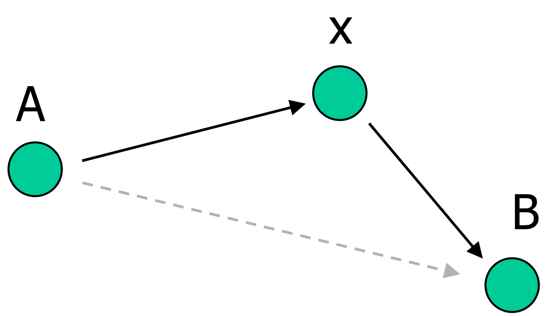
Indirection

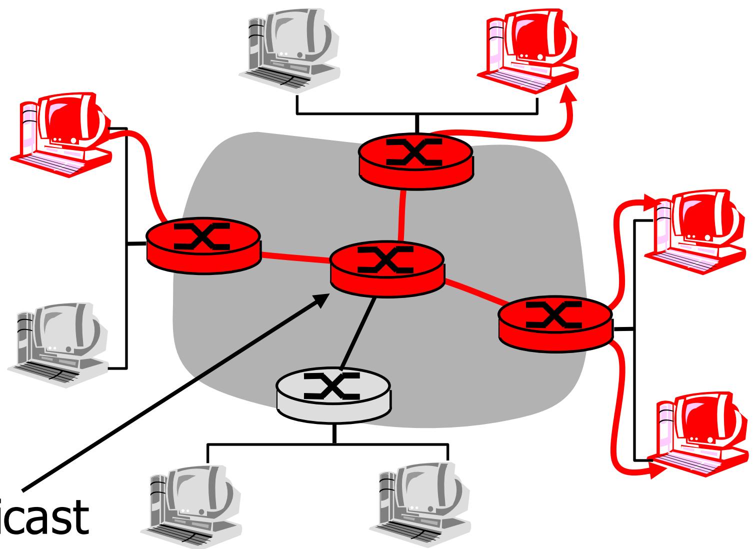
Indirection: rather than reference an entity directly, reference it ("indirectly") via another entity, which in turn can or will access the original entity



"Every problem in computer science can be solved by adding another level of indirection"
-- Butler Lampson

Multicast: One sender to many receivers

- Multicast: Act of sending datagram to multiple receivers with single “transmit” operation
  - Analogy: One teacher to many students
- Question: How to achieve multicast

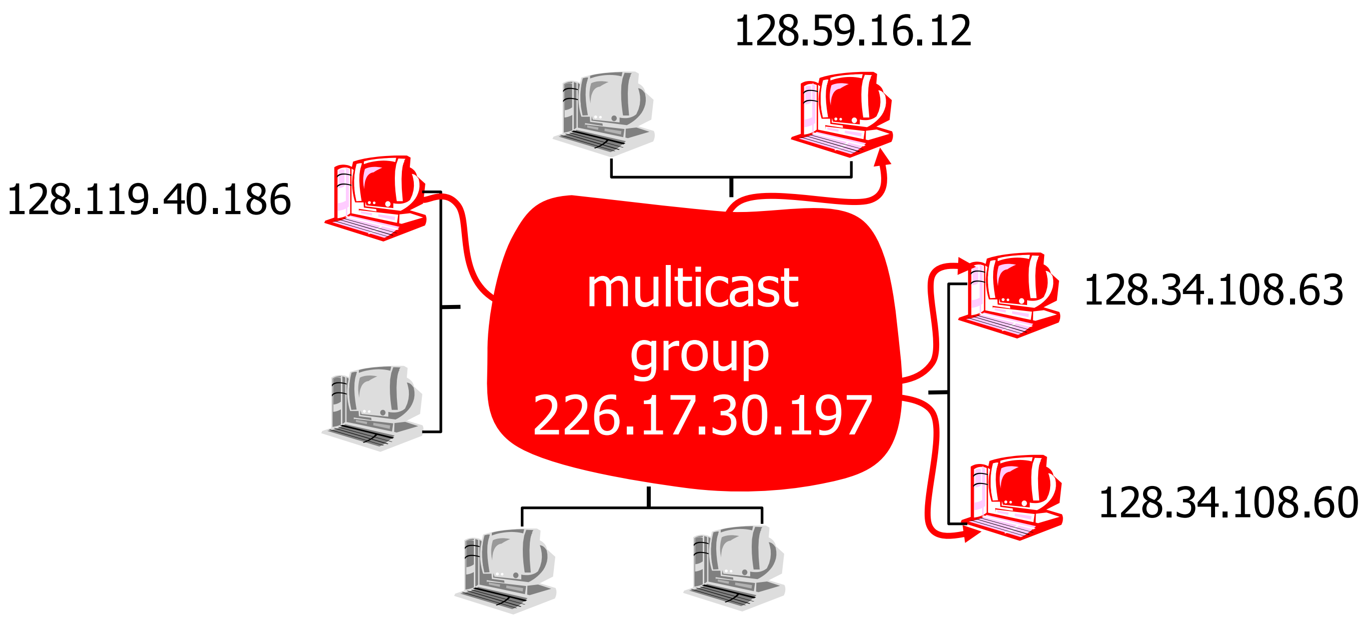


Multicast routers (red) duplicate and forward multicast datagrams

Network multicast

- Router actively participate in multicast, making copies of packets as needed and forwarding towards multicast receivers

Internet Multicast Service Model

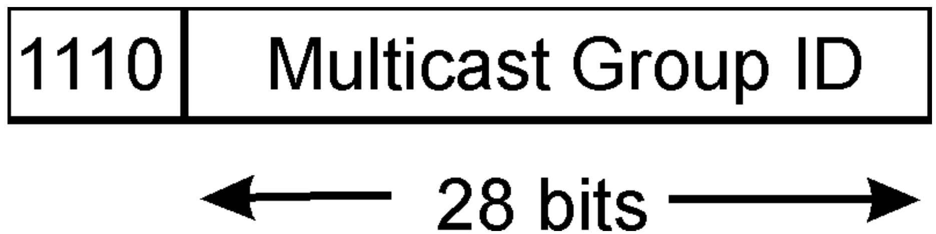


multicast group concept: use of indirection

- hosts addresses IP datagram to multicast group
- routers forward multicast datagrams to hosts that have "joined" that multicast group

Multicast groups

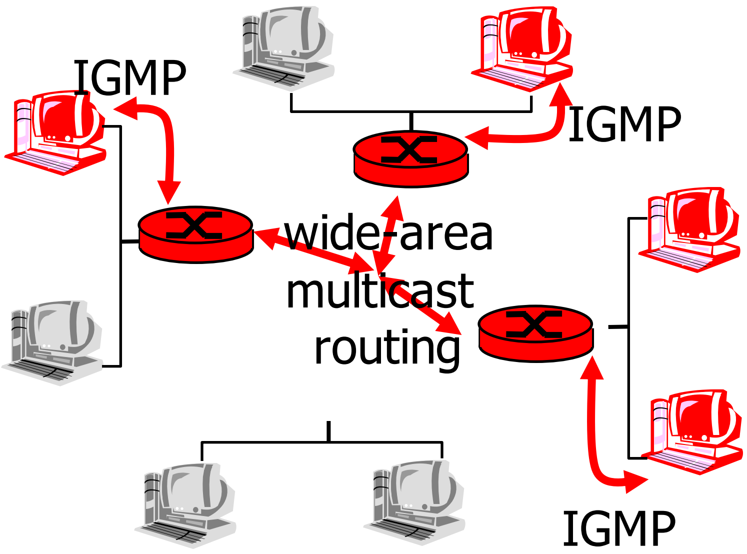
- Class D Internet addresses reserved for multicast:



- Host group semantics:
  - anyone can "join" (receive) multicast group
  - anyone can send to multicast group
  - no network-layer identification to hosts of members
- *Needed:* Infrastructure to deliver mcast-addressed datagrams to all hosts that have joined that multicast group

Joining a mcast group: Two-step process

- *Local:* Host informs local mcast router of desire to join group: IGMP (Internet Group Management Protocol)
- *Wide area:* Local router interacts with other routers to receive mcast datagram flow
  - many protocols (e.g., DVMRP, MOSPF, PIM)



Multicast via Indirection: Why?

