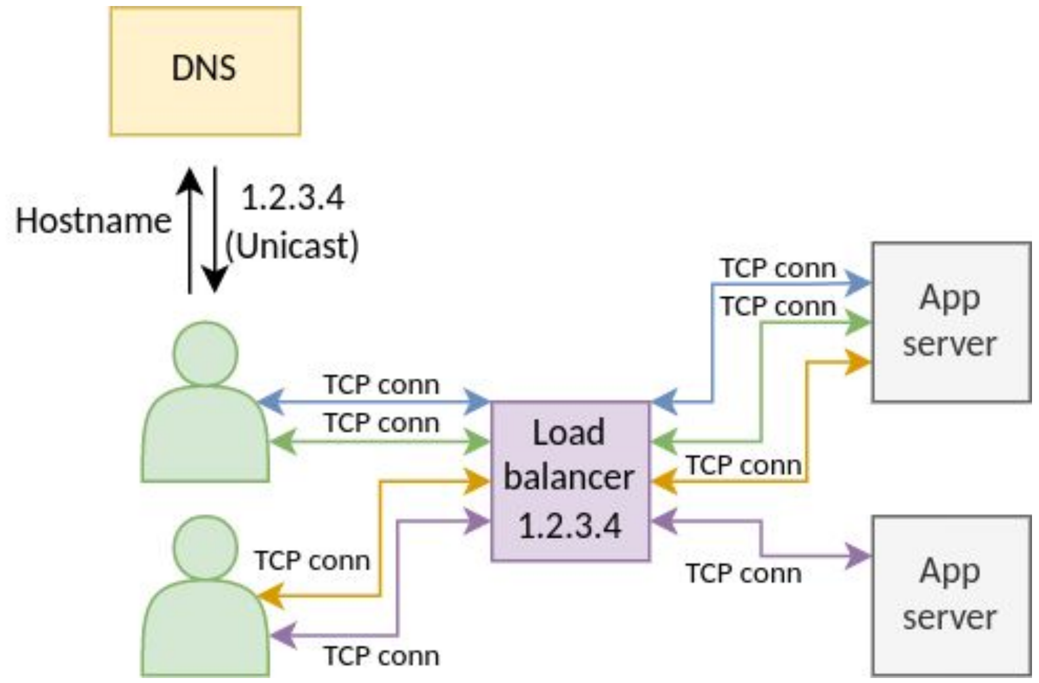
Layer 4 load balancing - “proxy”



- Clients establish TCP connections to the LB
- LB establishes TCP connections to backends
- Load balancing algorithm operates at connection establishment time

Layer 4 load balancing - “proxy”



- LB copies data from client connection to associated server connection
- In a plain TCP proxy, the proxy does not parse the TCP stream contents

Layer 4 load balancing - “proxy”

Examples:

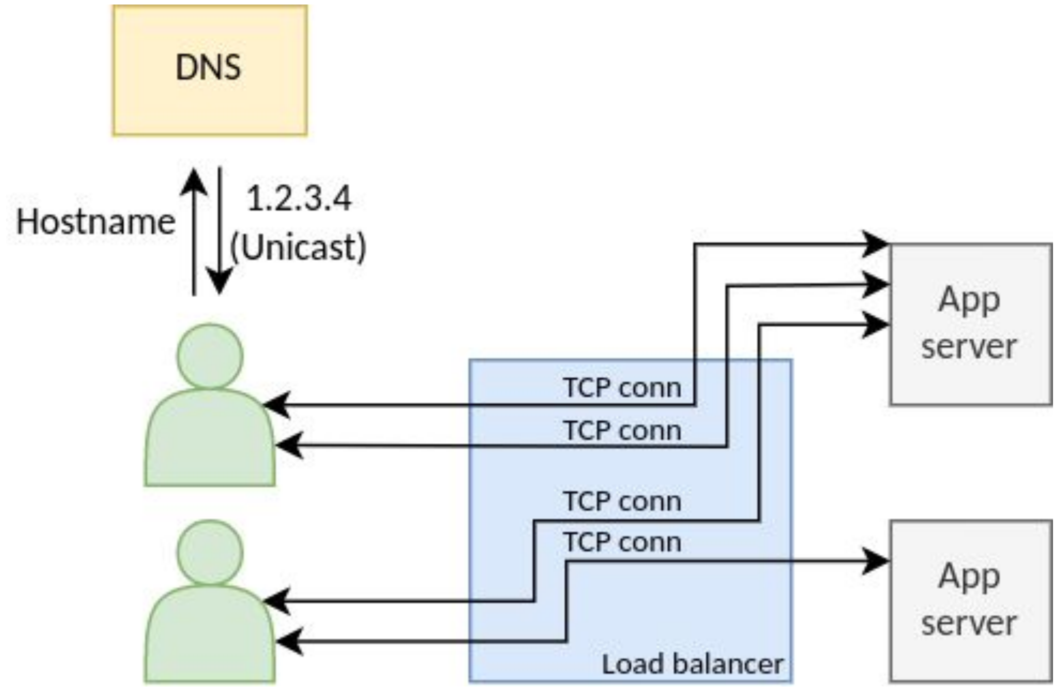
- AWS: Network Load Balancer (Elastic Load Balancing)
  https://docs.aws.amazon.com/elasticloadbalancing/latest/network/introduction.html

