Content Distribution over IP: Developments and Challenges

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Introduction

- Currently, two important developments in telecom
  - Irreversible move towards IP-based networking
  - Deployment of broadband access, e.g., DSL, WiMAX
- Consequence
  - Appearance of more advanced and more bandwidth-demanding applications, e.g., VoIP, IPTV, online gaming
- Plethora of requirements
  - Multicast facilities, high bandwidth, low delay/jitter, low packet loss
- More constraints (e.g., billing, authentication, copy right)
- Need for unified architectural solution

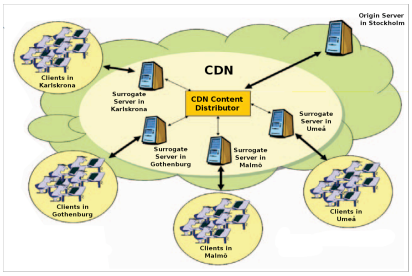
Content Distribution Networks, why?

- CDNs are networking solutions where high-layer network intelligence is used to improve the performance in delivering media content over the Internet
- Internet is used for
  - Content acquisition
  - Content creation
  - Content delivery
  - Management
- History
  - First generation: focused on Web documents
  - Second generation: focused on Video on Demand (VoD) and audio and video streaming
- Example of offerings:
  - Triple/Quadruple Play
  - Transaction-based Web content
  - Streaming media
  - Real-time video, radio

CD value chain

CDNs in Practice

- Fundamental concepts
  - Distributing content to cache servers located close to end users
  - IP routers are used to deliver content to the optimal surrogate server
  - Use of overlay routing to obtain better delivery performance
  - Client-server communication flow is replaced by two communication flows
  - Accounting mechanism to provide logs and other information to the origin servers
  - Two types of data
    - Encoded/multimedia data
    - Metadata (to allow identifying, finding and managing the encoded data)



CDN in Practice (cont'd)

- Main functional components
  - Content distribution
    - Moving the content from source towards users
  - Request routing
    - Selecting the best location for retrieving the requested content
  - Content routing
    - Delivering the content from the most appropriate place to the client requesting it
  - Content processing
    - Creating and adapting content to user preferences and device capabilities
  - Authorization, authentication and accounting
    - Enabling of monitoring, logging, accounting, and billing of content usage

Current Status of CDNs

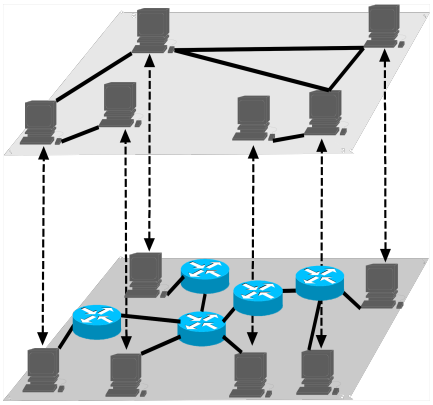
- Today, more than 3k companies use CDN
- Most popular CDN providers
  - **Akamai Technologies**
    - www.akamai.com
    - Market leader for CDN (80%)
  - **Mirror Image Internet, Inc.**
    - www.mirror-image.com
    - Large range of services
  - **LimeLight Networks**
    - www.limelightnetworks.com
    - Large range of services
  - **Inktomi**
    - www.inktomi.com
    - Yahoo company

Important Challenges for CDN

- Where to place the surrogate servers?
- Which content to outsource and what practice to use for the selected content outsourcing?
- How many CDN architectures do we need, one CDN per application or just one CDN shared by all applications?
- How to exploit P2P technology, overlay routing and caching to improve the performance?
- How to exploit data mining over CDN to improve the performance?
- How to exploit content personalization to improve the performance?
- What model to use for CDN pricing?

Routing in Overlay Networks, why?

