CS 5450

Content Distribution Networks

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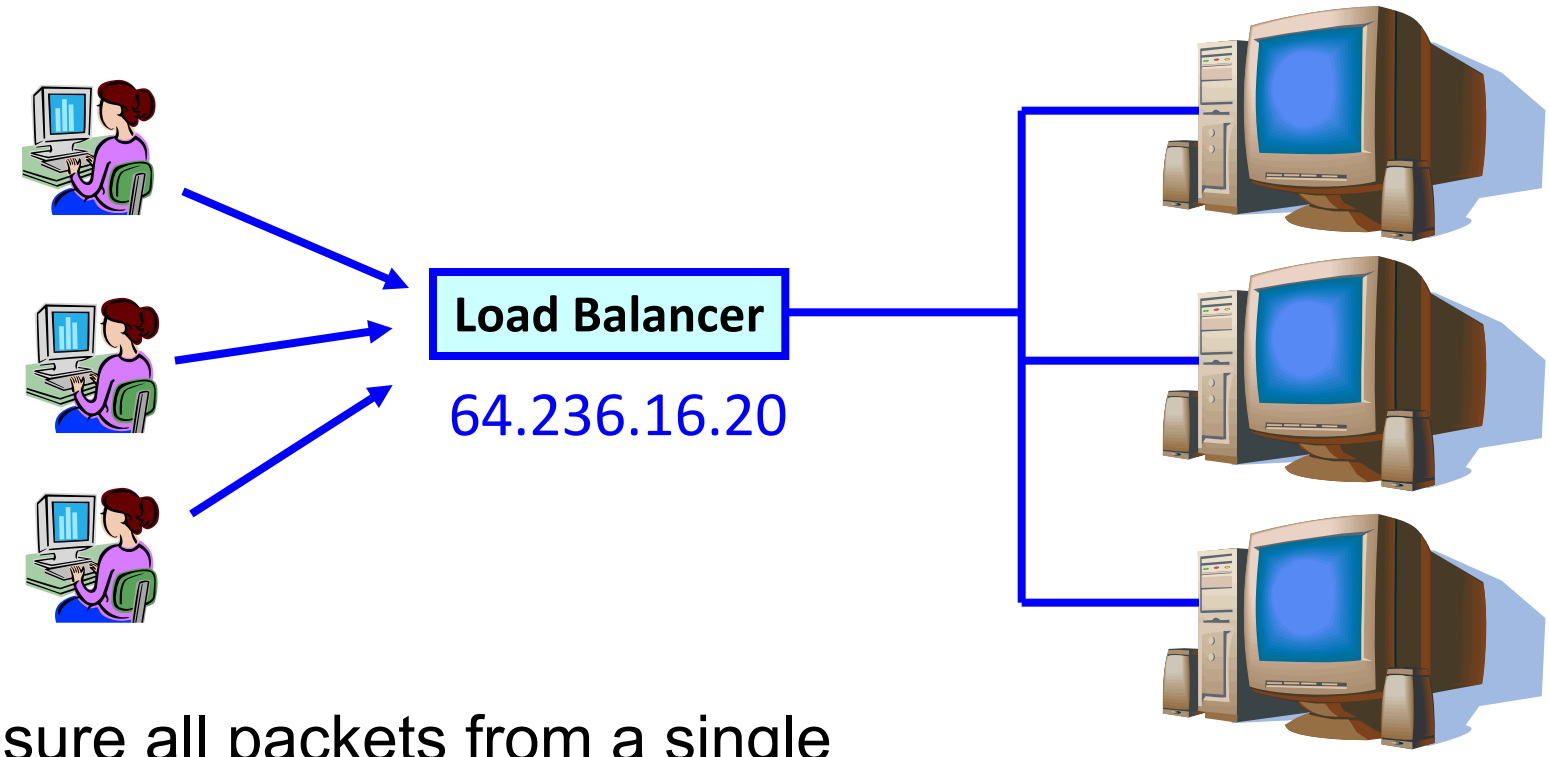
Problem: Overloaded Website

- Solution: replicate site across multiple machines
- Need to direct client to a particular replica
  - Goal: balance load across server replicas
- Solution #1: manual selection by client
  - Each replica has its own site name
  - Some webpage lists replicas (by name or location), asks clients to click link to pick

Load-Balancer Approach

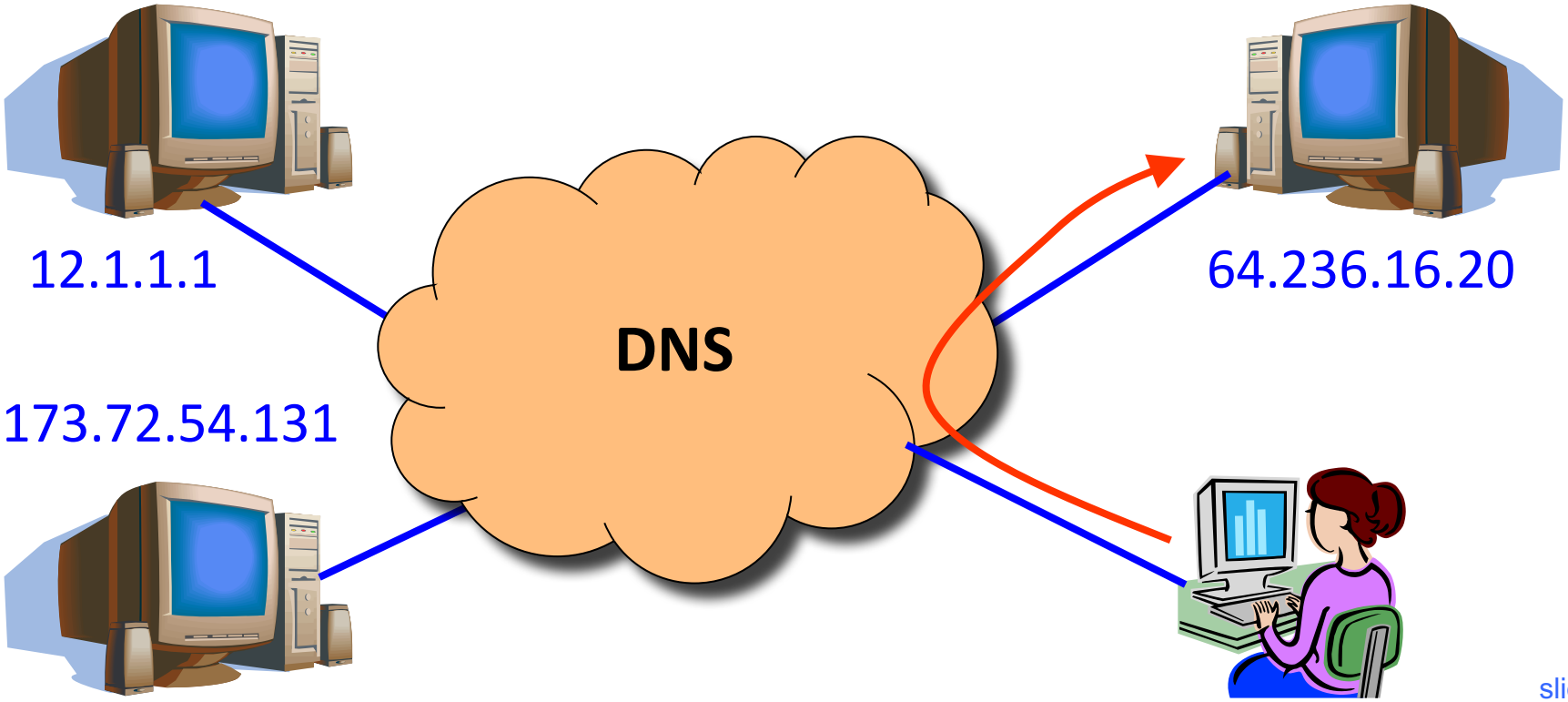
- Solution #2: single IP address, multiple machines



