Information-Centric Networking for Multimedia Dissemination & the Internet-of-Things

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Outline

- Pub-Sub Internetworking (PSI): overview & unique features
- Other ICN research projects
  - I-CAN: Information-Centric Access Networks (GR)
  - POINT: IP Over ICN - The Better IP? (EU H2020)
- ICN for the IoT: observations and vision
- CoAP over ICN
  - CoAP over PSI / for POINT
  - CoAP over CCN
- MMlab Research & People
Internet History and Outlook

- At the **beginning**…
  - cooperation; no competition…
  - no commercial traffic! (…flames…)
  - endpoint-centric services/E2E
- **Now**…
  - Content distribution…
    - >70% of traffic is video↑
  - Overlays… DPI by ISPs…
  - Trust? Endpoint trust?
    - viruses, phishing, DoS attacks…
  - E2E?
    - NAT, firewalls, middleboxes, CDNs
  - The sender has the power…
  - Tussles…
    - e.g.: privacy vs. accountability

- **Connecting Wires**
  - the past…

- **Interconnecting Computers**
  - the current Internet
  - evolutionary development
  - … started decades earlier

- **Interconnecting Information**
  - the Future Internet
  - ‘revolutionary’ research
  - tussle resolution at or near run-time
  - Trust-to-Trust principle

towards… Information-Centric Networking

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Content Centric Networking (CCN) / Named Data Networking (NDN)

- CCN
  - @ PARC
- NDN /2
  - NSF
  - UCLA, ...

- CR A
  - PIT Name Requested
    - /aueb.gr/ai/new.htm Subscriber
  - CS Name Data
    - /aueb.gr/ Data

- CR C
  - FIB Name Next
    - /aueb.gr/ CR C
    - /aueb.gr/cs CR B
  - PIT Name Requested
    - /aueb.gr/ai/new.htm Subscriber
  - CS Name Data
    - /aueb.gr/ Data

- CR B
  - PIT Name Requested
    - /aueb.gr/cs Publisher 2
    - /aueb.gr/ Data

- Publisher 1
  - PIT Name Requested
    - /aueb.gr/ Publisher 1
    - /aueb.gr/ Data

- Publisher 2
  - PIT Name Requested
    - /aueb.gr/cs Publisher 2
    - /aueb.gr/ Data

- Link
- (1-3) Interest Message
- (4-6) Data

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MobilityFirst

- 160 bit Globally Unique Identifier (GUID)
  - for each information object, device, service
- GUID translated into a network address (IP) through a Global Name Resolution Service (GNRS)
- publishers register GUIDs to GNRS and subscribers perform requests/queries
- routing takes place based on the network address
Our ICN-related Research Projects

- **PSIRP**: Publish Subscribe Internet Routing Paradigm
  - FP7 ICT STREP, 2008-2010
    - the basis
    - focus on (inter)-networking

- **PURSUIT**: Publish Subscribe Internet Technologies
  - FP7 ICT STREP, 2010-2013
    - extending, above & below the Internet layer
    - optical, wireless, mobility, transport...

- **Euro-NF**: Anticipating the Network of the Future—From Theory to Design
  - FP7 ICT Network of Excellence, 2008-2012
    - ASPECTS, GOVPIMIT, E-key-nets

- **EIFFEL**: Evolved Internet Future For European Leadership
  - FP7 ICT SSA, 2008-2010; Think-Tank continued
  - June 2011 TT @ MIT: *Information-Centric Networking*

- **φSAT**: The Role of Satellites in Future Internet Services
  - European Space Agency funded
  - 2011-2013

- **I-CAN**: Information-Centric Future Access Networks
  - NSRF (Greece), 2014-2015

- **POINT**: **iP Over ICN** - the betTer IP
  - H2020 ICT STREP, 2015-2017

- **SatNEx IV**, ESA, 2015-2016
  - Y1 WI 5: ICN over MAC
  - Y2, WI 4: Caching
Publish-Subscribe Internetworking (PSI) Key Functions and Components

