IEEE ISCC 2011 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, Limelight)
  - 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!**
The Emerging Content-Oriented Internet

IPv4/IPv6 Backbone

Content access

ISCC'2011 Keynote - 3
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

• It will take over 2 years to watch the amount of video that will cross global IP networks every second in 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

2009
2010
2011
2012
2013
2014

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

ISCC’2011 Keynote - 5
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

ISCC’2011 Keynote - 8
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
Scalable Cache-based Content Distribution

“Time-shifted multicast” model
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!)

• Coordinated 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 2nd 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
  – 4WARD/SAIL experiments indicate 100ms per resolution is possible

• Aggregation at the publisher level may possibly allow a DNS-like solution
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 (“breadcrumbs”) 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
Application Programming Interface

• All ICN approaches use information-centric APIs
  – Location-independence a key feature
  – A pull-based or receiver-driven approach
• Get,ID) and Put(ID) are the key primitives
  – Get/Subscribe can even request content of certain type which is not yet in place
  – Put/Publish places content in the global content space

• The publish/subscribe API semantics has led researchers to also consider a pub/sub routing paradigm
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, content 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
  - Cache-aware transport protocol
- 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”
  - 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
- Two-phase approach, with resolution through Content Mediation Servers (CMSs) and delivery influenced by them
  - DONA-style resolution but adds information scoping/filtering and also anycast based on server load and network conditions
  - Delivery can use paths configured by the CMSs for better user QoE
  - Proactive caching at the network-edge (“content-aware routers”)

- Evolutionary approach with minimal network modifications for better-than-best-effort content delivery
The content mediation plane can be also implemented in a radical manner within the network.
Coupled Content Resolution and Routing in COMET

• Follows domain-level *hop-by-hop gossip-like communication*
  – Content resolution is driven by ISP business relationships, BGP routing and content consumer preferences
  – Requires a content ID based on aggregatable labels which can be sequentially ordered
• *Register/Publish* and *Consume* messages
• Content can be only published to specific areas using INCLUDE e.g. BBC iPlayer content to be only available from within the UK
  – The same applies to content consumption i.e. from specific areas
• Pre-established state in the network is required (“breadcrumbs”)

*ISCC’2011 Keynote - 27*
Content Publication in COMET

X1→A.A
X2→A.B

Publish(A.A, X1)

X1→A.A.A
X3→S3

Publish(A.A.A, X1)

S1::Register(*, X1) Wildcard Mode
S3::Register(INCLUDE(A.A), X3) Scoped Publication

X1→S1
X2→S2
X4→S4
X4→S5

S2::Register(*, X2) Multi-homed

Peering link
Provider-customer link

Content aggregation example

ISCC'2011 Keynote - 28
ICN Research Group in the IRTF

- Proposal in the forthcoming IETF to bring ICN researchers together, exchange research results, create a common ICN framework and feed input to existing IETF WGs
  - Longer term plan an IETF ICN WG
- Possible research topics to be addressed:
  - ICN naming schemes
  - Scalable name resolution for flat names
  - Scalable routing
  - Protocol framework
  - Security
  - API / application design
  - Business, legal and regulatory framework
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