Ensure all packets from a single TCP connection go to the same replica

DNS Redirection Approach

- Solution #3: multiple IP addrs, multiple machines
  - Same DNS name, different IP for each replica
  - DNS server returns IP addresses "round robin"

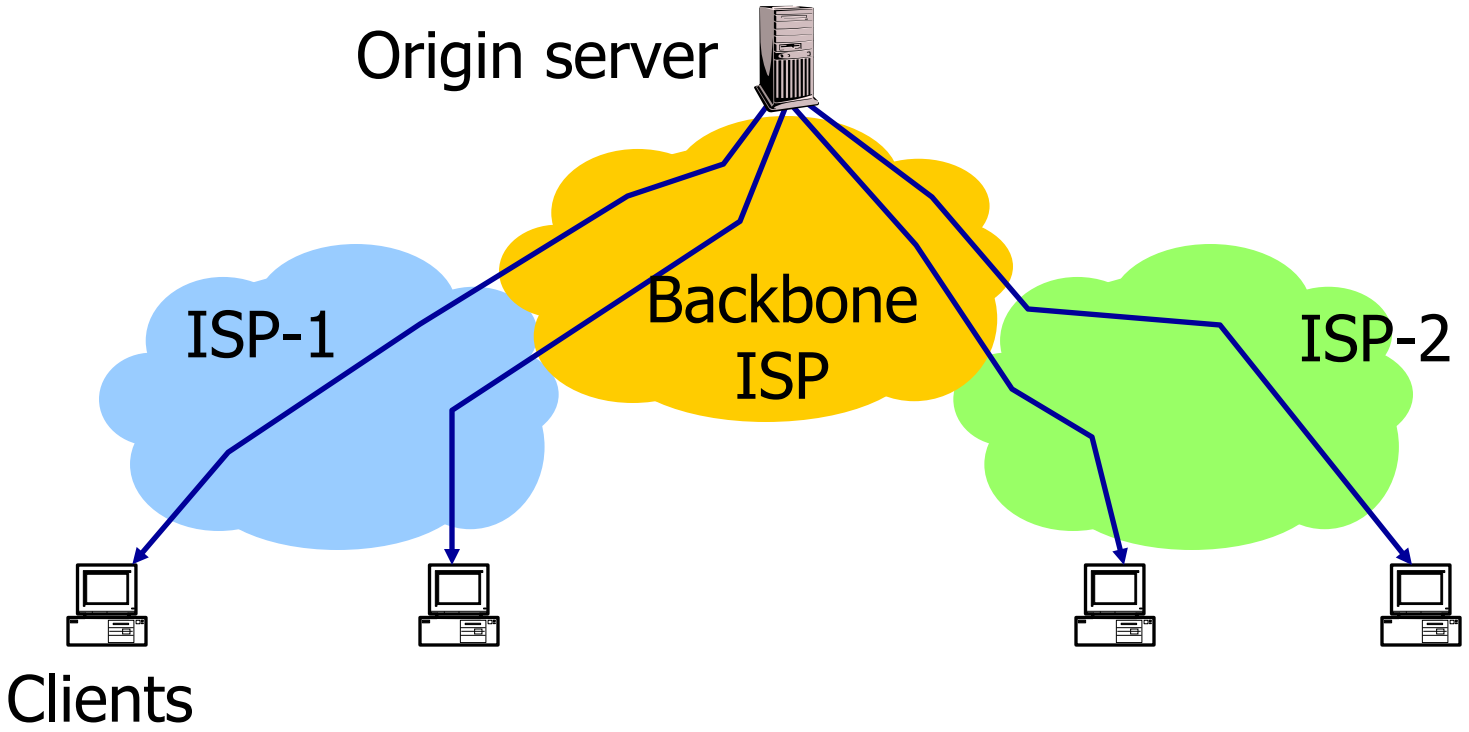


Distributing Client Requests

- Load-balancer approach
  - No geographical diversity ✘
  - TCP connection issue ✘
  - Does not reduce network traffic ✘
- DNS redirection approach
  - No TCP connection issues ✔
  - Simple round-robin server selection
    - May be less responsive ✘
  - Does not reduce network traffic ✘

Motivation for Web Caching

- Many clients request the same information
  - Generates redundant server and network load
  - Clients may experience high latency

