COMET-ENVISION Workshop Keynote

Information-Centric Networking: Overview, Current State and Key Challenges

Prof. George Pavlou
http://www.ee.ucl.ac.uk/~gpavlou/
Communications and Information Systems Group
Dept of Electronic & Electrical Engineering
University College London, UK
Internet-based Content

• The Internet plays a central role in our society
  – Work and business, education, entertainment, social life, …

• The vast majority of interactions relate to content access
  – P2P overlays (e.g. BitTorrent, eMule, live streaming)
  – Media aggregators (e.g. YouTube, GoogleVideo)
  – Over-the-top video (e.g. Hulu, iPlayer)
  – Content Delivery Networks (e.g. Akamai, Limelighet)
  – Social Networks (e.g. Facebook, MySpace)
  – Photo sharing sites (e.g. Picasa, Flickr)

• New approaches are required to cater for the explosion of video-based content and for creating novel use experiences

• Continue throwing more capacity cannot work anymore!
**Expected IP Traffic Growth 2009-2014**

- According to the Cisco Visual Networking Index 2010:
  - Global IP traffic will quadruple every year until 2014
  - 64 exabytes per month is expected by 2014
  - Global Internet video traffic will surpass P2P traffic in 2010
  - Approx. 55% of the overall Internet traffic will be video by 2014
  - Global mobile data traffic will double every year until 2014
  - Approx. 65% of the overall mobile traffic will be video by 2014

- Infrastructure evolution needs to be partnered with novel approaches and associated business models
Expected IP Traffic Growth 2009-2014 (cont’d)

Exabytes per Month

- Online Gaming
- Video Calling
- VoIP
- Web and Data
- File Sharing
- Internet-Video-to-TV
- Internet Video

2009: 0
2010: 32
2011: 65
2012: 27%
2013: 46%
2014: 15%

Total Exabytes per Month: 65
P2P Overlays and CDNs

• **Peer-to-Peer (P2P) Overlays**: started from file sharing and evolved to multicast-streaming real-time video through overlay nodes
  – Self-organized, adaptive, fault-tolerant content distribution
  – Content object names are resolved to candidate peers

• **Content Distribution Networks (CDNs)**: pioneered by Akamai, they support anycast by choosing the most appropriate (i.e. topologically close) content replica to maximise user QoE
  – Use DNS-based redirection
  – Mostly offline content replica placement based approach

• Both P2P overlays and CDNs make the content server transparent for accessing “named content”, allowing access to cached copies
  – A first step towards an information-oriented communication model
Current Content Naming and Security Problems

• Content URIs are effectively object locators, resolving to the IP address of the hosting server i.e. location-dependent
  – Binding breaks when object moves or when site changes domain
  – Replicas all have different URIs, appearing as different objects
    – Unique, persistent, location-transparent naming is required

• The current Internet security model provides connection endpoint as opposed to content object authentication
  – Once an object copy has left the origin server, its authenticity cannot be verified anymore, which is a problem for caching
  – In an information-centric approach it is important to be able to authenticate content objects as opposed to connection endpoints
Current Paradigm Shift

Node-centric design: sharing network resources

Information-centric design: content access and distribution
Information-Centric Networking

- Given that users are interested in named content and not in node endpoints, is there a clean architectural approach to address the relevant requirements?
  - All encompassing instead of add-ons to specific domains
  - Provide an enhanced P2P/CDN-like paradigm within the network

- **Information-Centric Networking (ICN)** targets general infrastructure that provides in-network caching so that content is distributed in a scalable, cost-efficient & secure manner
  - Receiver-driven model – subscribe/get objects of interest
  - Support for location transparency, mobility & intermittent connectivity
  - Needs also to be able to support interactivity (e.g. voice) and node-oriented services (e.g. telnet)
Flash-Crowd Effect Due to Content Popularity

Popular content

ISP

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Scalable Cache-based Content Distribution

Popular content

“Time-shifted multicast” model

ISP
Caching Approaches

- Two general approaches: offline proactive (as in CDNs) and dynamic reactive (as in P2P overlays)
- Different options for the granularity of caching:
  - Object-level: caching whole information objects
  - Chunk-level: caching information chunks
  - Packet-level: caching individual packets (yes, this is a possibility!)
- Intelligent decision making is required w.r.t. what/where to cache/drop for maximizing gain
Information Objects

Relationship between information object, its representations and copies of the latter – all these share the same ID
Content Naming Issues

- Information objects are identified by location-independent IDs, with all the object copies sharing a unique ID.
- Given that in ICN security applies to information, object IDs in many ICN architectures incorporate security:
  - Non human-friendly IDs
  - Human-friendly names can also be associated with IDs.
- Flat, hierarchical or combined ID schemes.
- Scalability a concern in particular for flat naming schemes.
Naming Scalability

• A vast amount of information objects
  – Currently more than 1 trillion unique URLs (Google 2008)
  – 26 billion web pages (www.worldwidewebsize.com)
  – 119 million 2\textsuperscript{nd} level domain names in the DNS (end of 2010)

