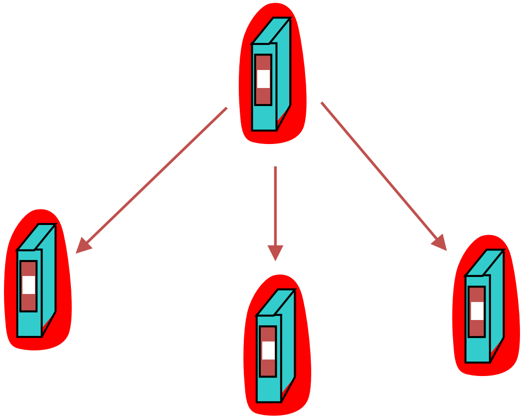
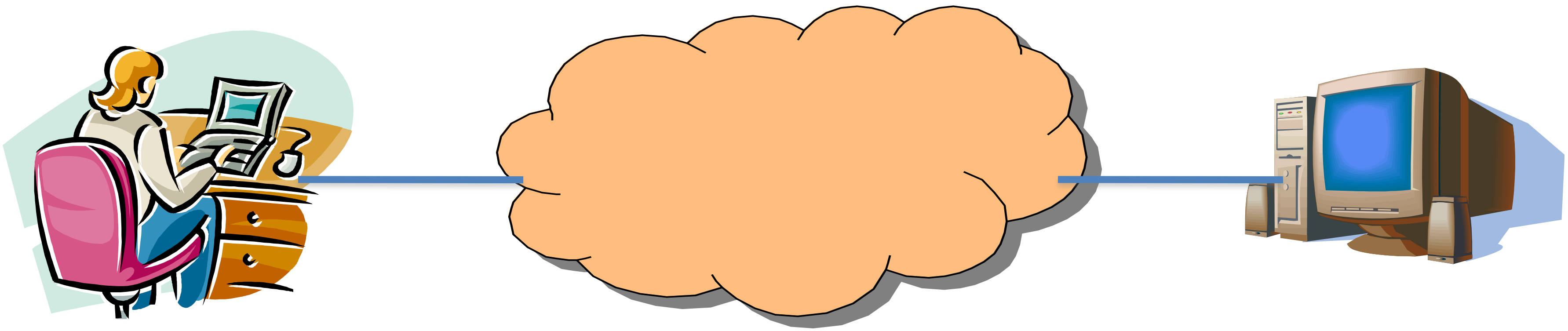


Content Distribution Networks (CDNs)

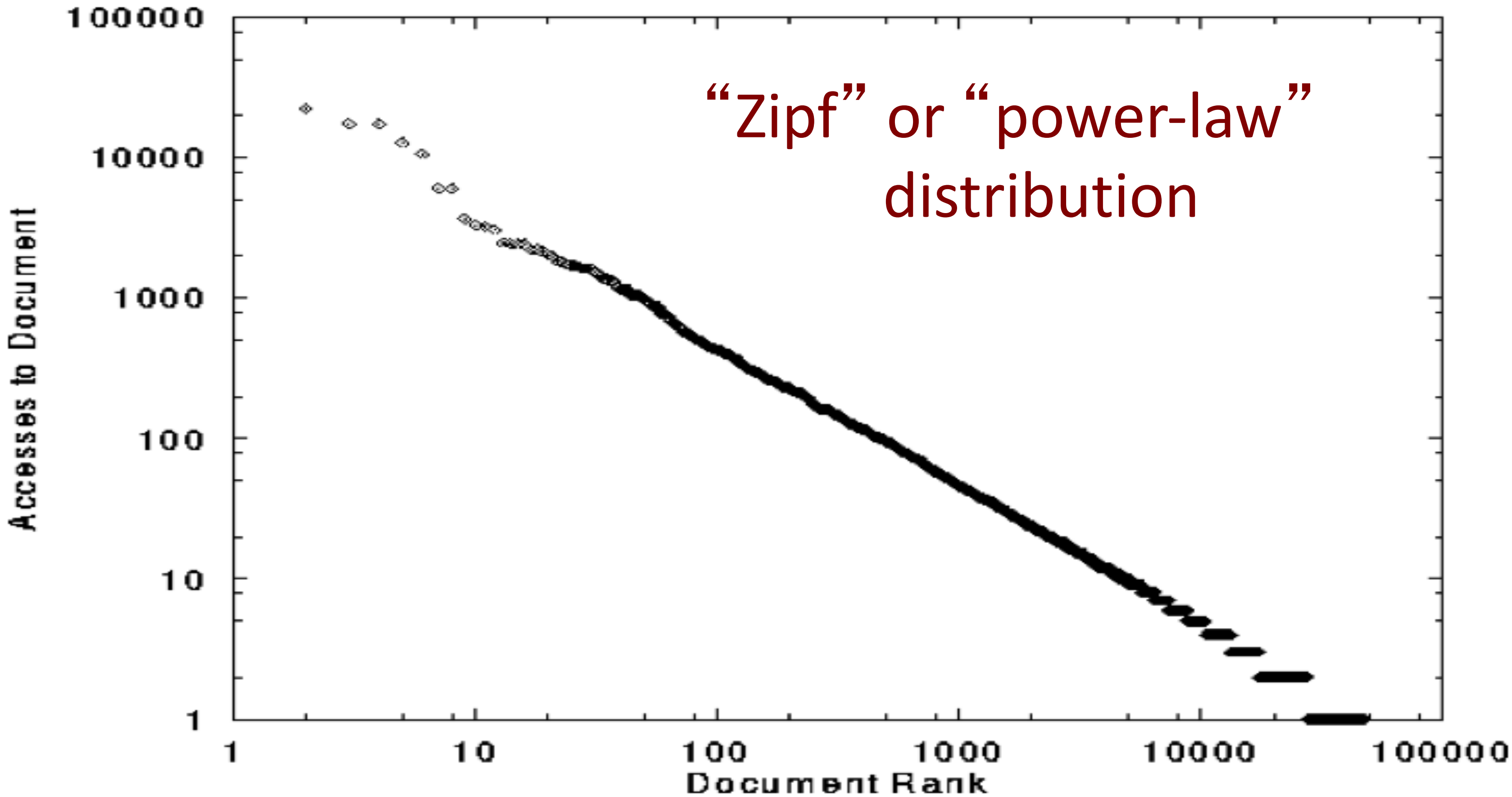
Note: The slides are adapted from the materials from Prof. Richard Han at CU Boulder and Profs. Jennifer Rexford and Mike Freedman at Princeton University, and the networking book (Computer Networking: A Top Down Approach) from Kurose and Ross.

Single Server, Poor Performance



- Single server
  - Single point of failure
  - Easily overloaded
  - Far from most clients
- Popular content
  - Popular site
  - “Flash crowd” (aka “Slashdot effect”)
  - Denial of Service attack