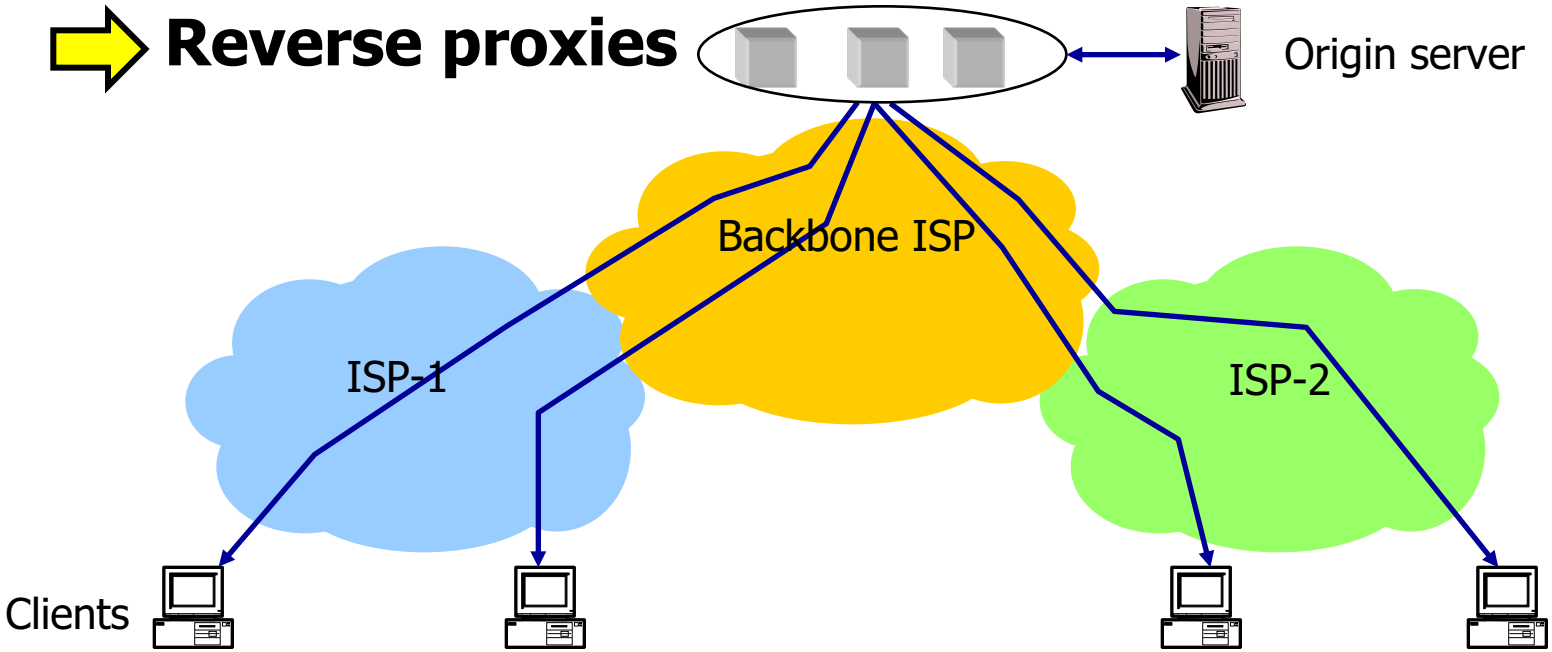


Web Caching

- Why place content closer to client
  - User gets better response time
  - Content providers get happier users
  - Network gets reduced load
- Why does caching work?
  - Exploits locality of reference
- How well does caching work?
  - Very well, up to a limit
  - Large overlap in content, but many unique requests

Caching with Reverse Proxies

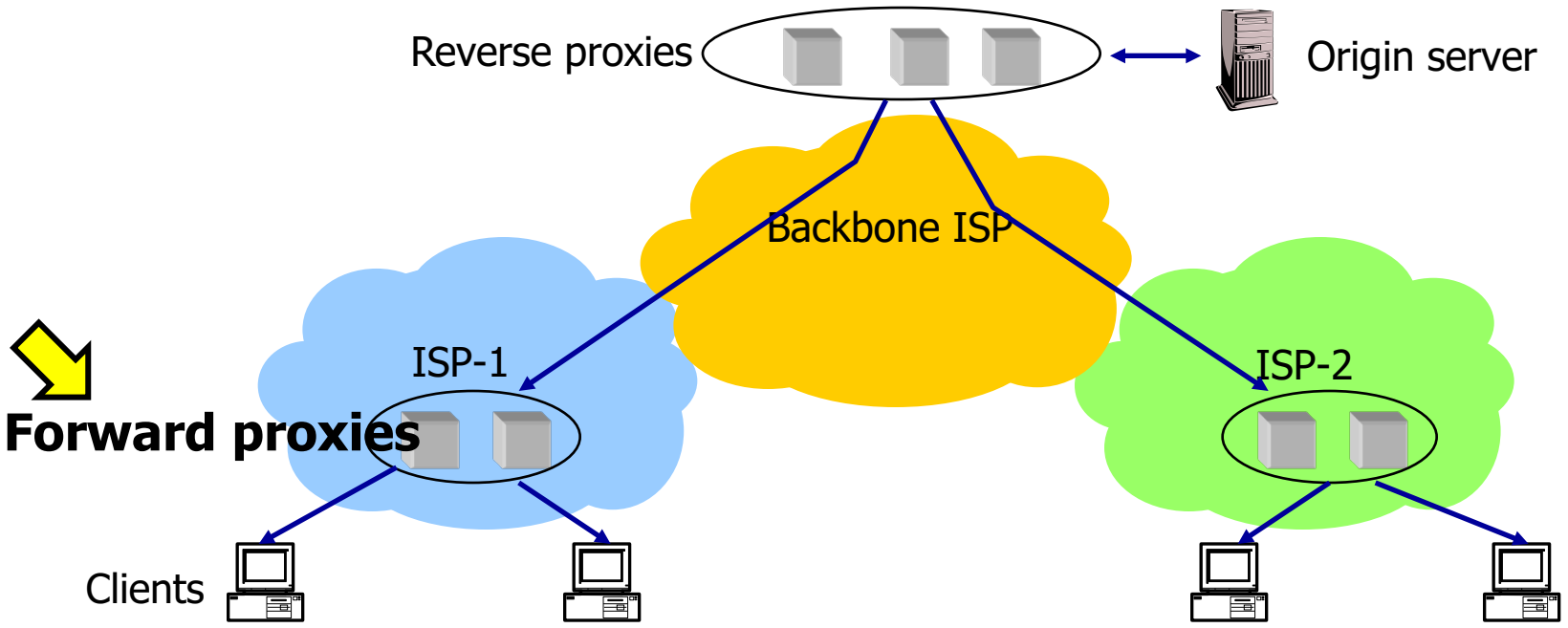
- Cache data close to origin content server
  - Typically done by content providers to reduce load
  - Client thinks it is talking to the origin server
- Does not work for dynamic content



Caching with Forward Proxies

- Cache close to clients → less network traffic, less latency
  - Typically done by ISPs or corporate LANs
  - Client configured to send HTTP requests to forward proxy
- Reduces traffic on client ISP's access link, origin server, and backbone ISP

Proxies


Reverse proxies
Origin server
Backbone ISP
ISP-1
ISP-2
Forward proxies
Clients

Challenges

- Problem ca. 2002: How to reliably deliver large amounts of content to users worldwide?
  - Popular event: "flash crowds" overwhelm (replicated) web server, access link, or back-end database infrastructure
  - More rich content: audio, video, photos
- Web caching: Diversity causes low cache hit rates (25–40%)

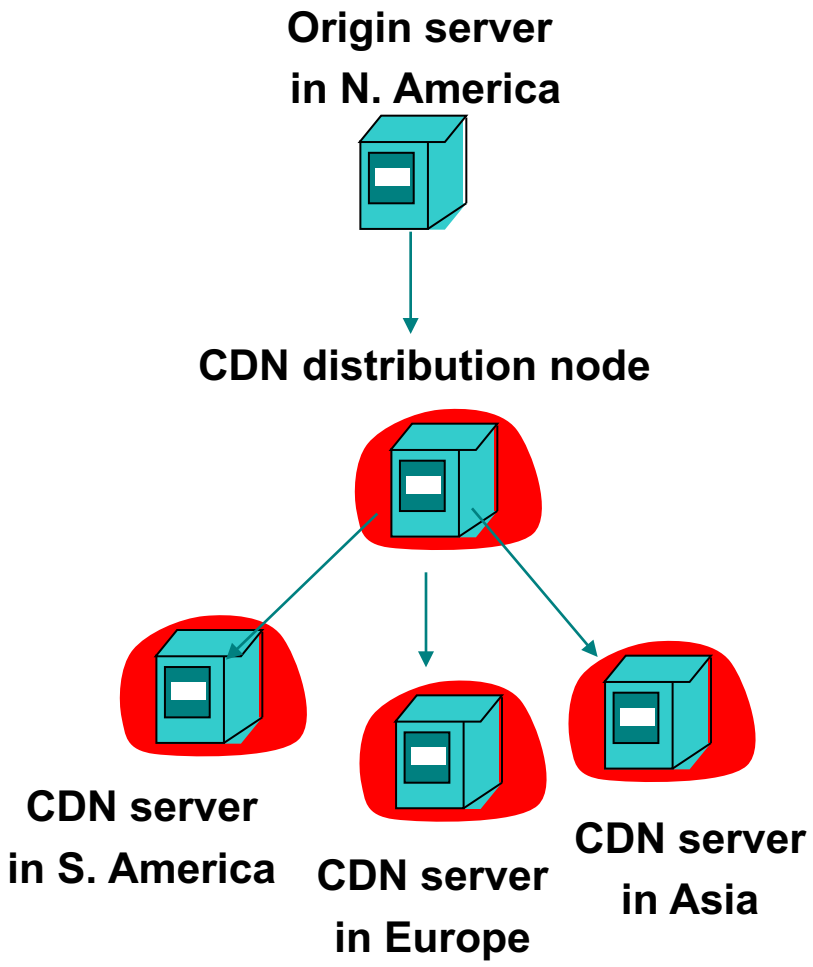
Typical Webpage Workload

- Multiple (typically small) objects per page
- File sizes are heavy-tailed
- Embedded references
- This plays havoc with performance. Why?