• Possible to operate DHTs with >2 million nodes
  – For 1000 trillion objects \((2^{15})\) with 100 bytes per record and no replication, 50Gb of DRAM is necessary
  – With 10 times replication and 1Kb per record 5Tb of RAM is necessary and can be supported with SSD, albeit expensively
  – Early experiments indicate 100ms per resolution is possible
Name Resolution and Routing Issues

- Two general approaches: **two-phase** and **one-phase**
  - Approach heavily dependent on namespace/ID properties
- In the two-phase approach, name resolution takes place first by mapping the ID to locators, with the most suitable one selected (anycast)
  - Content name resolution servers are required e.g. DNS++
  - Routing to the content source and subsequent content delivery simply use locators i.e. IP addresses
  - The locator is typically not visible to the application which uses a `Get(ID)` API abstraction
Name Resolution and Routing Issues (cont’d)

- In the one-phase approach, in-network content ID-based routing to the source is used
  - Content-ID based routing uses a “structured” ID, content state in the network (“breadcrumps”) and includes anycast
- The content delivery path can be the reverse path of the request or (user) ID-based routing can be used

- Different characteristics of the two approaches:
  - The two-phase one can be *incrementally deployed* over the current Internet given that locator-based routing is used
  - The one-phase ID-based routing is *radical*
Key Projects

- **UCB DONA** - Data-Oriented Network Architecture
- **4WARD/SAIL NetInf** - Network of Information
- **PSIRP/PURSUIT PubSub** - Publish Subscribe Routing
- **Xerox PARC CCN** - Content-Centric Networking
- **COMET CMP** - Content Mediation Plane

- Also other projects and research efforts worldwide
Data-Oriented Network Architecture (DONA)

- Originated at University of California Berkeley
  - Follow on to the Routing on Flat Labels (ROFL) first effort
- One-phase approach through Resolution Handlers (RHs) that exhibit a hierarchical structure
  - IDs are also hierarchical and incorporate security
  - Query/Response packets, with the closest object copy returned
  - In pure data-oriented fashion, delivery uses the reverse path

- DONA was the first ICN approach and has had significant influence on other approaches
Network of Information (NetInf)

- Started in the EU project 4WARD and is currently continued in the follow-on project SAIL
- Both one-phase and two-phase approaches
  - One-phase approach uses a hierarchy of DHTs
  - Two-phase approach uses “late locator construction” that targets dynamic environments with high mobility

- Significant European industry support
Publish Subscribe Routing

- Started in the EU project PSIRP and is currently continued in the follow-on project PURSUIT
- Two-phase resolve/retrieve model but a radical revolutionary approach
  - Resolvers are called Rendezvous points
  - After content matching resolves to a rendezvous ID, Subscription/Data packets fetch the content
  - Data packets use source routing with Bloom filters

- A high-level data-oriented architecture with potentially different instantiations (two current implementations)
Content-Centric Networking (CCN)

- Originated by Van Jacobson
- One-phase approach through *Interest/Data* packets flowing in a “reverse ack/data TCP-style”
  - Data packets are cached *everywhere* along the delivery path as they may be useful to other consumers
  - Least Recently Used (LRU) packet discard policy implements the “time-shifted multicast” model
  - Hierarchical naming scheme

- CCNx implementation is publicly available while the recently started NSF NDN project looks at more general CCN-related research issues
CCN-like In-Network Content Caching
Content Mediation Plane (COMET)

- EU project COMET
- Mediation plane “tightly coupled” with the network, resolution through Content Mediation Servers (CMSs) and delivery influenced by them
  - Two-phase decoupled approach uses DNS-like hierarchy of CMSs
  - One-phase coupled approach follows DONA-style resolution but adds information scoping/filtering
  - Both support anycast based on server load and network conditions
  - Delivery can use paths configured by the CMSs for better user QoE

- Evolutionary approach with minimal network modifications for better-than-best-effort content delivery
The content mediation plane may be also implemented in a radical manner within the network.
Future Internet Requirements…

- Better mobility support
  - Impact on addressing
- More flexible and reliable routing
  - Multi-path as opposed to current single path
- Better service-aware resource control
  - Service-aware mapping of traffic to resources => better QoE
- Better security and spam protection
  - Possibly other paradigms of identity/presence, e.g. default-off
…to which ICN could be the Answer

• ICN can deal with:
  – **Mobility** - content/user ID not bound to location
  – **Multi-path routing** – anycast through in-network caching
  – **Content-aware resource mapping** – using metadata
  – **Security** – integrated with the content
  – **Spam protection** - receiver-driven model
Key ICN Challenges

• **Naming** – intricately linked with resolution and ID-based routing, so essential to get it right
• **Scalability** - cope with at least $10^{15}$ information objects
• **Security** per object, *privacy* concerns given that the network “sees” the information objects, *spam control*
• **Manageability**, real-time usage data to drive e.g. opportunistic caching through closed loop control
• **Incremental deployment**, the ability to gradually migrate without obliterating existing IPv4/v6 infrastructure
• **Incentives** and **novel business models** to engage involved stakeholders
ICN Could Make This Much Better!

- ICN can provide tangible benefits to most stakeholders in an Internet that will be engineered according to its prevailing use
- Pave the way towards new media applications and user experiences