CDN and P2P

To do …

- CDNs
- P2P
- Hybrid CDN+P2P

Northwestern

Network trends and application need

- Some clear trends
  - Growing number of networks
  - Faster networks
  - Growing availability and demand for content
- For applications, higher demand on performance and reliability
  - Small degradation are expensive in lost revenue
    - $2.8m/hour in 2009
  - … damage reputation
  - … reduced productivity

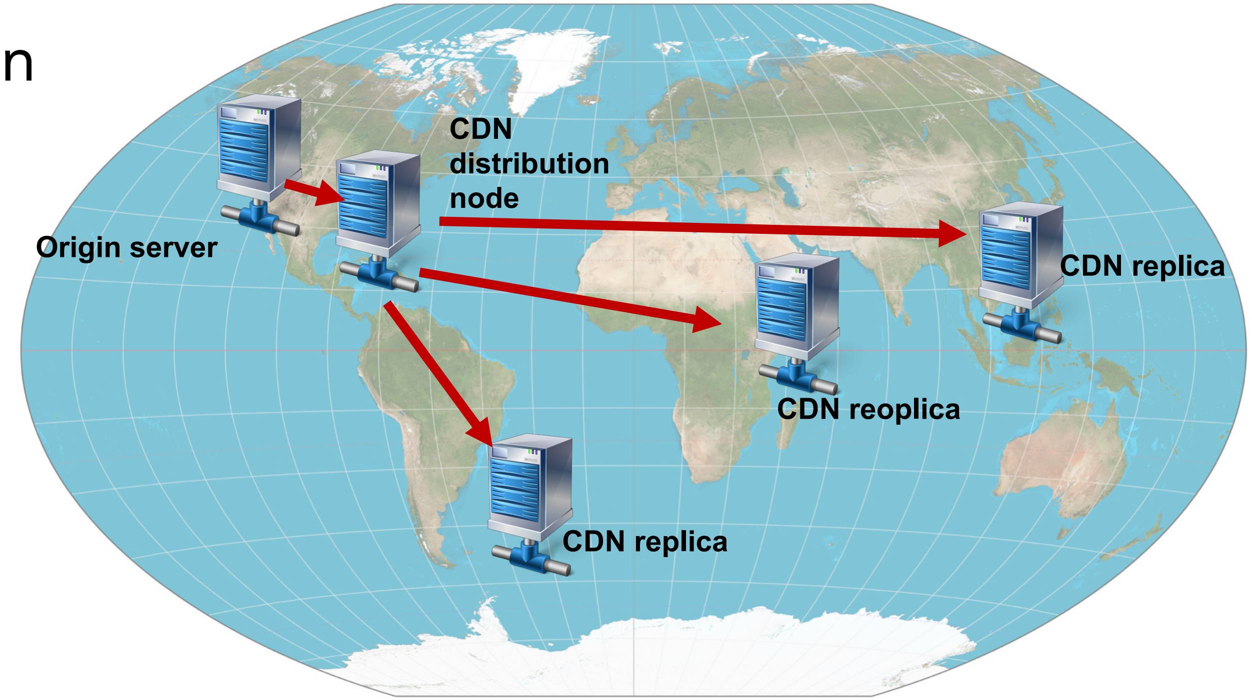
Content delivery

- The common answer
  - Replicate content around the world, closer to users
  - Bring users to nearby content, “nearby” in a network sense

- Challenges
  - How to replicate content
  - Where to replicate it
  - How to choose among known replicas
  - How to direct clients toward a replica

Content Distribution Network

- Proactive content replication
  - Content provider (e.g., NY Times) contracts with a CDN
- CDN replicates the content
  - On many servers spread throughout the Internet
- Updating the replicas
  - Updates pushed to replicas when the content changes



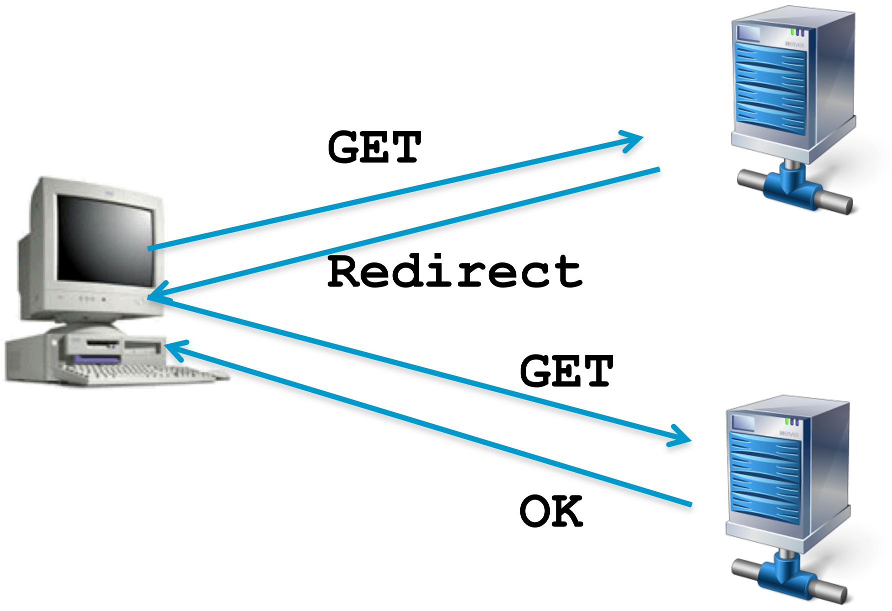
Server selection policy

- Live server
  - For availability
- Lowest load
  - Balancing load across servers
- Closest
  - Nearest geographically, or in round-trip time
- Best performance
  - Throughput, latency, …
- Cheapest bandwidth, electricity, pollution, …

Requires continuous monitoring of liveness, load, and performance

Server selection mechanism

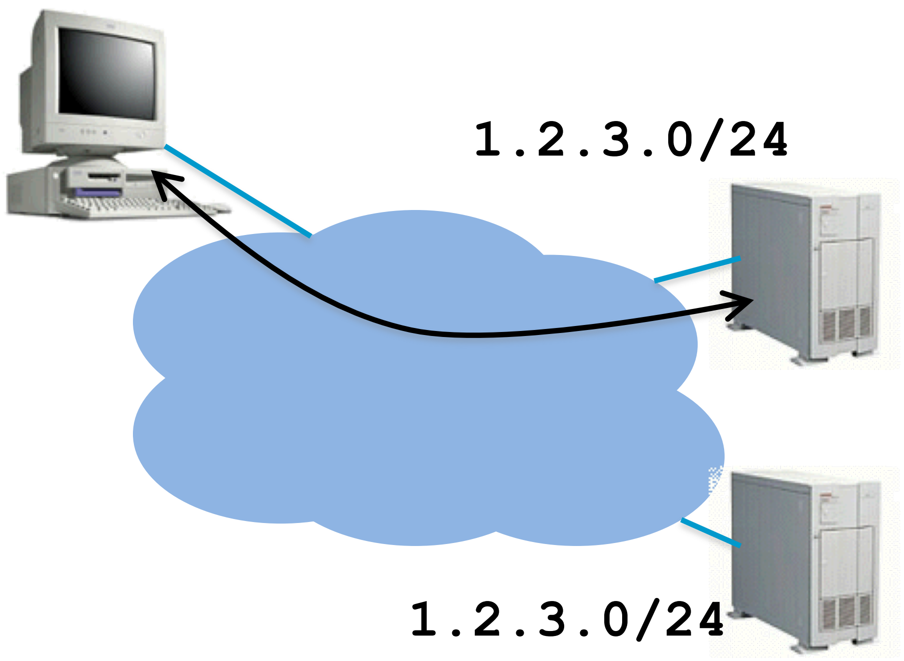
- Application
  - URL redirection (HTTP 3xx)