Skewed Popularity of Web Traffic

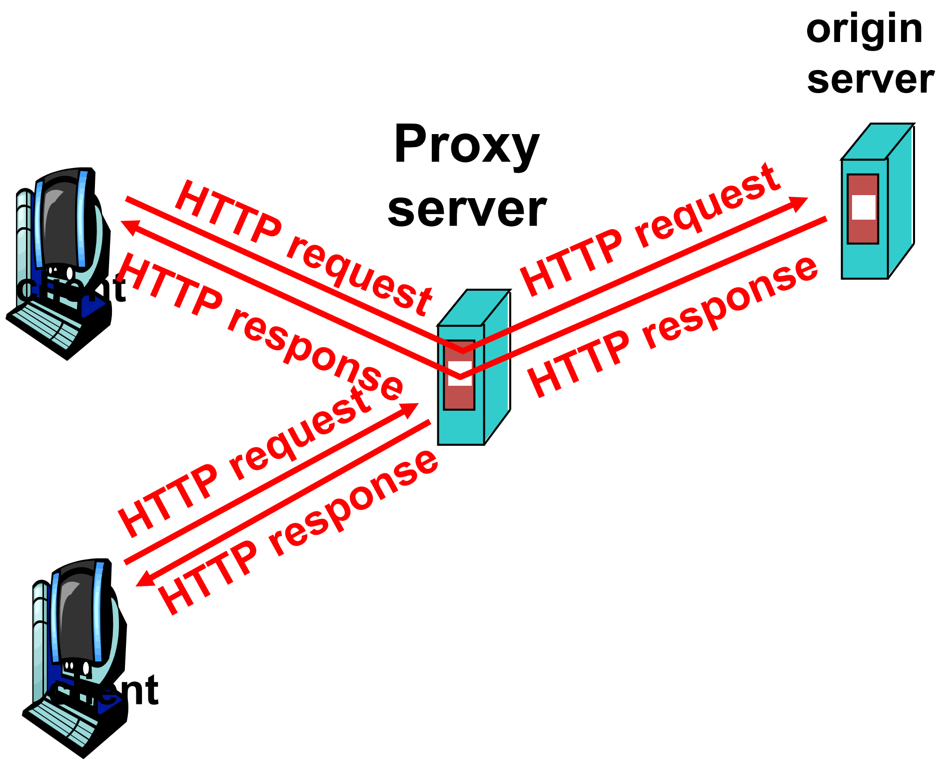


Characteristics of WWW Client-based Traces

Carlos R. Cunha, Azer Bestavros, Mark E. Crovella, BU-CS-95-01

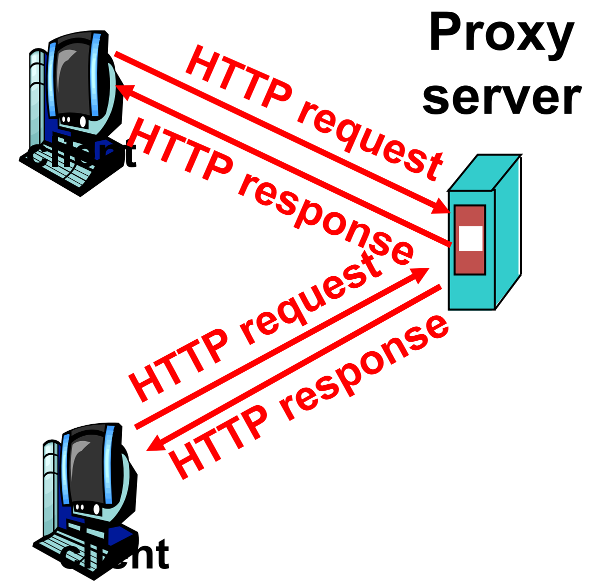
Web Caching

Proxy Caches



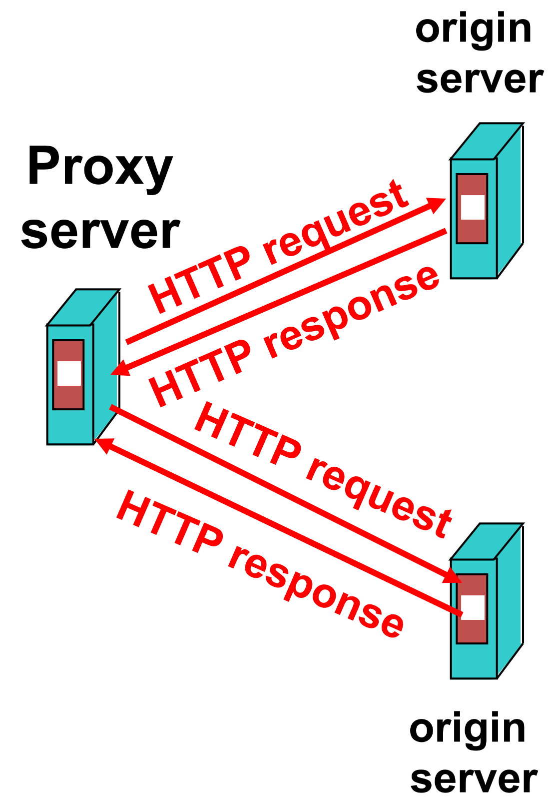
Forward Proxy

- Cache "close" to the client
  - Under administrative control of client-side AS
- Explicit proxy
  - Requires configuring browser
- Implicit proxy
  - Service provider deploys an "on path" proxy
  - … that intercepts and handles Web requests

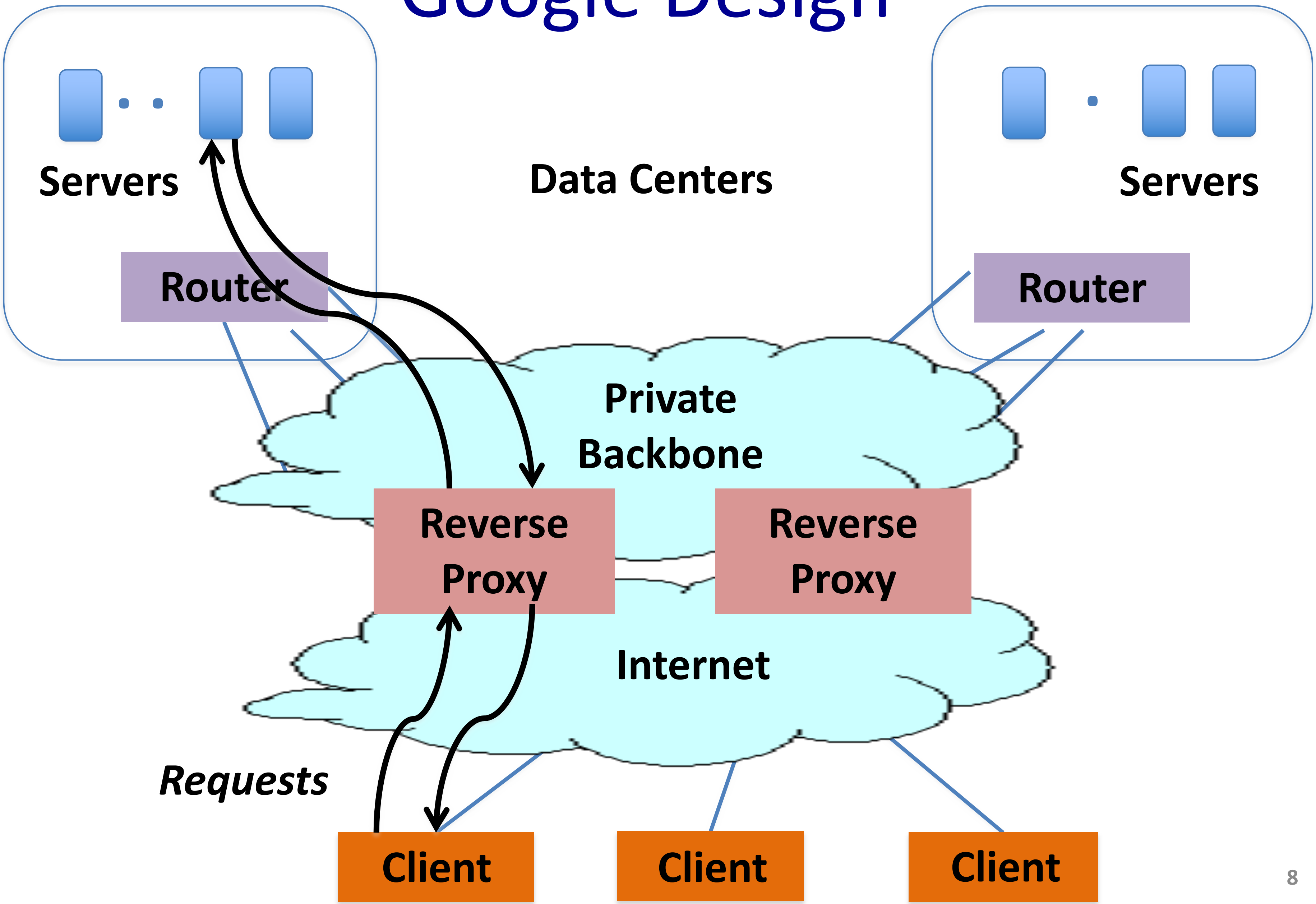


Reverse Proxy

- Cache "close" to server
  - Either by proxy run by server or in third-party content distribution network (CDN)
- Directing clients to the proxy
  - Map the site name to the IP address of the proxy



Google Design



Proxy Caches

(A) Forward (B) Reverse (C) Both (D) Neither

- Reactively replicates popular content
- Reduces origin server costs
- Reduces client ISP costs
- Intelligent load balancing between origin servers
- Offload form submissions (POSTs) and user auth
- Content reassembly, transcoding on behalf of origin
- Smaller round-trip times to clients
- Maintain persistent connections to avoid TCP setup delay (handshake, slow start)

Proxy Caches

(A) Forward (B) Reverse (C) Both (D) Neither

- Reactively replicates popular content (C)
- Reduces origin server costs (C)
- Reduces client ISP costs (A)
- Intelligent load balancing between origin servers (B)
- Offload form submissions (POSTs) and user auth (D)
- Content reassembly or transcoding on behalf of origin (C)
- Smaller round-trip times to clients (C)
- Maintain persistent connections to avoid TCP setup delay (handshake, slow start) (C)

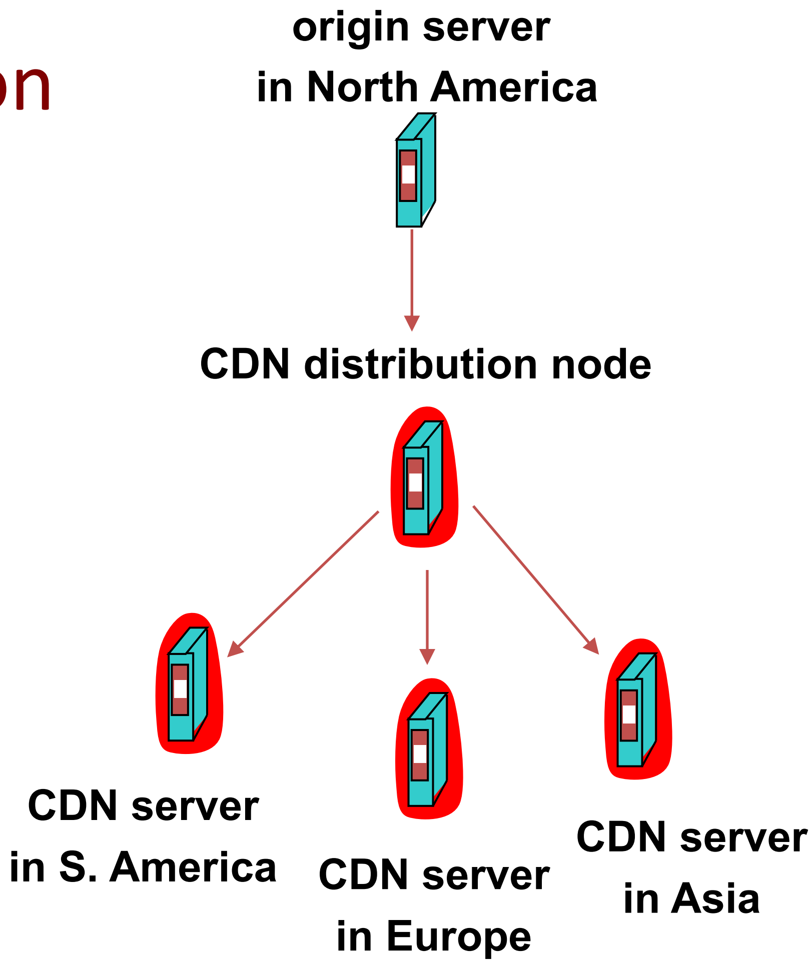
Limitations of Web Caching

- Much content is not cacheable
  - Dynamic data: stock prices, scores, web cams
  - CGI scripts: results depend on parameters
  - Cookies: results may depend on passed data
  - SSL: encrypted data is not cacheable
  - Analytics: owner wants to measure hits
- Stale data
  - Or, overhead of refreshing the cached data