- Overlay networks are application-layer overlays operating on the inter-domain level, which allow alternative routing services and better performance
- Motivation
  - Ability to work, self-organize and scale in the presence of a highly transient number of nodes, network and computer failures
- New facilities
  - Designers can develop own routing and management algorithms on top of the Internet
- Main advantage
  - New protocols and functionality can be deployed atop of IP routers without the need to upgrade the routers



Routing Protocols for Overlay Networks

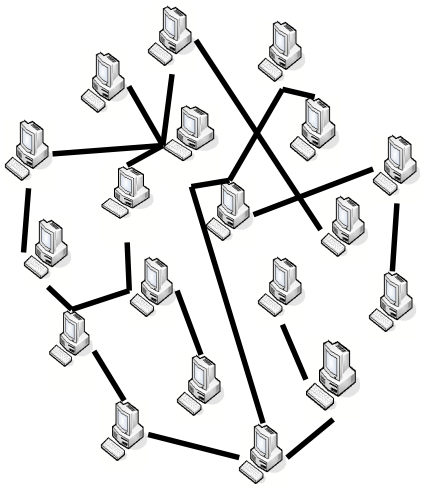
- Main functionalities in overlay networks
  - Overlay link performance monitoring
  - Topology construction
  - Overlay service composition
  - Provision of services to applications with soft QoS guarantees
- Fundamental concept overlay routing
  - Knowledge of underlying network performance is used to adapt the e2e performance to
    - Asymmetry of nodes in terms of, e.g., connectivity, network bandwidth and processing power
    - Lack of structure among them
- Ways to do routing
  - Source routing
  - Flat (or distributed) routing
  - Hierarchical routing
- Main categories of routing protocols for overlay networks
  - Proactive protocols
  - Reactive protocols
  - Hybrid protocols

Routing in Overlay Networks, how?

- Edge hosts learn of each other
- Based on knowledge of underlying network performance, they form loosely coupled neighboring relationships
- These relationships are used to induce a specific graph
  - Nodes are representing hosts
  - Edges are representing neighboring relationships
- Graph abstraction and associated graph theory can be used to formulate routing algorithms in overlay networks
- Graphs may range from star-like trees to complex k-node connected graphs

Important Challenges for Overlay Routing

- Extreme complexity
- Overlay measurements
- QoS-aware overlay routing
- Multicast overlay routing
- Multipath overlay routing



Extreme Complexity

- Network dynamics
  - Caches, proxies, dynamic overlay topology, churn, free-riding, failure of IP links, route flapping
- Node dynamics
  - Available bandwidth for access, average throughput, error rate, delay, delay jitter
- Group dynamics
  - Process of formation and change of groups of users over the time
- Traffic dynamics
  - Different traffic characteristics, process of aggregation of traffic flows, Long-Range Dependence
- Routing optimization
  - Finding the optimal routes subject to diverse QoS, topological and other constraints
  - Two classes of optimization procedures
    - Optimization of network flows (e.g., shortest path algorithms, maximum flows algorithms, minimum cost algorithms)
    - Constraint optimization (e.g., particle swarm optimization, ant colony optimization)

Overlay Measurements

- Tasks
  - Focused on the performance of overlay links instead of individual IP links
  - Measuring of parameters like, e.g., average bandwidth (for streaming media), packet loss rate, latency, frame rate (for streaming video)
  - Two categories of measurements
    - Internal measurements: internal network performance
    - External measurements: end user performance as experienced by the customers themselves
- Current solutions
  - Combination of distributed hardware and software-based probes as well as using logs from various servers (e.g., from caches and streaming media servers)
  - Use of algebraic tools to compute link distances for links not directly measured
- Important challenges
  - Scalability with increasing number of nodes
  - Impact of the measurement probe traffic on network performance
  - Compensation for the effect of measurement traffic
  - Difficulties in mapping large systems
  - Reducing the monitoring overhead while maintaining the measurement accuracy
  - Sharing monitoring results