- Advantages
  - Fine-grain control
  - Selection based on client IP address
- Disadvantages
  - Extra round-trips for TCP connection to server
  - Overhead on the server

Server selection mechanism

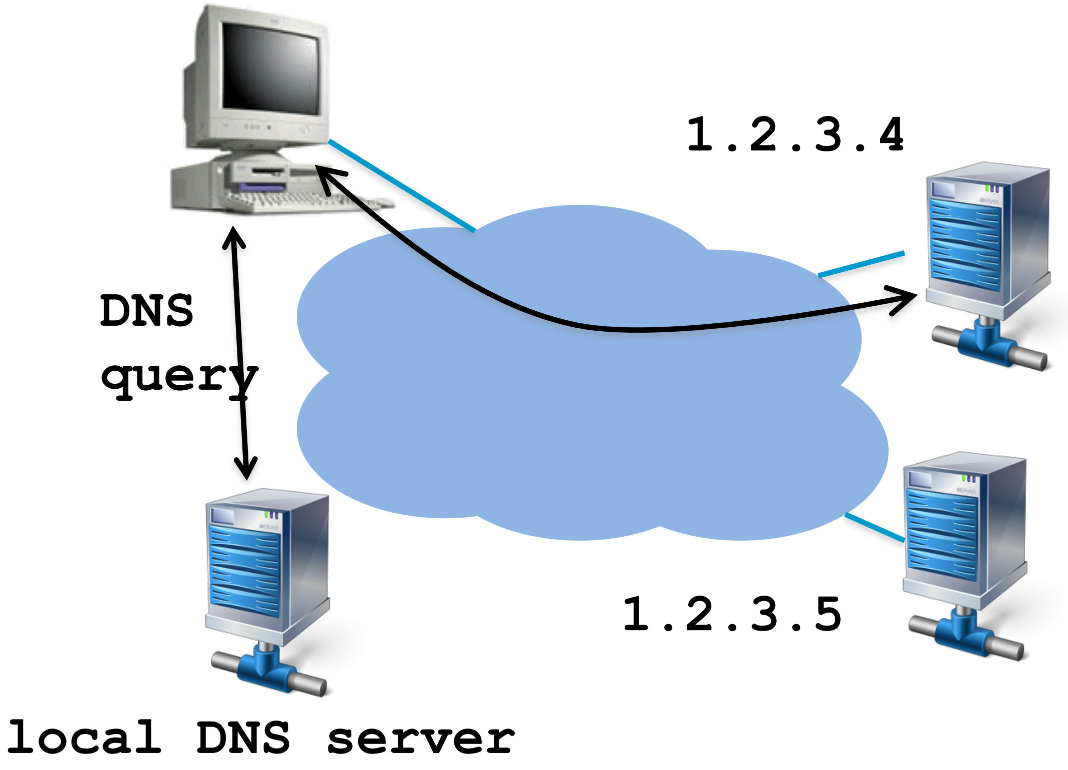
- Routing
  - Anycast routing



- Advantages
  - No extra round trips
  - Route to nearby server
- Disadvantages
  - Does not consider network or server load
  - Different packets may go to different servers
  - Used only for simple request-response apps

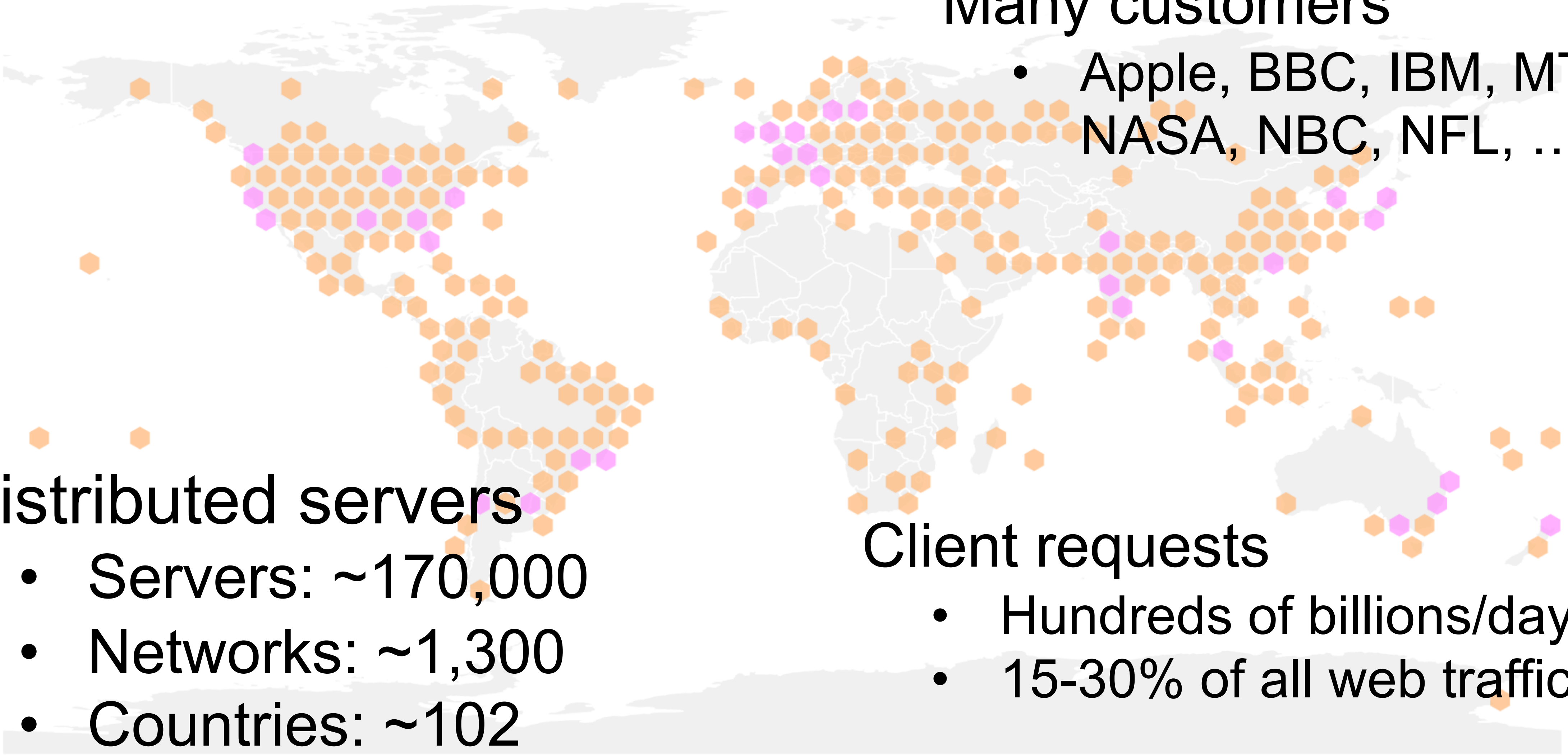
Server selection mechanism

- Naming
  - DNS-based server selection



- Advantages
  - Avoid TCP set-up delay
  - DNS caching reduces overhead
  - Relatively fine control
- Disadvantage
  - Based on IP address of local DNS server / recursive resolver
  - “Hidden load” effect
  - DNS TTL limits adaptation

