Content may be King, but (Peering) Location Matters:

A Progress Report on the Evolution of Content Delivery in the Internet

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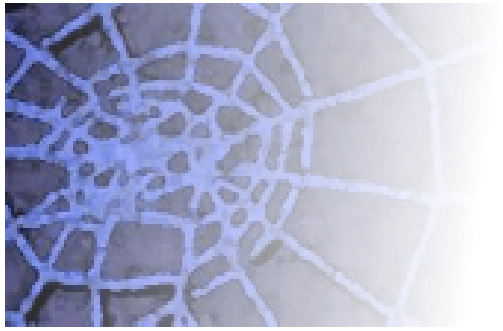
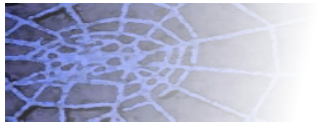


Increasing Complexity in the Internet Ecosystem

- Demand for content is ever increasing
  - Wide array of different content types (static vs. dynamic; passive vs. interactive, etc.)
- Providers of this different content are diverse
  - E.g., individuals, non-profits, and for-profit businesses

➢ Distribution requirements of (commercial) content and application providers are highly differentiated, heterogeneous and in constant flux

➢ Challenges arise regarding delivery performance and cost efficiency of content delivery

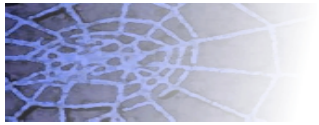


The "Basic Internet" is not Enough

- Internet's "best effort" design not well-suited for meeting the distribution requirements of today's demand

- Internet suite of protocols expanded to include enhanced capabilities to better deliver content or offer QoS differentiations

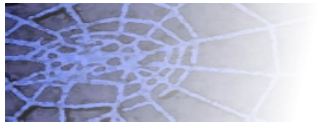
➢ But: Due to its decentralized design, coordinating the migration to a new Internet architecture turns out to be a daunting challenge



CDNs may (partially) fill this Gap

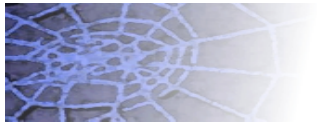
- CDNs employ a scalable distributed architecture of servers that is overlaid on the Internet's basic packet transport infrastructure
- CDNs and access ISPs form a symbiotic relationship
  - CDNs rely on the public Internet for the packet delivery
  - ISPs make routing decisions in the data plane
  - ➢ But: typically no information sharing

➢ CDNs offer supplemental functionality to address the need for better options for content distribution



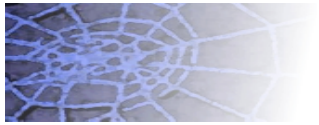
CDNs: Innovation & Competition

- CDN innovation allows to flexibly adapt to changing market conditions and add new capabilities and services at a faster pace than the underlying Internet
- Over time, a complex and competitive landscape of CDN architectures and business models emerged to address changing needs
  - Complex array of CDN providers pursuing diverse business strategies
  - Market for value-added CDN services expanded (e.g., security or analytics)
  - Complex mix of vertical and horizontal business strategies and cross-linking organizational strategies



A Taxonomy of CDN Architectures

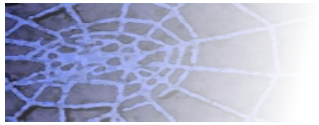
CDN Architecture	Examples of Providers	Deployment Strategy	Bandwidth	Latency	Business Model	Typical Applications
Datacenter-based	Limelight, CacheFly, CloudFlare	Servers at strategically connected facilities	High	Medium	Buy bulk resources	Video Streaming, static Web, software updates
Highly Distributed	Akamai	Servers at peering points and inside access networks	High	Very Low	General-purpose, provide global footprint, best quality	Various applications, including dynamic and interactive Web
Peer-to-peer	BitTorrent	Serverless, functionality at end-user equipment	Low	High	No investment in dedicated infrastructure	File sharing, bulk transfers
Hybrid	Akamai NetSession	Dedicated servers combined with functionality at end-user equipment	Low	High	Partial outsourcing of delivery to end-user equipment	Software updates, file sharing
Specialized	Netflix Open Connect, Google Global Cache, Amazon CloudFront	Specialized servers at peering points and inside access networks	High	Low	Reduce delivery costs for specialized service	Video delivery, specialized applications
Broker	Conviva, Cedexis	Relies on existing deployments of CDN functionality	Custom	Custom	Opportunistic cost management	Video and Web delivery
Licensed	Akamai AURA, Edgecast licensed CDN	Inside access networks	High	Very Low	Telco CDN, or ISP-CDN collaboration	All of above
Federated	Edgecast OpenCDN	Relies on existing deployments of CDN functionality	High	Low	Interconnection of CDNs to expand geographic footprint	All of above