- **publish – subscribe – rendezvous**
  - Rendezvous **ID: hash of content** (/name)
    - asynchronous and multicast
    - restores the imbalance of power sender/receiver(s)
    - + Scope ID: aggregation, policies…

- **PSI Basic Functions: RTF**
  - **Rendezvous**: Matches *publications* with *subscriptions* and initializes forwarding
  - **Topology**: Monitors the network and creates information delivery paths
  - **Forwarding**

PSI Identifiers

1. Publish / Subscribe
2. Meta
3. Data
   - Application Identifiers (AId)
   - Rendezvous Identifiers (RId)
   - Forwarding Identifiers (FId)

Diagram:
- Scope Identifiers (SId) associated with...
- Includes...
- Resolved to...
- Define...
- Network Transit Paths

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Publish-Subscribe Internetworking (PSI)
On-path caching

- Very lightweight
  - bypasses rendezvous network
- Good for
  - multicast error control
Off-path caching

- Uses the rendezvous network
  - to serve more users
- Good for
  - local (access network) caching
Content replication

- The rendezvous network chooses the best source

- Good for CDN-like proactive replication
Proactive Selective Neighbor Caching for enhancing Mobility Support in ICN

- Delay can be reduced by using proxies to pre-fetch and cache data
  - Mobile obtains data from local cache rather than remote server
  - Local network can have low capacity backhaul (e.g. femto/small-cells, hotspots)
- Proactive Selective Neighbor Caching
  - Mobile initially connected to proxy i
  - ICN receiver-driven model reveals which data items are requested
  - Select optimum subset of neighbor proxies to proactively cache requested data
  - If mobile connects to one of these proxies it can immediately receive data not obtained due to disconnection
- Selection of neighbor caches to pre-fetch data depends on
  - Probability mobile connects to caches
  - Available cache space
  - Delay reduction gains

PSI Unique Features

- **Fast forwarding**
  - Bloom filter based forwarding (→ forwarding identifiers)
    - simple, stateless, fast forwarding
    - incl. for multicast
  - path (‘source’) routing
    - path as compact Bloom filter carried on packets

- **Centralized – ‘SDN compatible’ approach**
  - (intra-domain) routing/resource allocation
  - topology discovery/management

- **‘recursive’ use of pub/sub …**
  - object level
  - chunk/packet level…
    - pull transport, error control, rcvr flow control
    - = slow & fast rendezvous
  - topology formation: handover = subscribe to network…

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Prototype Implementations & Testbeds

1. **PSIRP Testbed (w/ Blackhawk)**
   - 6 countries: UK, FI, GR, D, BU, **US**
   - In addition: Belgium during ICT demos
   - Tunneled over the public Internet
     - +dedicated fiber where available

2. **PURSUIT Testbed (w/ Blackadder)**
   - 25 nodes
   - 5 countries: UK, FI, GR, D, **US**
   - Tunneled (VPN)
     - over the public Internet

3. **φSAT Testbed w/ SAT emulation**

Multimedia over ICN
Multimedia (streaming) over PSI

- **Motivation:**
  - “YouTube” a la PSI …

- **Streaming videos**
  - without RTP/TCP/IP
  - only native PSI

- **Basic Components of the application:**
  - **Publisher**: the owner of the video
  - **Subscriber**: the user that seeks to view the video

- **Technologies Involved**
  - Java-JMF player
  - JPSI
  - JNI
  - PSI

- **We tried different applications**
  - Video
  - Audio/voice (VoPSI)
  - …
Mobile Multi-Source Video Streaming

- Exploit multi-source & multi-interface
  - for lower cost
  - resilience
  - better QoE
- Mobility-based proactive caching
- Influence of multi-rate Wi-Fi

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I-CAN Video-Streaming Emulation Experiments (& Demos…)  

● Topology Description
  ◆ Each of the experiments involves a topology and a route
    ■ described by an xml file
  ◆ An Android device parses this file in order to learn the topology and scenario

● Scenarios
  ◆ Streaming w/ & w/out Caching
  ◆ Multisource Streaming
    ■ Fault Tolerance
  ◆ Wi-Fi Direct