Akamai as an example



Many customers

- Apple, BBC, IBM, MTV, NASA, NBC, NFL, …

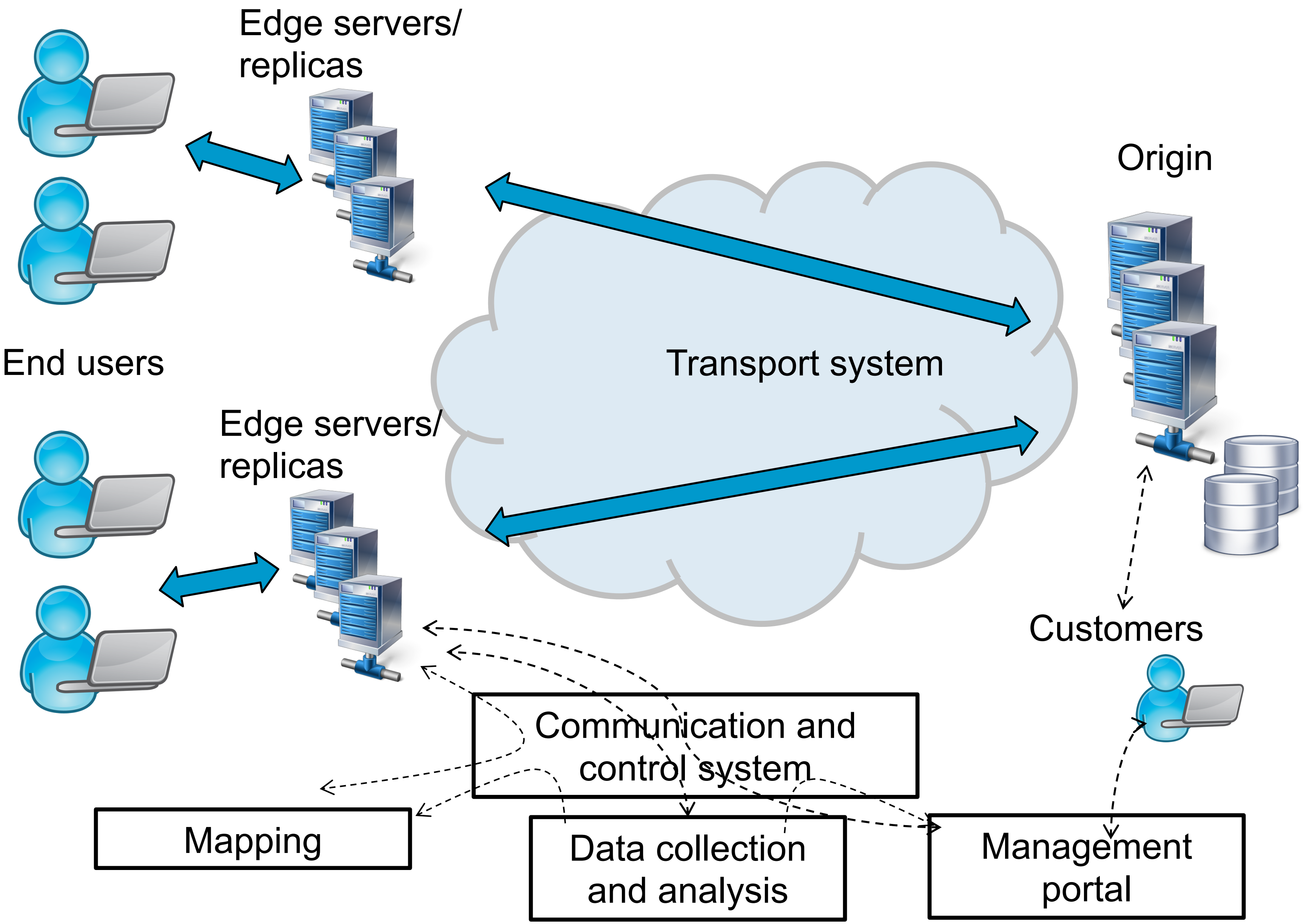
Distributed servers

- Servers: ~170,000
- Networks: ~1,300
- Countries: ~102

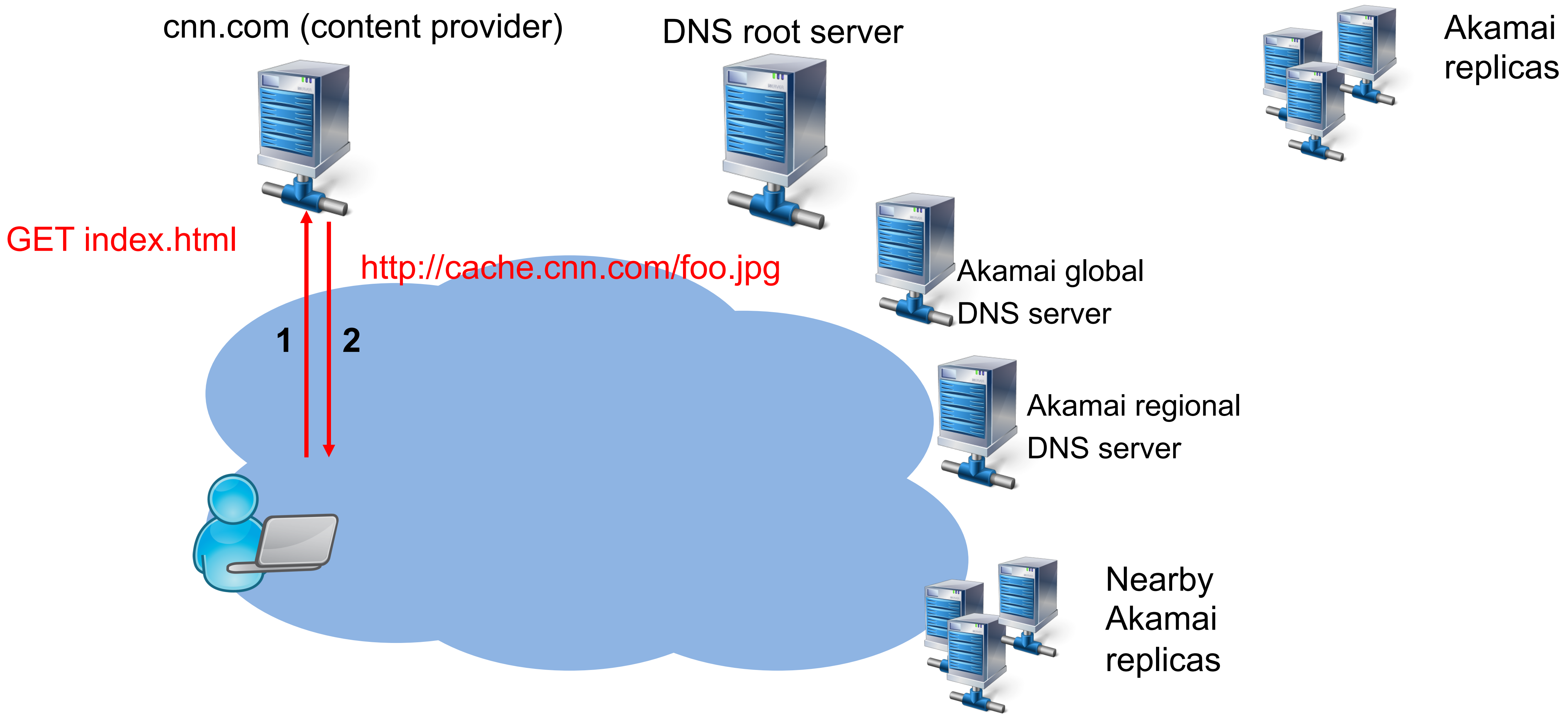
Client requests

- Hundreds of billions/day
- 15-30% of all web traffic

Components of a delivery network (Akamai)



