Information Centric Network (ICN): the post IP era

Somnuk Puangpronepitag, PhD
E-mail: somnuk.p at msu.ac.th

Information Security & Advanced Network (ISAN) Group
Faculty of Informatics, Mahasarakham University, Thailand.

http://isan.msu.ac.th
Agenda

• Background (What & Why?)
• Impact to us
• How does it work
• Research challenges
• What we have done
• Q&A + Discussion
Background: Network History and Evolution
Phase I: Circuit Switching (1970s) – Telephone system

The focus is on communication “PATH”.

Source: David Morgan (2015)

Phase II (current): **Packet Switching**

- Internet Protocol (IP) and Transmission Control Protocol (TCP) – Vinton Gray Cerf & Robert (Bob) Elliot Kahn (1973)
- The **focus** is on end “HOST”.
- **Point-to-Point** Communication – IP Addressing
Internet Growth

1983 (600 nodes [Claffy]), 1997 (16-20 million nodes [Paxson]), July 2017 (1,074,971,748 [ISC])
Source: http://www.internetworldstats.com
Inter Planetary Network

• IRTF Research Group: IPNSIG
• Setup (2003); The first phase progression (2013)
18 Oct 2013: NASA has successfully transmitted data between the moon and Earth, using laser beams sent from this device. The transmission set new communication records with download rates of 622 megabits per second.

Source: https://www.nasa.gov/sites/default/files/llcdfactsheet.final_.web_.pdf
Phase III (current + adapted): Content Distribution (or Delivery) Network (CDN)

Content Distribution (or Delivery) Network (CDN)

IP Network
Content Producer
Cache
Cache
Cache
Consumers
Consumers
Consumers

Youtube, Google, Facebook,
Akamai, Limelight Network,
Amazon CloudFront, Cloudflare,
Operator Carrier Exchange (OCX)

Hit: 1,285,020,651
CDN Techniques

• Reversed Proxy (caching)
• CNAME & Alias
• DNS-based request routing
• Domain Hosting
  • Domains are managed by CDN Operator
• Anycasting
• URL & HTML rewriting
• Global Server Load Balancing
• Dynamic metafile generation
Information Centric Network: Where -> What

- CDN = Using Middle-boxes to accelerate application and improve scalability!
- The focus is on “CONTENT” or “INFORMATION”.

(a) Conventional networking

(b) Information centric networking
Why not enough?

- So, CDN is good! Why not enough?
  - Proprietary, not yet standardised!
  - Security
    - Data Spoof?
    - Data Steal?
  - Other problems
    - ... that CDN is not enough!
Motivations to evolve
(1) Host Commu. ➔ Content Focus

• No more point-to-point communication
  • Don’t mind about the source addresses ✗
  • Maybe, NO NEED for IP Addressing

• Content Distribution is the main purpose!
  • Caching ✓
  • The network requirement are actually 
    content centric or information centric.
Classical TCP/IP Problems

TCP/IP care about Alice.com

Not focus on content??

A

B
ACTUALLY, Users identify their contents by names!

- File: https://drive.google.com/drive/folders/0B18sTaqaMQWFUW3SHpHVUs5QjQ
- Video: A New Way to look at Networking https://www.youtube.com/watch?v=gqGEMQveoqg
- Real-time video conference https://plus.google.com/u/0/events/cs84k48jjktpfthq907ubida6ps

- Contents are actually identified by their names.
- Name is more readable and easy to use than IP address.
The Change of Network Abstraction

• Host communication -> Content Distribution
• Where → What
• Named hosts → Named Contents

• Use router memory to cache the content
• Focus on Secure Content instead of Hosts
(2) TCP/IP overhead is a big hindrance!

- High data loss and large delay due to the TCP end-to-end window flow control ✗
- Maybe, no more TCP!
HTTP(S) is the narrow waist of the Internet!

IP, TCP and HTTP cause too much overhead!

Popa et al. “HTTP as the Narrow Waist of the Future Internet”, SIGCOM, 2010

(3) Mobility is essential!

• IP was designed initially for wired network!

• Wireless and Mobility are big matters.

• Oct 2016
  • Internet usage by mobile and tablet devices exceeded PC desktops & notebooks worldwide for the first time!
Particularly, ... for very fast mobility

- Can we be connected on these vehicles?