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PSI MM dissemination – WAN design

- RVZ system **tracks active subscriptions**
  - Soft-state (expires after timeout)
  - Explicit un-subscribe
- Upon subscription
  - RVZ system requests multicast tree (from TM)
  - LIPSIN forwarding identifier sent to publisher
- Suitable for real-time information delivery
  - Live media streaming
  - Notifications
    - Twitter, Facebook updates
  - On-line gaming
  - On-line storage synchronization
    - Dropbox
Optimization Opportunities

Exploit

1. Functional organization
   - Item resolution part of network layer **BUT** decoupled from forwarding path establishment

2. In-network resources
   - TM nodes → (logically) centralized path/tree formation

3. Stateless multicast forwarding
   - Compute minimum cost (Steiner) trees for multicast delivery
   - Cost of optimization:
     - Signaling cost: resolve the subscription
       - analogous to a DNS or DHT resolution
     - Computation delay at TM
Motivate Shift in Network Architecture

- What is new here?
- Steiner trees studied extensively in the past
  - BUT not implemented in IP
- Why?
- In principle, functions are not separated
  - Each IP router participates in distributed (multicast) routing and forwarding protocols
  - Group membership messages also install forwarding state
- Very hard to establish Steiner trees
Evaluation: Streaming over Planetlab

Case study: simple streaming application
- Deployed in Planetlab Europe
  - 20 forwarders
  - 30 users
  - 6 available streaming channels
- Java-based

In the meantime
- Prototype ported to click
- Open-source release
- Supports native layer-3 (over Ethernet) and overlay (over UDP) operation
- Steiner-tree computation not part of the public release
Bandwidth Savings

- Steiner-tree byte footprint **reduced** by
  - 30% compared to Shortest-path trees
  - 48% compared to multiple unicasts
- Steiner-tree savings are subject to graph density
  - Architecture exploits path redundancy
  - Network planning?

- Computation Delay at TM
  - At this scale, computation of Steiner tree required less than 10ms
  - Additional delay is unnoticeable
Scalability

- Centralized operations were considered an anathema in networking
  - but SDN/OpenFlow is changing the mindset
- Yet, we do not expect to perform centralized path/tree formations at a global level
- Networks organized in PSI (sub)networks
  - PSI backbone / PSI access networks (users)
- PSI subnet aggregates subscriptions before forwarding them to backbone
- De-multiplex incoming data
Evaluation: Emulation of Real Network

- *Emulated AS 224* (Norwegian University & Research Network)
  - 233 routers → PSI backbone
  - 75 access routers → 75 PSI access networks
  - 10 users in each access network → 750 users
- Abandoned Planetlab, installed the prototype in a single workstation
  - An instance for each node, communication according to topology
- Applied TM intelligence in the backbone
- Ran the system for the two multicast policies
  - Shortest-path tree
  - Steiner tree
- Same workload
- Measured how much is flow establishment delay increased in the Steiner-tree case against Shortest-path tree case
Flow establishment delay

- For 90% of subscriptions,
  - delay for Steiner tree multicast increased less than 2ms compared to Shortest-path tree multicast
- For 99.6%, less than 60ms
- A few outliers, believed to be artifacts of workstation load and software implementation
ICN for the IoT
A vision for the IoT

- many consider the IoT as an extended WSN
- need to move one step further!
  - fully exploiting connected things
    - smart things
  - & things with no computational power whatsoever
    - dumb, but potentially ‘dynamic’; indirectly connected
      - their state changes; observed or set by others
        - proxies...
- focus on **information**, not things
  - **application independent**
    - no silos!
    - information obtained for one app (silo) to be available to another (originally unexpected) app
      - under user/owner control...
ICN for the IoT

● Opportunity!
  ◆ Unsettled technologies/architectures
  ◆ Vertical (silo) applications/technologies → interoperability… lacking
  ◆ ICN could enable interoperability
    ■ play the role of middleware … in cleaner & leaner way

● Access Control!

● Privacy? Potential for ‘privacy attacks’ so widespread…
  ◆ Privacy: through access control in rendezvous architectures
ICN + IoT

Many recent publications... research...