How Akamai uses DNS



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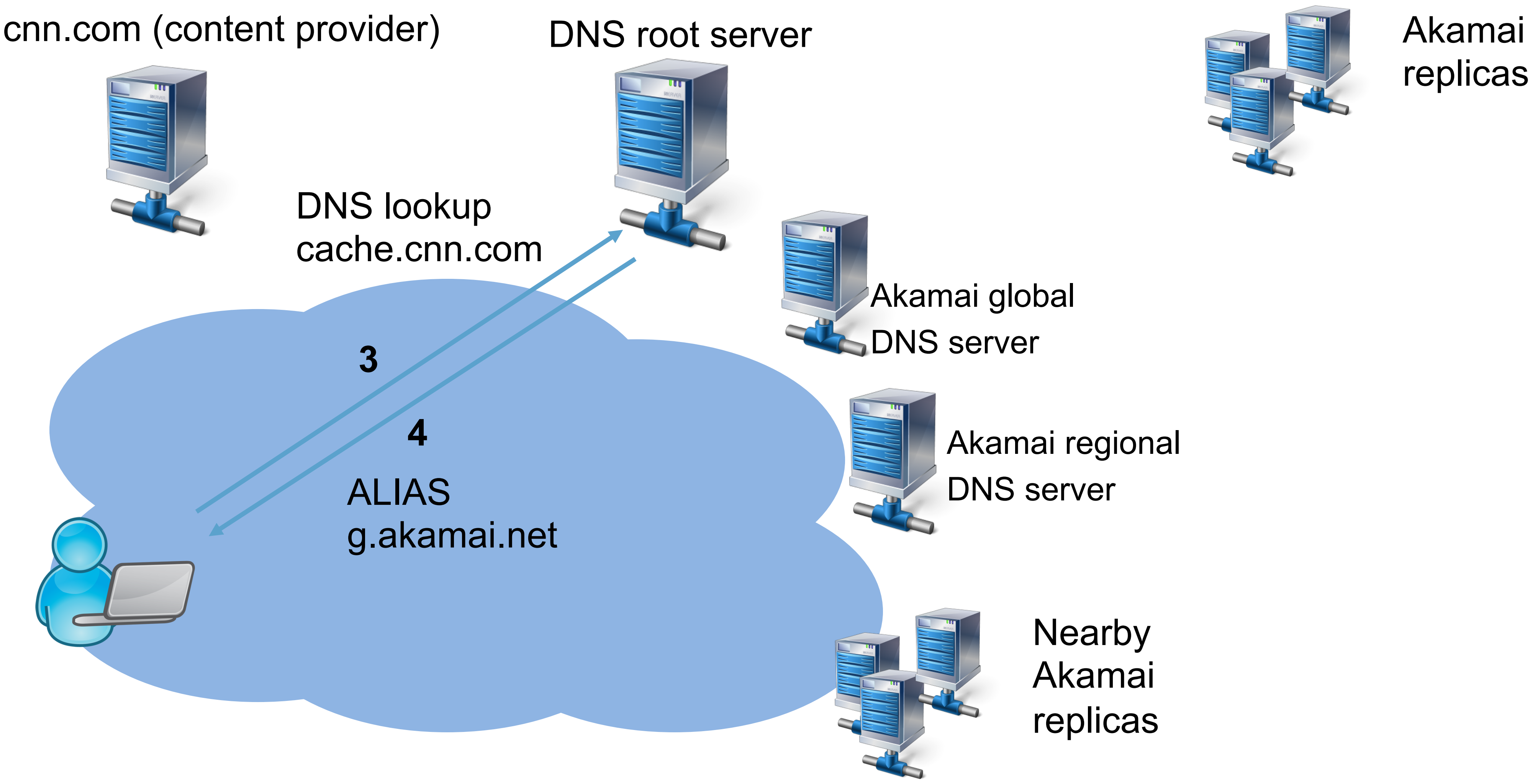

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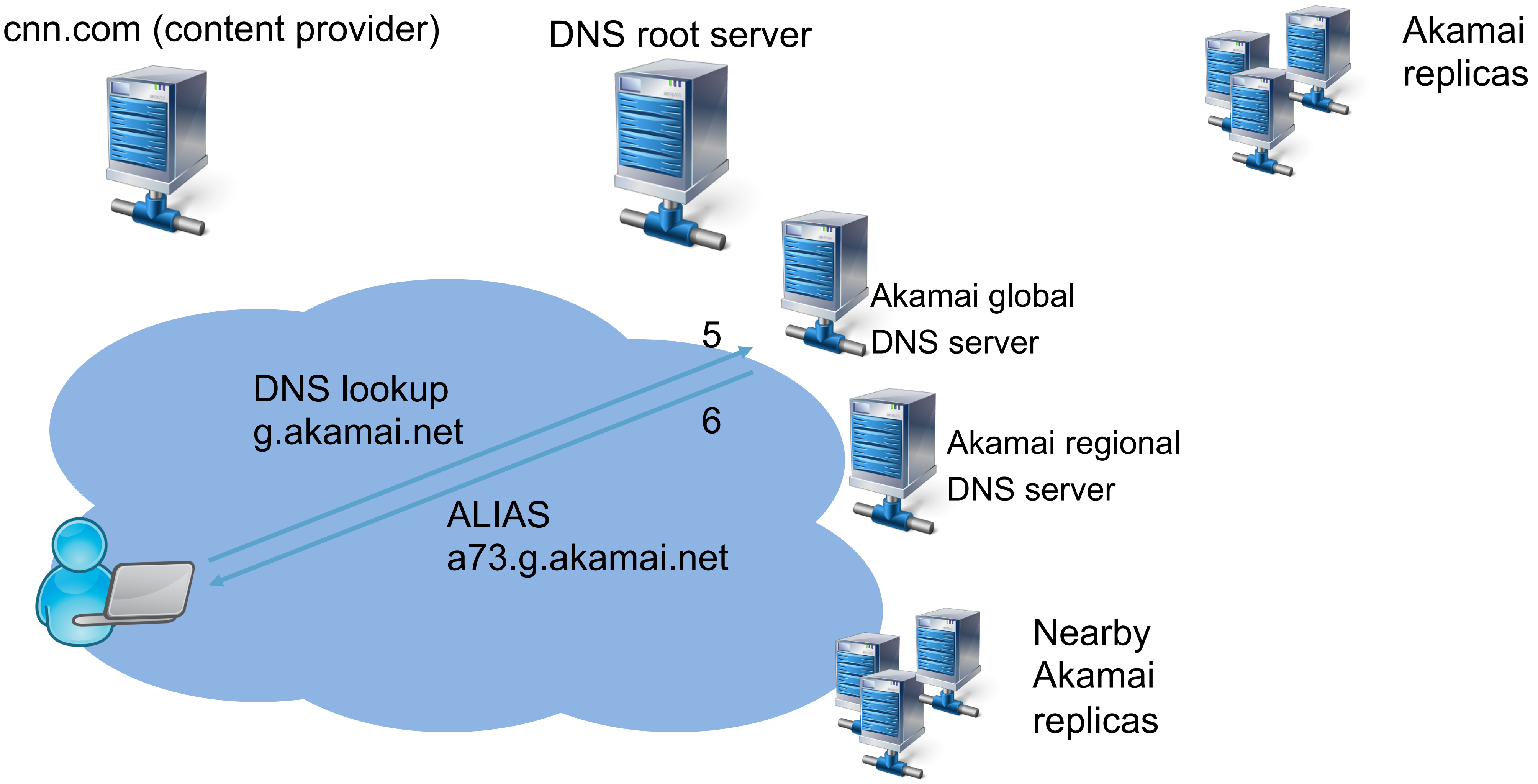