High Speed Train
574.8 km/hr

High Speed Aircraft
7,200 km/hr
So, should we make a revolution?

- 50 - 100 billion connected devices by 2020
- Over half of all IP traffic will come from non-PC devices.
- Three billion people will be online.
Phase IV : ICN Variants

- DONA (Data-Oriented Network Architecture)
  - Teemu Koponen et al. (UC Berkeley) – start 2006 – paper Aug 2007

- CCN (Content Centric Network)

- NDN (Named Data Networking)
  - Lixia Zhang (UCLA) -- US NSF Fund (Sep 2010) for future internet architecture project
  - [https://named-data.net](https://named-data.net)
  - Extending the CCN, code forked in 2013

- ICN (Information Centric Network)
  - Internet Research Task Force (IRTF ICNRG) -- 17 Apr 2012
  - [https://irtf.org/icnrg](https://irtf.org/icnrg)
ICN Variants

- NetInf (Network of Information)
  - D. Kutscher, S. Farrell, and E. Davies (Trinity College Dublin) -- Oct 2012
  - [http://www.netinf.org](http://www.netinf.org)

- POINT: IP Over ICN – the better IP
  - European ICN project : H2020-EU.2.1.1.3 (Jan 2015 - Dec 2017)

- PSIRP (Publish-Subscribe Internet Routing Paradigm)
  - European ICN project (2008-2010)
  - [https://dl.acm.org/citation.cfm?id=1839409](https://dl.acm.org/citation.cfm?id=1839409)

- and etc.
Benefits of ICN

• Scalability of data distribution
• Cost Efficiency for data distribution
• Better Mobility & Multi-homing support
  • For example, Voice-over CCN (VoCCN) can seamlessly connected even while moving.
• Hopefully, better Security
• Standardizing CDN

Source: Jacobson et al., Networking Named Content, CACM, 2012
So, let get rid of the TCP and IP layers!

- Crazy Idea ???
- Well ...

A similar idea was not accepted previously!
  - ALF (Application Level Framing)
  - by Clark & Tennenhouse 1990
Without IP & TCP, would it still be called the INTERNET?

Would this radical idea become true?
• Jacobson is one the fathers of TCP.
  • presented the idea of “network channels” at linux.conf.au (Jan 2006)

• A lot of Internet creators (such as Kahn) are supporting this idea.

• IRTF is also in!
IRTF ICNRG since April 2012

Information-Centric Networking Research Group  ICNRG

Background

Distributing and manipulating named information is a major application in the Internet today. In addition to web-based content distribution, other distribution technologies (such as P2P and CDN) have emerged and are promoting a communication model of accessing data by name, regardless of origin server location.

In order to respond to increasing traffic volume in the current Internet for applications such as mobile video and cloud computing, a set of disparate technologies and distribution services are employed that employ caching, replication, and content distribution in different specific ways. These approaches are currently deployed in separate silos – different CDN providers and P2P applications rely on proprietary distribution technologies. It is not possible to uniquely and securely identify named information independently of the distribution channel, and the different distribution approaches are typically implemented as an overlay, leading to unnecessary inefficiency.

Information-centric networking (ICN) is an approach to evolve the Internet infrastructure to directly support this use by introducing uniquely named data as a core Internet principle. Data becomes independent from location, application, storage, and means of transportation, enabling in-network caching and replication. The expected benefits are improved efficiency, better scalability with respect to information/bandwidth demand and better robustness in challenging communication scenarios. These concepts are known under different terms, including but not limited to: Network of Information (NetInf), Named Data Networking (NDN) and Publish/Subscribe Networking.