- ACM SIGCOMM ICN 2014

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<th>15:40-16:40 Session 4: Internet of Things</th>
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Multi-Source Data Retrieval in IoT via Named Data Networking
Marica Amadeo (University Mediterranea of Reggio Calabria, Italy); Claudia Campolo (University Mediterranea of Reggio Calabria, Italy); Antonella Molinaro (University Mediterranea of Reggio Calabria, Italy)

Information Centric Networking in the IoT: Experiments with NDN in the Wild
Emmanuel Baccelli (INRIA, France); Christian Mehlis (Freie Universitaet Berlin, Germany); Oliver Hahn (INRIA, Germany); Thomas C. Schmidt (Hamburg University of Applied Sciences, Germany); Matthias Wahlisch (Freie Universitaet Berlin, Germany)

- ICNRG
  - Information-centric Networking: Baseline Scenarios -- “2.8. Internet of Things”
  - Requirements and Challenges for IoT over ICN
  - Proposed Design Choices for IoT over Information Centric Networking
Why ICN for the IoT

- integrate (vertical application) **silos** into an *Internet* of Things
- ICN semantics: pub/sub, asynchronous…
- better/easier network resource management
  - multicast, multi-homing, caching
- easier network attachment and “thing” configuration
- easier “QoS” management
  - explicit naming of traffic (information/content)
  @ the (inter-)network layer
IoT Challenge: Naming

- ... as the integration enabler
  - identifiable ➔ potentially accessible
    - compound names?
- a name (+? metada…) should identify
  - the thing’s identity
    - RFID, QRCode, Barcode
      - @ type level
      - individual thing
  - the thing’s owner & context
  - properties...
- related issues
  - information authentication and provenance verifications
  - manageability, revocability
  - group names
ICN-IoT Semantics

- ICN semantics
  - pub/sub, asynchronous, in either order…
  - persistent interests, group communication
  - metadata
    - facilitate service discovery, service composition…

- (IoT) application (protocol) semantics
  - … the same… consider CoAP…
  - easier to implement CoAP, MQTT… over ICN
    - their semantics match better
  - leaner/more efficient protocol stacks
  - multipoint, across domains & apps
    - multicast, anycast, multi-homing
  - caching: allows separation/disconnection of things
Better/more Flexible Resource Utilization
… with an ICN approach

- better/easier network resource management
  - multicast, anycast, multi-homing, caching
- easier network attachment and “thing” configuration
- easier “QoS” management
  - explicit naming of information/content at the (inter-)network layer
- smaller ICN stack (than IP) => simpler implementations
  - energy efficiency, cost (maintenance etc.) reduction
- easier to create in network security mechanisms
  - filtering, application layer firewalls
More IoT Challenges:

- Contextual Information Lookup
  - Name, metadata, user context…
  - API hides the complexity of the underlay topology and architecture

- Information Forwarding
  - Delay tolerance, mobility
  - Permanent and ephemeral subscriptions

- Trust
  - Limited (or no!) computational power
  - Things can be tampered with; software on things not easily updated
  - Transitive trust and trust delegation
  - Eliminate the need for CA?
Related Projects
Information-Centric future mobile and wireless Access Networks

- **Motivation**: Mobility presents new challenges and opportunities
  - Mobiles have multiple wireless interfaces
  - Different wireless access technologies have different characteristics

- **Objectives**: investigate
  - ICN requirements & features for mobile/wireless access networks
  - multi-source, multi-path, multi-interface
  - in-network and proactive caching
  - privacy support

- Nationally funded project – ARISTEIA II
I-CAN Architecture Features

- **Publication proxies**
  - store and advertise content on behalf of content owners
  - content remains available even when owner is offline

- **Subscription proxies**
  - send subscriptions on behalf of actual receivers
    - beneficial if users are mobile and have disconnections
    - can exploit proactive caching

- **Future content & persistent subscriptions**
  - can reduce signaling overhead in cellular and contention-based access networks

- **Use case-scenario: D2D (multimedia) content sharing**
  - (provider controlled) sharing of content among clients
    - e.g., travelling on a train
      - 1st copy (maybe) obtained over cellular
      - train cache may also participate…
    - content (chunk) naming facilitates operation
      - can be adapted to work with IP (& D2D/P2P) technologies

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POINT: IP Over ICN - The Better IP?