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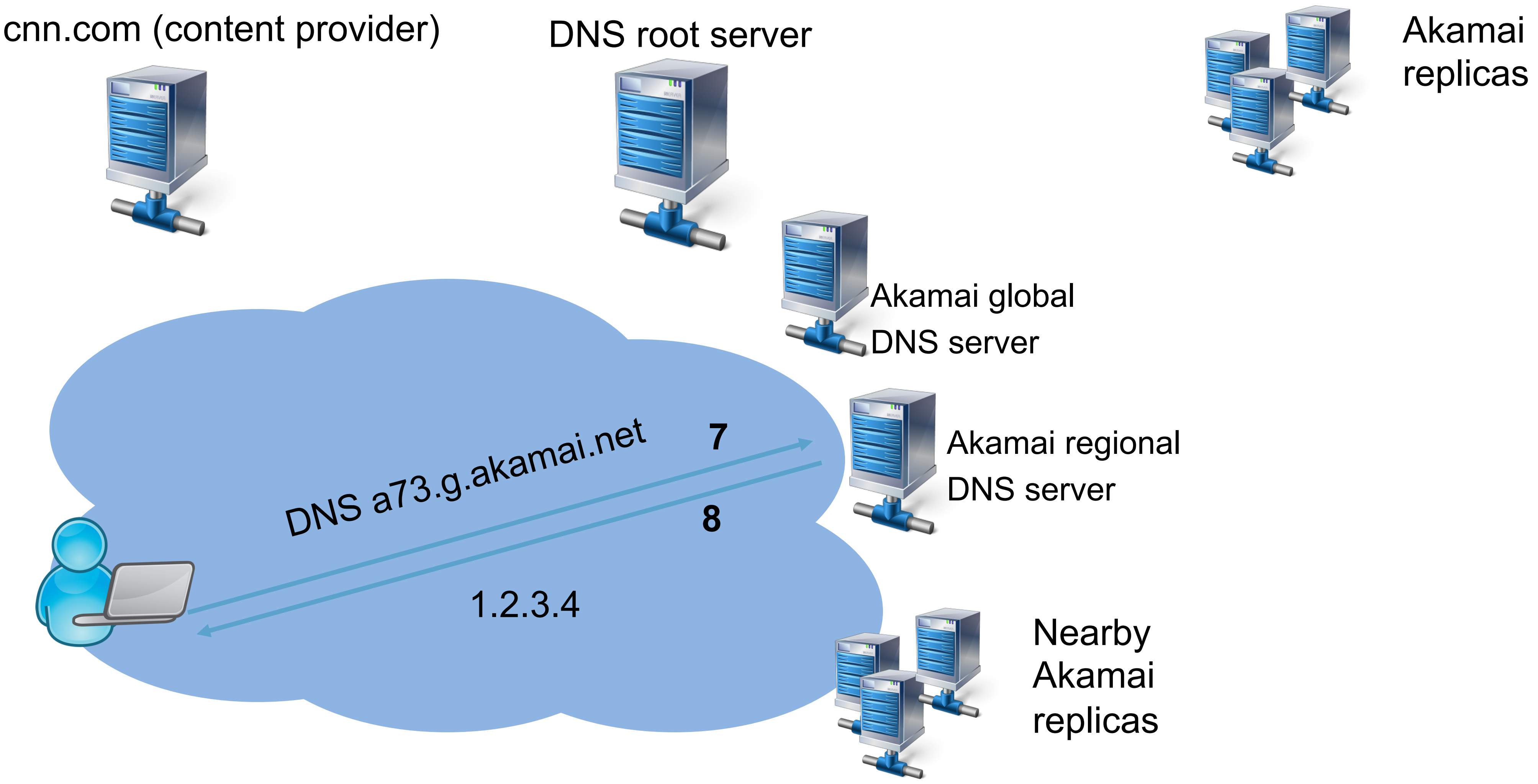

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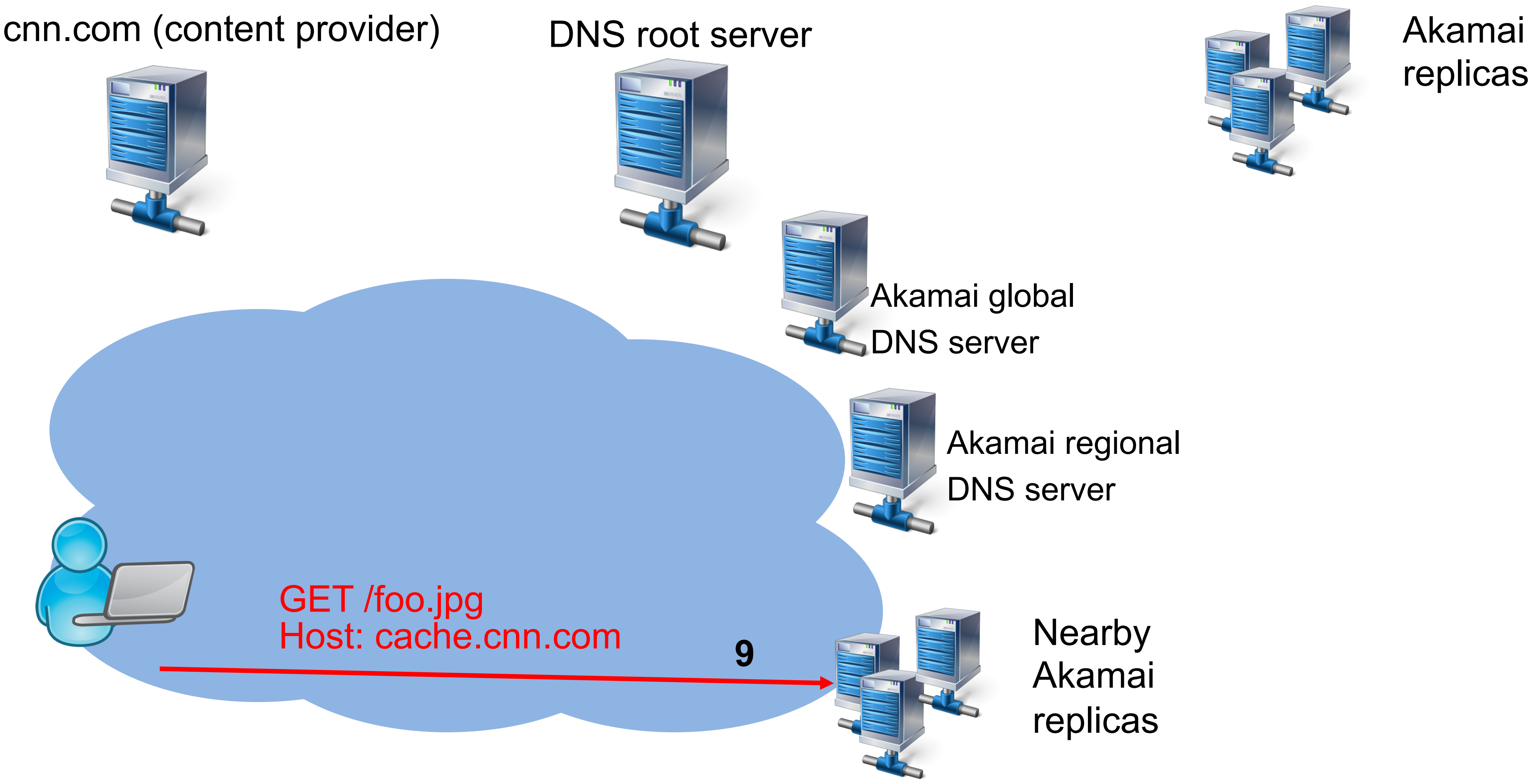