- Google Cloud: TCP Proxy
  https://cloud.google.com/load-balancing/docs/tcp

- HAProxy (one of possible load balancing modes)
  https://www.haproxy.org/

- Nginx (one of possible load balancing modes)
  https://nginx.org/en/docs/

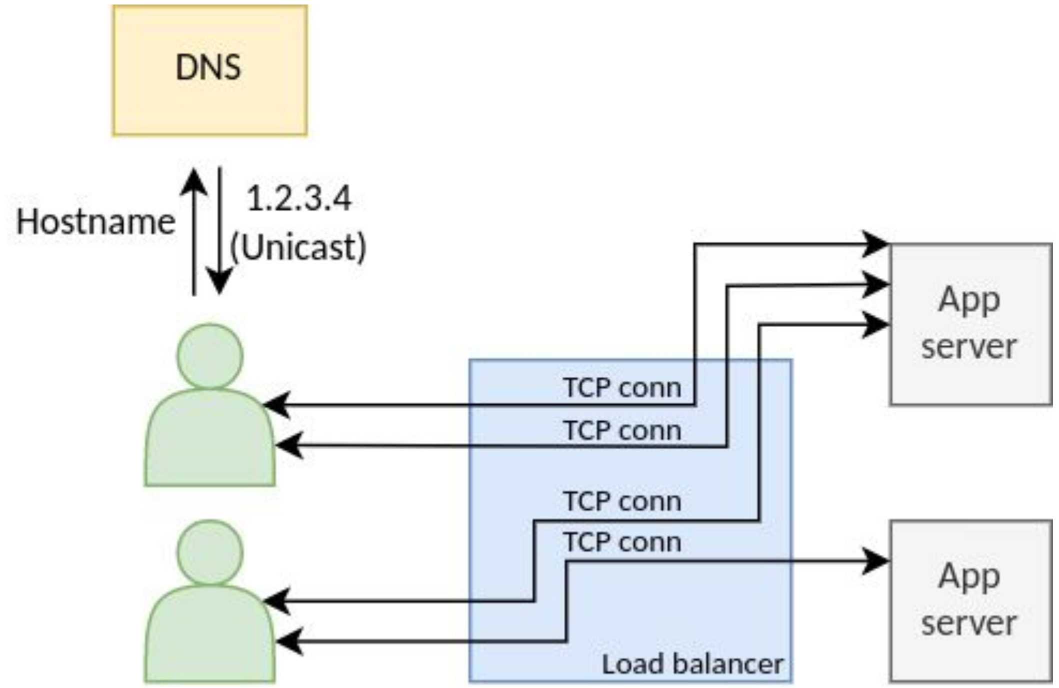
Layer 4 load balancing - “pass-through”



Variant A:

- 1.2.3.4 is the IP of the load balancer
- Load balancer performs NAT, rewriting the destination IP to a selected app server IP
- Needs to keep a table of client<->server associations

Layer 4 load balancing - “pass-through”



Variant B:

- 1.2.3.4 is an anycast IP, used by all the app servers (on loopback interface)
- Load balancer must be in charge of routing 1.2.3.4
- Load balancer maps (client IP, client port, server IP, server port, TCP/UDP) to specific app server via a hash function