ICN concepts can be applied to different layers of the protocol stack: name-based data access can be implemented on top of the existing IP infrastructure, e.g., by providing resource naming, ubiquitous caching and corresponding transport services, or it can be seen as a packet-level internetworking technology that would cause fundamental changes to Internet routing and forwarding. In summary, ICN is expected to evolve the Internet architecture at different layers.
Internet Standard Organizations

Internet Society (ISOC)

Internet Architecture Board (IAB)

Internet Engineering Task Force (IETF)
  - Internet Engineering Steering Group (IESG)
    - Working Group #1
    - Working Group #2
    - Working Group #3

Internet Research Task Force (IRTF)
  - Internet Research Steering Group (IRSG)
    - Research Group #1
    - Research Group #2
    - Research Group #3

Source: http://www.tcpipguide.com/free/t_InternetStandardsOrganizationsISOCIABIESGIETFIRSGI.htm
Information Centric Network (ICN)

The New Concept to Learn and to Create

A Big Impact on Network Technologies!!
ICNRG (started 2012)
So far .... 2018

Half way through ...
Applications

- **VoCCN** -- A version of VoIP
- **RTC** over NDN: NDN Video
- **NFD home routers** -- NDN-OpenWrt, NDN-DD-WRT
- **Cisco ASR9000 router** >20Gbps
- **Hadoop** on NDN,
- **NDN-Raspberry Pi**,  
- **NaNET**, **ACT**, **FileSync(p2p)**
**Application Development Libraries**

- NFD
- NDNLPv2 -- Shi & Zhang 2016 (Link layer)
- NDN-CCL,
- PyCCN,
- NDN-ChronoSync,
- NDN-Js,
- NDN Lighting (NDN for SCADA),
- NDN V2V, {Vehicular Adhoc Network: VANET}
- NDN Transducer
Impact to our Network Education/Research

- CDN would be standardized.

- What if IP & TCP will be gone!!

- Should we also contribute to the born of the future internet?
How does it work?
The Current Internet Vs. ICN

<table>
<thead>
<tr>
<th>the current Internet</th>
<th>ICN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sender</td>
<td>Content Provider</td>
</tr>
<tr>
<td>Receiver</td>
<td>Content Consumer</td>
</tr>
<tr>
<td>Host to Host</td>
<td>Service Access/Information Retrieval</td>
</tr>
<tr>
<td>Host Name</td>
<td>Content Name</td>
</tr>
<tr>
<td>Explicit Destination</td>
<td>Implicit Destination</td>
</tr>
<tr>
<td>Secure Channel Server Authentication</td>
<td>Integrity &amp; Trust on Content Delivery</td>
</tr>
</tbody>
</table>
Host Centric to Content (information) Centric

- Naming scheme is human-readable.
- Hierarchically structured
Layering

NDN over TCP/IP

NDN over Link-layer
Data Units

<table>
<thead>
<tr>
<th>IP</th>
<th>Src IP</th>
<th>Dst IP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>172.16.20.114</td>
<td>128.252.87.149</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NDN</th>
<th>Name</th>
<th>Interest / Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/ndn/th/ac/msu/info</td>
<td></td>
</tr>
</tbody>
</table>
Focus on Data

Interest → data
Operation Model
Node Model

- CS
- PIT
- FIB
- Faces
CS | PIT | FIB

Content Store

<table>
<thead>
<tr>
<th>Name</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>/parc.com/videos/WidgetA.mpg</td>
<td>v3/s0</td>
</tr>
</tbody>
</table>

Pending Interest Table (PIT)

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Requesting Face(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>/parc.com/videos/WidgetA.mpg</td>
<td>v3/s1</td>
</tr>
</tbody>
</table>

Index

<table>
<thead>
<tr>
<th>ptr</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td></td>
</tr>
</tbody>
</table>

FIB

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Face list</th>
</tr>
</thead>
<tbody>
<tr>
<td>/parc.com</td>
<td>0, 1</td>
</tr>
</tbody>
</table>
NDN Interest

Interest packet

Content Name

Selector
(order preference, publisher filter, scope, ...)

Nonce

Diagram:

- Interest
  - Content Store
    - Data
  - Pending Interest Table (PIT)
    - add incoming interface
  - FIB
    - forward
      - drop or NACK
NDN Data
NDN building block

- Data Dissemination
- Intelligence Routing
- Security

Interest and Data processing in NDN
Ceng Yi and colleagues, UCLA, SIGCOM 2012.
Security Model

NDN Chain of Trust

- **Key-Signing-Key (KSK)**
  - sign keys belonging to the same identity
- **Data-Signing-Key (DSK)**
  - sign data generated by the identity
  - sign keys belonging to other identities
Identity Management

/ndn/DSK-1

/ndn/ucla.edu/KSK-1 /ndn/ucla.edu/KSK-2
/ndn/ucla.edu/DSK-11

/ndn/ucla.edu/yingdi/KSK-1
/ndn/ucla.edu/yingdi/DSK-13
/ndn/ucla.edu/yingdi/chronshare/KSK-3

chronoshare
macbook

/ndn/ucla.edu/yingdi/DSK-14
/ndn/ucla.edu/yingdi/chronshare/KSK-5

chronoshare
mac
Research Challenges
PKI on ICN??