Content Distribution Networks

Content Distribution Network

- Proactive content replication
  - Content provider (e.g., CNN) 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



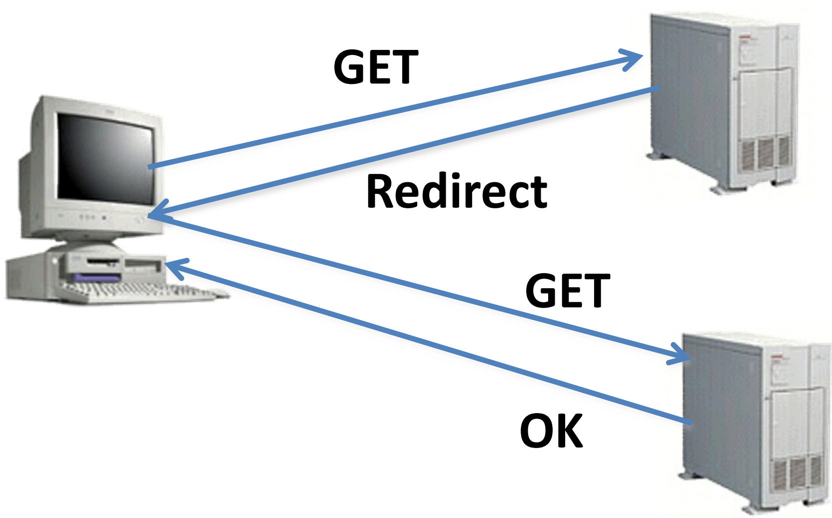
Server Selection Policy

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

Requires continuous monitoring of liveness, load, and performance

Server Selection Mechanism

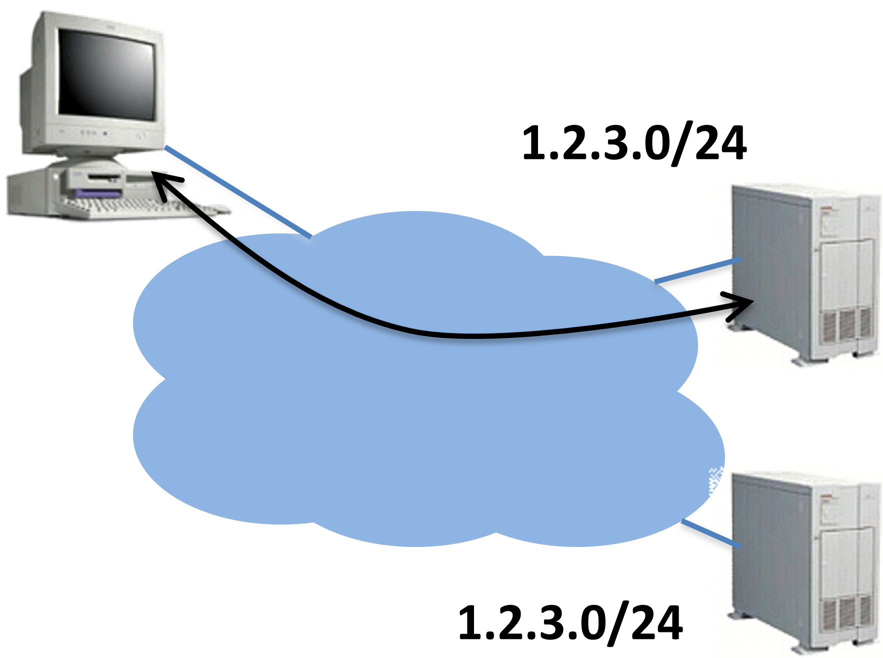
- Application
  - HTTP redirection



- 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

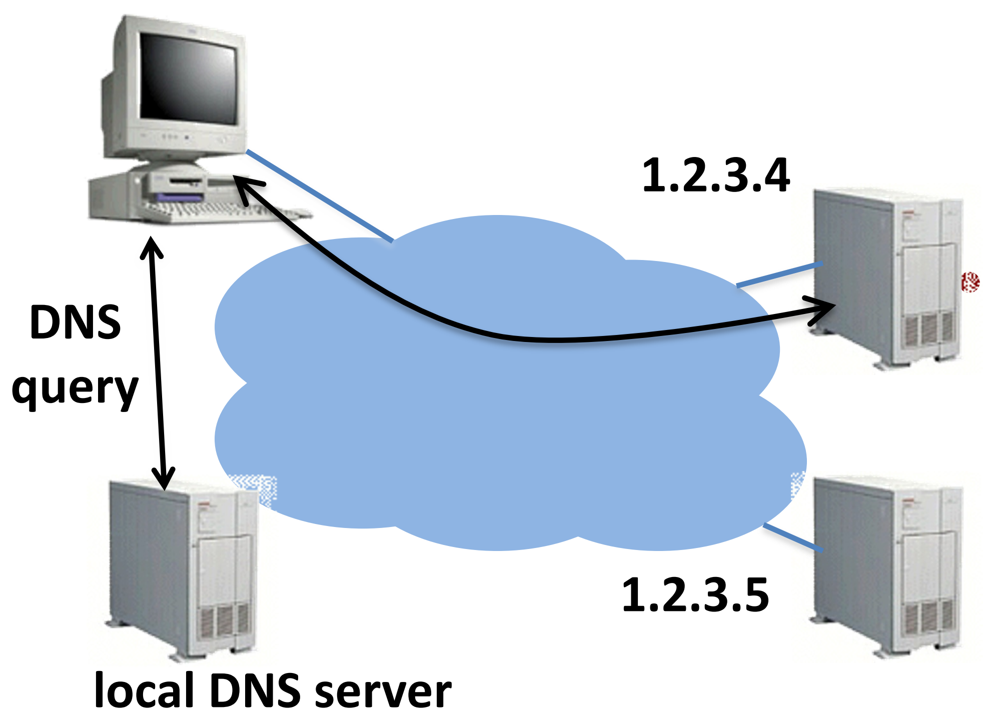
- Routing
  - Anycast routing



- 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



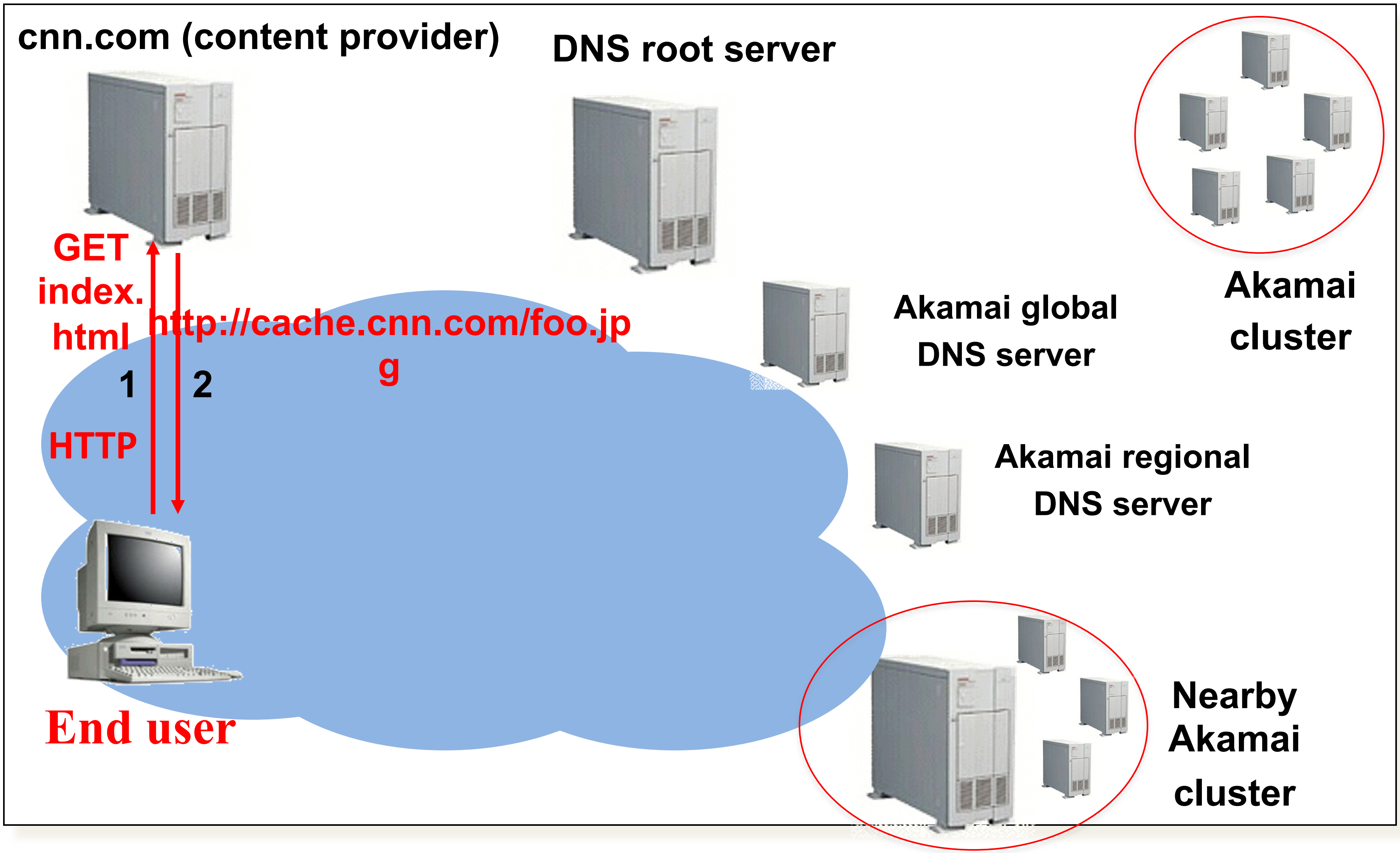
- Advantages
  - Avoid TCP set-up delay
  - DNS caching reduces overhead
  - Relatively fine control
- Disadvantage
  - Based on IP address of local DNS server
  - "Hidden load" effect
  - DNS TTL limits adaptation