- Lots of small objects & TCP
- 3-way handshake
- Lots of slow starts
- Extra connection state

Content Distribution Network

- Proactive content replication
  - Content provider (e.g. CNN) pushes content out from its own origin server
- CDN replicates the content
  - On many servers spread throughout the Internet
- Updating the replicas
  - Updates pushed to replicas when the content changes



CDN Challenges

- How to replicate content
- Where to replicate content
- How to find replicated content
- How to choose among known replicas
- How to direct clients towards replica

Replica Selection

Requires continuous monitoring of liveness, load, and performance

- Which server?
  - Lowest load → to balance load on servers
  - Best performance → to improve client performance
    - Based on geography? RTT? Throughput? Load?
  - Any alive node → to provide fault tolerance
- How to direct clients to the chosen server?
  - As part of routing → anycast, cluster load balancing
  - As part of application → HTTP redirect
  - As part of naming → DNS

Application-Based Selection

- HTTP supports a simple way to indicate that Web page has moved
  - 30X responses
- Server receives GET request from client, decides which server is best suited for particular client and object, returns HTTP redirect to that server
- Additional overhead
  - Multiple connection setup, name lookups, etc.
- HTTP redirect has some design flaws – especially with current browsers

Naming-Based Selection

- Client does name lookup for service
- Name server chooses appropriate server address
  - "A" record returned is the "best" one for the client
- How does the name server choose?
  - Server load and location (info must be collected!)
  - Information in the name lookup request
    - … typically from the local name server for client

How Akamai Works

- Akamai creates new domain names for each customer
  - Ex: a73.g.akamaitech.net
  - Akamai's DNS servers are authoritative for these names
- Clients fetch HTML document from origin server
  - Ex: fetch index.html from cnn.com
- URLs for replicated content are replaced in HTML
  - Ex:<img src="http://cnn.com/af/x.gif"> becomes <img src="http://a73.g.akamaitech.net/7/23/cnn.com/af/x.gif">
- Client's browser issues GET to CDN instead of origin server

Content Replication in Akamai

- Akamai only replicates static content
  - Akamai also lets sites write code that can run on Akamai's server, but that's different
- Modified name contains original file name
- Akamai server is asked for content
  - First checks local cache
  - If not in cache, requests file from primary server and caches file

DNS-Based Redirection

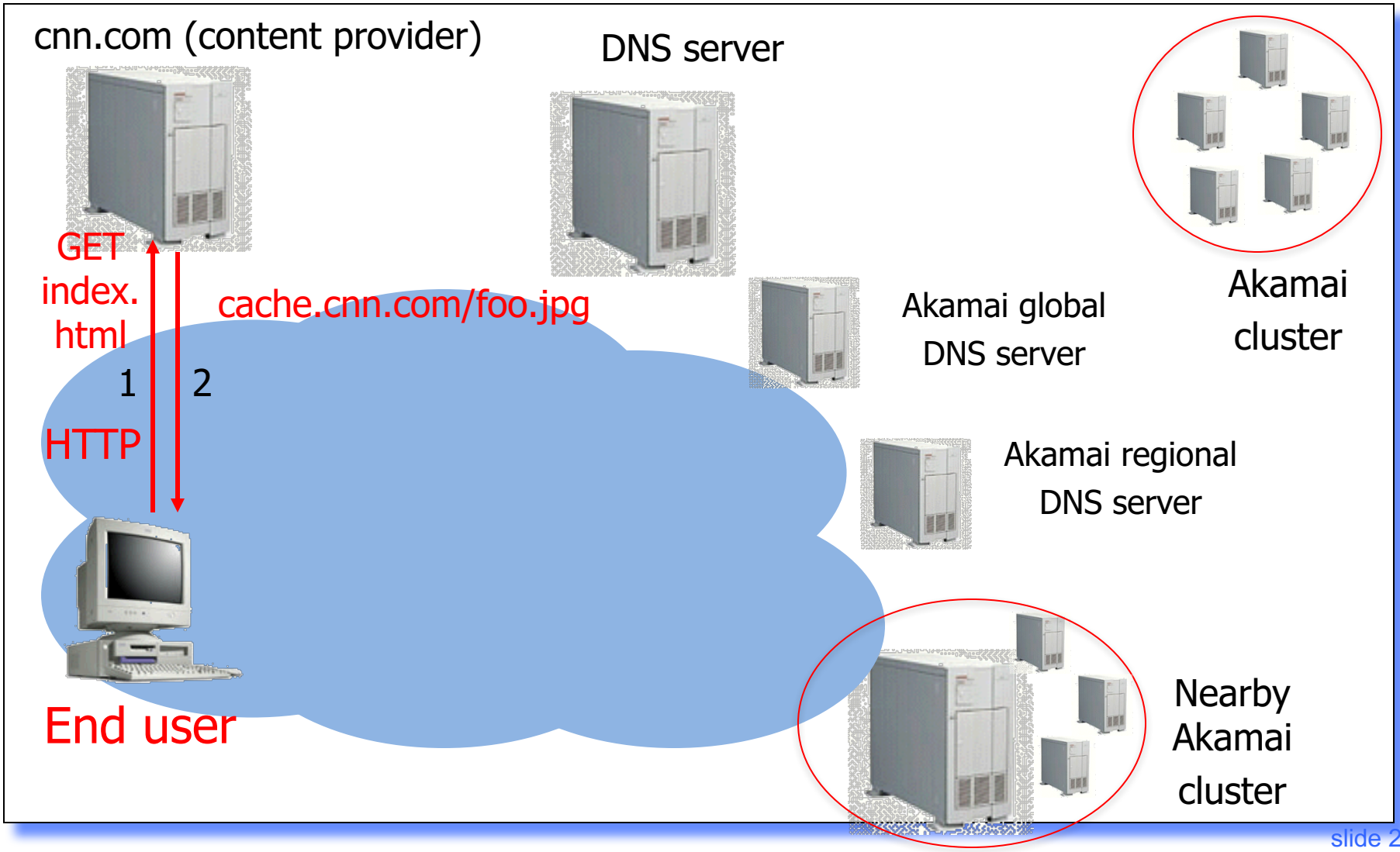
Two levels of DNS indirection

- Akamai top-level name servers (TLNSs)
  - 4 in the U.S., 4 in Europe, 1 in Asia
  - TLNSs return eight LLNSs in three different regions
    - Chosen to be close to the requesting client
    - Handles complete failure of any two regions
- Akamai low-level name servers (LLNSs)
  - Point to Akamai edge servers, which serve content
  - Do most of the load-balancing

Using DNS in Akamai

- Root server gives NS record for akamai.net
- akamai.net name server returns NS record for g.akamaitech.net
  - Name server chosen in the region of client's name server
  - TTL is large
- g.akamaitech.net name server chooses server in the client's region
  - Should try to choose server that has file in cache (how?)
  - Uses aXYZ name and hash
  - TTL is small (why?)

