Information-Centric Networking

6th GI/ITG KuVS Workshop on Future Internet

Leibniz Universität Hannover
2010-11-22

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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
Information-Centric Networking

Today’s Internet

Focus on nodes

Evolution

Web  CDN  P2P

Future Information-centric Network

Focus on information objects and real world objects

In today’s Internet, accessing information is the dominating use case!
Web-based Information Retrieval

Web caching infrastructure

DNS infrastructure

HTTP request

HTTP response

Web browser

Origin servers

IP forwarding infrastructure
Web-based Information Retrieval

Web caching infrastructure

Plus Inter-Cache Communication, CDN

DNS infrastructure

Plus DNSSec

IP forwarding infrastructure

Plus IP routing, ICMP, ARP, mapping to L2

Origin servers

HTTP request

HTTP response

Web browser
ICN-based Information Retrieval
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

Original Content "XY1"
Owner "Joe"
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

Web browser

OriginalContent "XY1"
Owner "Joe"
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

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

Transport
- Different from e2e TCP
- In overlay approach: hop-by-hop transport could be employed
- For L3 approach: receiver-oriented transport is 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
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 in-efficiency

• 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

[Diagram showing a network flow with name resolution and forwarding layers.]

Name resolution layer:
- Resolve XY1
- XY1 => [a.b.c.d]

Forwarding layer:
- Web browser
- Content “XY1” at [a.b.c.d]
- Owner “Joe”

Get XY1

XY1 => [a.b.c.d]
**Name Resolution-Based ICN**

Name resolution layer

```
| a.b  |
|      |
| GET XY1 |
| a.c  |
|      |
| a.b.c |
```

Forwarding layer

```
| Content “XY1” at [a.b.c.d] |
| a.b.c.d |
| a.b.b |
| a.c.b |
| a.b.c |
```

Web browser

```
Get XY1
```

Owner “Joe”

```
XY1 from [a.b.c.d]
```

**Plus topology-based routing**

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**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

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**Name Resolution-Based ICN**

**Name resolution layer**

- Get XY1
- Resolve XY1
- XY1 => [a.b.c.d]

**Forwarding layer**

- Web browser
- Content "XY1" at [a.b.c.d]
- Owner "Joe"
- XY1 from [a.b.c.d]

Plus topology-based routing
**Name Resolution-Based ICN**

- **Name resolution layer**
  - Resolve XY1
  - XY1=>[a.b.c.d]
- **Forwarding layer**
  - GET XY1 from [a.b.c.d]
  - XY1 from [a.b.c.d]
  - Content “XY1” at [a.b.c.d]

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

**Plus topology-based routing**
Name Resolution-Based ICN

**Names**
- 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

Web browser

Get XY1

Resolve XY1

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

Resolve XY1

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

Forwarding layer

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

XY1 from [a.b.c.d]

Name resolution layer

Resolves XY1

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

Plus topology-based routing
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>ID</th>
<th>Type</th>
<th>A=Hash(PK_{IO})</th>
<th>L={attributes}</th>
</tr>
</thead>
</table>

- Security Metadata
- Data
- SK_{IO}
Naming Stacks

Internet Naming

Name-Based Routing Naming

Name Resolution-Based Naming

Search

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

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

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

- Name resolution layer
  - Get XY1
  - Resolve XY1
  - XY1 => [a.b.c.d]

- Forwarding layer
  - GET XY1 from [a.b.c.d]
  - XY1 from [a.b.c.d]
  - a.b
  - a.c
  - a.c.b
  - a.b.b

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

- SCALABLE & ADAPTIVE INTERNET SOLUTIONS

- Web browser
- Owner “Joe”

Plus topology-based routing
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

Options For Way Forward

GET XY1

Resolve XY1

GET XY1 from Y/B/A

GET XY1 from [1.2.2.1]

SCALABLE & ADAPTIVE INTERNET SOLUTIONS
Options For Way Forward

Name-based routing and Name resolution layer

Get XY1

Web browser

Owner "Joe"

Domain X

Domain Y

Content "XY1" at [1.2.2.1] in Domain Y

GET XY1

Resolve XY1

GET XY1 from Y/B/A

GET XY1 from [1.2.2.1]
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)
ICN Hour Glass Waist

- Application-specific
  - Application-specific names
- Core ICN Elements
  - Object names
  - Topological Names
- Network-specific
  - IP Addr., UDP endpoint addr., MAC-Addr. etc.

Domain-specific
- Domain-local implementation of resolution systems
- Domain-local routing and forwarding
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