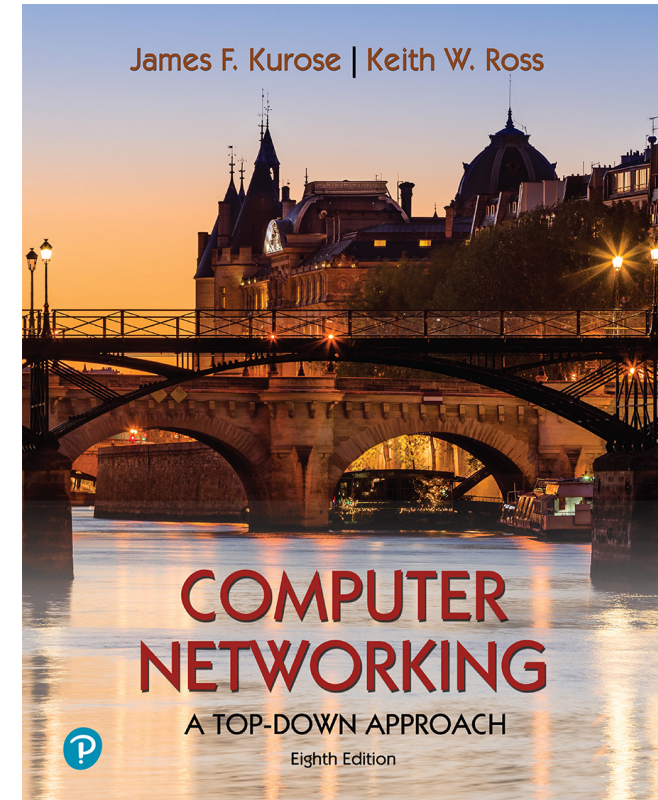


Chapter 2

Application Layer



Computer Networking: A Top-Down Approach

8th edition

Jim Kurose, Keith Ross
Pearson, 2020

Acknowledgement: Based on the textbook's website:
https://gaia.cs.umass.edu/kurose_ross/index.php

Application layer: overview

- Principles of network applications
- Web and HTTP
- E-mail, SMTP, IMAP
- The Domain Name System DNS
- P2P applications
- video streaming and content distribution networks
- socket programming with UDP and TCP



Video Streaming and CDNs: context

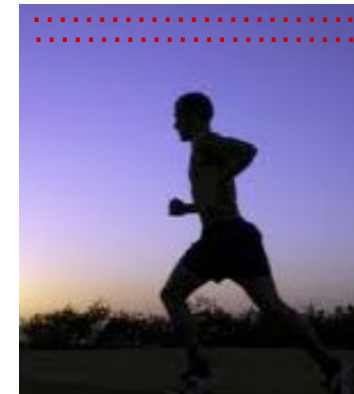
- stream video traffic: major consumer of Internet bandwidth
 - Netflix, YouTube, Amazon Prime: 80% of residential ISP traffic (2020)
- *challenge*: scale - how to reach ~1B users?
- *challenge*: heterogeneity
 - different users have different capabilities (e.g., wired versus mobile; bandwidth rich versus 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

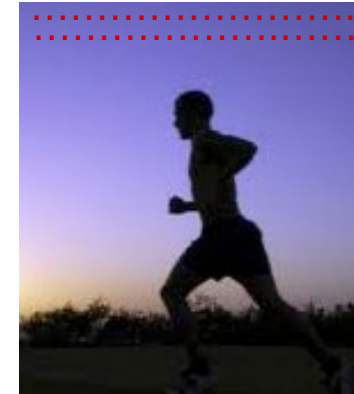


frame $i+1$

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, 64Kbps – 12 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