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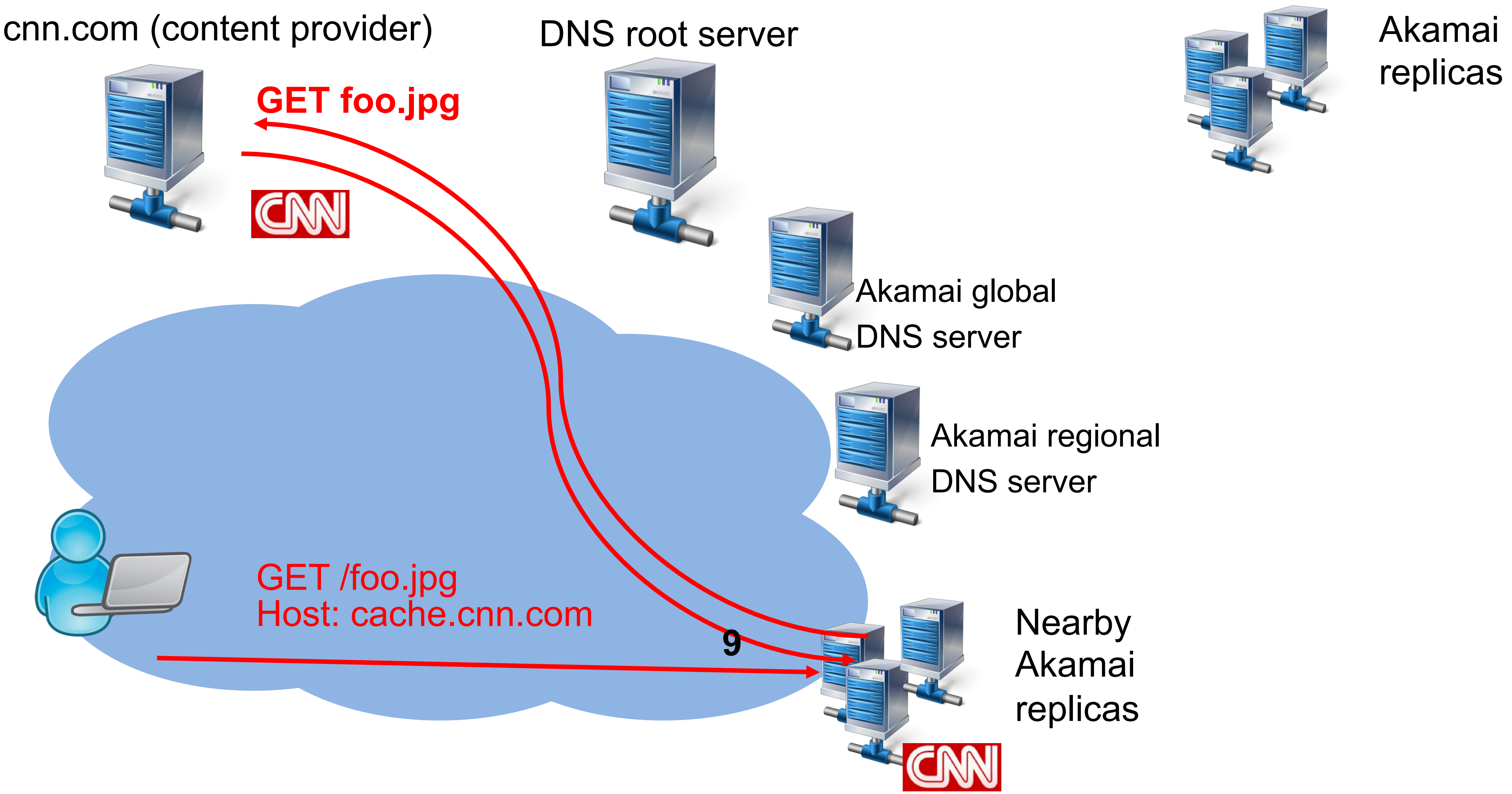

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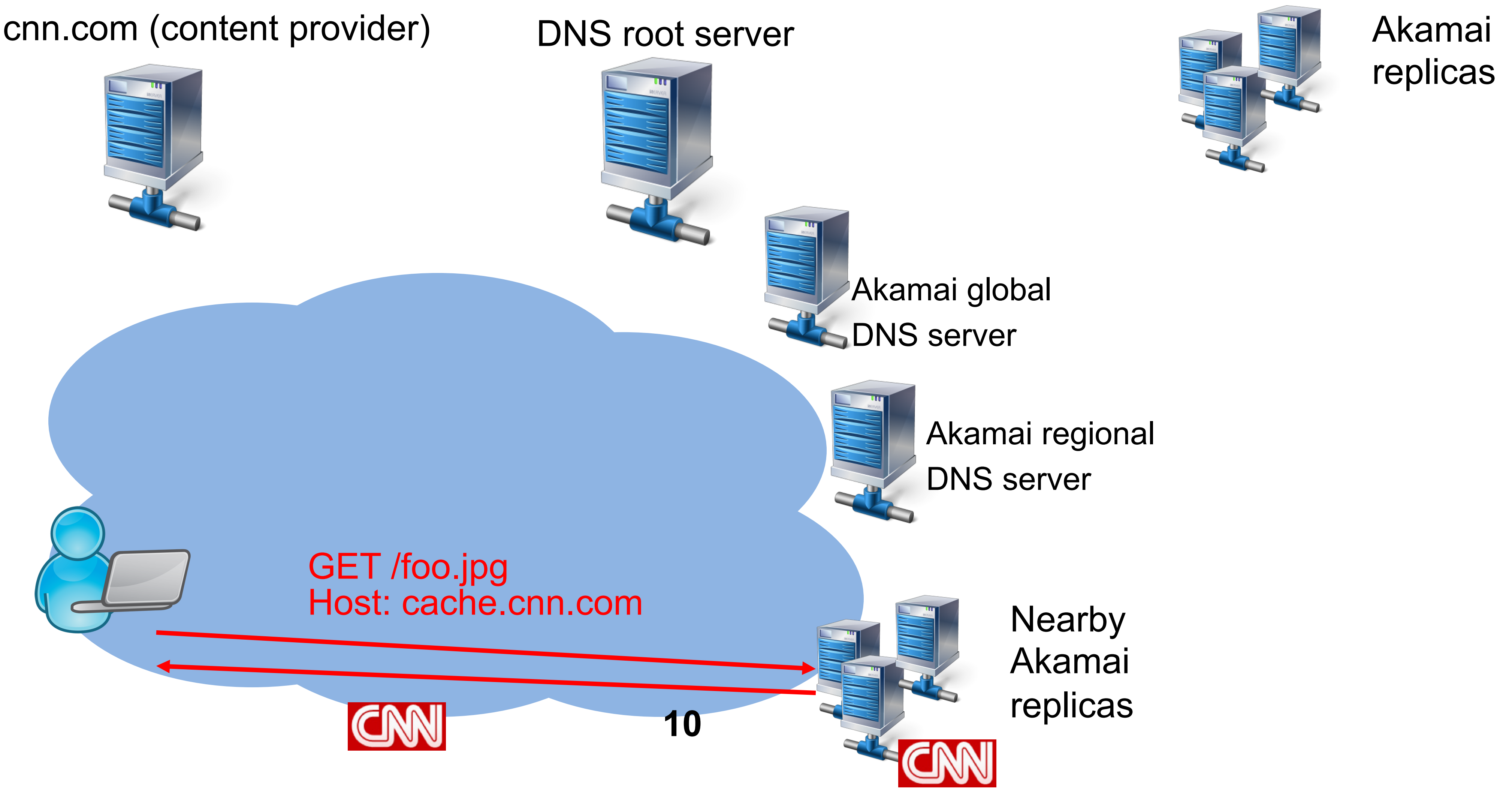


Mapping System

- Equivalence classes of IP addresses
  - IP addresses experiencing similar performance
  - Quantify how well they connect to each other
- Collect and combine measurements
  - Ping, traceroute, BGP routes, server logs
  - Network latency, loss, and connectivity
- Map each IP class to a preferred server cluster
  - Based on performance, cluster health, etc.
  - Updated roughly every minute
- Map client request to a server in the cluster
  - Load balancer selects a specific server (e.g., to maximize cache hit rate)