How Akamai Uses DNS



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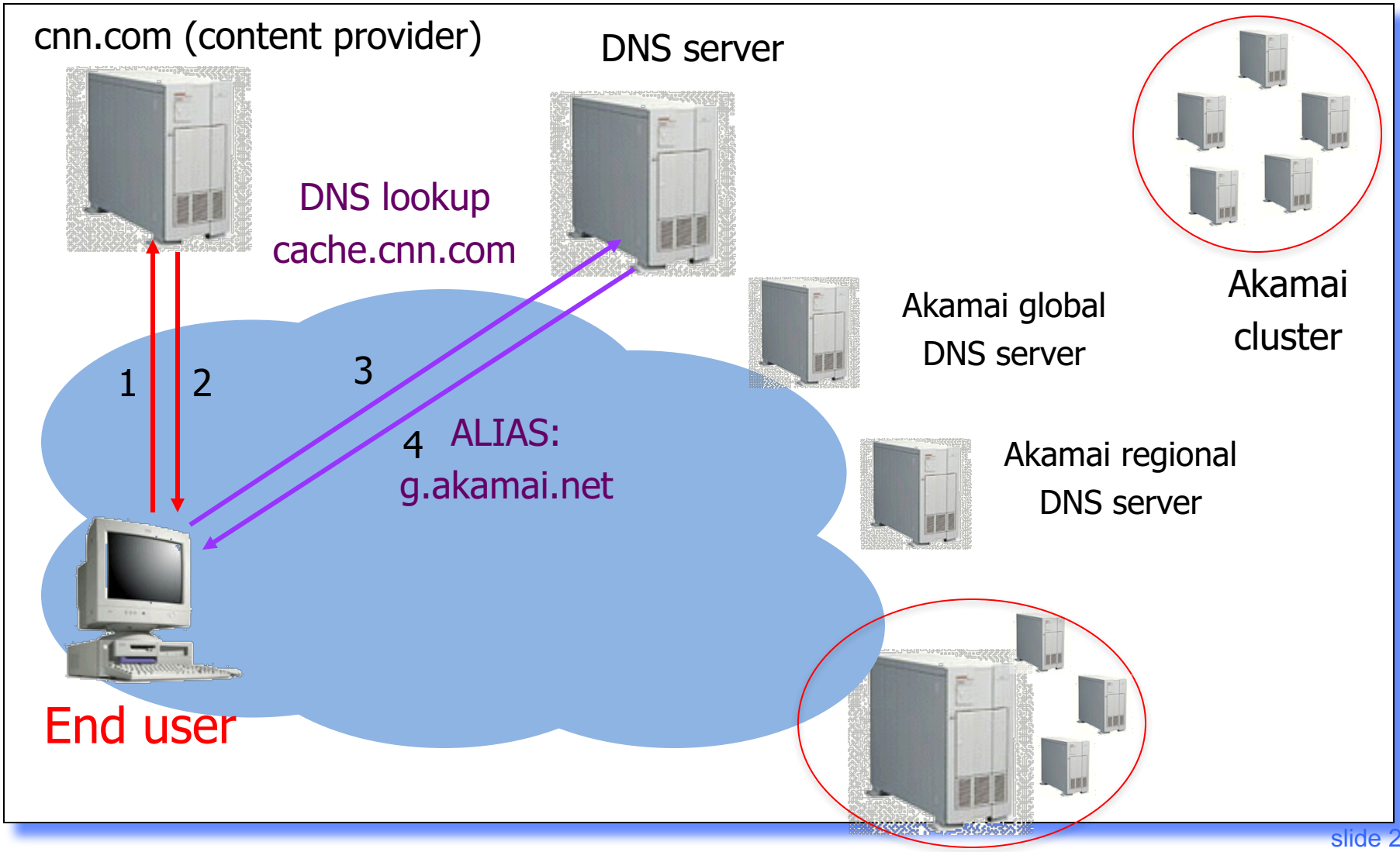

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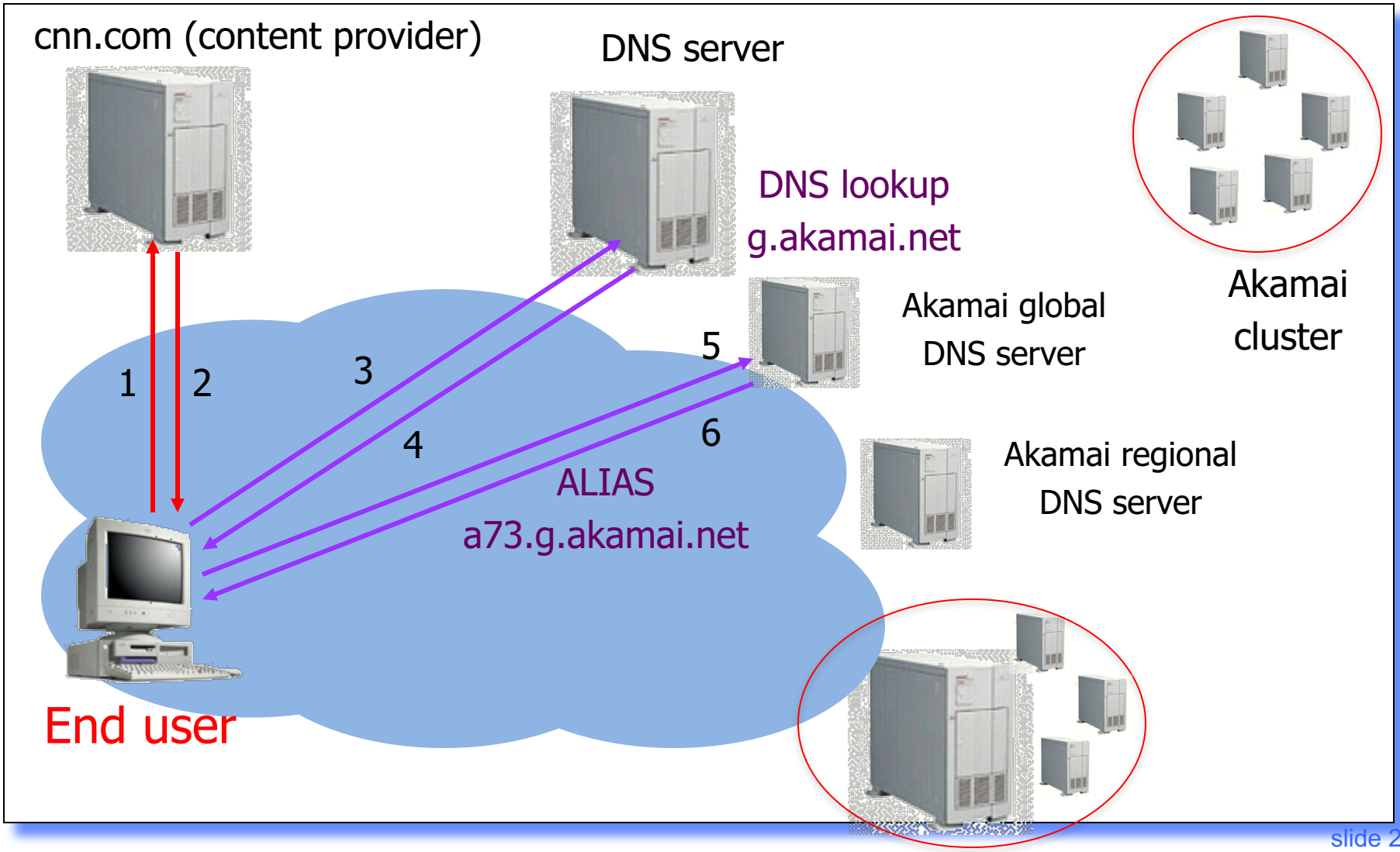