How Akamai Works

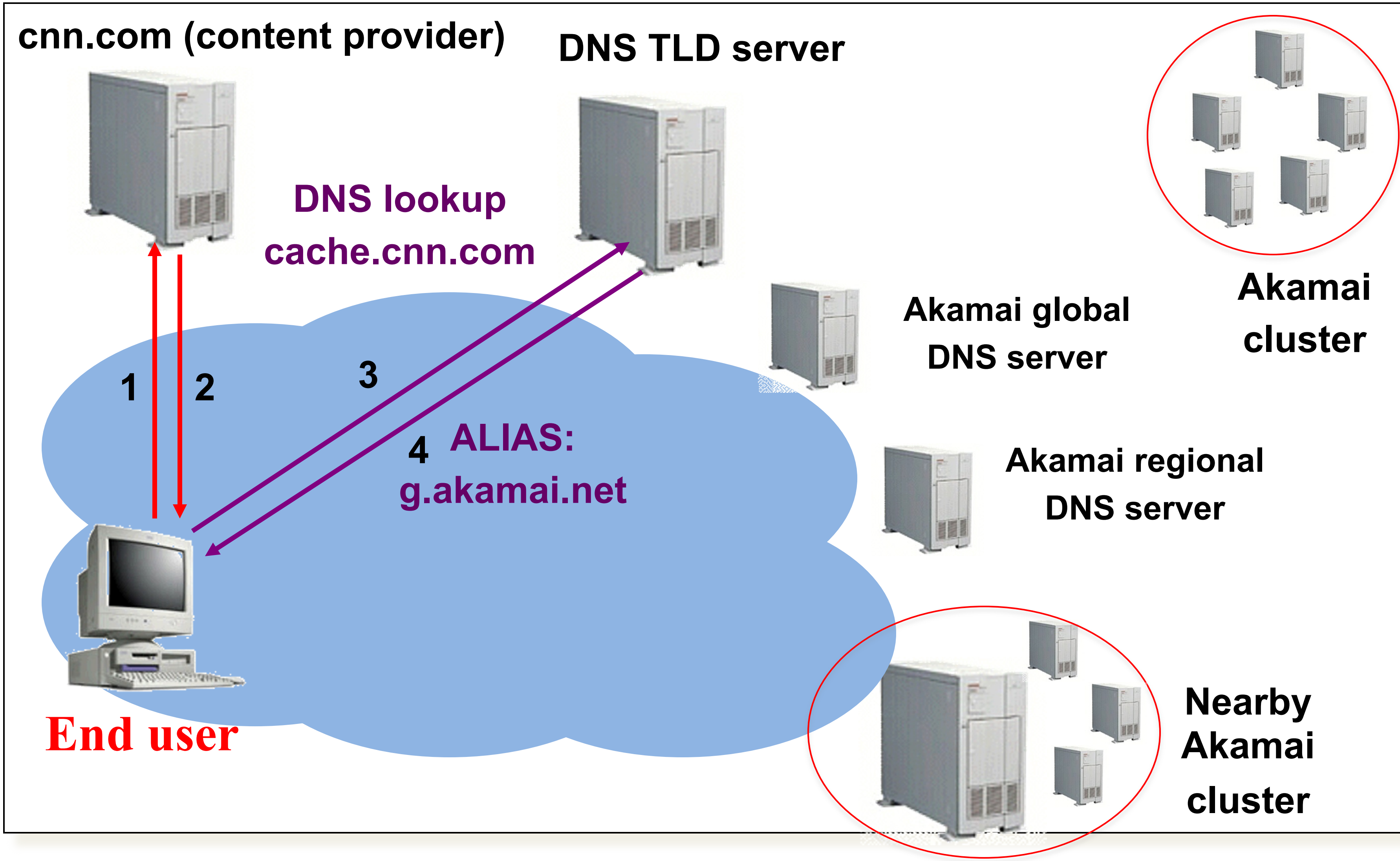
Akamai Statistics

- Distributed servers
  - Servers: ~100,000
  - Networks: ~1,000
  - Countries: ~70
- Many 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