Layer 4 load balancing - “pass-through”

Examples:

- AWS: Gateway Load Balancer (Elastic Load Balancing)
  https://docs.aws.amazon.com/elasticloadbalancing/latest/gateway/introduction.html

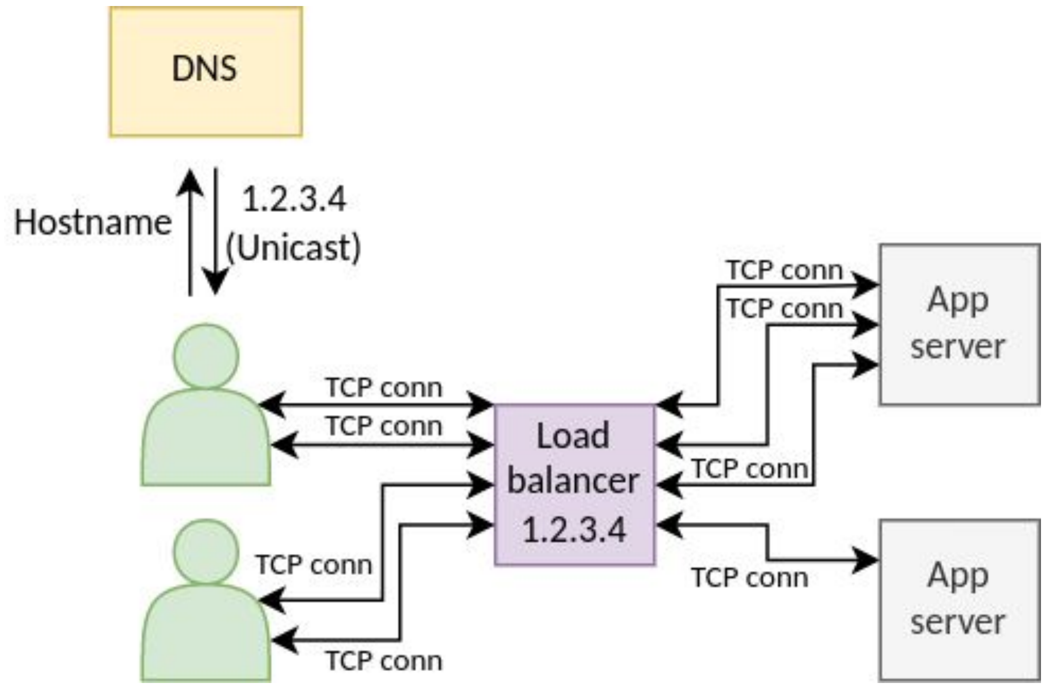
- Google Cloud: External TCP/UDP Network Load Balancing
  https://cloud.google.com/load-balancing/docs/network

- Google Cloud: Internal TCP/UDP Network Load Balancing
  https://cloud.google.com/load-balancing/docs/internal

- Kubernetes kube-proxy load balancing:
  https://sookocheff.com/post/kubernetes/understanding-kubernetes-networking-model/

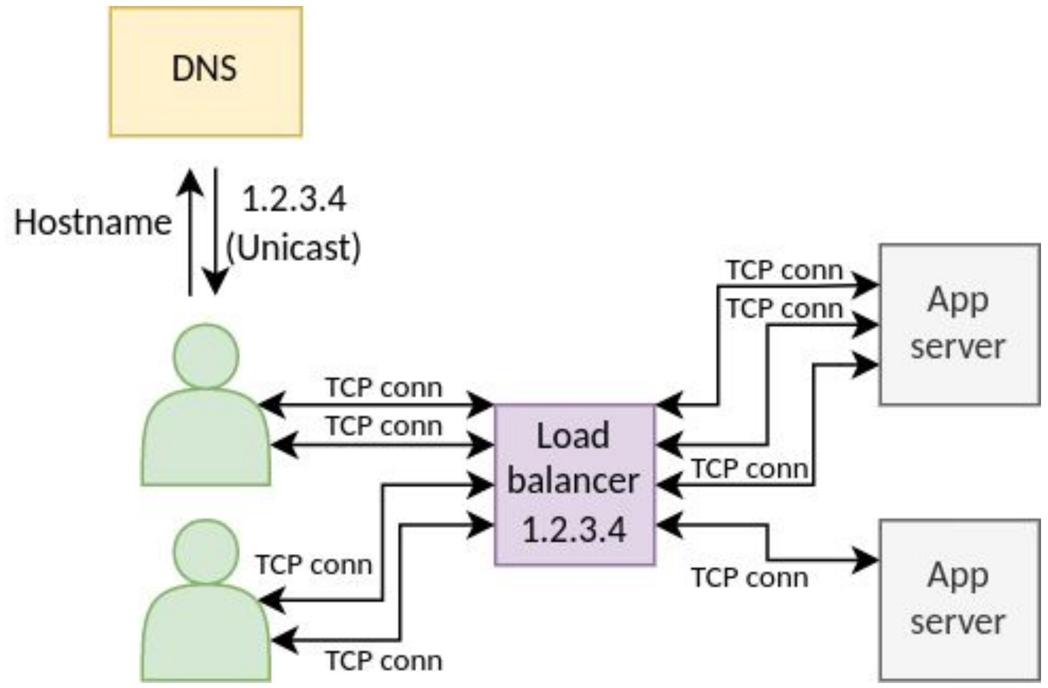
- Linux Virtual Server:
  http://www.linuxvirtualserver.org/