QoS-Aware Overlay Routing

- Tasks
  - Provide QoS guarantees in delivering media to end users
  - Provide global efficiency in resource utilization
- Current solutions
  - Solutions based on ideas used in wireless ad-hoc routing and/or P2P systems
  - Use of proactive and/or reactive routing protocols
  - Network caching is used as an orthogonal (and complementary) solution
- Important challenges
  - Design of overlay routing protocols that perform well under churn/selfish nodes
  - Solving the optimization problem related to QoS constraints associated with each route
  - Answering questions related to the interaction between overlay routing and BGP routing, e.g., finding the Nash equilibrum of the overlay routing game
  - Design of scalable multimedia cache architectures
    - Multimedia caching
    - Dynamic caching
    - Segmentation of streaming objects
    - Self-organizing cooperative caching techniques

Multicast Overlay Routing

- Tasks
  - Supporting group communication applications, e.g., audio and video distribution, multimedia conferencing, distributed interactive simulation, multi-player gaming
  - Minimizing server and network overhead
- Current solutions
  - Group management, tree construction and overlay routing are done without any support from Internet routers
  - Different forms, suitable for different applications: tree, dedicated intermediate servers (so-called reflector, to split and retransmit streaming media), mesh-based, application level virtual rings
- Important challenges
  - Scalability and robustness
  - Efficient multicasting, e.g., with reference to QoS
  - Channel and client heterogeneity with reference to bandwidth, delay performance, loss patterns and processing capabilities
  - Conflict: heterogeneity of client resource capabilities vs asynchrony of user requests
  - Content heterogeneity
  - Error control (reactive and proactive schemes, e.g., Forward Error Correction)
  - Congestion control (need to behave ”TCP friendly”)
  - Security

Multipath Overlay Routing

- Tasks
  - Open up the achievable throughput as compared to single path policy routing/BGP
  - Compensate for time-varying congestion on Internet paths
  - Compensate for software, hardware and configuration errors
- Current solutions
  - Simplest solution: mesh routing
  - Can be based on IP routing concepts, e.g., Distance Vector
  - New solutions, e.g., ant colony, dispersity routing, combining redundant coding with dispersity routing, parallel TCP flows, use of erasure codes, adaptive response by attractor selection (biologically inspired approach)
- Important questions
  - Given a specific amount of data, how to select the number of paths?
  - Given a specific topology, how to select efficient, loop-free paths such as to provide the requested QoS and to balance traffic loads?
  - Given a specific topology, how to determine the sending rate on each path (rate control) such as to maximize the aggregate utility of the sources?
  - What is the effect of multipath overlay routing on TCP stability and performance?
  - Given a specific topology and a specific multipath routing algorithm, how does one design a stable TCP congestion control mechanism that exploits the multipath routing capability?

Conclusions

- Challenges for emerging Internet services
  - Decentralization
  - Failure resilience
  - Ubiquity
  - QoS guarantees
- New architectural solutions based on CDN and overlay routing
- Many important research activities and results in the area
- There are however still many research challenges
- Strong need for move towards real-live deployment, e.g., PlanetLab in a first phase

References

- IETF Content Distribution Internetworking (CDI) Working Group, http://www.ietf.org/html.charters/cdi-charter.html
- Androutsellis-Theotokis S. and Spinellis D., "*A Survey of Peer-to-Peer Content Distribution Techniques*", ACM Computing Surveys, Vol. 36, No. 4, December 2004
- Pallis G. and Vakali A., "*Insight and Perspectives for Content Delivery Networks*", Communications of the ACM, Vol. 49, No. 1, January 2006
- Plagemann T., Goebel V., Mauthe A., Mathy L., Turletti T. And Urvoy-Keller G., "*From content distribution networks to content networks – issues and challenges*", Computer Communications 29 (2006), 551-562
- Li Zhi, Yuan L. and Mohapatra P., "*An Efficient Overlay Link Performance Monitoring Technique*", NETWORKING 2006, 5th International IFIP-TC6 Networking Conference, Coimbra, Portugal, May 2006
- Popescu A., Kouvatsos D., Remondo D. and Giordano S., "ROVER - Routing in Overlay Networks", EuroNGI project JRA.S.26, 2006

THANK YOU!