How Akamai Uses DNS



How Akamai Uses DNS



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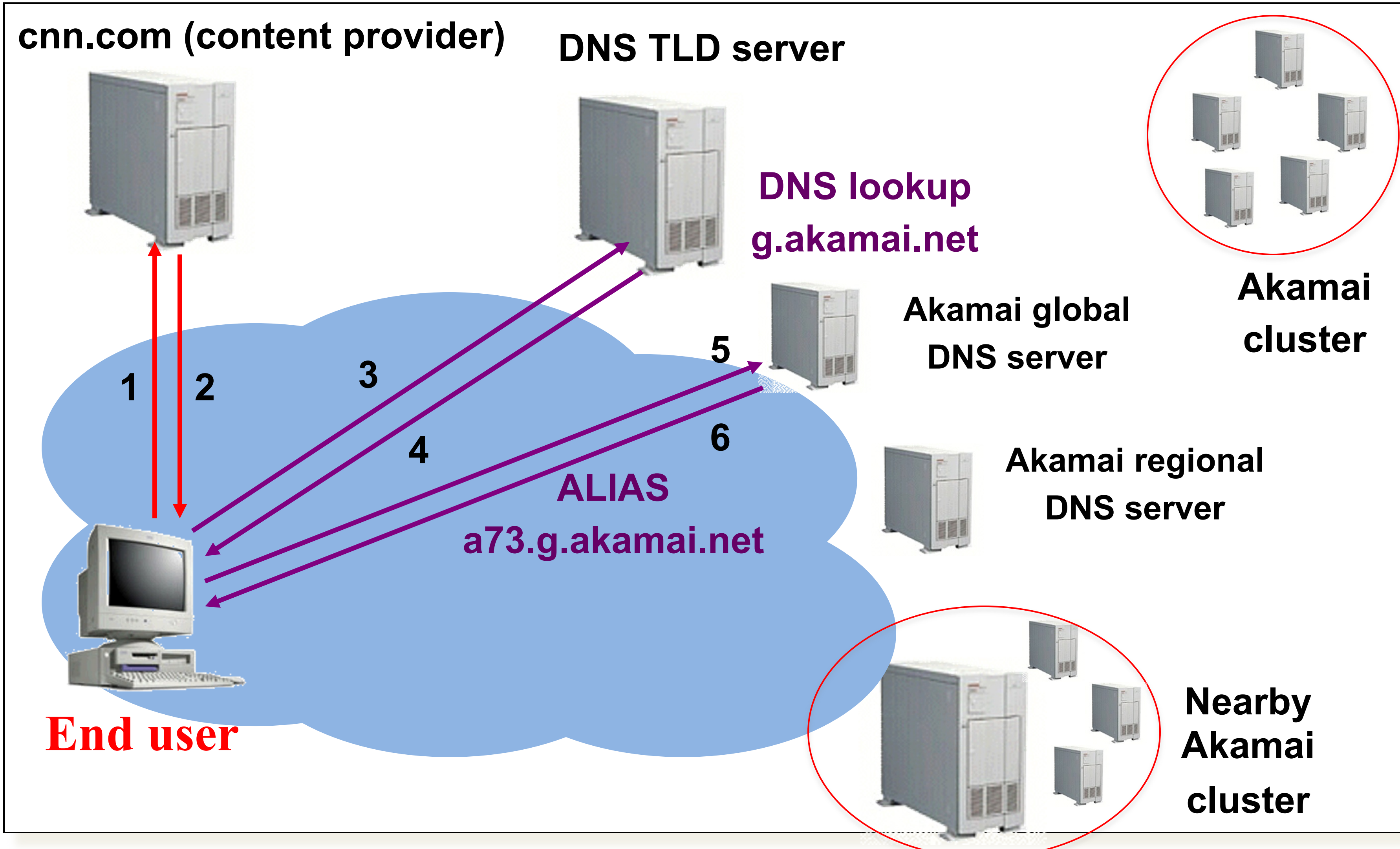
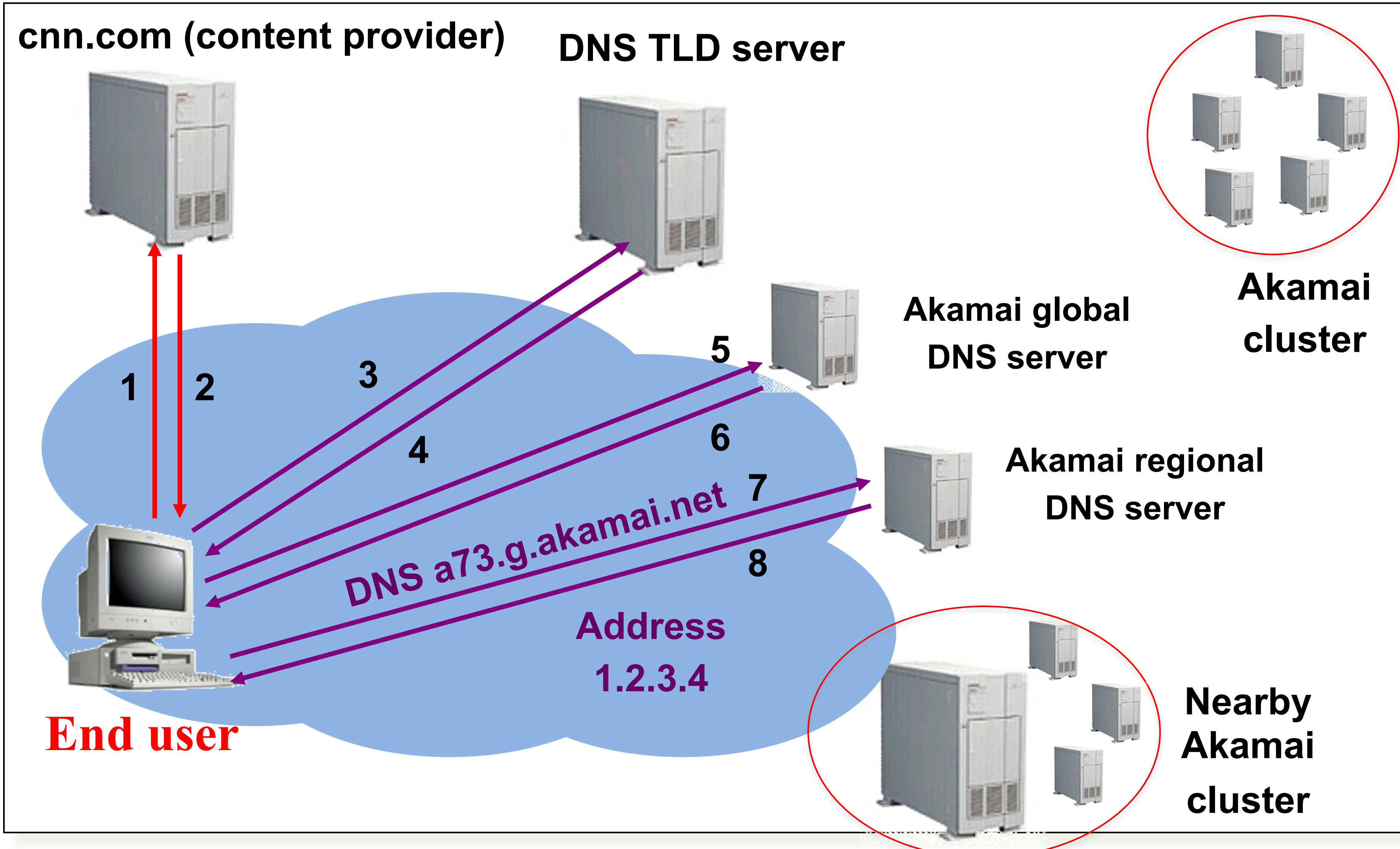