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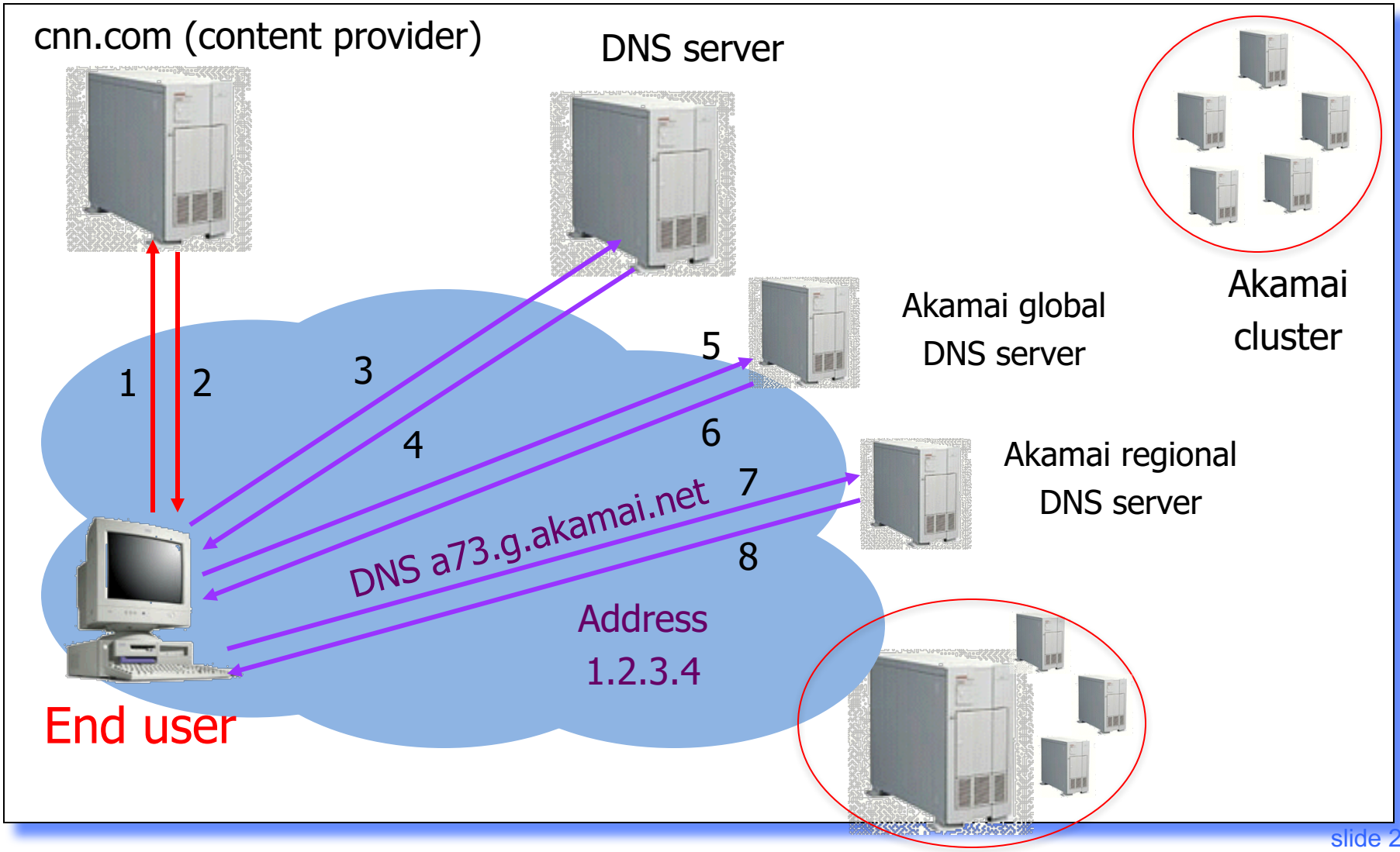

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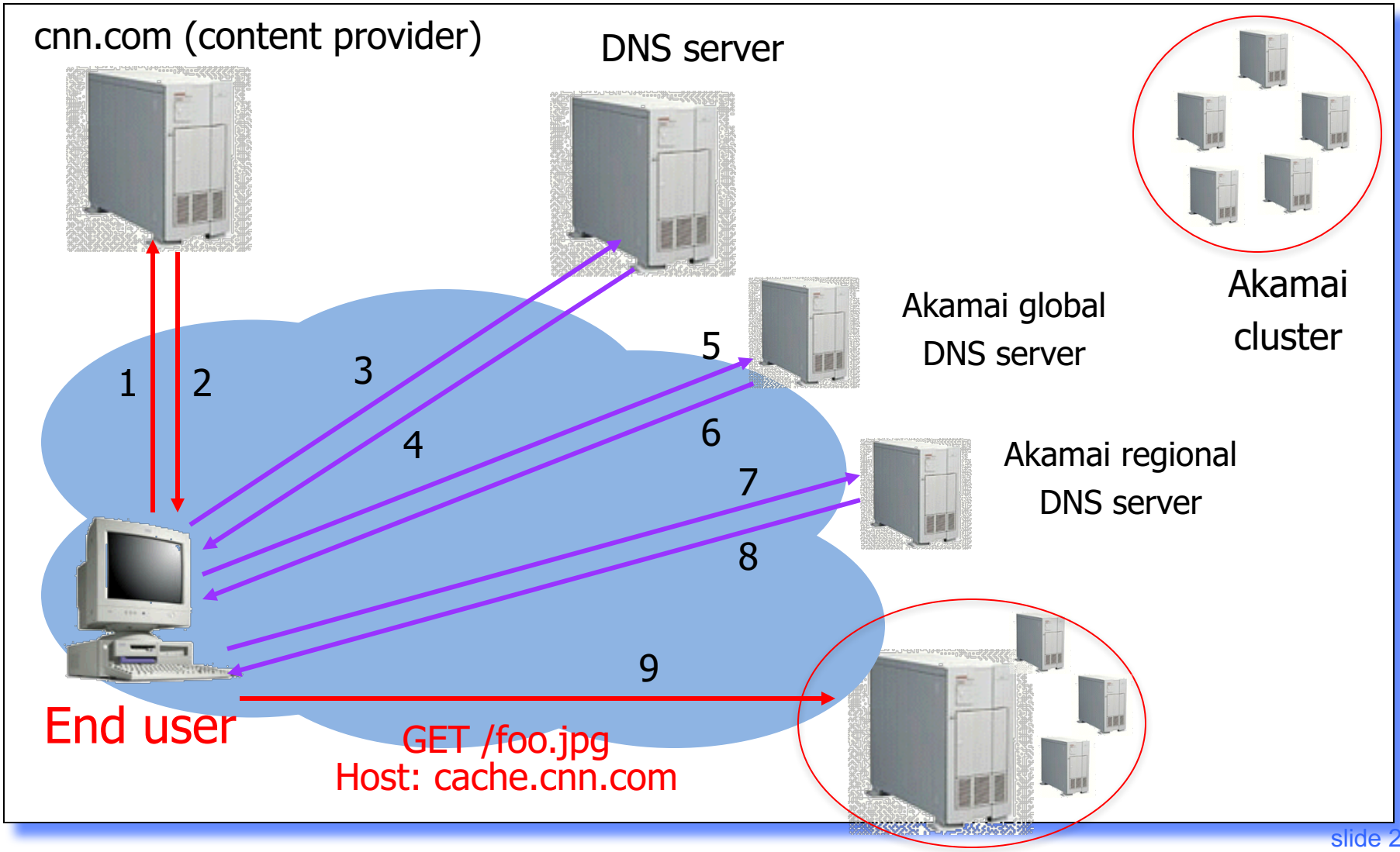