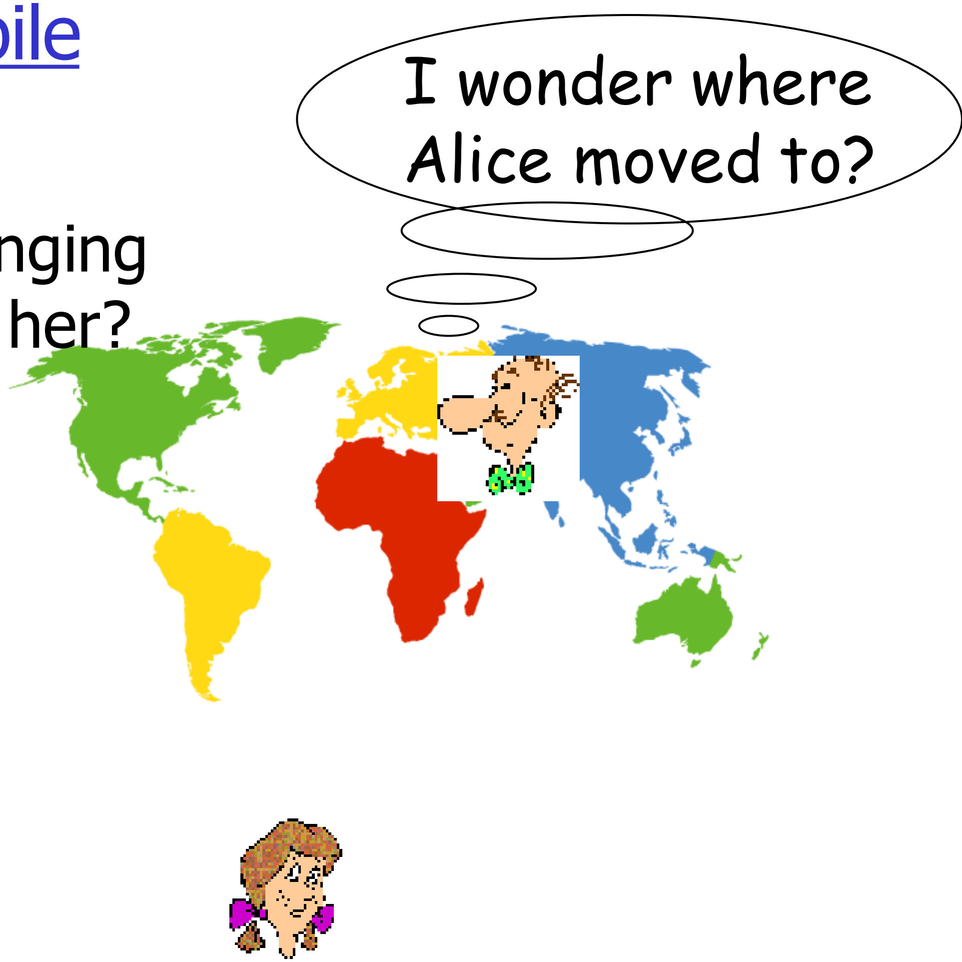
- Don't need to individually address each member in the group: header savings
- Looks like unicast; application interface is simple, single group
- Abstraction, delegating works of implementation to the routers
- More scalable because, sender doesn't manage the group, as receivers are added, new receivers must do the work to add themselves

Mobility and Indirection

How do *you* contact a mobile friend?

Consider friend frequently changing addresses, how do you find her?

- Search all phone books?
- Call her parents?
- Expect her to let you know where he/she is?



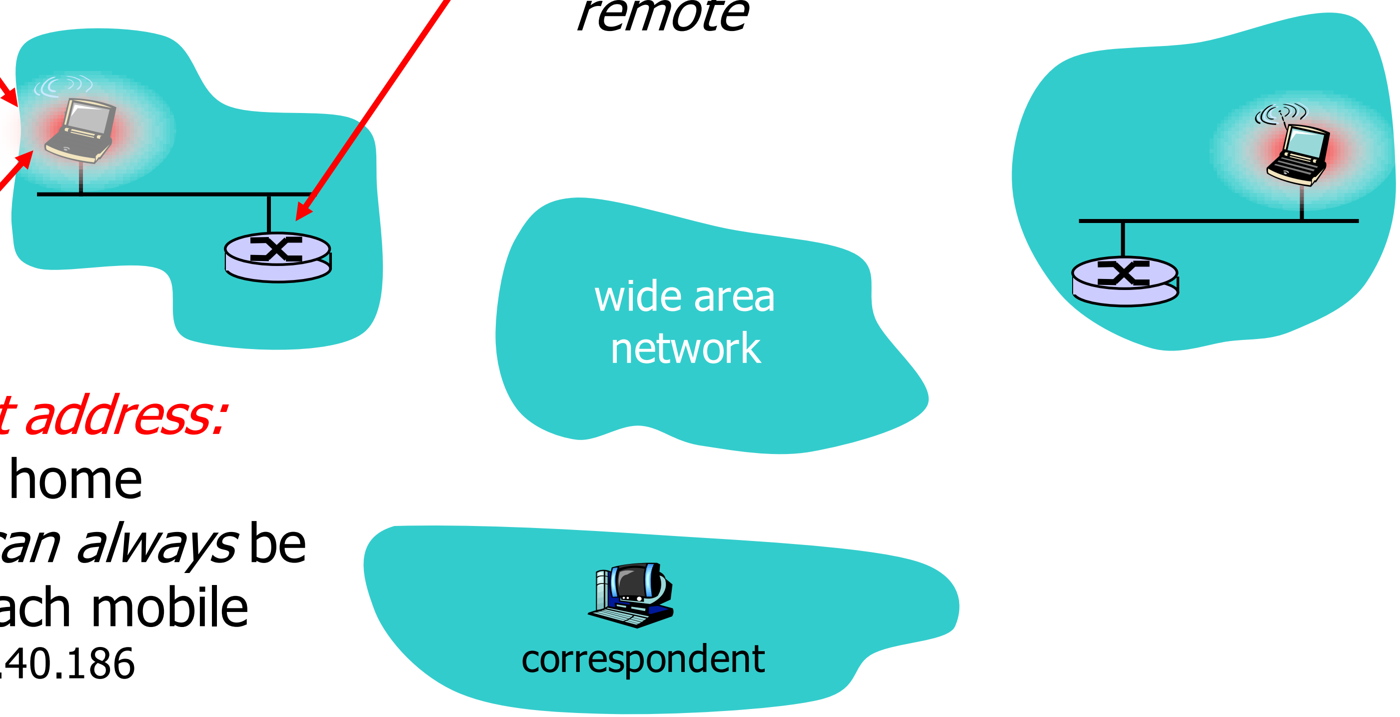
Mobility and indirection:

- Mobile node moves from network to network
- Correspondents want to send packets to mobile node
- Two approaches:
  - *Indirect routing:* Communication from correspondent to mobile goes through home agent, then forwarded to remote
  - *Direct routing:* Correspondent gets foreign address of mobile, sends directly to mobile

Mobility: Vocabulary

Home network: permanent "home" of mobile
(e.g., 128.119.40/24)

Home agent: entity that will perform mobility functions on behalf of mobile, when mobile is remote