How Akamai Uses DNS



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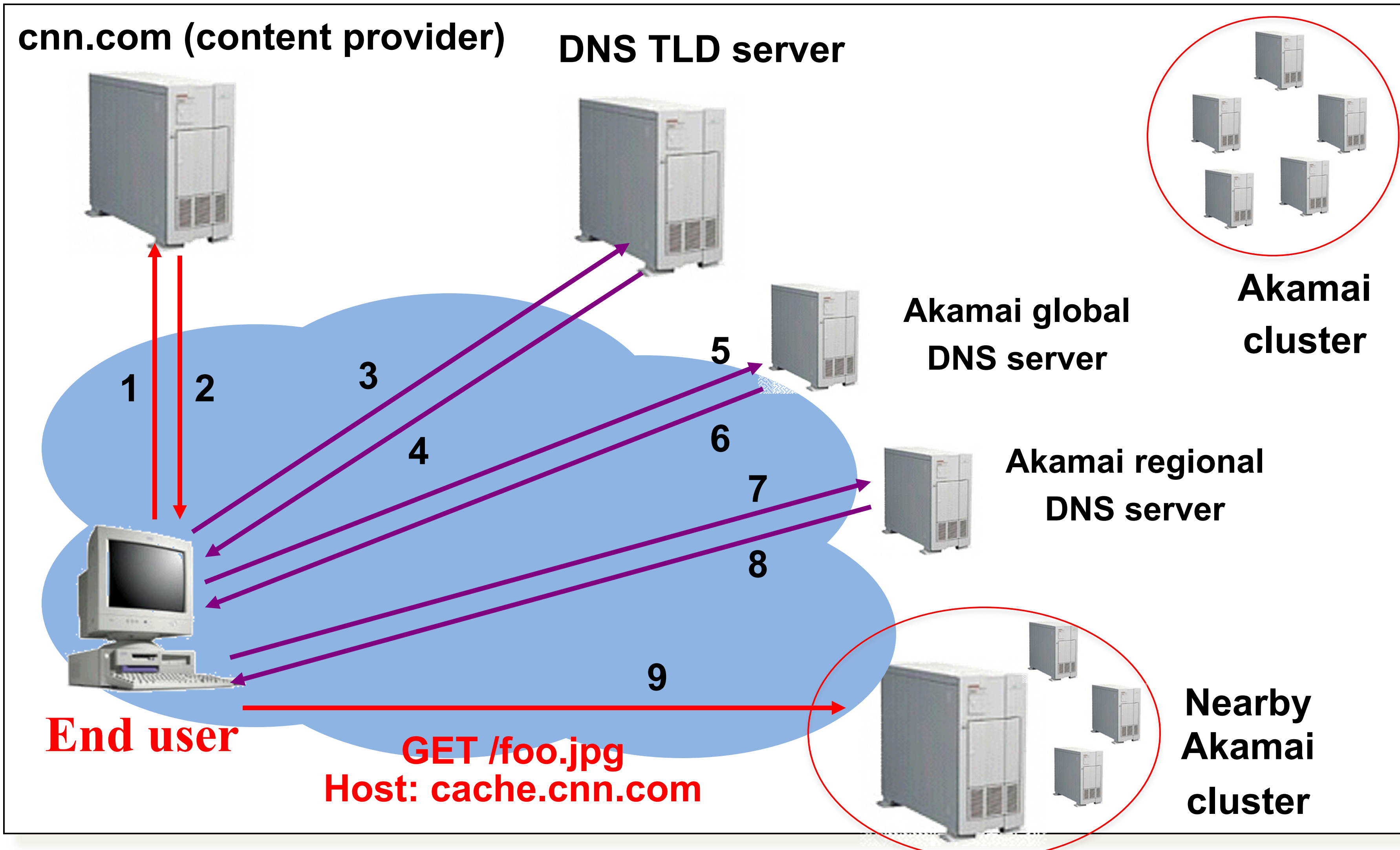
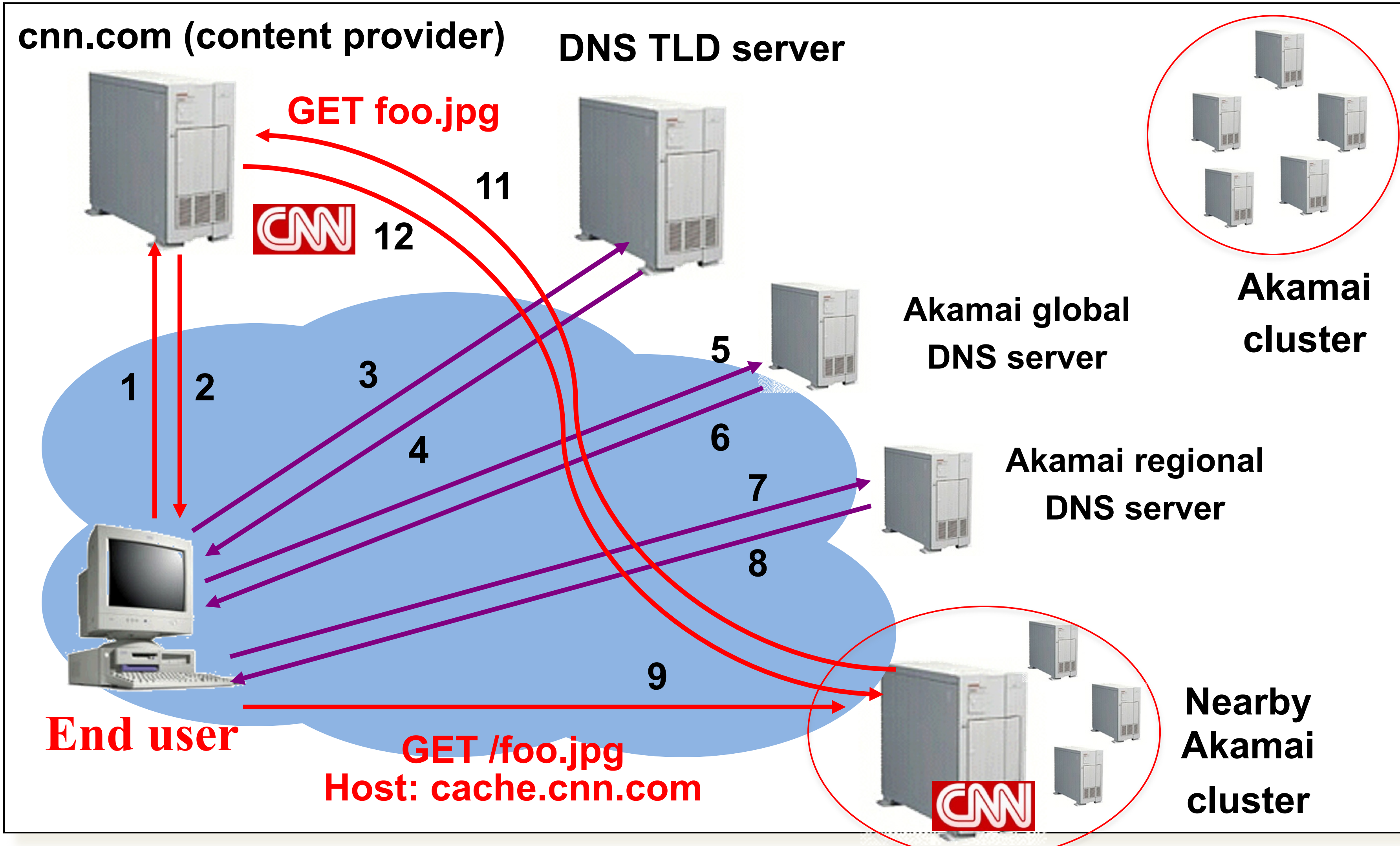
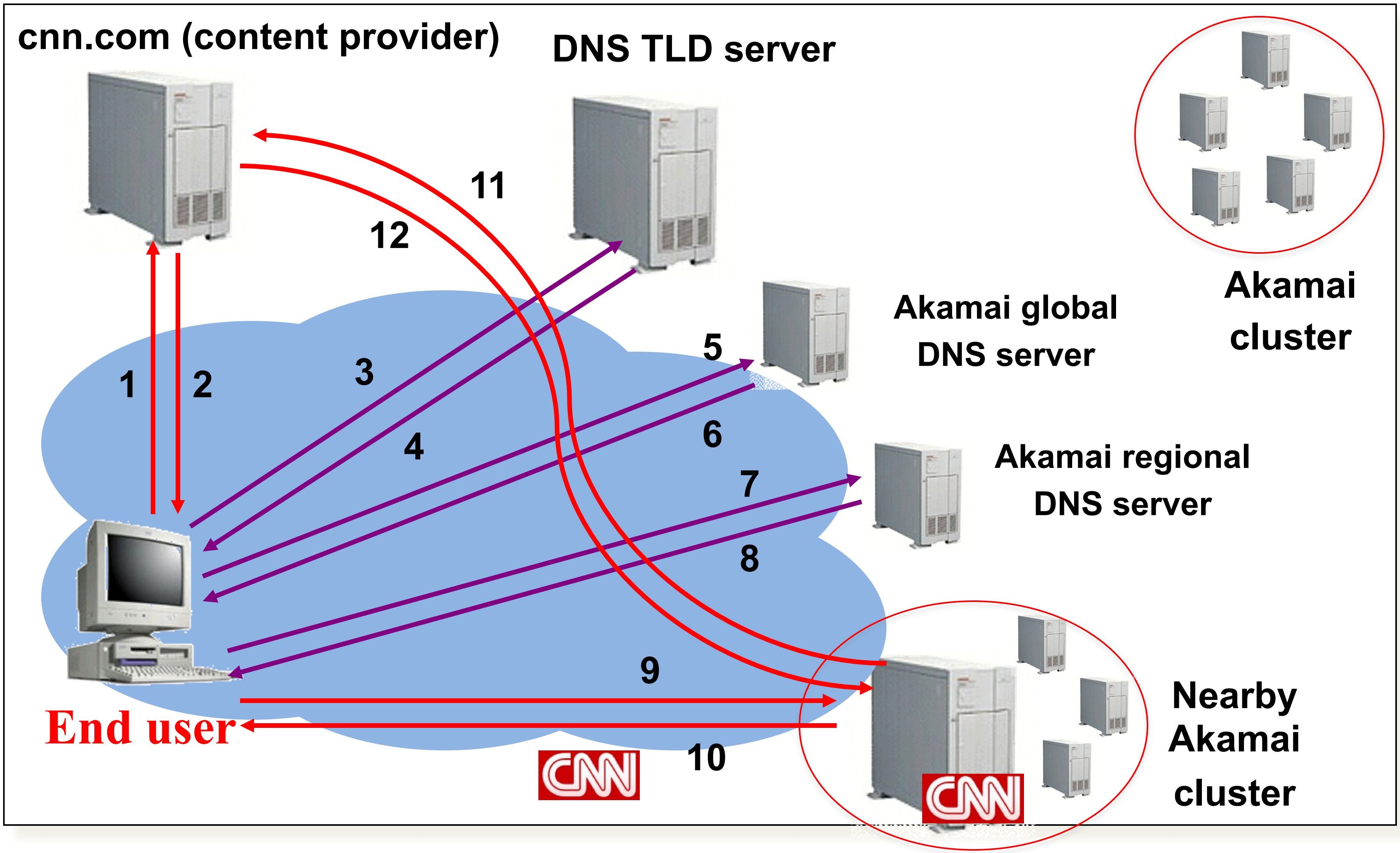


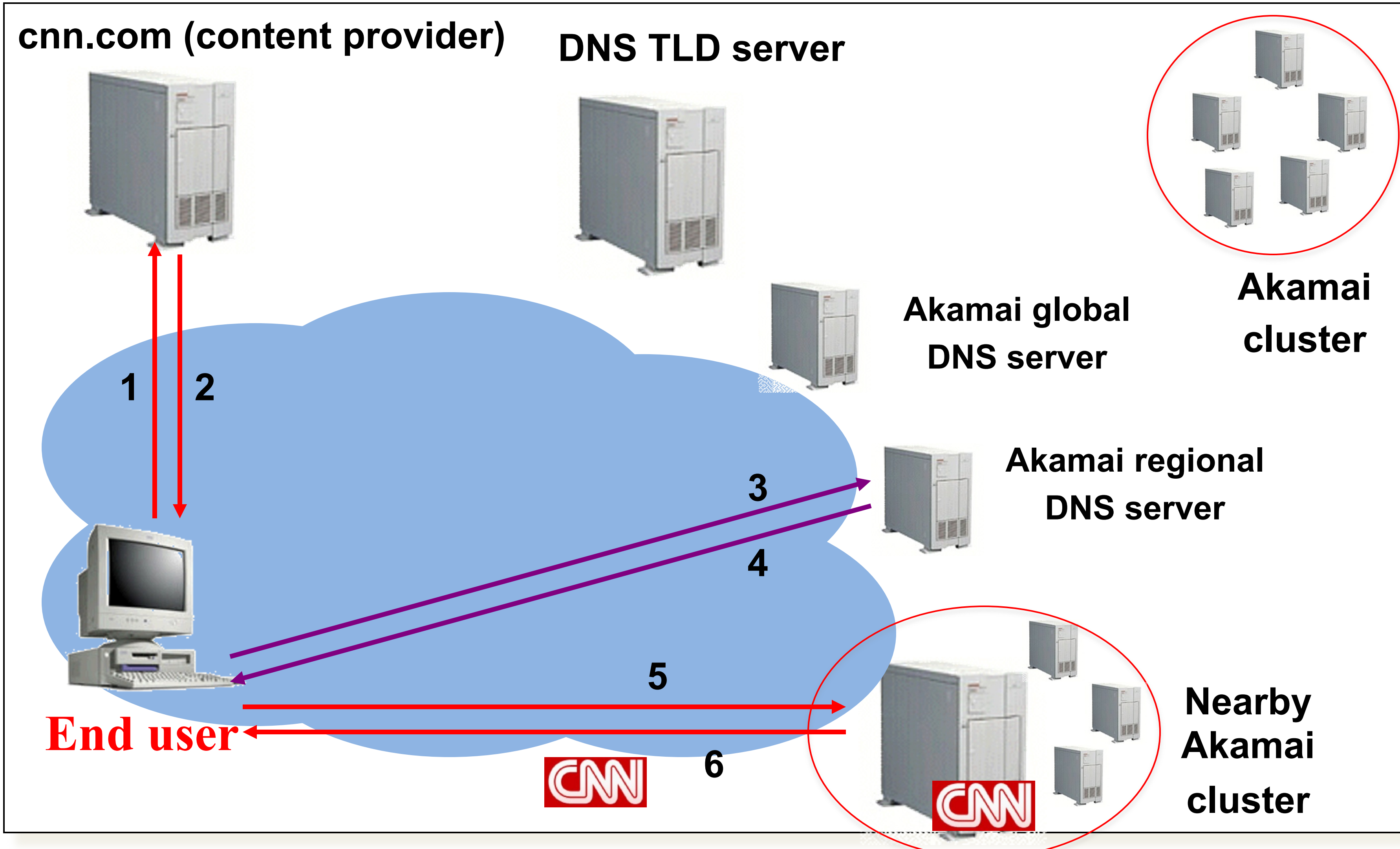
How Akamai Uses DNS



How Akamai Uses DNS



How Akamai Works: Cache Hit



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
    - E.g., over 100 TB of logs per days
  - Network latency, loss, and connectivity