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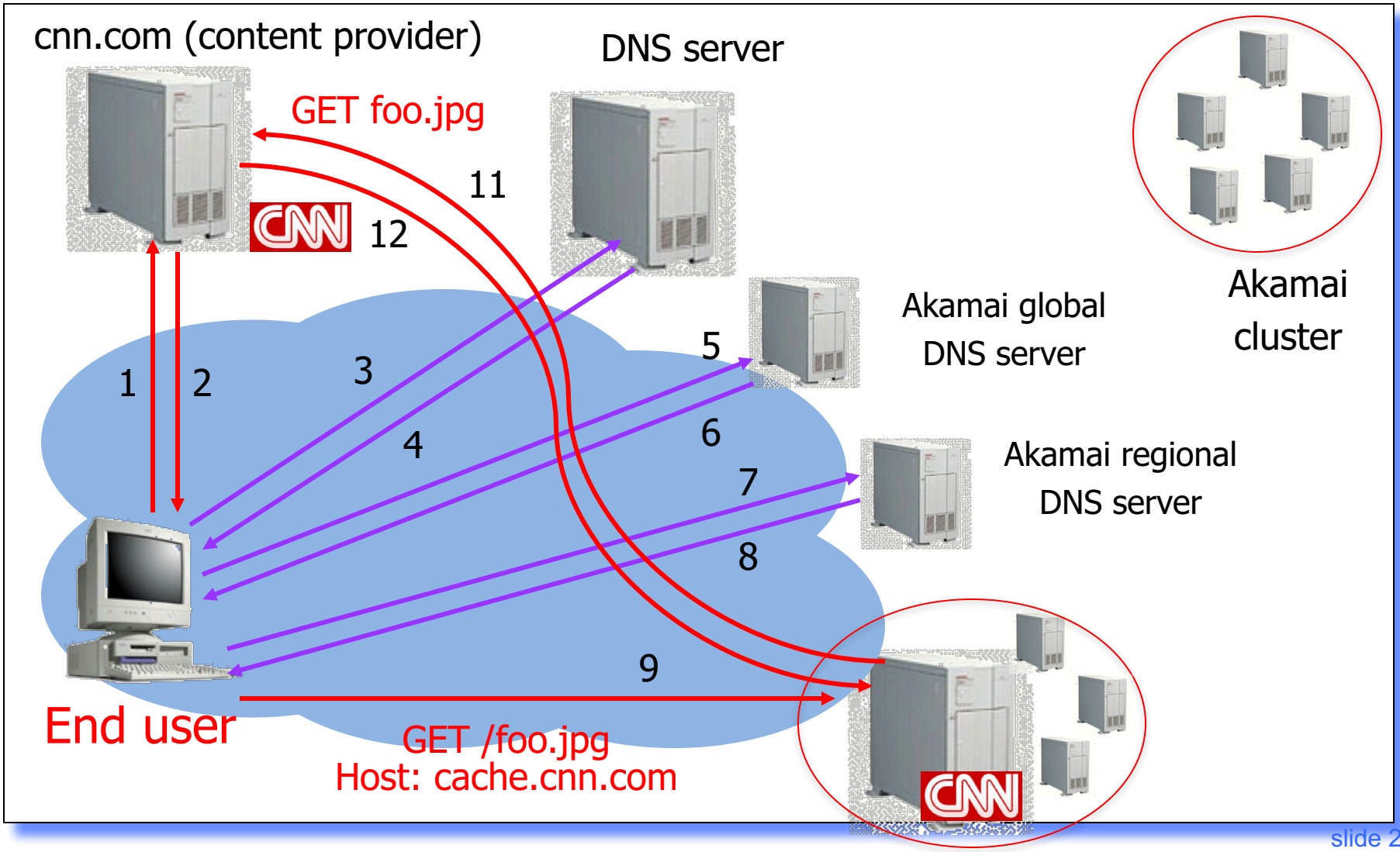

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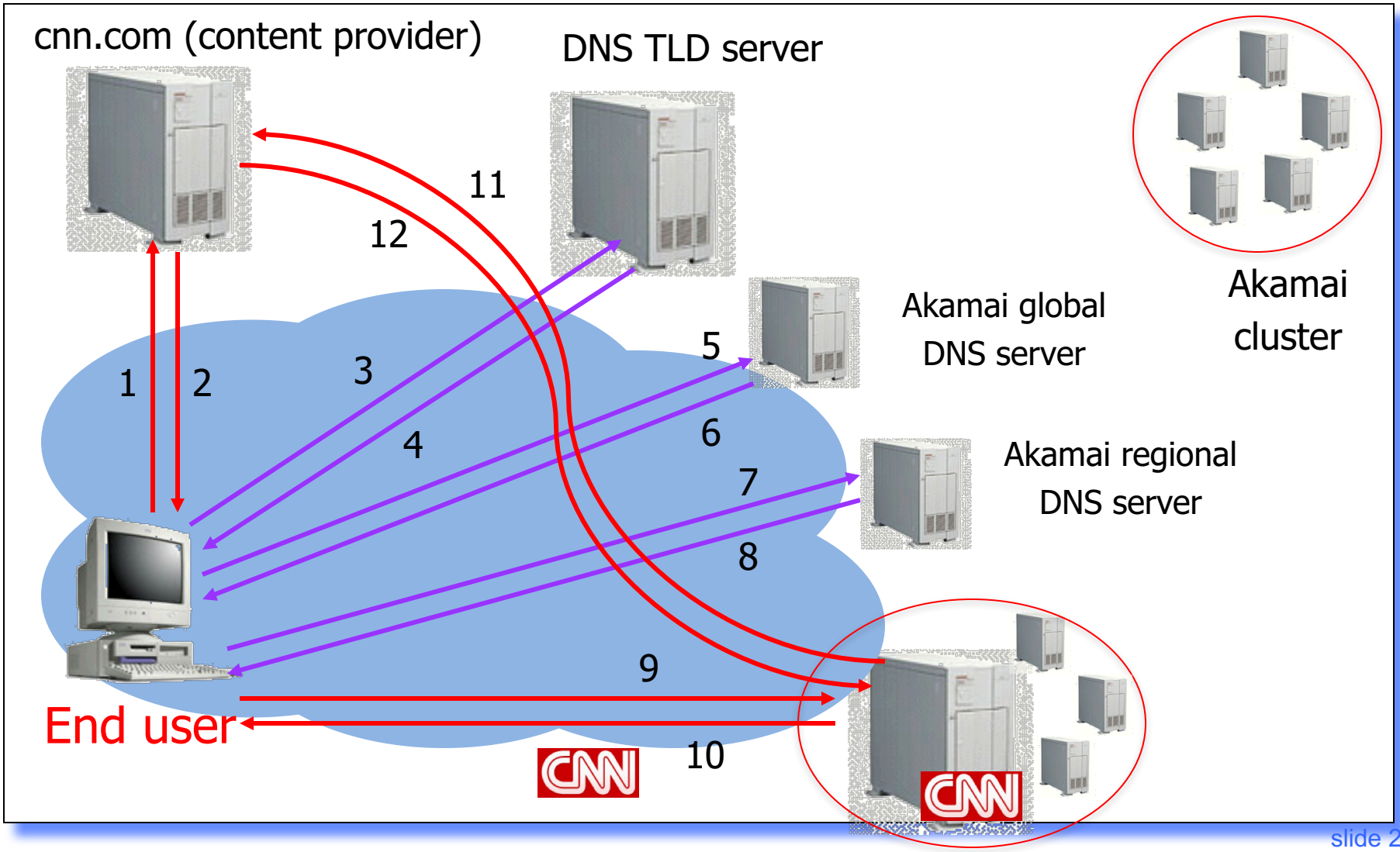