Layer 7 load balancing - “reverse proxy”



- Clients establish TCP connections to the LB
- LB establishes TCP connections to app server
- No permanent association between:
  client<->LB conn.
  &
  LB<->app-server conn.

Layer 7 load balancing - “reverse proxy”



- Load balancing algorithm operates when a (part of) request arrives over the client<->LB TCP connection
- LB parses the L7 protocol operating over TCP stream,
  can make decisions based on HTTP request method, path etc.

Layer 7 load balancing - “reverse proxy”

Examples:

- AWS: Application Load Balancer (Elastic Load Balancing)
  https://aws.amazon.com/elasticloadbalancing/application-load-balancer/?nc=sn&loc=2&dn=2
- Google Cloud: External HTTP(S) Load Balancing
  https://cloud.google.com/load-balancing/docs/https
- Google Cloud: Internal HTTP(S) Load Balancing
  https://cloud.google.com/load-balancing/docs/l7-internal
- HAProxy (one of possible load balancing modes)
  https://www.haproxy.org/
- Nginx (one of possible load balancing modes)
  https://nginx.org/en/docs/

Layer 7 load balancing - “reverse proxy”

Examples:

- Envoy
  https://www.envoyproxy.io/

- Traefik
  https://traefik.io/

Server side layer 7 load balancing

How to select a server for the incoming request?

Things to consider:

- Requests can take varying amount of time to process

- Servers can differ in performance

Server side layer 7 load balancing

Weighted round robin algorithm:

- Servers “take turns” handling requests

Server side layer 7 load balancing

Weighted least connections algorithm:

- Select the server that has the least number of active connections
- Least number of active connections == least requests “in progress”
- A request that takes longer to process will also longer contribute to the number of active connections

Server side layer 7 load balancing

Consistent hashing algorithm:

- Hash the client IP onto one of the servers

Server side layer 7 load balancing

Features: TLS termination

- Often the layer 7 proxy terminates TLS: connections from client to proxy are encrypted HTTP/1.1 or HTTP/2.0 connections, connections from proxy to backends are unencrypted HTTP/1.1 connections

- TLS handling is complicated and might require shared state, layer 7 proxies are typically better at handling it than application servers and there are fewer proxies than application servers

Server side layer 7 load balancing

Features: HTTP routing

- Since a layer 7 proxy parses HTTP contents it can decide which server to use based on request method, request path, headers, client IP etc.

Server side layer 7 load balancing

Features: rate limiting

- Layer 7 proxies can rate limit connections/s or requests/s to protect from DoS attacks or to provide user quotas etc.