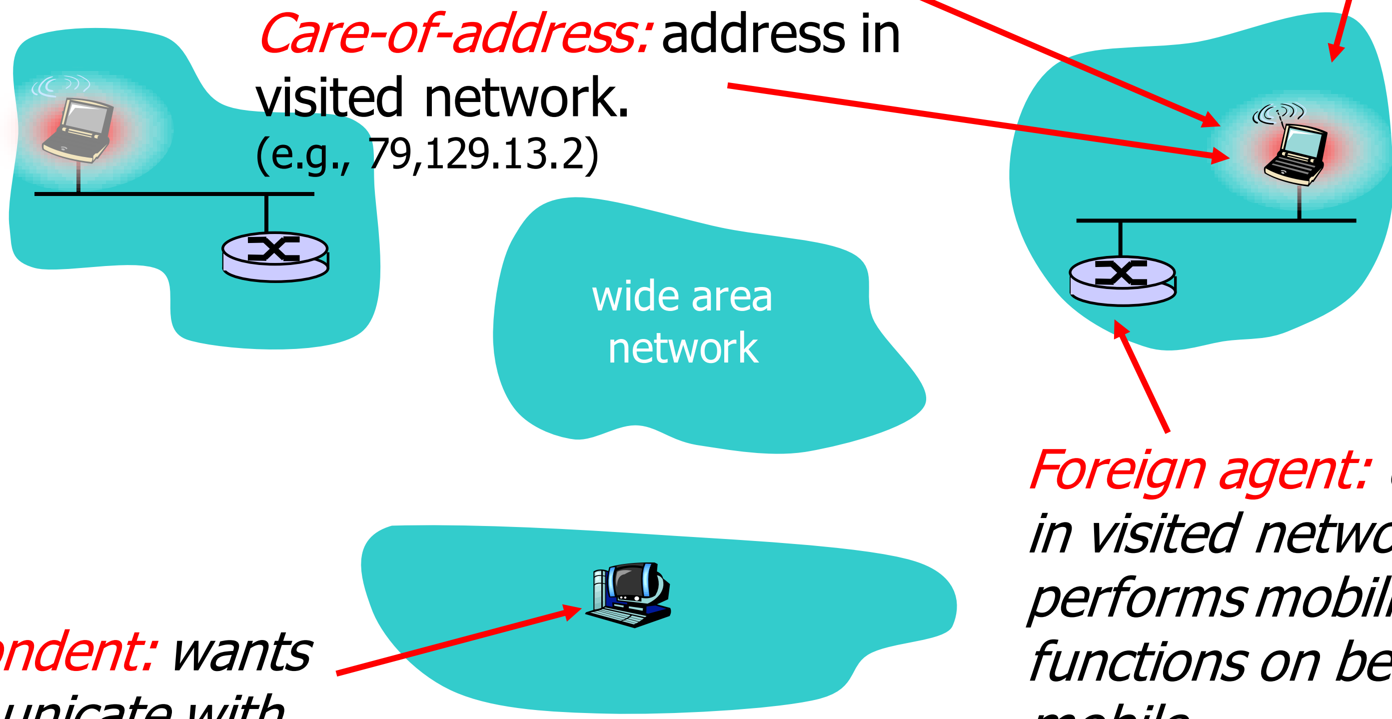
Permanent address: address in home network, *can always* be used to reach mobile
e.g., 128.119.40.186

Mobility: more vocabulary

Permanent address: remains constant (e.g., 128.119.40.186)

Visited network: network in which mobile currently resides (e.g., 79.129.13/24)

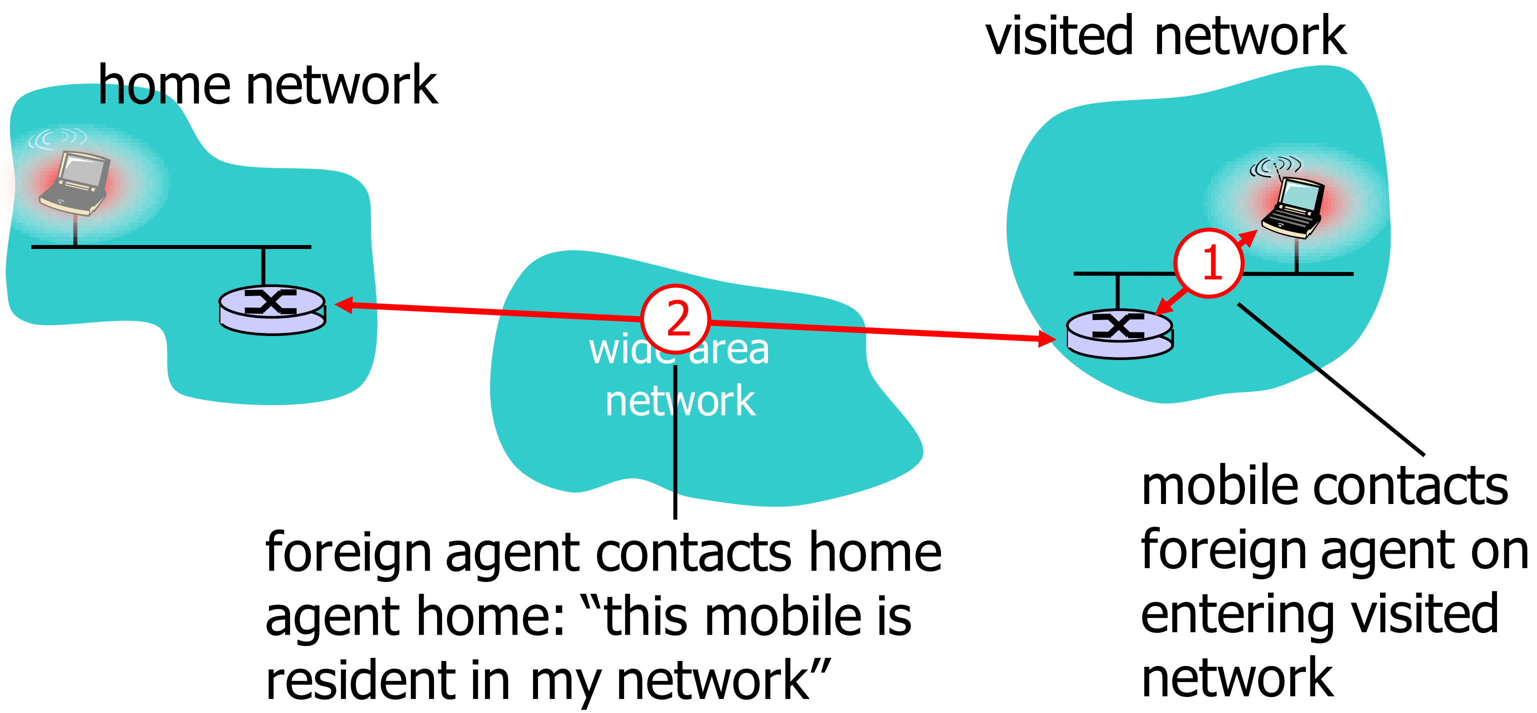
Care-of-address: address in visited network. (e.g., 79,129.13.2)



Foreign agent: entity in visited network that performs mobility functions on behalf of mobile.

Correspondent: wants to communicate with mobile

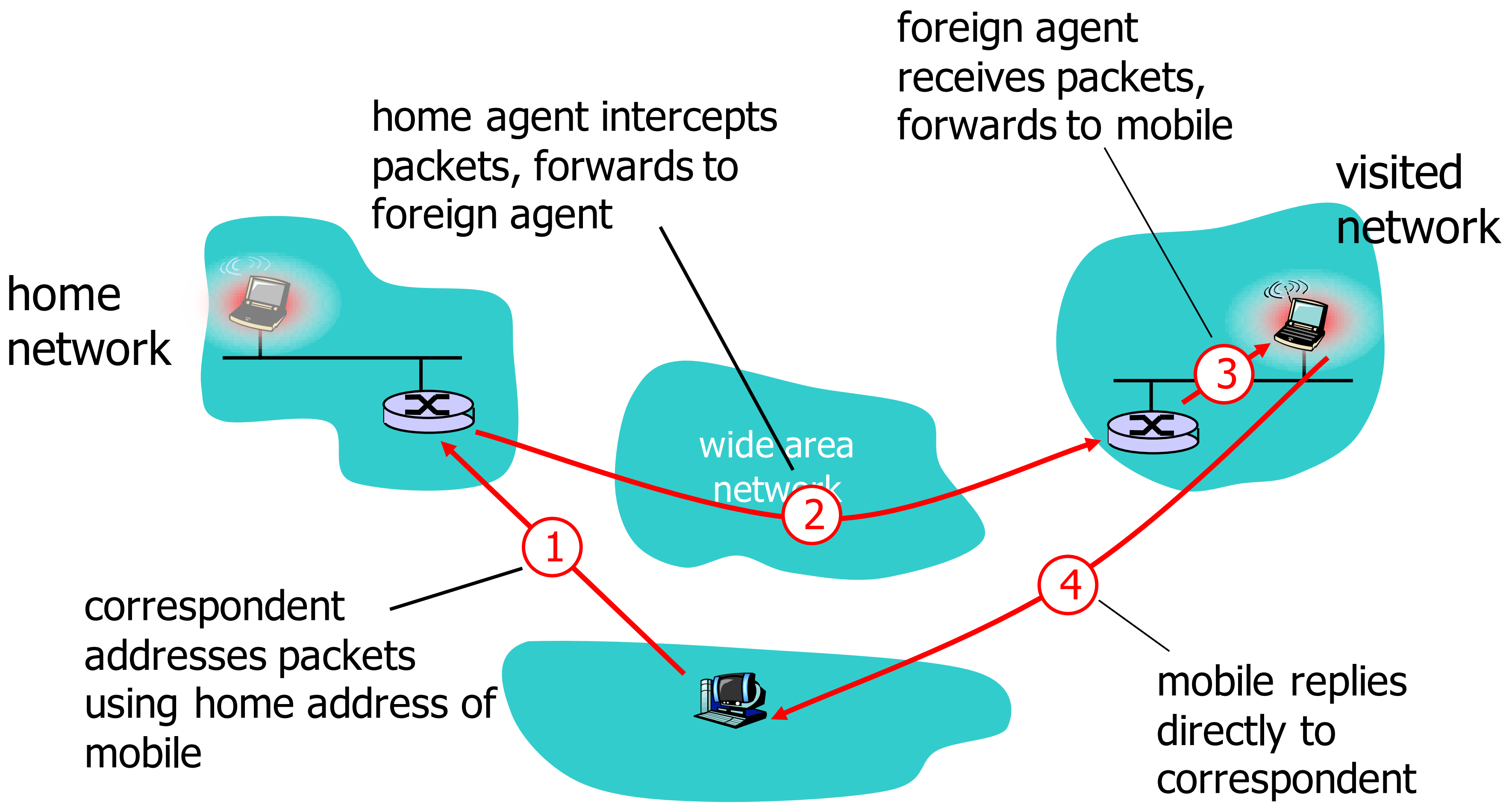
Mobility: registration



End result:

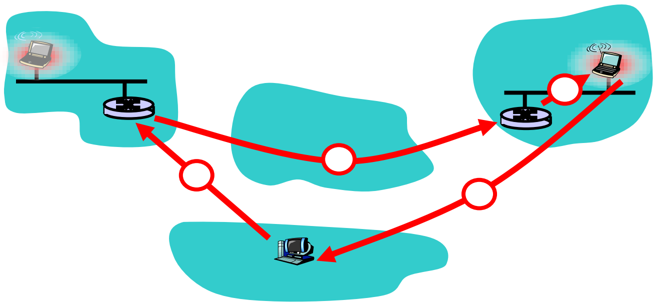
- Foreign agent knows about mobile
- Home agent knows location of mobile

Mobility via Indirect Routing



Indirect Routing: comments

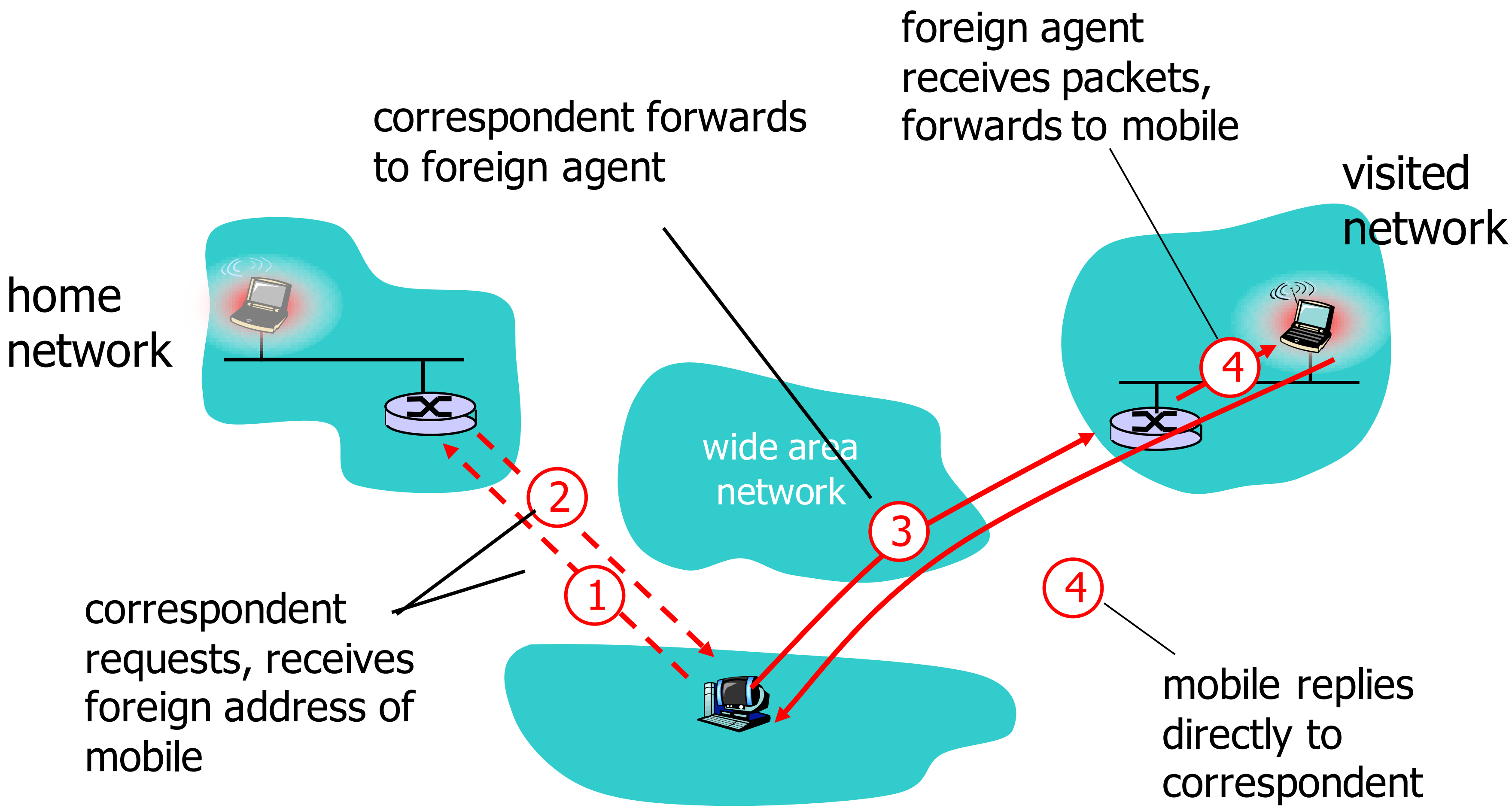
- Mobile uses two addresses:
  - Permanent address: used by correspondent (hence mobile location is *transparent* to correspondent)
  - Care-of-address: used by home agent to forward datagrams to mobile
- Foreign agent functions may be done by mobile itself
- Triangle routing: correspondent-home-network-mobile
  - Inefficient when correspondent, mobile are in same network



Indirect Routing: moving between networks

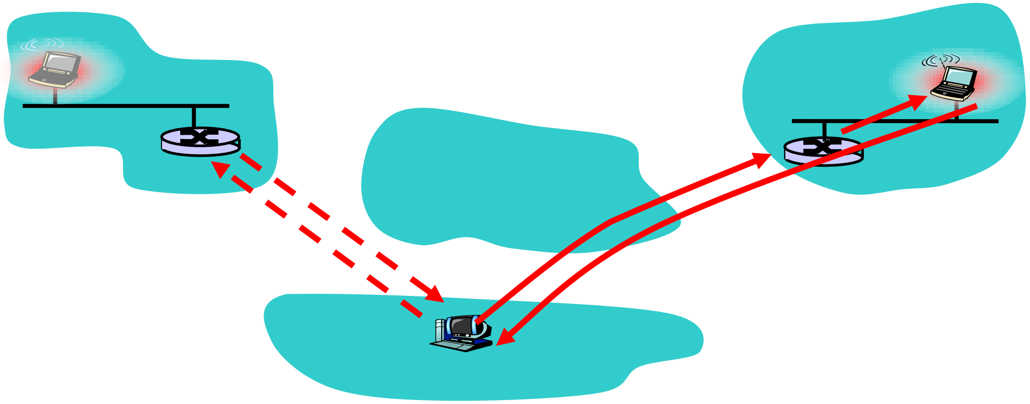
- Suppose mobile user moves to another network
  - Registers with new foreign agent
  - New foreign agent registers with home agent
  - Home agent update care-of-address for mobile
  - Packets continue to be forwarded to mobile (but with new care-of-address)
- Mobility, changing foreign networks transparent: *Ongoing connections can be maintained!*

Mobility via Direct Routing



Mobility via Direct Routing: comments

- Overcome triangle routing problem
- Non-transparent to correspondent: Correspondent must get care-of-address from home agent
  - What happens if mobile changes networks?



Mobile IP

- RFC 3220
- Has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)
- 3 components to standard:
  - agent discovery
  - registration with home agent
  - indirect routing of datagrams

Mobility via indirection: Why indirection?