- Project: Running: 1/1/2015-31/12/2017
- Partners:
  - Aalto U (co-ordinator), ELL-i (FI)
  - Intracom Telecom, AUEB (GR)
  - RWTH Aachen (DE)
  - Primetel (CY)
  - CTVC Ltd, Interdigital, U Essex (UK)
- Trials in Cyprus (@Primetel)
- Concept: IP over ICN (PSI) over SDN
  - Premise: IP apps can do better over ICN
    - Need to define what “better” means
  - Better utilisation in HTTP streaming scenarios
  - Better privacy of personal data and metadata
  - Better management of virtual network paths
  - Better (fairer) content distribution
POINT Domain

- Focus
  - 1 ISP
  - User Equipment (UE): no changes (required)
    - i.e. IP
  - ICN used internally in the network
  - NAP: Network Access Point
  - ICN could be exposed to UE

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POINT Platform Architecture

Blackadder +

- Application-facing abstractions
  - HTTP, CoAP,…

- Novel dissemination strategies
  - For access networks

- Integration with SDN
  - ICN over SDN

- Flexibly-grained QoS
  - per abstraction

- Key target protocols/services
  - HTTP
  - CoAP
  - IP

Fine-grain QoS abstraction

ICN-over-SDN shim layer

L2 Transport Networks
The **POINT** IoT story

- **IoT / IP**
  - CoAP over ICN
  - CoAP handler at the NAP
  - UE: no changes (required)
    - i.e. IP

- **IoT / ICN**
  - native ICN

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An IoT reference architecture

- Caching
- Aggregation
- ...

CoAP Client

Host #1

Host #2

FW-Proxy

GW #1

GW #2

Thing #1

RD/GW #1

RD/GW #2

RD/GW #3

Network #1

Network #2

Network #3

CoAP Server

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A POINT rendition of the IoT reference architecture
Scenario #1: Coincidental multicast
(asynchronous requests, coap-observe RFC 7641)
Scenario #2: One-to-Many Requests (group-communication RFC 7390)

CoAP GET all.networks/Purple

lookup all.networks

A.B.C.D

CoAP GET all.networks/Purple

JOIN A.B.C.D

RD/GW #1 #2 #3

Network #1 #2 #3

Host #1

GW #1

FW-Proxy

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Scenario #3: Service Composition

GW #1 -> CoAP GET AVG/Purple -> AVG/Purple

AVGer

RD/GW #1

Purple

RD/GW #2

Purple

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CoAP over ICN

- CoAP ~ ICN
  - asynchronous communication
  - persistent interests
  - group communication

- advantages (to CoAP application developers & operators)
  - applications do not have to deal with IP multicast
  - no modifications to DNS
  - state overhead moved from the (constrained) endpoints to the network
    - for requests to … not yet available resources & “observe” extension
      - the CoAP server receives a single request
      - all other requests are suppressed by the NAPs
  - (~operator): CoAP and CoAP “observe” create opportunities for multicast
    - the network then uses multicast to handle bursts of traffic

- CoAP over DTLS
POINT IoT Experimentation

- ‘things’ with Power over Ethernet
- Connected at the edges of the POINT testbed
Observations

- ICN has some common key features across architectures
  - Content distribution has been the initial key motivation for ICN (CCN)
  - Information dissemination and access (on the IoT) might be the real application
- ICN is well positioned to provide for the IoT
  - caching: client-provider (thing) separation, asynchrony, energy efficiency
  - multihoming: access/unify multiple separate networks/applications
  - traffic management: exploiting explicit information naming in the network
  - mobility support: where relevant—many things are mobile
  - security: new models, new attempts, new problems…
  - privacy: through access control in rendezvous architectures

- Outlook
  - Scalability, efficiency, acceptance, deployment …
  - Security and privacy