Information-Centric Networking

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EU-FP7 Project SAIL
Trends

• Imminent traffic volume explosion
  – Video distribution as (literally) a killer application
  – Resource management issues unsolved today

• Information-centric communication is applied to individual applications
  – CDNs: transparent redirection of requests to topologically close servers
  – P2P: location-agnostic exchange of content chunks
  – Machine-to-Machine Communication

• Information-centric research activities
  – 4WARD NetInf: Information-centric networking with a flat naming scheme
  – CCN: Content-centric networking with a hierarchical naming scheme
  – PSIRP: Publish/subscribe for Internet-level communication
  – DTN: Delay-Tolerant Networking based on Bundle protocol

Cisco Forecasts 3.6 Exabytes per Month of Mobile Data Traffic by 2014
**Information-Centric Networking**

Today’s Internet

- Focus on nodes

Evolution:
- Web
- CDN
- P2P

In today’s Internet, accessing information is the dominating use case!

Future Information-centric Network

Focus on information objects and real world objects

SCALABLE & ADAPTIVE INTERNET SOLUTIONS
Web-based Information Retrieval

Web caching infrastructure

DNS request

HTTP response

HTTP request

Web browser

DNS infrastructure

Origin servers

IP forwarding infrastructure
ICN-based Information Retrieval

Web browser

Original Content “XY1”

Owner “Joe”

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Challenges for ICN

Naming of information objects

- Unique object identification
- Secure binding of names to objects and owners
- Names as keys for request/content routing
Challenges for ICN

Routing and Name Resolution

- Want to locate “best” copy of named objects
- Need a mapping/link between named objects and underlying network topology
- Want to support mobility and multi-homing
- Name-based forwarding: forward on names (based on corresponding routing protocol)
- Name resolution: resolve names to locators (leveraging underlying forwarding and routing infrastructure)
Challenges for ICN

**Transport**

- Reliable, congestion- and flow-controlled transport of objects from a given location to interested receiver
- Good support for caching, multi-path, disruption tolerance
- Options
  - Receiver-oriented transport
  - End-to-end vs. hop-by-hop
Challenges for ICN

Security

- Host-based e2e security no longer applies
- Receiver is agnostic to object location
- Objects can be replicated, distributed without owner control
- Receiver (and network elements) MUST be able to
  - Validate name-content binding
  - Validate object integrity
  - Validate object-owner binding
Summary of Challenges

• Architectural / Technical
  – Naming: properties of a naming system for ICN
  – Routing / resolution: finding suitable object copies
  – Transport: moving information objects
  – Security: object/content security instead of connection security

• Operational / organizational
  – Resource and performance management
  – Federating network domains

• Economic
  – Role of operators
  – Changes in communication paradigms: receiver-orientedness
ICN Design Space

• Different approaches to ICN
  – With different implications for naming, routing, transport, security

  • Name-based routing
    – Object names are used for forwarding decisions
    – Network is able to route and forward directly on names
    – Only next-hop names are resolved into lower-layer locators

• Name resolution and locator-based forwarding
  – Names are directly resolved to locators (of object caches)
  – Forwarding based on locators in the lower layer

• Plus hybrid variants of these approaches…
Name-based Routing

Overview
- Receivers send *Interest Packets* for named content to (selected) neighbor nodes
- Nodes have routing information to decide on next hop for Interest Packets
- Interest Packets reach a node with (a copy of) the named object
- Object (chunks) are (often) returned on the same path
- Nodes (often) have to maintain Interest tables
Name-based Routing

- Nodes need to know where to forward Interest Packets to
- Requires a routing protocol that distributes information about where to find what named content
- Scalability through aggregation of names (name prefixes)
- No resolution to end-to-end-relevant locators required
Name-based Routing

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Naming
- Fits well with hierarchical naming scheme
- E.g.: com/example/video/a.mp4 com/example/audio/b.mp3
- Content providers register content name (prefixes)
- Requests for fully qualified names match aggregated prefix
- Names likely to have some topological relevance
Name-based Routing

- Different from e2e TCP
- In overlay approach: hop-by-hop transport could be employed
- For L3 approach: receiver-oriented transport is a good candidate
  - Receiver requests packets over one or multiple interfaces
  - Requests are answered by intermediate nodes (caches) or origin node
  - Receivers control flow and other transport functions
Protocol Stacks in Name-based Routing ICN

Internet Hour Glass
- SMTP, HTTP, RTSP, SIP
- TCP, UDP, RTP
- IP
- Ethernet, WLAN
- Copper, Fiber, Radio

Name-Based Routing ICN
- Object / Stream Delivery
- Security
- Named Content Chunks
- IP, UDP, P2P
- Copper, Fiber, Radio
- Security
- Named Content Chunks
- IP, UDP, P2P
- Copper, Fiber, Radio
Naming Stacks in Name-based Routing ICN

Internet Naming

Search
- URIs
- DNS Names
- IP Addr.
- MAC-Addr. etc.