- Transparency to correspondent
- "Mostly" transparent to mobile (except that mobile must register with foreign agent)
  - transparent to routers, rest of infrastructure
  - potential concerns if egress filtering is in place in origin networks (since source IP address of mobile is its home address): spoofing?

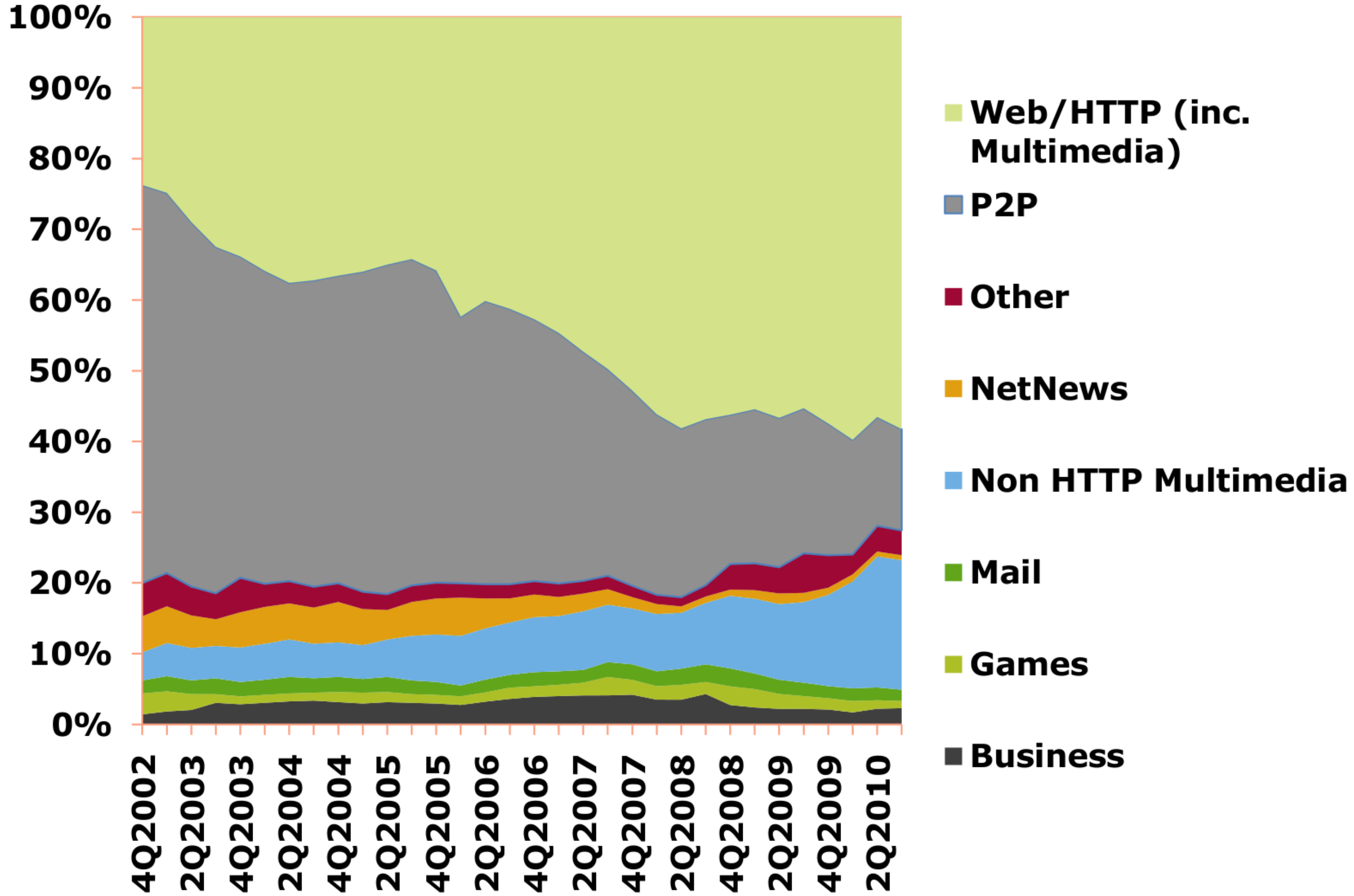
Content Delivery Networks: Indirection with DNS

Internet Content

- Content is
  - static web pages and documents
  - images and videos, streaming, …
- Content becomes more and more important!
  - 500 exabytes (10^{18}) created in 2008 alone [Jacobson]
  - Estimated inter-domain traffic rate: 39.8 TB/s [Labovitz]
  - Annual growth rate of Internet traffic: ~40%-60% [Labovitz]
  - Much of web growth due to video (Flash, RTSP, RTP, YouTube, etc.)
- How to deliver content?
- How to cope with growth of content?

Following slides adapted from Wolfgang Mühlbauer

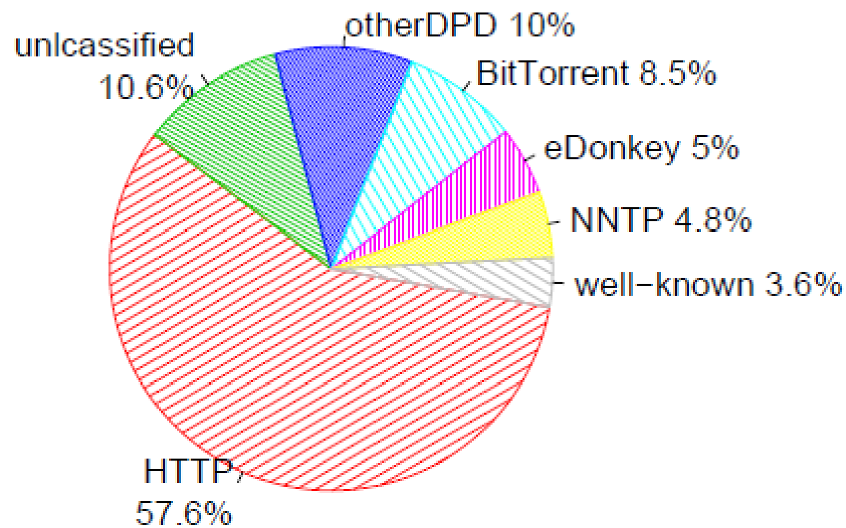
Application mix

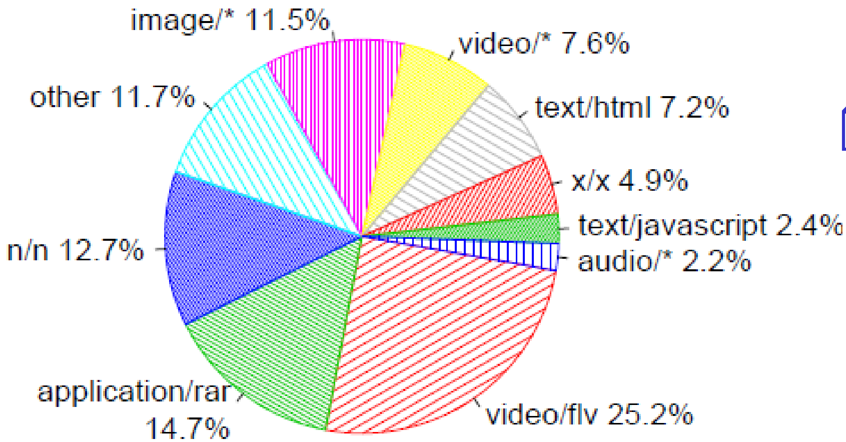


Source: Alexandre Gerber and Robert Doverspike. Traffic Types and Growth in Backbone Networks. AT&T Labs – Research 2011.

Application mi

- HTTP dominates





- Inside HTTP
  - Flash-video dominates
  - Images and RAR files next

Source: Gregor Maier et al. On Dominant Characteristics of Residential Broadband Internet Traffic. IMC 2009.