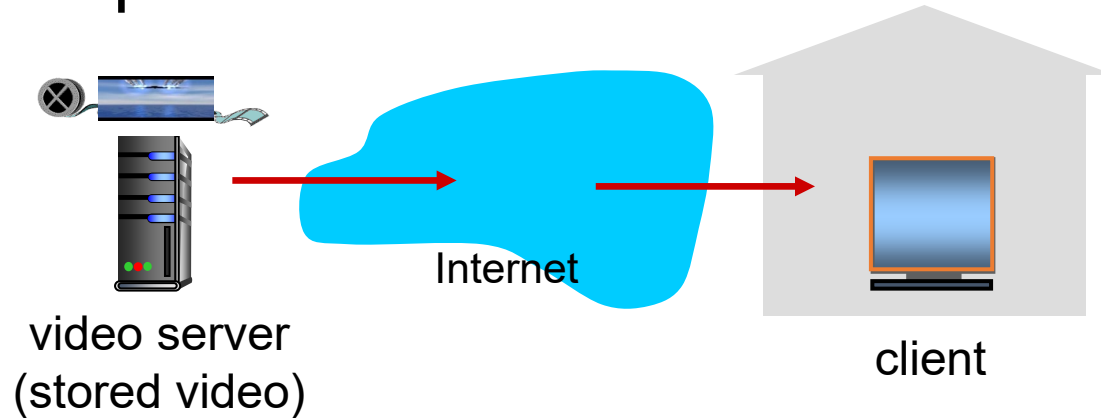
temporal coding example: instead of sending complete frame at $i+1$, send only differences from frame i



frame $i+1$

Streaming stored video

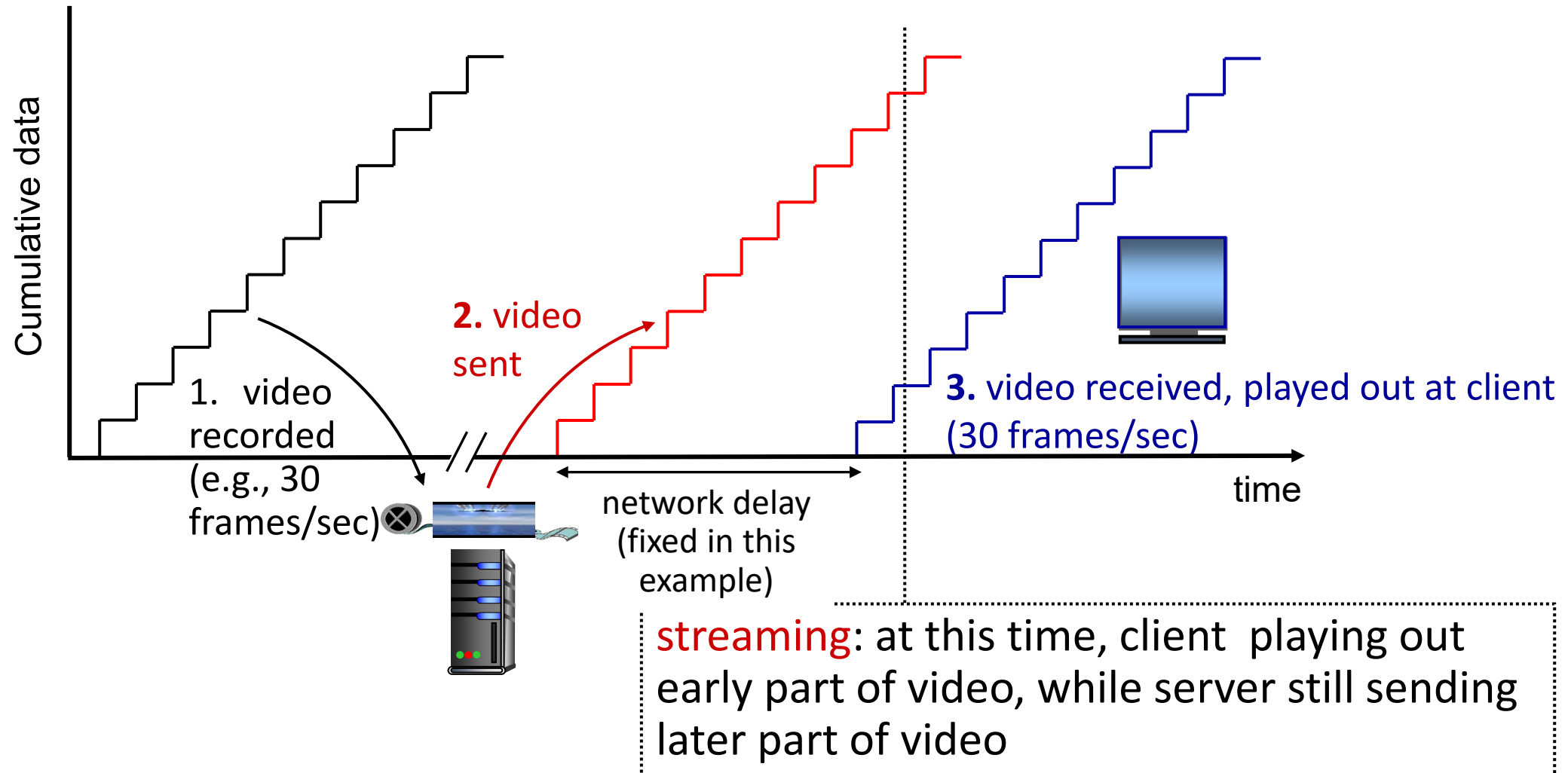
simple scenario:



Main challenges:

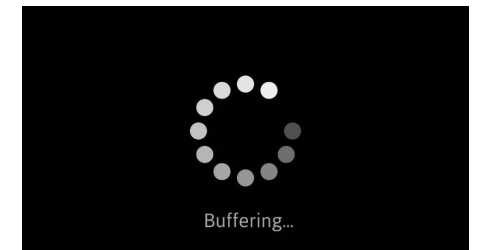
- server-to-client bandwidth will *vary* over time, with changing network congestion levels (in house, access network, network core, video server)
- packet loss, delay due to congestion will delay playout, or result in poor video quality

Streaming stored video

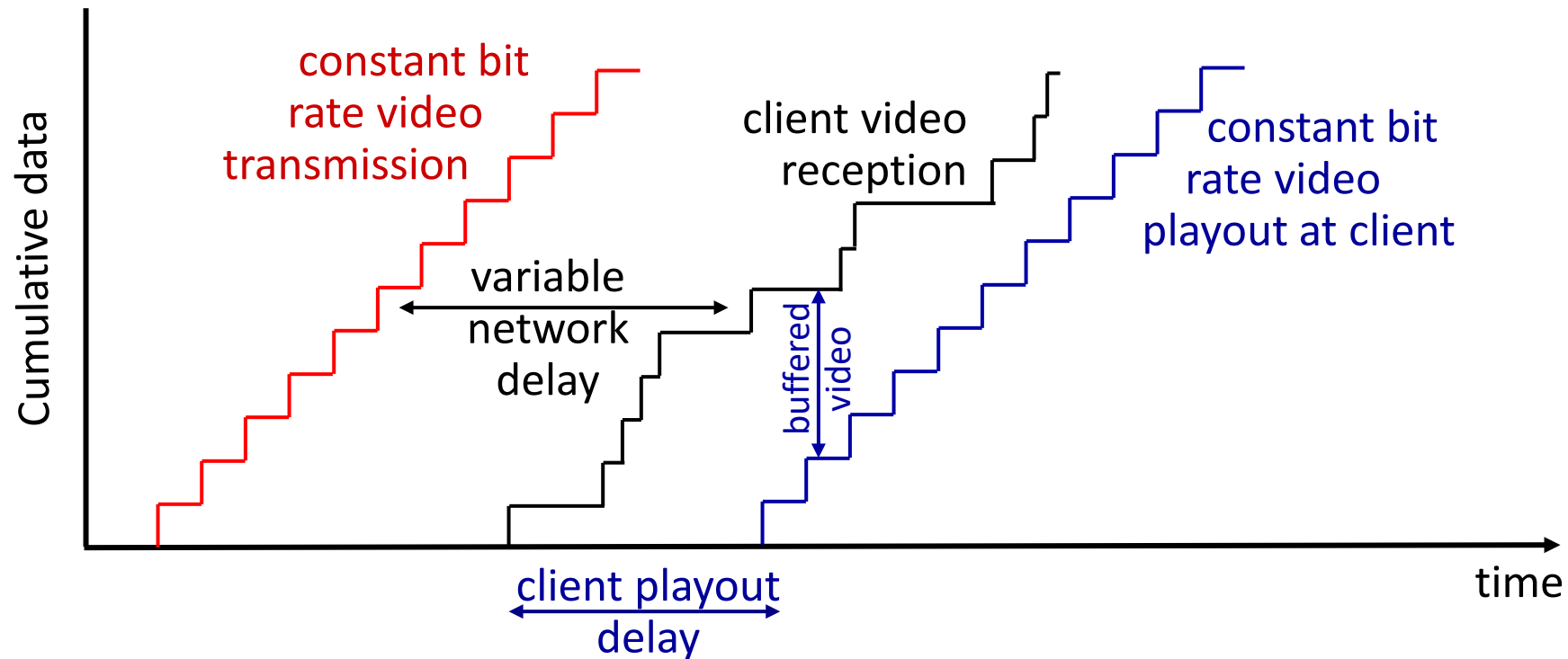


Streaming stored video: challenges

- **continuous playout constraint**: during client video playout, playout timing must match original timing
 - ... but **network delays are variable** (jitter), so will need **client-side buffer** to match continuous playout constraint
- other challenges:
 - client interactivity: pause, fast-forward, rewind, jump through video
 - video packets may be lost, retransmitted



Streaming stored video: playout buffering



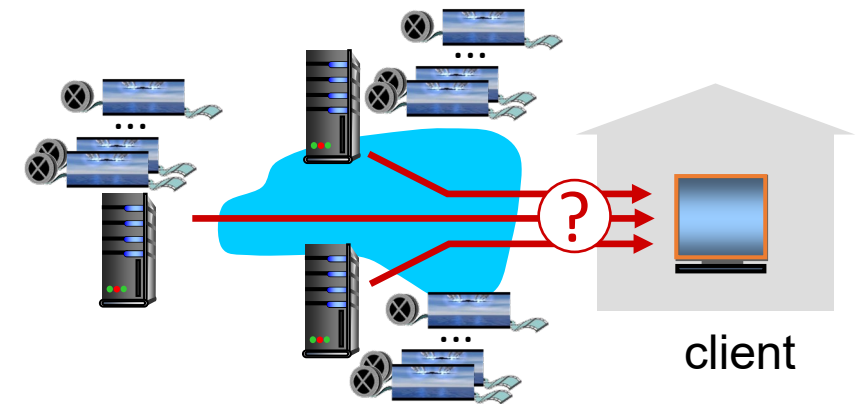
- *client-side buffering and playout delay*: compensate for network-added delay, delay jitter

Streaming multimedia: DASH

*D*ynamic, *A*daptive
*S*treaming over *H*TTP

server:

- divides video file into multiple chunks
- each chunk encoded at multiple different rates
- different rate encodings stored in different files
- files replicated in various CDN nodes
- *manifest file*: provides URLs for different chunks

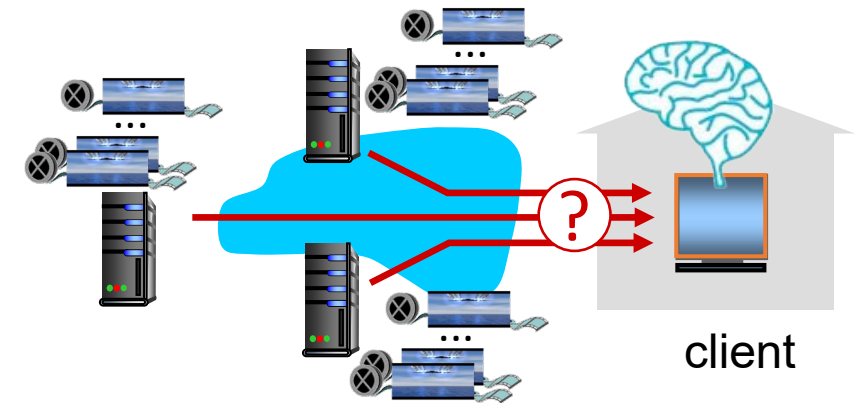


client:

- periodically estimates 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), and from different servers

Streaming multimedia: DASH

- “*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)



Streaming video = encoding + DASH + playout buffering

Content distribution networks (CDNs)

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 (and possibly congested) path to distant clients

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

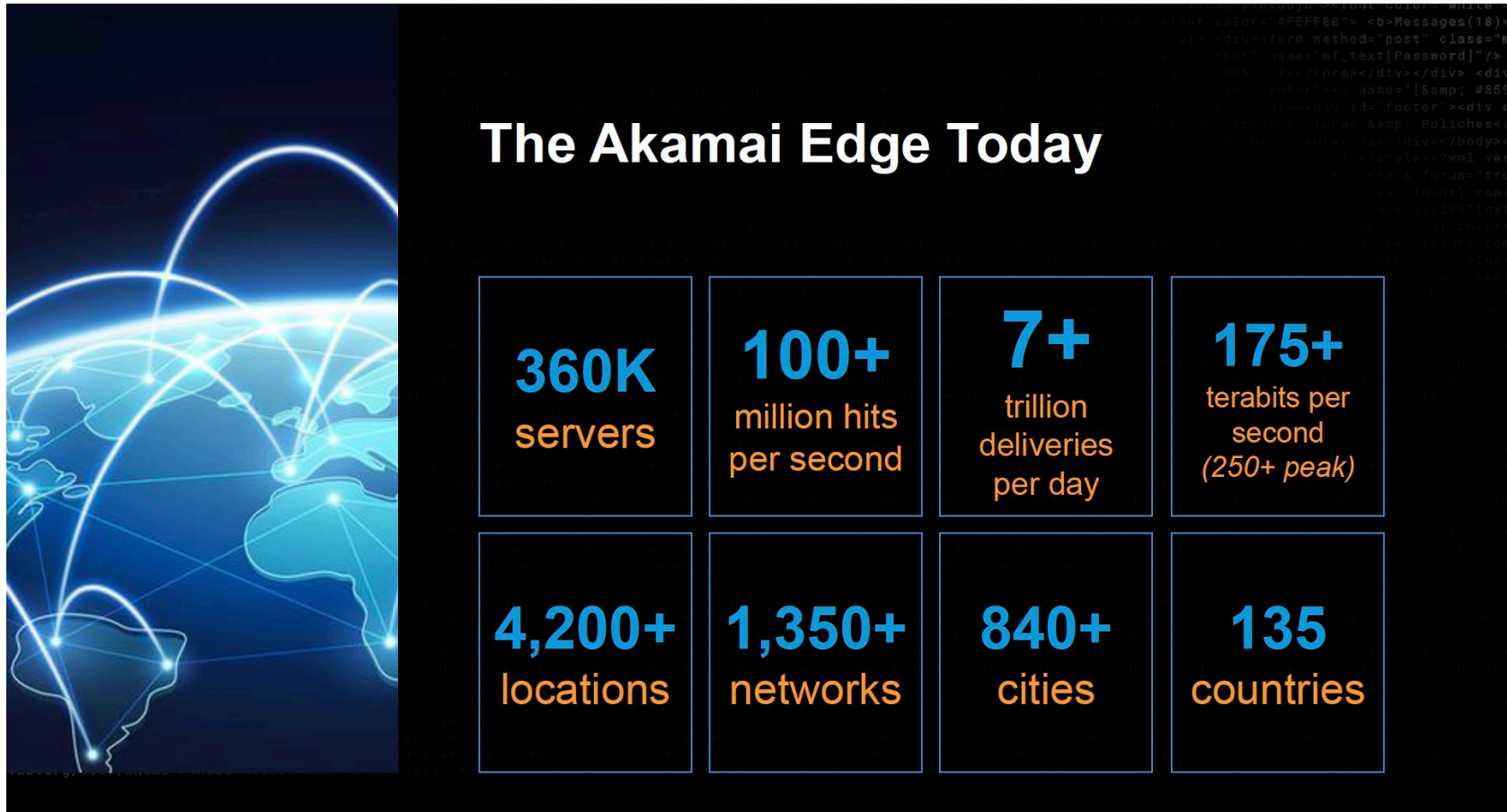
Content distribution networks (CDNs)