Mapping System

- 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 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
- Failed cluster
  - High-level map updated quickly
- Failed path to customer's origin server
  - Route packets through an intermediate node

Akamai Transport Optimizations

- Bad Internet routes
  - Overlay routing through an intermediate server
- Packet loss
  - Sending redundant data over multiple paths
- TCP connection set-up/teardown
  - Pools of persistent connections
- TCP congestion window and round-trip time
  - Estimates based on network latency measurements

Akamai Application Optimizations

- Slow download of embedded objects
  - Prefetch when HTML page is requested
- Large objects
  - Content compression
- Slow applications
  - Moving applications to edge servers
  - E.g., content aggregation and transformation
  - E.g., static databases (e.g., product catalogs)

Modern HTTP Video-on-Demand

- Download "content manifest" from origin server
- List of video segments belonging to video
  - Each segment 1-2 seconds in length
  - Client can know time offset associated with each
  - Standard naming for different video resolutions and formats: e.g., 320dpi, 720dpi, 1040dpi, …
- Client downloads video segment (at certain resolution) using standard HTTP request.
  - HTTP request can be satisfied by cache: it's a static object
- Client observes download time vs. segment duration, increases/decreases resolution if appropriate

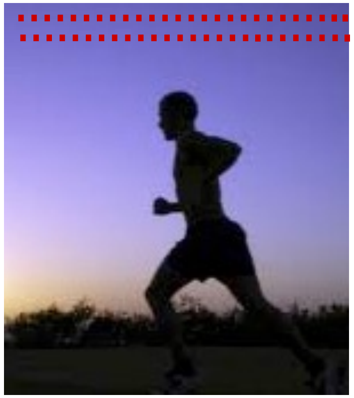
Video Streaming and CDNs: context

- **video traffic: major consumer of Internet bandwidth**
  - **Netflix, YouTube: 37%, 16% of downstream residential ISP traffic**
  - **~1B YouTube users, ~75M Netflix users**
- **challenge: scale - how to reach ~1B users?**
  - **single mega-video server won't work (why?)**
- **challenge: heterogeneity**
  - **different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus bandwidth poor)**
- ***solution:* distributed, application-level infrastructure**

Multimedia: video

- video: sequence of images displayed at constant rate
  - e.g., 24 images/sec
- digital image: array of pixels
  - each pixel represented by bits
- coding: use redundancy *within* and *between* images to decrease # bits used to encode image
  - spatial (within image)
  - temporal (from one image to next)

spatial coding example: **instead of sending *N* values of same color (all purple), send only two values: color value (*purple*) and number of repeated values (N)**



frame *i*

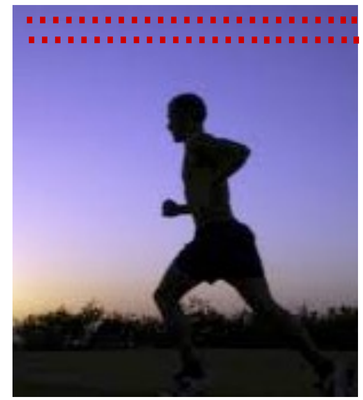
temporal coding example: **instead of sending complete frame at i+1, send only differences from frame i**

frame *i+1*

Multimedia: video

- **CBR: (constant bit rate):** video encoding rate fixed
- **VBR: (variable bit rate):** video encoding rate changes as amount of spatial, temporal coding changes
- **examples:**
  - MPEG 1 (CD-ROM) 1.5 Mbps
  - MPEG2 (DVD) 3-6 Mbps
  - MPEG4 (often used in Internet, < 1 Mbps)

spatial coding example: instead of sending *N* values of same color (all purple), send only two values: color value (*purple*) *and number of repeated values* (N)



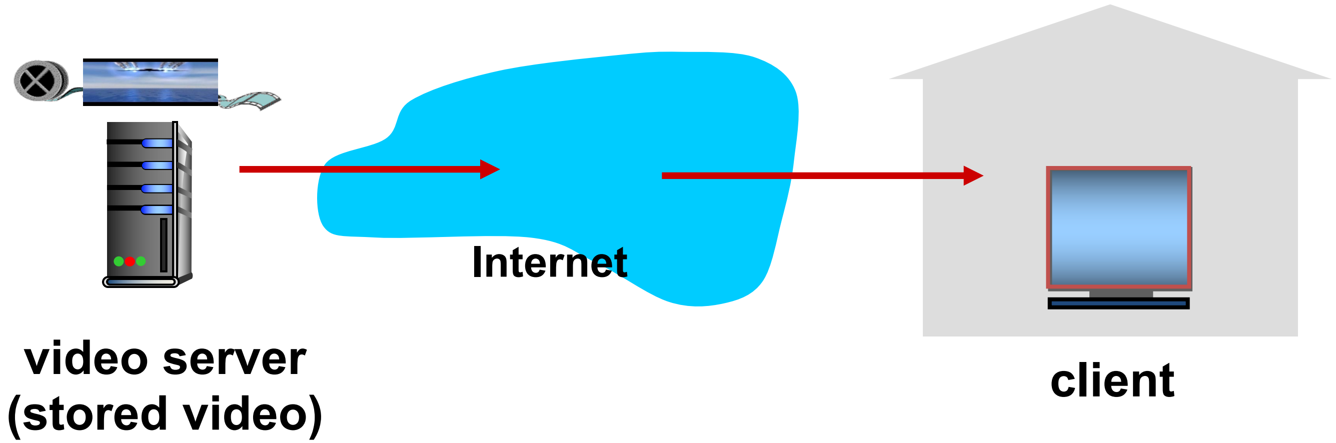
frame *i*

temporal coding example: instead of sending complete frame at i+1, send only differences from frame i

frame *i+1*

Streaming stored video:

simple scenario:



Streaming multimedia: DASH

- *DASH: D*ynamic, *A*daptive *S*treaming over *H*TTP
- *server:*
  - divides video file into multiple chunks
  - each chunk stored, encoded at different rates
  - *manifest file:* provides URLs for different chunks
- *client:*
  - periodically measures server-to-client bandwidth
  - consulting manifest, requests one chunk at a time
    - chooses maximum coding rate sustainable given current bandwidth
    - can choose different coding rates at different points in time (depending on available bandwidth at time)

Streaming multimedia: DASH

- *DASH: Dynamic, Adaptive Streaming over HTTP*
- "*intelligence*" at client: client determines
  - *when* to request chunk (so that buffer starvation, or overflow does not occur)
  - *what encoding rate* to request (higher quality when more bandwidth available)
  - *where* to request chunk (can request from URL server that is "close" to client or has high available bandwidth)

Content distribution networks

- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of *simultaneous* users?
- *option 1:* single, large "mega-server"
  - single point of failure
  - point of network congestion
  - long path to distant clients
  - multiple copies of video sent over outgoing link

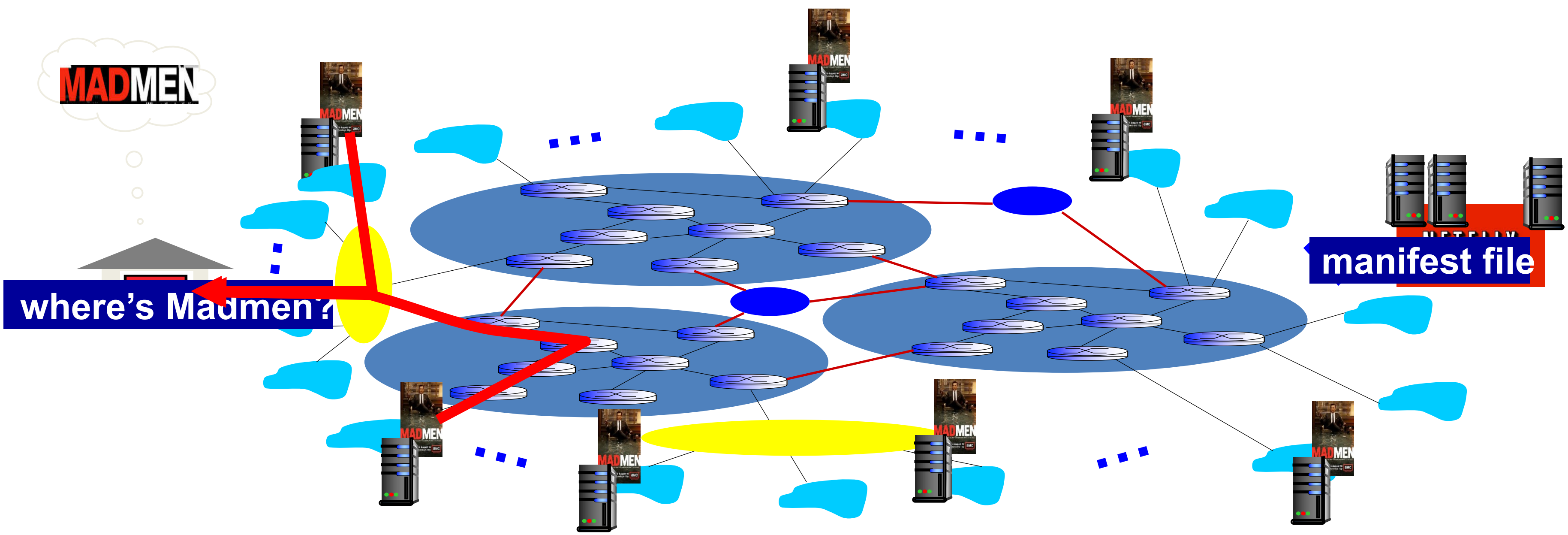
….quite simply: this solution *doesn't scale*