Prevalence of CDNs

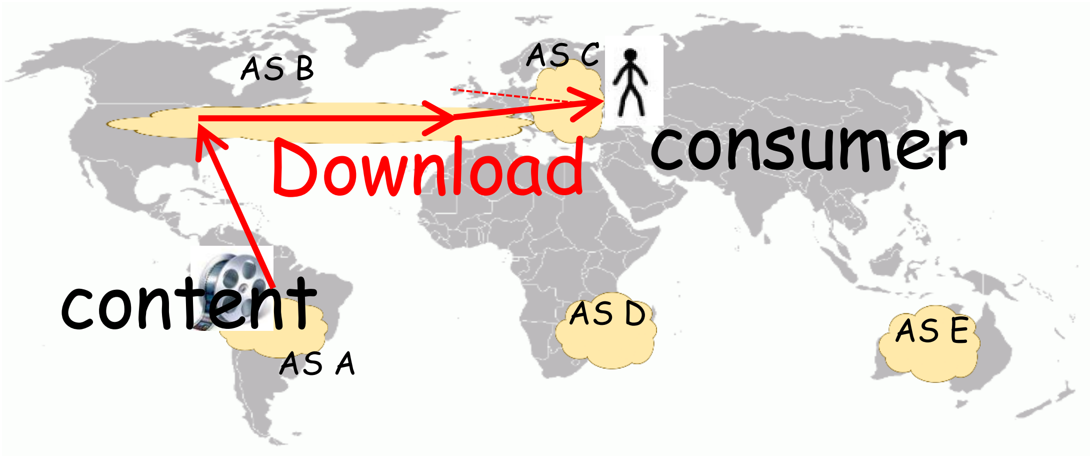
- 30 (out of ~30000) ASes contribute 30% of inter-domain traffic
- July 2009: CDNs originate at least 10% of all inter-domain traffic
- Top ten origin ASes in terms of traffic

Rank	Provider	Percentage
1	Google	5.03
2	ISP A	1.78
3	LimeLight	1.52
4	Akamai	1.16
5	Microsoft	0.94
6	Carpathia Hosting	0.82
7	ISP G	0.77
8	LeaseWeb	0.74
9	ISP C	0.73
10	ISP B	0.70

Source: Craig Labovitz et al. Internet Inter-Domain Traffic. SIGCOMM 2010.

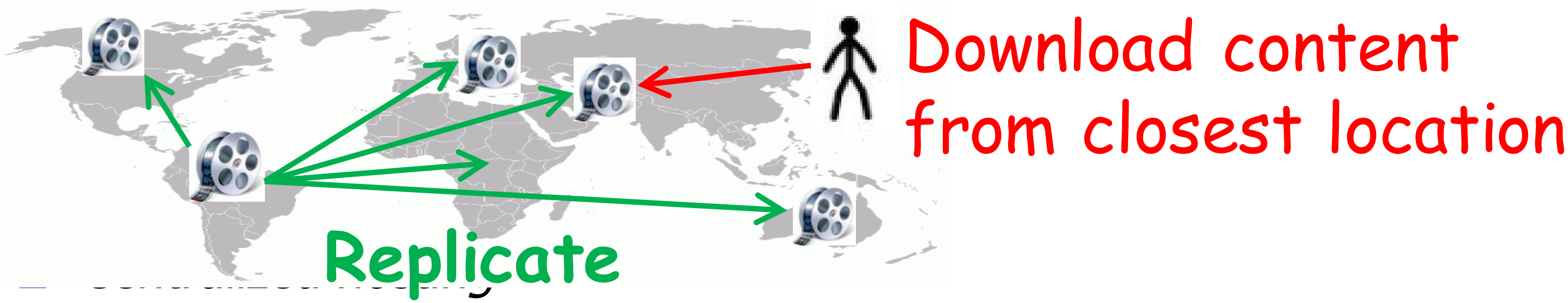
Why not Serving Content from One's Own Site?

- Enormous demand for popular content
  - Cannot be served from single server
- Bad performance
  - Due to large distance: TCP-througput depends on RTT!
  - Bad connectivity?
- Single point of "failure"
  - High demand leads to crashes or high response times (e.g., flash crowds)
- High costs
  - Bandwidth and disk space to serve large volumes (e.g., videos)



Approaches to Content Delivery

- **Idea**: replicate content and serve it locally



- *Content distribution networks* (CDN)
  - Offload content delivery to large number of content servers
  - Put content servers near end-users
- *Peer-to-peer networks*
  - In theory: infinite scalability
  - Yet: download capacity throttled by uplink capacity of end users

Akamai – A Large CDN

- Akamai (Hawaiian: “intelligent”)
  - Evolved out of MIT research effort: handle flash crowds
  - > 70000 Servers located in 72 countries, > 1000 ASs
  - Customers: Yahoo!, Airbus, Audi, BMW, Apple, Microsoft, etc.
- Why using Akamai?
  - *Content consumer*: Fast download
  - *Content provider*: Reduce infrastructure cost, quick and easy deployment of network services
- Task of CDNs: Serve content
  - *Static web content*: HTML pages, embedded images, binaries …
  - *Dynamic content*: break page into fragments; assemble on Akamai server, fetch only noncacheable content from origin website:
  - *Applications*: audio and video streaming

Akamai: Is the Idea Really That Novel?

- Local server cluster
  - Bad if data center or upstream ISP fails
- Mirroring
  - Deploying clusters in a few locations
  - Each mirror must be able to carry all the load
- Multihoming
  - Using multiple ISPs to connect to the Internet
  - Each connection must be able to carry all the load

- Akamai vastly increases footprint
  - monitors and controls their worldwide distributed servers
  - directs user requests to appropriate servers
  - handles failures

Akamai Relies on DNS Redirection

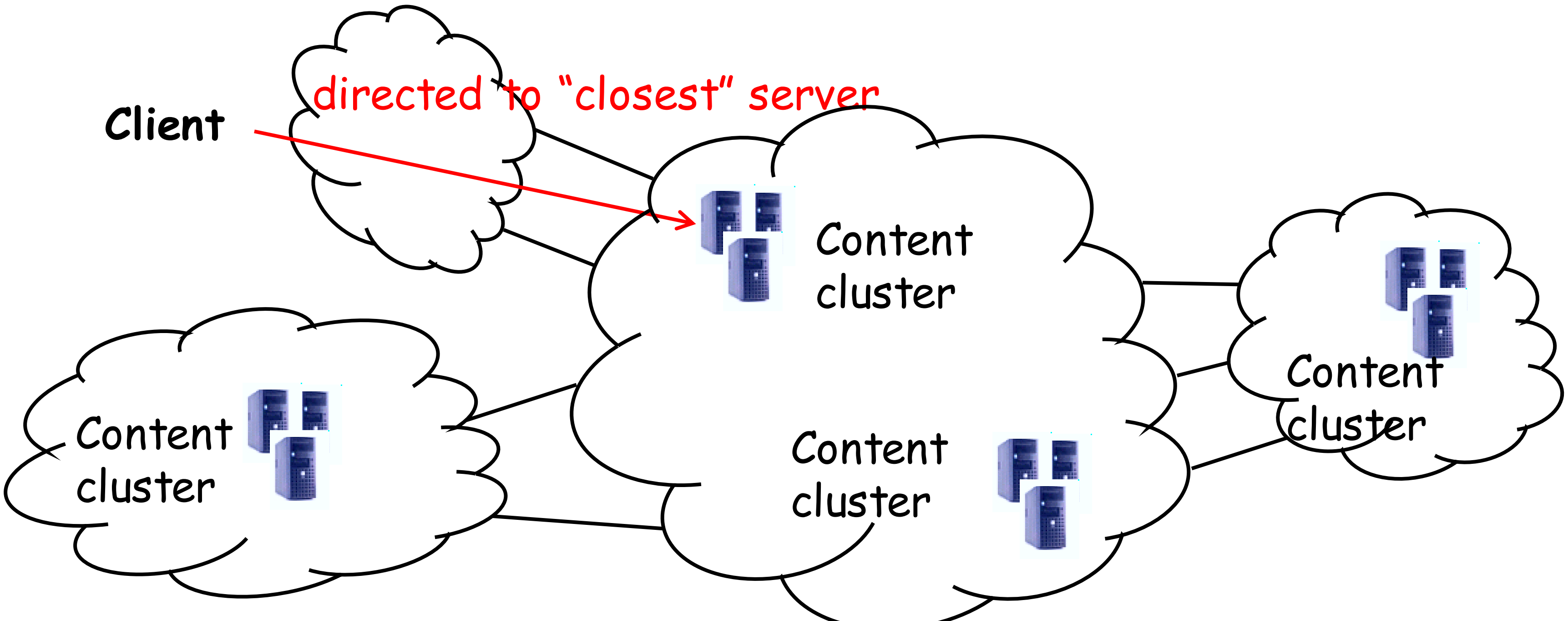
- Example: Access of Apple webpage (www.apple.com)
- Pictures are hosted by Akamai: images.apple.com
- Type: `dig images.apple.com` into your Linux shell

```
[...]
;; ANSWER SECTION:
images.apple.com.    3016    IN    CNAME images.apple.com.edgesuite.net.
[more CNAME redirections]
images.apple.com.edgesuite.net.globalredir.akadns.net.  2961 IN CNAME a199.gi3.akamai.net.
a199.gi3.akamai.net.    10    IN    A    184.84.182.56
a199.gi3.akamai.net.    10    IN    A    184.84.182.66
[...]
```