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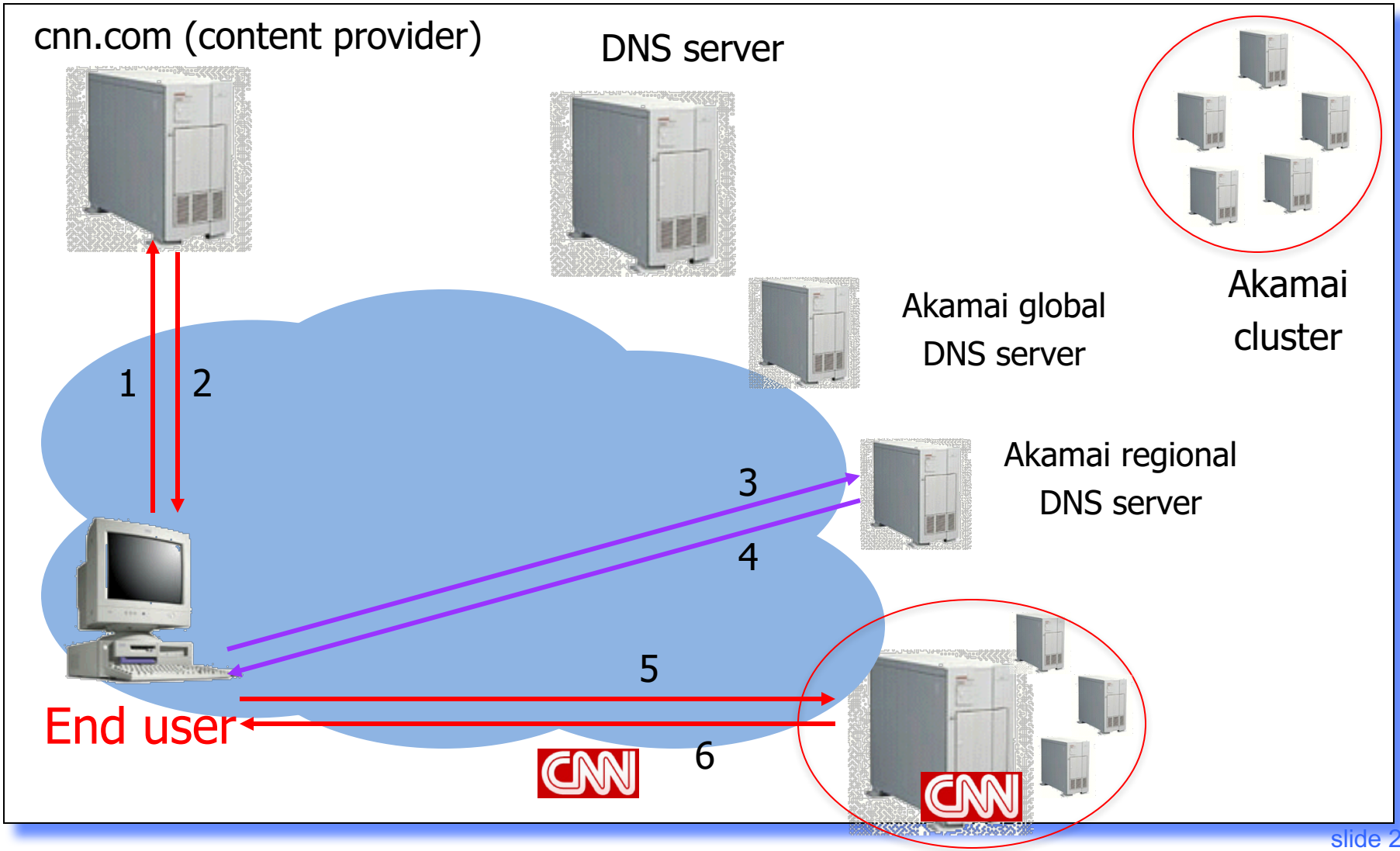

Akamai Statistics (Old)

- Distributed servers
  - Servers: ~100,000
  - Networks: ~1,000
  - Countries: ~70
- Customers
  - Apple, BBC, FOX, GM IBM, MTV, NASA, NBC, NFL, NPR, Puma, Red Bull, Rutgers, SAP, …
- Client requests
  - 20+M per second
  - Half in the top 45 networks
  - 20% of all Web traffic worldwide

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
    - Over 100 TB of logs per days
  - Network latency, loss, throughput, and connectivity

Routing Client Requests

- Create map of the Internet
  - BGP peering sessions with Internet border routers → coarse-grained AS map of the Internet

    + live traceroute, loss measurements betw. CDN servers
- Map each IP class to a preferred server cluster
  - Based on performance, cluster health, network status
  - Updated roughly every minute
    - Short, 60-sec DNS TTLs in Akamai regional DNS accomplish this
- Map client request to a server in the cluster
  - Load balancer selects a specific server
    - For example, to maximize the cache hit rate

Adapting to Failures

- Failing hard drive on a server
  - Suspends after finishing "in progress" requests
- Failed server
  - Another server takes over for the IP address
  - Low-level map updated quickly (load balancer)
- Failed cluster, or network path
  - High-level map updated quickly (ping/traceroute)

Take-Away Points on CDN

- Content distribution is hard
  - Many diverse, changing objects
  - Clients distributed all over the world
- Moving content to the client is key
  - Reduces latency, improves throughput, reliability
- Content distribution solutions evolved from load balancing and reactive caching to proactive content distribution networks