Content distribution networks

- *challenge:* how to stream content (selected from millions of videos) to hundreds of thousands of simultaneous users?
- *option 2:* store/serve multiple copies of videos at multiple geographically distributed sites *(CDN)*
  - *enter deep:* push CDN servers deep into many access networks
    - close to users
    - used by Akamai, 1700 locations
  - *bring home:* smaller number (10's) of larger clusters in POPs near (but not within) access networks
    - used by Limelight

Content Distribution Networks (CDNs)

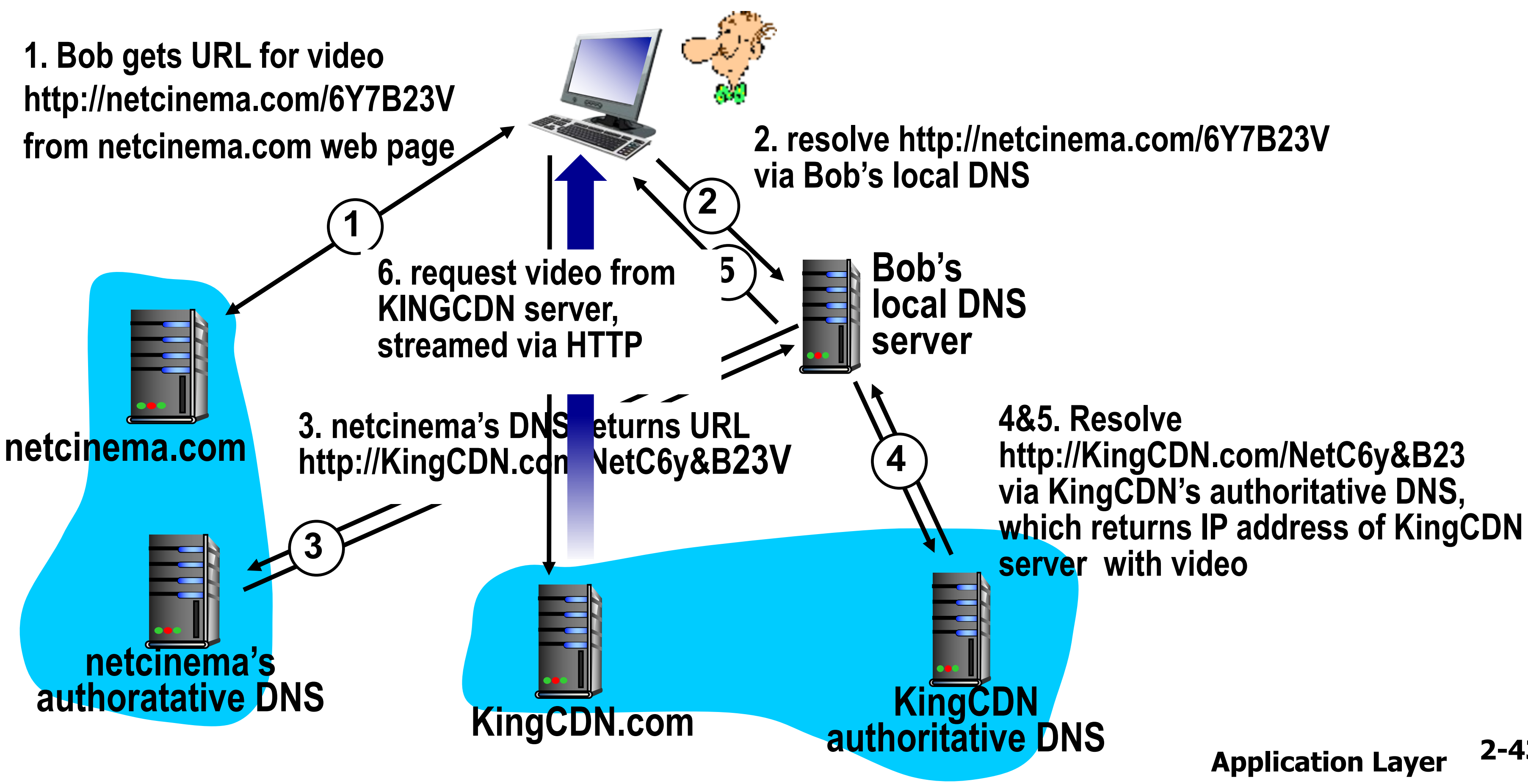
- **CDN: stores copies of content at CDN nodes**
  - **e.g. Netflix stores copies of MadMen**
- subscriber requests content from CDN
  - **directed to nearby copy, retrieves content**
  - **may choose different copy if network path congested**



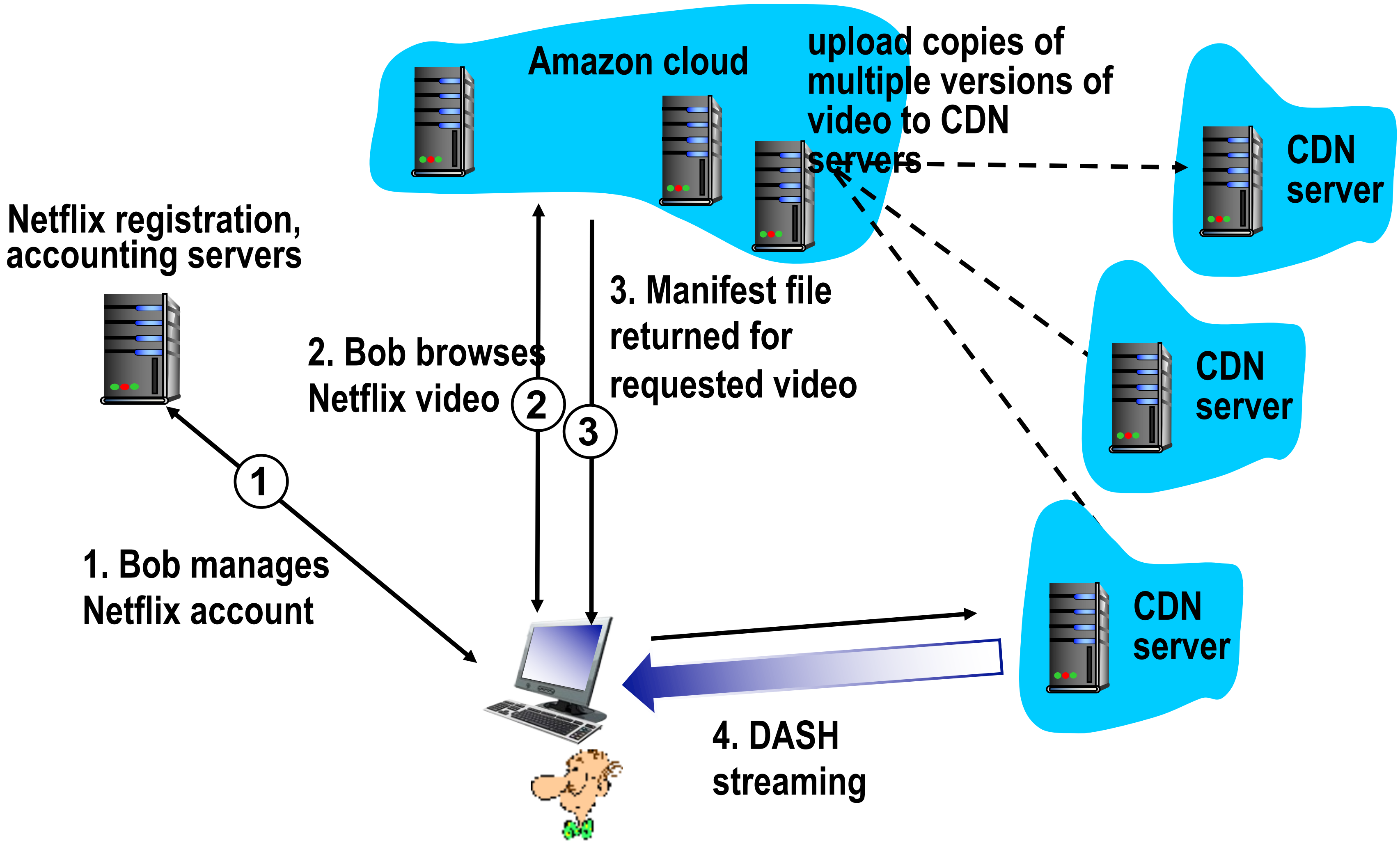
CDN content access: a closer look

Bob (client) requests video http://netcinema.com/6Y7B23V

- **video stored in CDN at http://KingCDN.com/NetC6y&B23V**



Case study: Netflix



Conclusion

- Content distribution is hard
  - Many, diverse, changing objects
  - Clients distributed all over the world
  - Reducing latency is king
- Contribution distribution solutions
  - Reactive caching
  - Proactive content distribution networks