The Multiple Facets of (Peering) Location

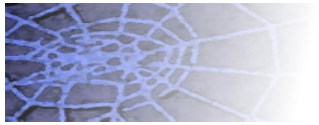
- The location in which CDN servers are positioned and where traffic between CDNs and other networks is exchanged affect both the performance and cost of content delivery

- Location has multiple facets:
  (1) Geographic Location (Peering diversity; distance to users)
  (2) Virtual Location (Local or global IP; Hosting vs. Interconnection)
  (3) Communication Hubs (IXPs, Interconnection Facilities)
  (4) Innovation Hubs (Multilateral peering, complex interconnections, SDN, Remote Peering, Blackholing)



Prospects for the future of CDNs and the Internet Ecosystem (I)

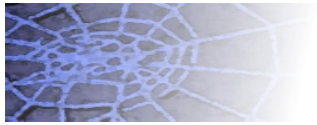
- CDN markets are highly competitive
- Predominant role of a small number of large general-purpose CDNs
- Smaller CDNs may enter the market and exploit a competitive advantage by appealing to niche markets by application, geographic market, or by customer type (type of traffic, type of customer)



Prospects for the future of CDNs and the Internet Ecosystem (II)

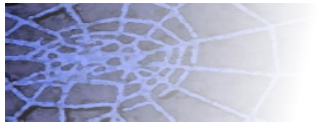
- Large content providers (e.g., Netflix, Google or Facebook) may find sufficient benefits from reducing costs and in increasing control over how content is delivered to their end-users to make it desirable to vertically integrate into self-provisioning (specialized) CDN services

- Access ISPs seek to vertically integrate into value-added services as revenues from legacy transport services are eroding
  - Make-vs-buy decisions
  - The softwarization of ISP networks increases their capabilities to offer value-added services
  - Proximity to end-users gives a natural advantage in hosting and managing edge-located content caches



Conclusions (I)

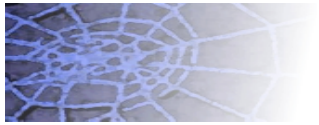
- Over time, a complex and highly diversified landscape of CDN architectures and business models reflecting the complex needs for content delivery has evolved
- Different CDN architectures aim at optimizing delivery performance and minimize delivery cost
- Further, many CDNs offer complementary value-added services



Conclusions (II)

We expect

- …to see growing efforts to integrate ISP and CDN functionality to take advantage of the mutual benefits to be realized from closer coordination
- …the coordination to be managed through contractual alliances rather than full vertical integration
- …fierce competition between CDNs for customers

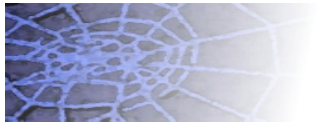


Conclusions (III)

- Opportunities and challenges will arise as ISPs increasingly evolve toward cloud service providers

- At the same time, CDNs are increasingly expanding their capabilities to support more dynamic, interactive, and diverse types of content

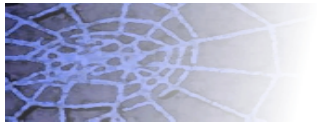
➢ The boundary between basic Internet functionality and value-added overlay functionality is increasingly being blurred



Conclusions (IV)

Reasons for keeping ISPs and CDNs separate

Strategic Perspective	Regulatory Perspective
• CDNs risk channel conflicts in their ability to negotiate last-mile delivery services with competing ISPs if they are too closely associated with particular ISPs	• Integration is likely to complicate efforts to regulate the provision of broadband Internet access services ➢ Implications for Network Neutrality Regulations ➢ CDNs as "unchartered territory"



Thank You!

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