Publish/Subscribe Internetworking & the H2020 POINT project

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Outline

- **Information-Centric Networking (ICN)**
  - Motivation, history, approaches
  - Introduction, overview: PSI, CCN/NDN, Mobility First

- **Pub-Sub Internetworking (PSI): unique features**
  - fast stateless (multicast) forwarding / 'source' routing
  - centralized routing & resource allocation, resemblance to SDN

- **Case studies**
  - Multimedia distribution
  - Security and privacy
  - (I-CAN: I-C Access Networks)
  - (Mobility support)

- **POINT: IP Over ICN - The Better IP?**
  - Motivation & hypothesis
  - Overview of approach
  - Plans

- **Discussion & Outlook**
Internet History and Outlook

- **At the beginning...**
  - cooperation; no competition...
  - **no** commercial traffic!
  - endpoint-centric services/E2E

- **Now...**
  - Content distribution...
    - >50% of traffic today 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
    - 10-15 years in the future
  - **tussle** resolution at or near run-time
  - **Trust-to-Trust principle**

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Publish-Subscribe Internet Vision

- **information centrism**
  - *everything is information & information is everything*
- **Recursive** & and generalized use of *publish-subscribe*
  - enables *dynamic change of roles between actors*
  - Network cache
    - publishes info (cached)
    - subscribes to get info to cache
- Access Points publish ID
  - mobiles subscribe

**Objectives**

- Specify, implement, & test an internetworked pub/sub architecture
  - follow a *clean-slate design* approach
- Perform qualitative and quantitative evaluation
  - Security and socio-economics important!
  - Migration and incentive scenarios important (e.g., overlay)!

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ICN timeline

papers/talks  projects

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

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

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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

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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
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…
Resource Sharing / Multicast

Publisher A

Publish FFF

Subscriber B

Subscribe FFF

Subscriber A

RP

Subscribe FFF

Subscribe FFF

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Caching, Multiple Information Sources & Multiple Paths
Caching and replication

- All content sources are equivalent in PSI
  - Origin, cache, or replication point
  - Chunks can be retrieved from different sources
  - Sources are visible to the network
    - Network-level caching

- Caching vs. replication
  - Similar to the user, different to the network
  - Replication is planned (as in CDNs)
  - Caching is opportunistic (as in P2Ps)
  - PSI handles both in a unified manner
Secure Forwarding Mechanism (LIPSIN)

- Forwarding based on Bloom filter (called zFilter) that contains all the link IDs through which a packet has to travel
- Supports multicast
- Hashing
  - False positives
  - Limitations in size
    - Hierarchical / inter-networks
- Link identifiers are unique
- zFilter creation involves an encryption mechanism
  - DoS attack resistant
  - Almost impossible to
    - redirect an information flow
    - send arbitrary packets to a destination
zFilters Based Forwarding (LIPSIN)


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**PubSub Inter networking**

- **RTF** functions realized appropriately/differently at different levels/contexts
- hierarchical approach (2-level?), e.g.:
  - fwd-ing with **path of domains**
    - also to counter Bloom filter limitations
  - **global rendezvous** with hierarchical DHTs


- **Mobility**
  - client/subscriber mobility
    - supported / ‘trivial’…
    - optimized through caching/pre-fetching
  - **Publisher mobility**
    - facilitated, by caching to fixed net
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 (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)
  - ...

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Outlook & Open Issues

- Scalability and Performance Issues
  - Scalable global rendezvous design
  - Transport protocols
  - Multimedia distribution optimization

- Security and privacy

- Deployment and Interoperability Issues
  - Cheap ICN? http only?

- Internet of Things opportunity!
Optimization of Real-Time Media Distribution

Exploit
1. Functional organization
   - Item resolution 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
- Evaluation: Emulation of AS 224 (Norwegian Univ. & Research Network)
  - 233 routers, 75 access routers → 75 PSI access networks...
  - For 90% of subscriptions, delay (Steiner - Shortest-path) < 2ms; For 99.6%, < 60ms
  - Steiner-tree byte footprint compared to Shortest-path trees: - 30%, multiple unicasts: - 48%

Challenges and Opportunities in Video & Multimedia Access & Distribution over ICN

- users express intent to watch video / access multimedia
  - without specifying filename/version/encoding or server location
- ICN locates/selects video source(s) and orchestrates delivery
  - system selects video source(s) for best available/affordable quality
    - takes into account video encoding/bitrate and user connectivity conditions
    - In PSI, ‘system’ = Rendezvous + Topology Manager
    - Requires algorithms and policies
- challenges
  - how to name video
    - Just hashing the video bits won't do...
    - need something richer… (automatic) perceptual hashing
  - chunk size?
  - how ICN selects video source (publisher)
  - how ICN selects actual data path
    - e.g. SDN-like route selection at the flow-level
    - Involves topology management, routing algorithms etc.
PSI Security & Privacy

- ... in addition to intrinsic ICN security features...
- Publisher and Subscriber do not know each other
  - Scopes: PSI’s information firewalls
  - Bloom filter path cannot be replayed
    - rotation of link IDs...
    - DoS attacks to publishers/subscribers eradicated
  - Rendezvous (point/network) knows much...
  - Privacy wrt:
    - publisher: great... (at network & higher layers)
    - rendezvous (broker): bad...
    - proposal: use **Homomorphic Encryption**

**Access Control Delegation**
- important for fast effective and efficient caching

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ICN Privacy Tutorial @ ACM ICN 2014 (Paris)

- ICN Privacy and Name based Security
  - [http://mm.aueb.gr/presentations/2014-ICN-Privacy-Tutorial.pdf](http://mm.aueb.gr/presentations/2014-ICN-Privacy-Tutorial.pdf)