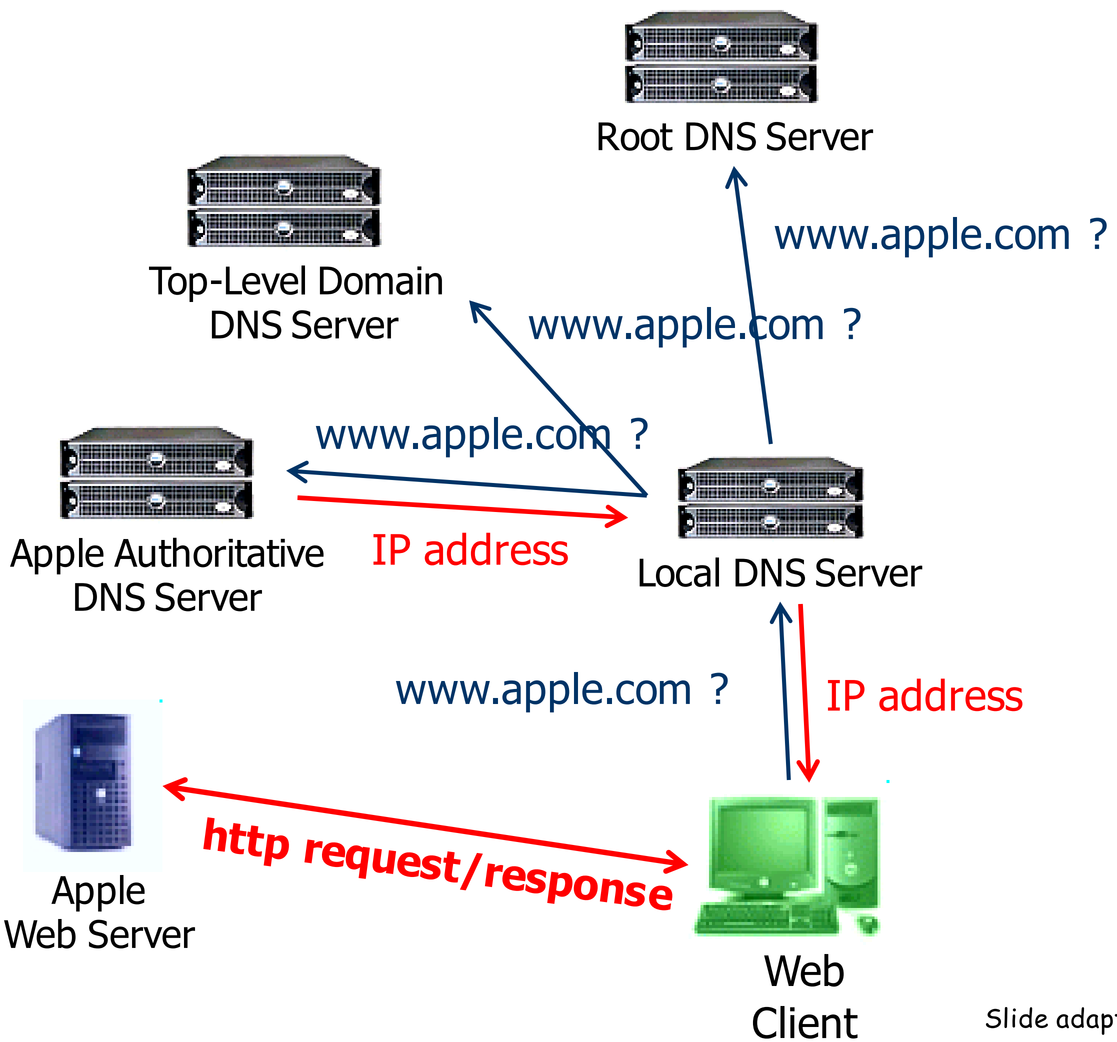
DNS redirects request to DNS servers controlled by Akamai!

Akamai Deployment

- Edge server organized as "content cluster"
  - in many Autonomous Systems
  - multiple servers
  - local "low-level" DNS server



How does Akamai work? (simplified)

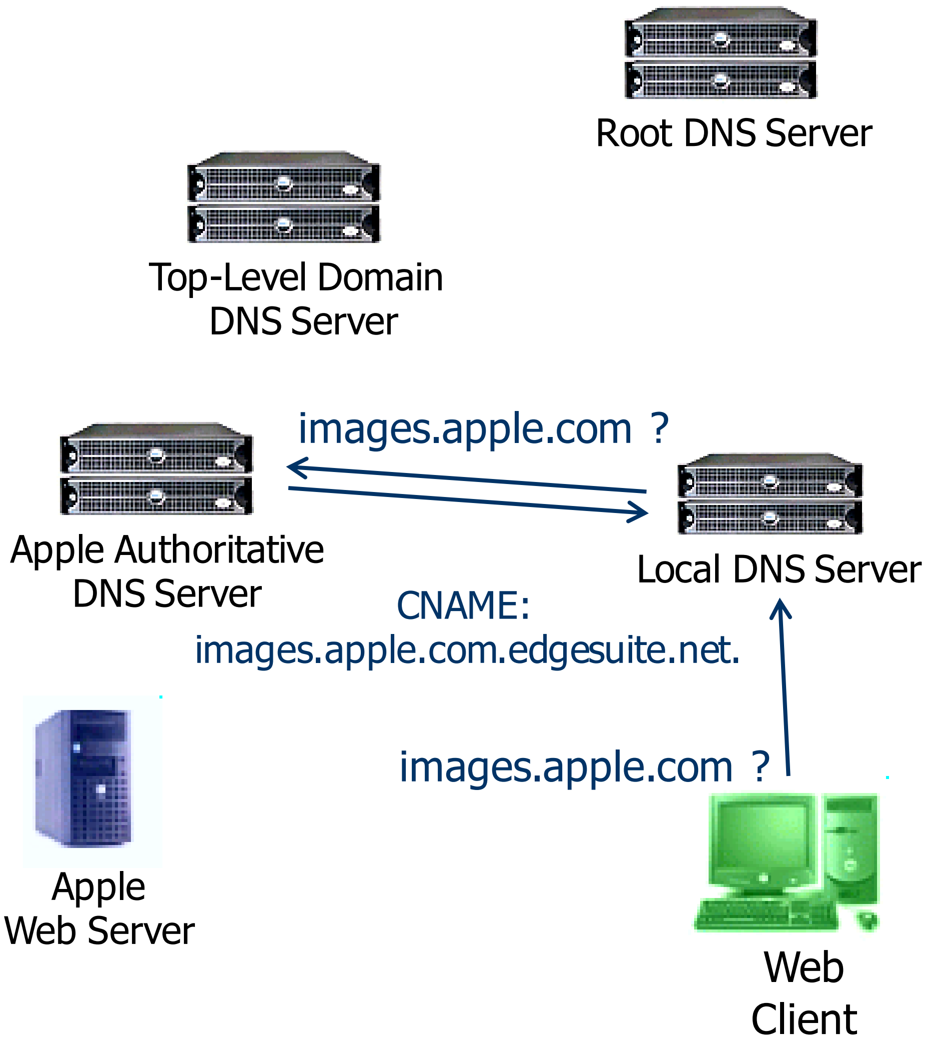


Normal web request:

- First DNS resolval
- Then HTTP connection

Slide adapted from "Drafting Behind Akamai", Sigcomm 2006

How does Akamai work? (simplified)