Server side layer 7 load balancing

Features: healthchecking

- We do not want to send requests to backends that will not be able to service client requests correctly

- Two (not exclusive) ways to healthcheck: **active** and **passive**

Server side layer 7 load balancing

Active healthchecking:

- Send HTTP request every X seconds

- Depending on the response, server is marked healthy or unhealthy

Server side layer 7 load balancing

Passive healthchecking:

- On the TCP level: when enough connection attempt fails, consider the server unhealthy, stop directing traffic to it
- On HTTP level: when enough HTTP requests fail, consider the server unhealthy
- Server gets healthy again when active healthcheck passes

Server side layer 7 load balancing

Features: service discovery

- Need to have a list of available application servers
- Naive solution: just have a list of IPs in configuration file
- Problem: hard to add/remove programatically from configuration file
- Problem: configuration file reload often requires proxy restart (which terminates connections), frequent restarts might destabilize the DC

Server side layer 7 load balancing

Features: service discovery

- Example of a better solution:
  have the proxy resolve a DNS name to get a list of servers

- DNS supports SRV records:
  `_service._proto.name. ttl IN SRV priority` **`weight port target`**

- Proxy can periodically poll DNS, refresh the SRV records and update the server list without terminating client connections

- Platform administrators can add/remove/reconfigure servers by doing DNS updates

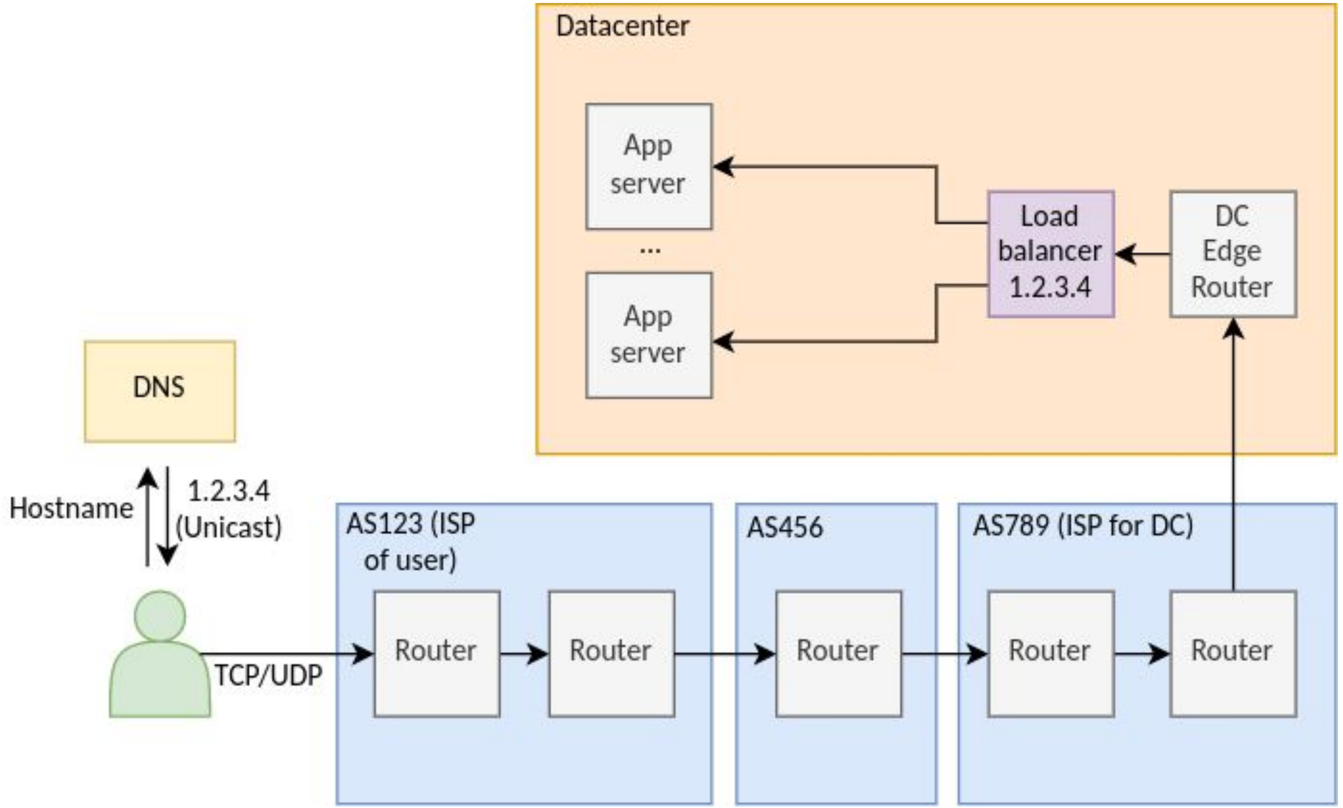
Server side layer 7 load balancing

Having a single layer 7 load balancer has two major shortcomings:

- Performance ceiling: eventually a single load balancer will saturate and will not be able to serve any more traffic

- Single point of failure: if the load balancer fails, the service will become unavailable

Server side layer 7 load balancing



IP Anycast to the rescue

IP protocol provides four adressing modes:

- Unicast
  delivers a message to a single specific node

- Broadcast
  delivers a message to all nodes in the network using a one-to-all association

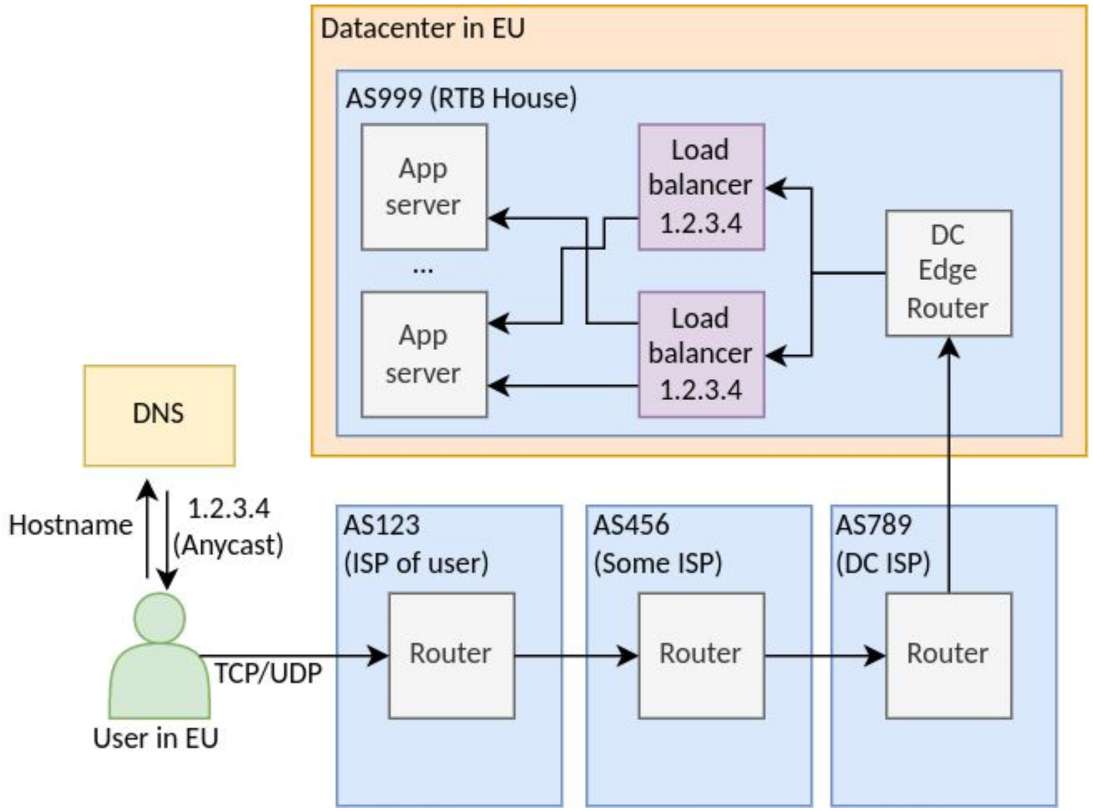
- Multicast
  delivers a message to a group of nodes that have expressed interest in receiving the message

- **Anycast**
  delivers a message to any one out of a group of nodes, typically the one nearest to the source

IP Anycast to the rescue

- Anycast can be implemented via Border Gateway Protocol (BGP)
- Multiple hosts are given the same unicast IP address and different routes to the address are announced through BGP.
- Routers consider these to be alternative routes to the same destination, even though they are actually routes to different destinations with the same address.
- As usual, routers select a route by whatever distance metric is in use (the least cost, least congested, shortest). Selecting a route in this setup amounts to selecting a destination.