- Remarks
  - **ICN-IP relationship**
    - Some of the techniques are adapted for ICN from the existing IP networks
    - More generally, many of techniques are also applicable to the existing IP networks
    - Same for threats and objectives
      - but there are also differences…
  
  - **Important open issues**
    - **Performance trade offs**
      - on a concrete system
      - Caching vs. Privacy vs. Confidentiality
    
    - **Governance and authorities**
      - On non random identifiers (human readable)
      - e.g., details on naming
    
    - **Shared responsibility** for important decisions or actions, departure from single TTP models
      - Bitcoin vs Certificates/PKI
      - Byzantine agreement,…
    
    - **“NSA free” architectures**
      - Global policies
      - Traffic engineering
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

Challenges & Opportunities for Enhancing Mobility Support in ICN

Challenges
- Selection of optimal subset of neighbors is hard
  - NP-complete (Knap-sack): different object sizes + limited capacity, different delay gains
  - Optimal Solution: Break to same sized chunks; but that is application-dependent
  - Good approximation: Iterative selection algorithm based on dynamic cache pricing

- Example: 3-level hierarchical proactive caching
  - Publisher and subscribers use ADSL links: Publisher – ADSL – Subscriber
  - Motivation: ADSL is the delay bottleneck
  - Hard to decide optimal cache selection; use centralized selection algorithm

Opportunities
- Support mobile publishers: content cached in proxies
- Accommodate many mobile users by exploiting mobility information + object popularity
- Get data from other proxies in case of a cache miss
  - Multilevel hierarchies implied
  - Taking cache misses into account during cache selection is NP-Hard
  - Parallel download of different chunks from many proxies
- ISP costs rather than delay costs as motivation for proactive caching
- More efficient cache utilization in dense femto-cells or WiFi hotspots
φSAT: The role of Satellites in FI Services

- **Aim:**
  - To investigate the technical feasibility & business viability of the integration of SatCom with terrestrial ICN architectures

- **Results**
  - Methodology to identify application/service scenarios where the capabilities of SatCom and ICN bring highest techno-economic gains
    - Key **SatCom** capabilities: Broadcast/Multicast, Wide Coverage
    - Key **ICN** capabilities: Data aggregation, Multipath Routing, Mobility Support, In-network Caching
  - Candidate scenarios identified
    - Hybrid Broadcast netTV
    - M2M Communications
    - 4G Backhauling
  - Socio-economic evaluation
    - Market evolution for each scenario
An Information-Centric Overlay Network Architecture for Content Distribution and Mobility Support

Ph.D. Dissertation by Konstantinos Katsaros

- **Multicast**
  - *Router Assisted Overlay Multicast (RAOM)*
    - Deploying multicast functionality in an overlay fashion
- **Multicast & Caching**
  - *MultiCache*
    - Enabling caching of data delivered by multicast trees
- **Adapting to the inter-network structure**
  - *H-Pastry*
    - Canonical version of Pastry
- **Mobility Support**
  - *Overlay Multicast Assisted Mobility (OMAM)*
    - Revisiting multicast assisted mobility

Conclusions

- ICN has some common key advantages (across architectures)
- ICN is well positioned to address
  - caching, multi-homing, traffic management, mobility, security...
- PSI: unique features
  - name/ID resolution (for each scope) @RP, rather than flooding
  - centralized routing & resource allocation \(\sim\) SDN
  - fast stateless (multicast) forwarding
  - separate forwarding from resolution
    - no use of reverse path, appropriate for asymmetric links/paths
  - added (to pub/sub) selected security mechanisms
    - secure forwarding (zFilters), scopes, bubbles...
- Outlook
  - Scalability, efficiency
  - Security and privacy
  - the IoT and home networking
  - evolution: tussles resolved at or near run-time

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ICN Research Community

- workshops…
  - with ACM SIGCOMM
    - ICN 2011 (Toronto)
    - ICN 2012 (Helsinki)
    - ICN 2013 (Hong Kong)
  - with IEEE INFOCOM
    - NOMEN 2012, 2013

- 1st ACM SIGCOMM ICN Conference
  - Paris Sept. 2014

- 2nd ACM SIGCOMM ICN Conference
  - San Francisco, end Sept. 2015

- ICNRG@IERTF
- Journals & Magazines Special Issues

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POINT: IP Over ICN - The Better IP?

● Project
  ◆ Duration: 1/1/2015-31/12/2017
  ◆ Partners:
    ▶ Aalto U (co-ordinator), ELL-I (FI)
    ▶ Intracom Telecom, AUEB-RC (GR)
    ▶ CTVC Ltd, Interdigital Europe, U Essex (UK)
    ▶ RWTH Aachen (DE)
    ▶ Primetel (CY)

● Concept
  ◆ 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 provider
  - UE: no changes (required)
  - ICN used internally in the network
  - ICN could be exposed to UE

The IP interface represents the various supported abstractions, such as HTTP, CoAP, TCP or IP.
Objectives

- Define KPIs from an IP viewpoint
  - Measure performance of IP over ICN
- Define a platform with clear interfaces
  - Allow adding hardware blocks and extensions
- Map Internet abstractions onto an ICN
  - IP, TCP, HTTP, CoAP
- Develop resource coordination mechanisms
  - Multiple resource optimization
- Implement a POINT platform prototype
  - Blackadder+ as IP underlay
- Deploy and evaluate in a field trial
  - Using Primetel’s operational network
- Evaluate the commercial viability of POINT
  - Same methodology as in PURSUIT
- Establish POINT in the wider ICN community
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
  - CoApp
  - IP

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Thank you!

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