TAKE 5

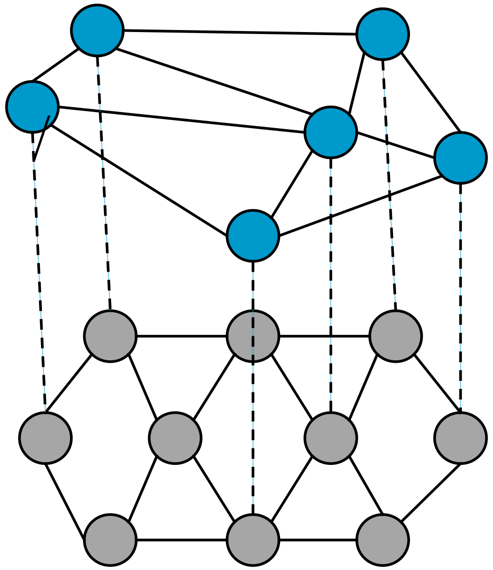
Overlay networks – virtual networks

- Different applications with a wide range of needs …

- Provide a service tailored to a class of applications
  - P2P file sharing, content distribution (CDNs)
- Support efficient operation in a given network environment
  - Wireless ad-hoc networks, delay tolerant networking
- Add extra features such as multicast or secure communication
  - IPv6, (overlay) multicast, resilience (RON), mobility, security (VPN)

Overlay networks

- A logical network built on top of a physical one
  - Overlay links are tunnels through the underlying network
- Nodes are often end hosts
  - Intermediate nodes contribute storage, CPU, just forward traffic for more reliable or faster communication
- Who controls the cooperating nodes?
  - The one who providing the service (e.g., Akamai)
  - A distributed collection of end users (e.g., P2P)
- The price to pay
  - Additional level of indirection
  - Opacity of the underlying network
  - Complexity of the network services



Peer-to-peer – A common overlays

- User computers talking directly (instead of via a central server)
  - Enabled by tech improvements in computing and networking
- A distributed architecture
  - No centralized control
  - Nodes are symmetric in function
- The promise
  - *Reliability* from many unreliable nodes – no central point of failure, multiple replicas, geographic distribution
  - High capacity through parallelism
  - Automatic configuration
  - Shifting control/power from organizations to users
  - …

Three generations of P2P

- (0) Many predecessors – DNS, Usenet, Grapevine, …
- (1) Unstructured and centralized
  - Napster – Sharing music; shutdown July 2001
- (2) Unstructured and decentralized
  - Gnutella, Kazaa, … - Peers are all equal and can connect to anyone
  - Super-peers to scale search and handle churn
- (3) Structured and decentralized
  - E.g. DHTs like Chord, Tapestry, Pastry, Kademlia and CAN

- Key common need – placing and finding resources on an overlay

Skype – an example overlay

- Peer-to-peer VoIP
  - Developed by Kazaa in 2003, acquired by Microsoft in 2011 (US$ 8.5B)
  - 40% of the International call market share (2014), 300M monthly users, 4.5M daily

- Notes on design*
  - Super-peer structure (super-peer selected based on availability, reachability, bandwidth, etc)
  - Users login through a well-known server, but connect to the network and others through super-peers
  - TCP for control, TCP or UDP for voice

*Baset & Schulzrinne's studies

Another classical example – BitTorrent

- A cooperative, popular service for content distribution
- Basic operation
  - User clicks on download link, gets torrent file with content hash and IP address of tracker
  - User’s BT app talks to the tracker, gets a list of other users with downloaded file
  - User’s BT app talks to one or more users with the file, and
  - tell tracker it has a copy too
  - User’s BT app servers the file to others for a while

The problem with trackers

- Hard to distribute files (need a tracker)
- Tracker may not be reliable
- Single point of failure
  - Easy target of copyright owners
  - Or people offended by content
- Could you use a distributed <key,value> store for this?
  - All apps cooperatively implementing it
  - Key is the torrent file content hash (“infohash”), value is the torrent IP
  - BT find other apps able to serve that content by asking around for <key,value> pairs
  - And adds itself as another one willing to help after it has it
  - … but how do you find the <key, value> pair(s) you want?

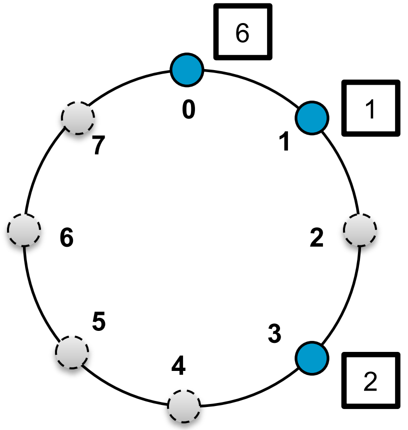
Distributed Hash Tables (DHTs)

- Goal – quick retrieval, storage of <key, value> pairs
- General approach
  - Map node IDs to a (large) circular space
  - Map keys to the same circular space
  - <key, value> pairs are stored in nodes with IDs that are close for some notion of closeness
- A simple interface
  - put(key, value) | get(key) ➔ value
- Weak consistency – likely that get(k) see put(k), no guarantees
- Two examples
  - Chord – one of the original DHTs [Stoica. 2001]
  - Kademlia – A popular second system [Maymounkov, Mazières, 2002]

Chord

- Basics
  - IDs space, m-bit long – 128-160 bits such as SHA-1
  - Identifiers are ordered in an identifier circle modulo 2^m (range $[0, 2^m-1]$)
  - Key k "belongs" to nearest node – node with the smallest id $\geq k$, the successor of k (closeness is "clockwise distance")

An id circle with $m = 3$
Three nodes: 0, 1 and 3



Key 2 is in node 3
pred(3) $< 2 \leq 3$

- To resolve k to address of succ(k)
  - Nodes keep track of their successor on the circle
  - Simplest way – go around the circle until we get k's successor