• Any points of Failure
• Trusted turn Evil
• 2011: DigiNotar, Comodo
• 2014: India CCA
• 2015: Symantec
• 2016: StartSSL
• Feb 2015: Lenovo Superphish
• Nov 2015: Dell Rogue CA
### NDP for ICN??

<table>
<thead>
<tr>
<th>Physical</th>
<th>Link-layer</th>
<th>IP</th>
<th>ARP</th>
<th>TCP</th>
<th>UDP</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>

- **ARP** (Address Resolution Protocol) – ipv4
- **NDP** (Neighborhood Discovery Protocol) – ipv6
- **DHCP** (Dynamic Host Configuration Protocol)

**NDN over TCP/IP**

**NDN over Link-layer**

<table>
<thead>
<tr>
<th>Application</th>
<th>NDN</th>
</tr>
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<tbody>
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<td></td>
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</tbody>
</table>

**NDN**

**IP**

**ARP**

**TCP**

**UDP**

**Application**

**NDN**

**Link-layer**

**Physical**

**NDN over TCP/IP**

**NDN over Link-layer**
Problems

• Multicast/Broadcast Issues
  • Currently, broadcasting over a specific multicast group for the NDN link-layer
    • 01:00:5E:00:17:AA
  • Causing traffic congestion
  • This is because there is no ARP or NDP!
Problems (2)

• MTU (Maximum Transfer Unit) Issues
  • MTU matters for fragmentation & reassembly process
  • Overhead & Transmission Efficiency
  • NDNLP MTU mismatch causes failure!
  • FIGOA uses minimum MTU, suffering the overhead.

• Security Issues
  • ARP spoofing/poisoning in IP network can reborn in NDN!
Other Recent Research

● Routing
  o NFD@UCLA
  o NLSR, SIGCOM 2013
  o Scalable routing schemes ??

● Caching
  o NDN forwarding plane (Concept), Washington
  o Caching strategies

● Congestion Control

● QoS approaches
Other Recent Research (2)

- **Security and Privacy**
  - scoping of information objects and access control to them
  - Cache Poisoning
  - PKI enhancement/replacement

- **Application Library**
  - Eg., NDN-Js ....
  - WEBRTC on NDN
  - Integrating NDN with SDN (Software Defined Network)

- **NDN Link Layer**
Start doing something..

Many thanks go to

Newton Fund from UK Royal Society

Mahasarakham University
School of Computing, University of Leeds
Office of the Higher Education Commission, Thailand

PhD students in ISAN Research Group
Implementation

• Two possible tools
  • CCNx, developed by PARC
    • Packet binary
    • Source code: $2,995
  • NFD, developed by NDN community
    • Open source

• We choose to extend ideas on NDN!
Experimental Tools

• Simulation
  • NS3

• Emulation
  • Use the virtualization technology
  • CORE (Common Open Research Emulator)

• Network Testbed
  • Our own Testbed
  • NDN Bone (NDN Testbed)
Our Testbed on the research case

Core Emulator
Link-layer network

/ndn/th/ac/msu/isan

Internet
NDN Testbed

NDN Testbed (26 nodes, 66 links with NLSR costs)

http://www.arl.wustl.edu/~jdd/ndnstatus/ndn_prefix/tbs_ndnx_new.html
http://ndnmap.arl.wustl.edu/
Network Setting

- Our NDN prefix
  /ndn/th/ac/msu/isan
• MSU, SRRU are our two nodes on NDN Testbed.

• We are among the first three nodes of South East Asia.
As of Sep’17

4 SEA nodes

MSU, SRRU, UI, UUM
Thank you!

Q&A
or
any discussion