Anycast-based inside-DC load balancing



Anycast-based inside-DC load balancing

Edge router supports **ECMP: Equal Cost Multipath**

When multiple routes are available for an IP, hash different TCP/UDP flows to different available routes

Flows are identified by the four tuple:
(source IP, source port, destination IP, destination port)

Global load balancing

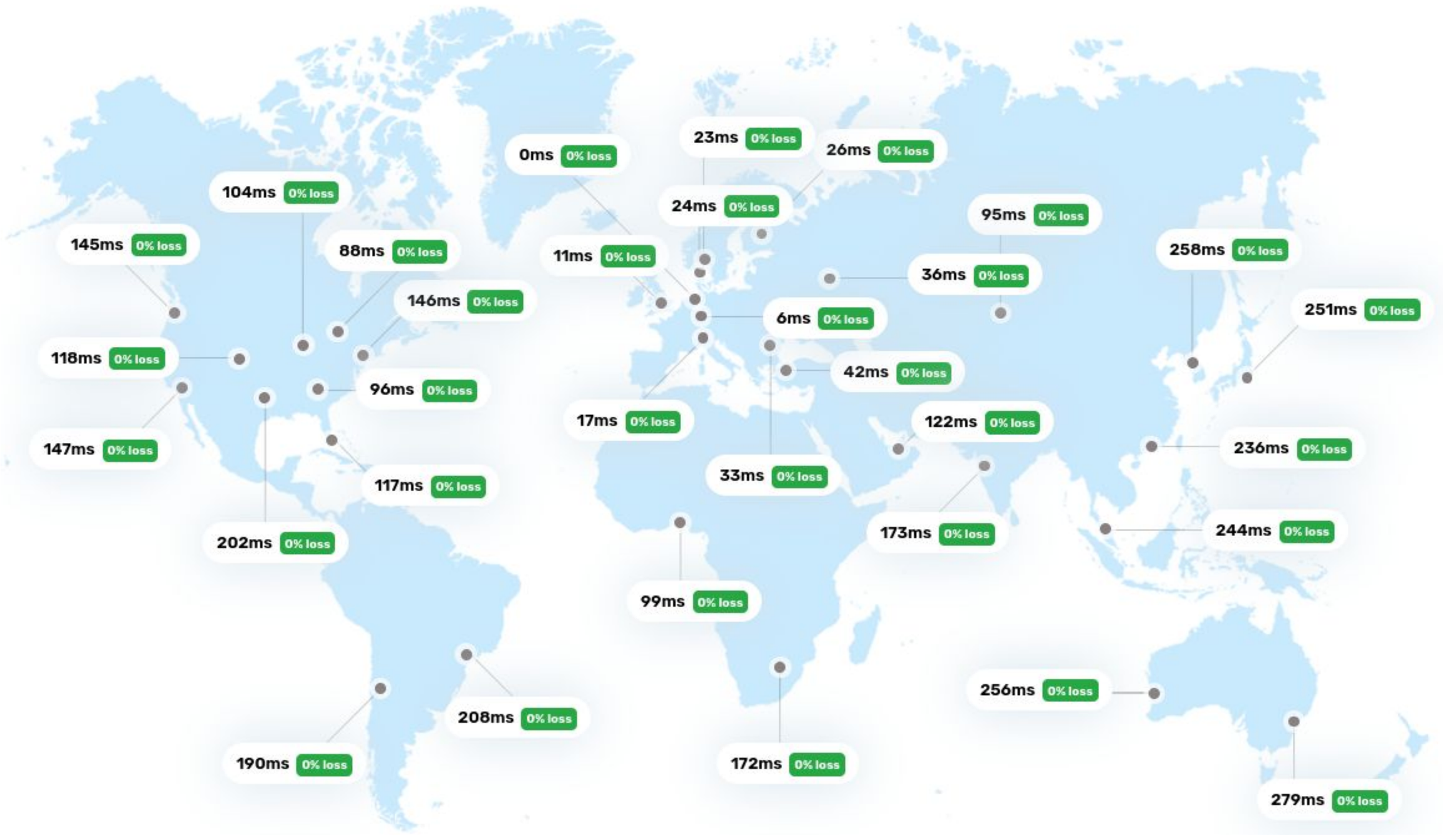
Problem:
For two given geographic locations of client and server,
roundtrip time has a physical lower limit given by speed of light