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
 - Akamai: 240,000 servers deployed in > 120 countries (2015)
 - *bring home:* smaller number (10's) of larger clusters in POPs near access nets
 - used by Limelight



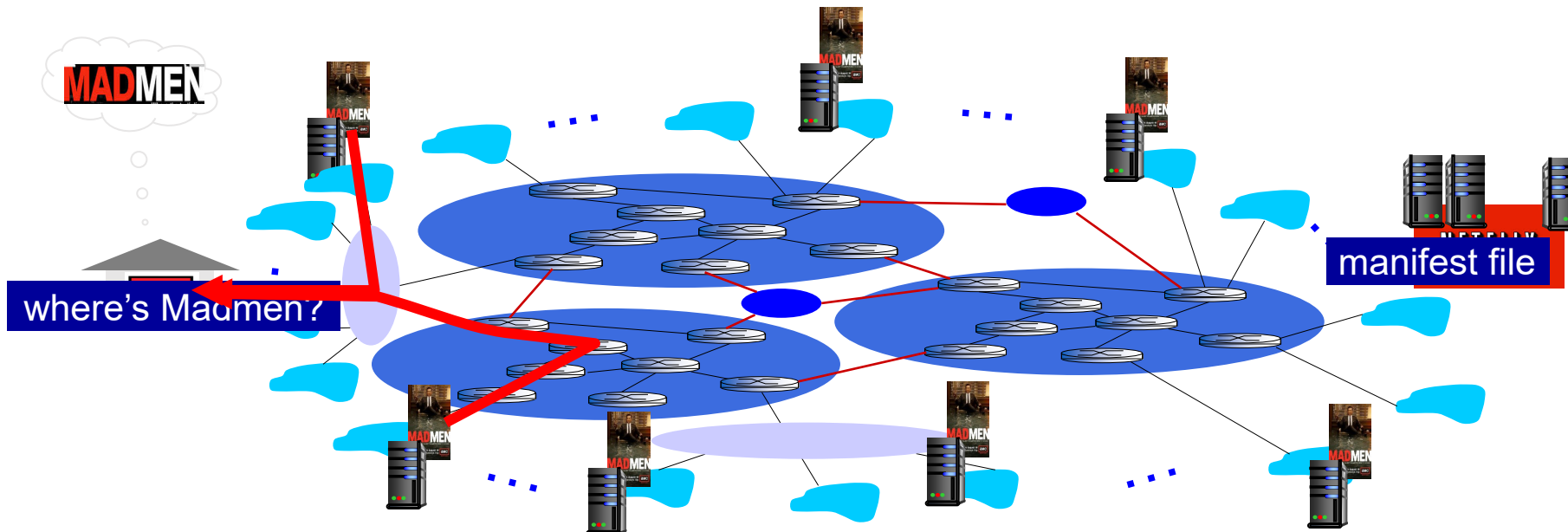
Akamai today:



Source: <https://networkingchannel.eu/living-on-the-edge-for-a-quarter-century-an-akamai-retrospective-downloads/>

How does Netflix work?

- Netflix: stores copies of content (e.g., MADMEN) at its (worldwide) OpenConnect CDN nodes
- subscriber requests content, service provider returns manifest
 - using manifest, client retrieves content at highest supportable rate
 - may choose different rate or copy if network path congested



Content distribution networks (CDNs)



OTT challenges: coping with a congested Internet from the “edge”

- what content to place in which CDN node?
- from which CDN node to retrieve content? At which rate?