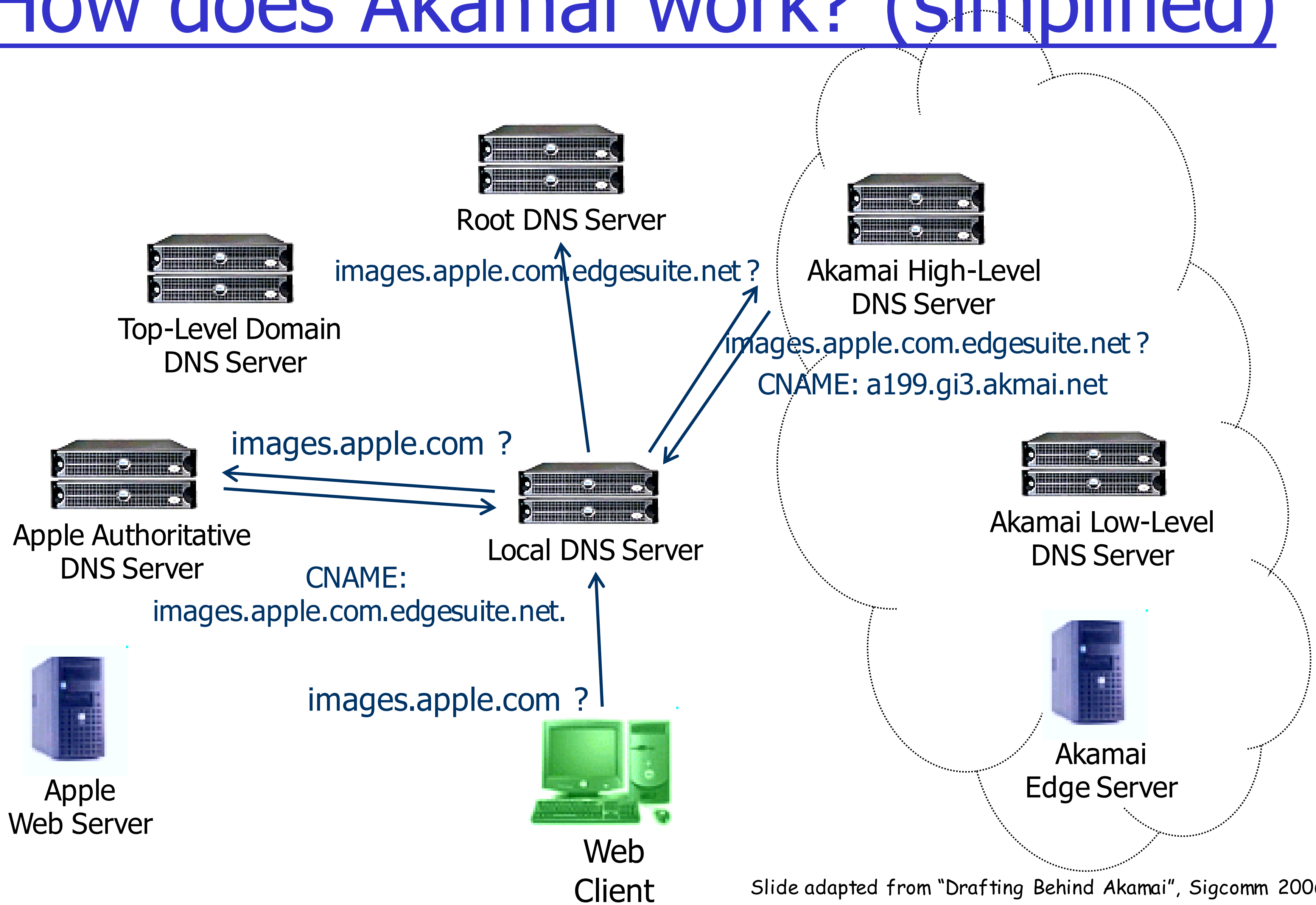


DNS request for "Akamized" content:

- Results in CNAME

Slide adapted from "Drafting Behind Akamai", Sigcomm 2006

How does Akamai work? (simplified)



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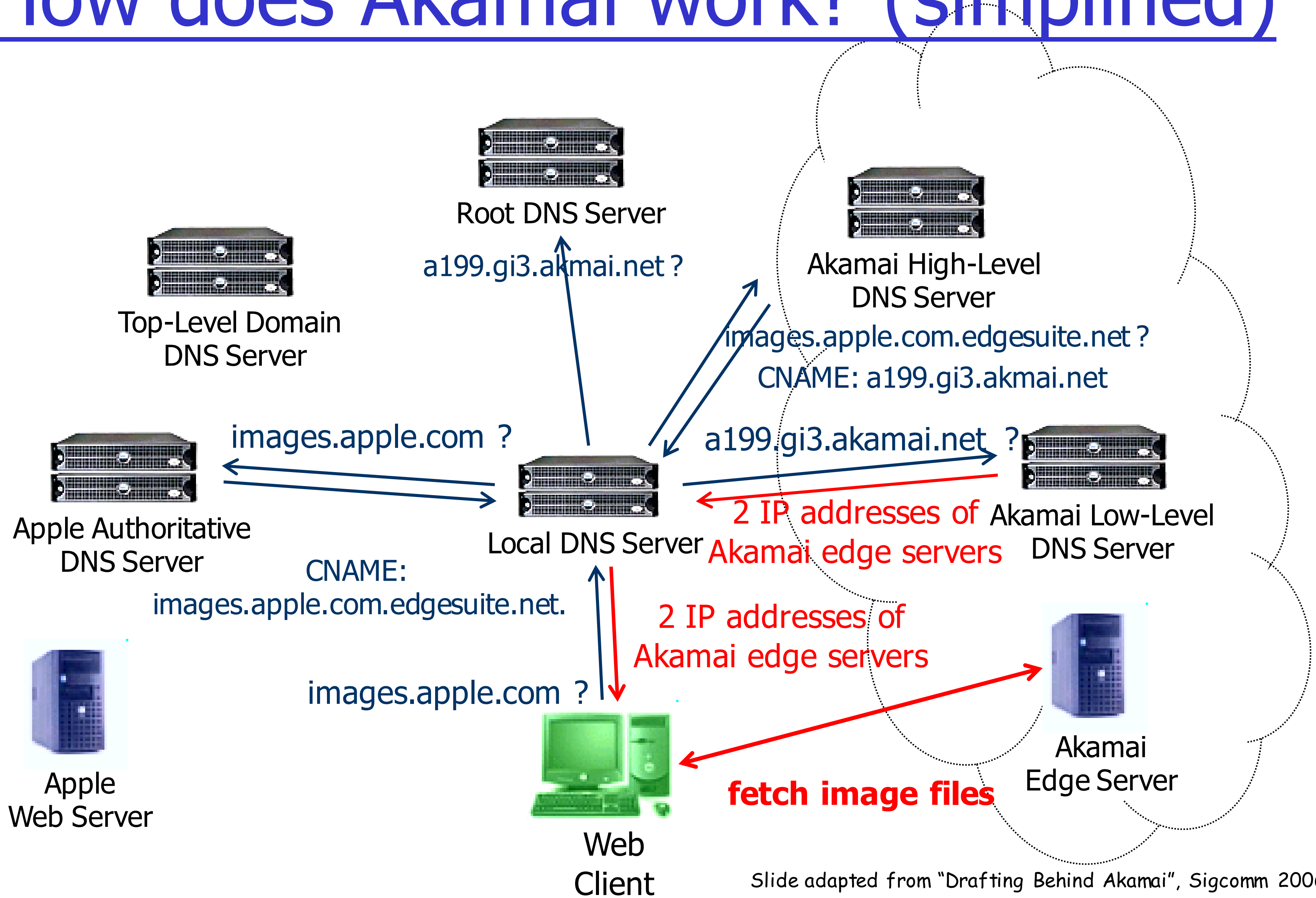

Slide adapted from "Drafting Behind Akamai", Sigcomm 2006

Two-level server assignment

- Akamai top-level DNS server
  - Anycasted
  - Selects location of “best” content cluster
  - Delegates to content cluster’s low-level name server
  - TTL 1 hour
- Akamai low-level server
  - Return IP addresses of servers that can satisfy the request: consistent hashing
  - TTL 20 seconds: quick adoption to load conditions
- Most CDNs use similar techniques
  - Some CDNs rely on Anycast to send traffic to closest content server (e.g., Limelight)

What is the „best“ location?

- Service requested
  - Server must be able to satisfy the request (e.g., QuickTime stream)
- Server health
  - Up and running without errors
- Server load
  - Server’s CPU, disk, and network utilization
- Network condition
  - minimal packet loss to client, sufficient bandwidth to handle requests
- Client location
  - Server should be *close* to client, e.g., in terms of RTT

Indirection: Summary

We've seen indirection used in many ways:

- Multicast
- Mobility
- CDNs

The uses of indirection:

- Sender does not need to know receiver id – do not *want* sender to know intermediary identities
- Load balancing
- Beauty, grace, elegance
- Transparency of indirection is important
- Performance: Is it more efficient?