Global load balancing

```
Speed of light in vacuum:           300 000 000 m/s
Speed of light in optical fiber:   200 000 000 m/s
Distance from Warsaw to Amsterdam:   1 100 000 m

1 100 000 m / 200 000 000 m/s = 0.0055 s = 5.5 ms

2 * 5.5 ms = 11 ms best-case round trip
```

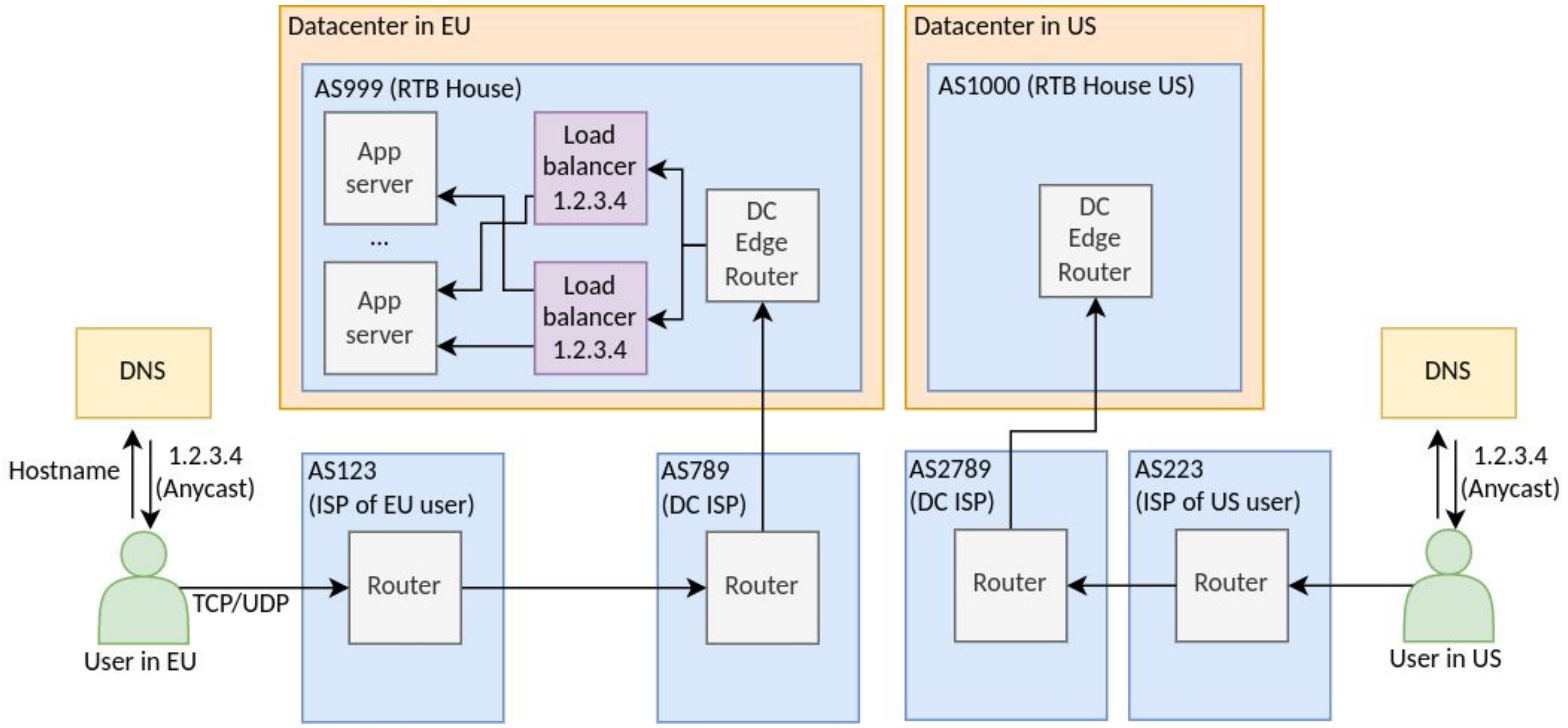


https://tools.bunny.net/latency-test?query=creativecdn.com

Global load balancing

Need to place servers within reasonable geographic distance to users

Anycast-based global load balancing



Anycast-based global load balancing

Available as a cloud service:

AWS: Global Accelerator
https://aws.amazon.com/global-accelerator/

Google Cloud: Global external HTTP(S) load balancer
https://cloud.google.com/load-balancing/docs/https