Naming in Name-Based Routing

Search
- Persistent names
- Object (chunk) names
- IP Addr., UDP endpoint addr., MAC-Addr. etc.
Name-based Routing Issues

- **Forwarding state in routers**
  - Often, routers have to maintain interest state
  - Could do without, but with some inefficiency

- **Agility with respect to topology changes**
  - When names are tied to network/organizational topologies, mobility of sources becomes costly
  - Names will change
    - For instance: source moves from net/isp1 to net/isp2
  - Can also lead to routing state explosion (depending on employed routing system)

Can be addressed by another naming layer and a name resolution service
Name Resolution-based ICN

• Layer of indirection – resolving names to
  – Other names
  – Locators
  – Rendezvous points

• Names: persistent information identifiers
  – Independent of network topology, copy locations etc.
  – Identifiers that are used by applications, receivers, content owners
  – But not necessarily by the network
Name Resolution-Based ICN

SCALABLE & ADAPTIVE INTERNET SOLUTIONS

- Get XY1
- Resolve XY1
- XY1 => [a.b.c.d]
- Content “XY1” at [a.b.c.d]
- Owner “Joe”
Name Resolution-Based ICN

Name resolution layer

Forwarding layer

SCALABLE & ADAPTIVE INTERNET SOLUTIONS

2010-11-24 24
Name Resolution-Based ICN

Overview
- Users request content by name
- Name is resolved to a locator (either by receiver or “in the network”)
- Name resolution system has a mapping of [name => locator]
- Receiver retrieves object from given node
- Forwarding layer employs independent routing system
**Name Resolution-Based ICN**

- **Routing**
  - Request routing can be part of resolution (DHT)
  - Resolution can be multi-step (DNS, multiple DHTs)
  - Actual routing takes place on forwarding layer

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**SCALABLE & ADAPTIVE INTERNET SOLUTIONS**

- **Web browser**
  - Get XY1
  - XY1 from [a.b.c.d]

- **Content “XY1” at [a.b.c.d]**
  - Owner “Joe”

- **Routing**
  - Plus topology-based routing

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**Name resolution layer**

- **Resolve XY1**
  - XY1->[a.b.c.d]

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**Forwarding layer**

- **GET XY1 from [a.b.c.d]**
  - a.b.c
  - a.b.b
  - a.c.b
  - a.c.c

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Name Resolution-Based ICN

- Information object names are not tied to topology
- Can be persistent
- Do not need to be aggregate-able (depending on resolution system)
- Can provide additional functions such as secure naming

Plus topology-based routing

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NetInf Naming Scheme Overview 1

- Information Object (IO) = (ID, Data, Metadata)
- Each IO has an owner
- All equivalent copies have the same ID
  - This might include different versions

<table>
<thead>
<tr>
<th>Type</th>
<th>A=Hash(PK_{IO})</th>
<th>L={attributes}</th>
</tr>
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<tr>
<td>Security Metadata</td>
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<td></td>
</tr>
<tr>
<td>Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SK_{IO}</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Naming Stacks

Internet Naming
- URIs
- DNS Names
- IP Addr.
- MAC-Addr. etc.

Name-Based Routing Naming
- Persistent names
- Object (chunk) names
- IP Addr., UDP endpoint addr.
- MAC-Addr. etc.

Name Resolution-Based Naming
- Application-specific names
- Object names
- Topological Names
- IP Addr., UDP endpoint addr.
- MAC-Addr. etc.
Name Resolution-Based ICN

Name resolution layer

Forwarding layer

Resolve XY1

XY1=>[a.b.c.d]

Plus topology-based routing

Transport
- Can be e2e transport between receiver and located node
- Support of caching not straight-forward

SCALABLE & ADAPTIVE INTERNET SOLUTIONS

Web browser

Get XY1

Content "XY1" at [a.b.c.d]

Owner "Joe"
Name Resolution-Based ICN Issues

• Two-step approach
  – Explicit resolution step required

• Separating data transport from requests
  – On-path caching not straightforward

• Scalability and performance of resolution system
  – Resolution system has to be able to resolve all object names
  – Different possible implementations
Options For Way Forward

Name-based routing and Name resolution layer

GET XY1@Y

Resolve XY1

GET XY1 from Y/B/A

GET XY1 from [1.2.2.1]

SCALABLE & ADAPTIVE INTERNET SOLUTIONS

Web browser

GET XY1

Domain X

Domain Y

Content “XY1” at [1.2.2.1] in Domain Y

Owner “Joe”
Options For Way Forward

Name-based routing and Name resolution layer

Topography layer

Domain X

X/A

X/B

Content "XY1" at [1.2.2.1] in Domain Y

Domain Y

Y/A

Y/B

Web browser

GET XY1

Resolve XY1

GET XY1 from Y/B/A

GET XY1 from [1.2.2.1]

Content "XY1" at [1.2.2.1] in Domain Y

Owner "Joe"

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Options For Way Forward

- **Hybrid Name-Based Routing & Resolution**
  - Object names without topological relevance
  - Global topology layer
  - Local domains with independent topology address space
  - Objects may not be resolvable in all domains => defer resolution (late binding)
  - Allow for shortest path routing and direct transport where possible
  - Allow for connecting incompatible addressing domains
  - Allow for non-permanently connected domains (Delay-Tolerant Networking)

- **Domain X**
  - a.c
  - a.h

- **Domain Y**
  - 1.2.2
  - 1.2.1

- **For Forwarding layer**
  - X/A
  - X/B
  - Y/A

- **Resolve XY1**
  - GET XY1 from Y/B/A
  - GET XY1 from [1.2.2.1]
Conclusions

- Information-Centric Networking: Different possible approaches
  - Name-Based Routing
  - Resolution-Based
  - (and hybrids)

- Need to understand implications and trade-offs
  - Scalability of Naming Resolution and Routing Systems
  - Effects of mobility

- SAIL Approach
  - ICN enabling interworking between different networking and addressing/naming domains: IPv4, IPv6, DTN
  - Persistent and secure naming as core concept

- Some interesting questions
  - Application-specific (human-friendly) names?
  - URIs and WWW hyperlinks?
  - Services and dynamic object in a Network of Information