Chord

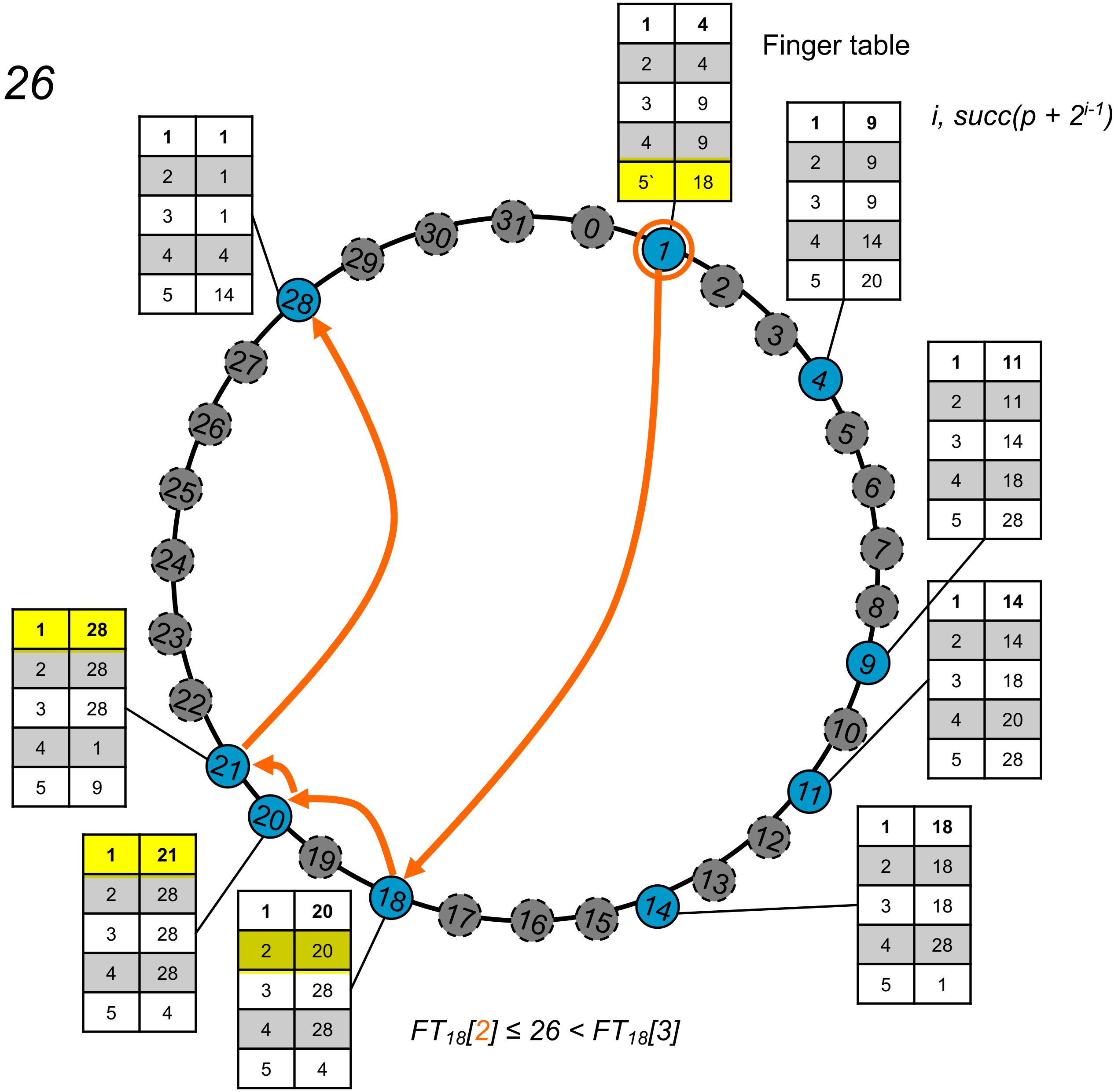
- Short-cuts to speeds things up (not for correctness)
- Nodes keep a finger table of at most *m* entries
  - If FT_p denotes the finger table of *p*, $FT_p[i] = succ(p+2^{i-1})$
    - i.e., the *i-th* entry points to the first node succeeding *p* by at least 2^{i-1} $(1 \leq i < m)$
  - FT entry contains Chord ID, IP and port
  - The first entry is *p* immediate *successor* on the circle
  - Shortcuts' distance increases exponentially with index
- To look up key *k*, node *p* will forward request to node *q* with index *j* in *p's* FT where

$$q = FT_p[j] \leq k < FT_p[j+1]$$

Resolving in Chord – example

Resolving $k = 26$ from node 1

Done, now return address of node 28 to node 1



Some details

- How much faster with FT?
  - Log(n) hops – one of the fingers takes you ~half-way to target
  - Is that good? 10 hops for 1m nodes
    - 50ms per hop, 0.5sec so, not bad
- How does a node gets correct tables?
  - Starting from scratch, add new nodes
  - Use DHT lookups to populate new nodes' finger tables
  - For a new node m
    - Send lookups for its own key, this yields m.successor
    - Gets successor's FT

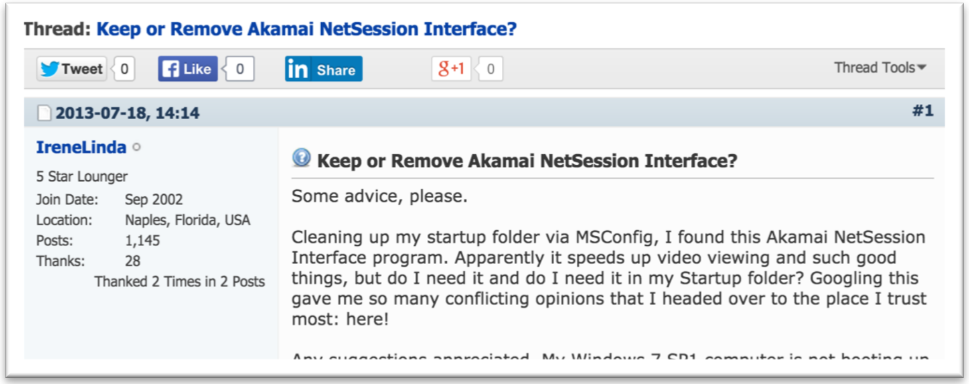
CDNs or P2P?

- P2P systems
  - Cheap, easy to scale
  - Security issues, potential low-quality, hard to find unpopular content, difficult accounting
- Infrastructure-based systems
  - Expensive to setup and scale
  - Akamai 137,000 servers in 87 countries (probably out of date)
  - Can provide predictable QoS and reliable accounting

CDNs or P2P? Both

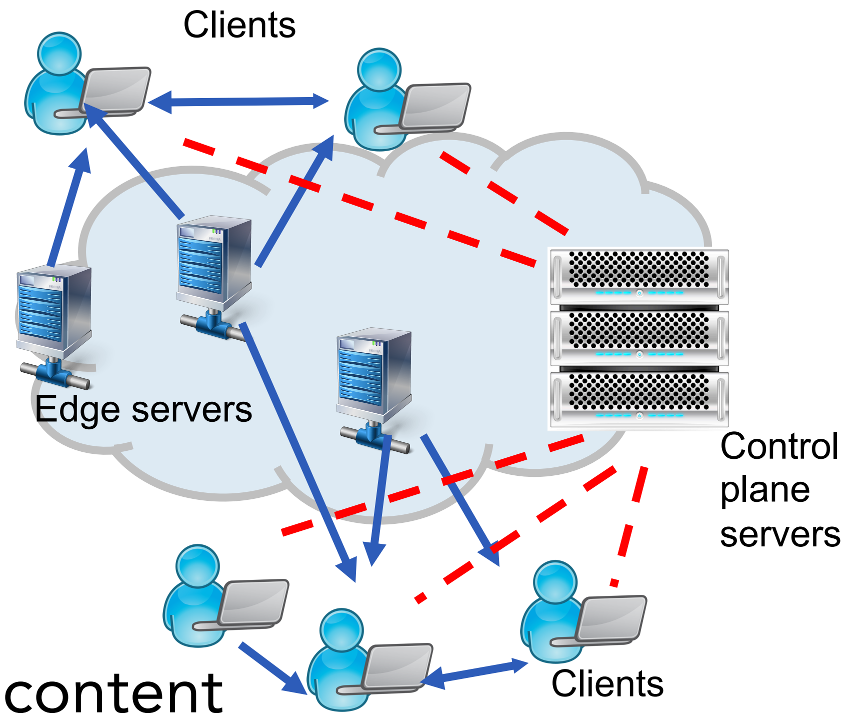
- Hybrid? Peer-assisted CDNs
  – Deliver content by peers, with operation coordinated (and backstopped) by dedicated infrastructure
  – Akamai's NetSession – Operating commercially since 2010
  – True global coverage – 239 countries in 2013

- Risks/Issues
  – Need for revenue, unlike P2P
  – No transparency – users are aware of them
  – Heterogeneity
  – NATs and firewalls
  – Impact to ISP – change of traffic patterns



NetSession's approach and some answers

- Download starts from edge servers
  - Standard HTTPS
- Ask control plane for nearby peers
- If anyone's around, download from them
  - ~Swarm – small pieces exchanged
  - No need for tit-for-tat
  - Edge servers generate unique secure IDs for content and hashes for validation
  - HTTPS connection is used for configuration and reporting



Recap

- New applications with new demands on the underlying network
- Architectural changes are, at best, difficult
- Overlays as a path to deployment and an experimental testbed
  - Deploying narrow fixes?
  - No demands on underlying network (to ensure deployment)
- From grassroots efforts and research labs to products
- Many open hard issues – security, churn, …