Update on the NSF-Intel ICN-WEN program
(Information Centric-Networking in Wireless Edge Networks)

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July 17, 2018
NSF-Intel ICN-WEN Partnership:
$6.5M over 3 years, 3 projects awarded

• Focus on Wireless Edge Networks
  • Ultra low-latency and massive IoT applications
• ICN approach impacting 3 aspects:
  • wireless device endpoints
  • wireless network infrastructure and architecture
  • wireless data security and privacy
• Consider Clean-slate design
• Research goals: NSF 16-586
  • Create new integrated ICN approach for wireless nets
  • Address fundamental challenges of wireless ICN data delivery
  • Demonstrate & quantify benefits of a potential ICN-WEN
  • Evaluate realistic deployments & implementation complexities
Update

• Solicitation July 2016 / Deadline January 2017
• Shared details @ IETF 98, March 2017
• Announced Awardees, May 2017
• Held Kick-off Workshop, June 2017
• Discussed Awardees @ IETF 99, July 2017
• Launched an affiliated project, January 2018
• 1st year ICN-WEN F2F, June 2018
ICN-WEN Program – Kick-off June 2017

**Title:** ICN-Enabled Secure Edge Networking with Augmented Reality  
**Lead PI:** Lixia Zhang  
**Universities:** UCLA, NMSU, Florida International University

**Title:** SPLICE: Secure Predictive Low-latency Information Centric Edge for Next-Generation Wireless Networks  
**Lead PI:** P. R. Kumar  
**Universities:** Texas A&M, WUSTL, Purdue, Ohio State, UIUC

**Title:** Light-Speed Networking (LSN): Refactoring the Wireless Network Stack to Dramatically reduce Information Response Time  
**Lead PI:** Arun Venkatramani  
**Universities:** U. Massachusetts-Amherst, U. Wisconsin-Madison
ICN-WEN Affiliated Project – Jan 2018

**Title:** Joint Optimization of Routing & Caching in Heterogeneous Wireless Networks

**co-lead PIs:** Edmund Yeh, Andrea Goldsmith

**Universities:** Northeastern, Stanford

Wireless HetNet with device-to-device (D2D) users, small cell (SC), macro cell (MC) Base Stations (BSs), and connections to backhaul
ICN-Enabled Secure Edge Networking with Augmented Reality (ICE-AR)

ALEX AFANASYEV, JEFF BURKE, JASON CONG, MARIO GERLA, SONGWU LU, JAY MISRA, LIXIA ZHANG

http://ice-ar.named-data.net/
ICE-AR – Augmented Reality App

Driving research along multiple dimensions

◊ Data naming
◊ Acceleration as a service
◊ Local resource discovery
◊ Security
◊ Lower layer support

Interconnecting pieces into a whole
Accomplishments – AR App

◇ Designed and prototyped e2e AR app over NDN.
  o Mobile device (MD) publish POV video, stores in a local NDN repo
  o Edge service nodes (EN) consume video, generate/publish annotations using multiple ML modules.
  o MD fetches the resulting context annotations, re-associated with the frame (all in perceptual real-time for the end-user)
  o integration of BTLE beacons provides additional context for frames
  o Continuous query of an edge database to find matching content

◇ Provided acceleration workload, security, and forwarding requirements to the rest of the team

◇ Feedback/refinement to NDN development
  o Further developed the NDN Common Name Library
    † enable app developers to interact with NDN data without handling Interest/Data exchange details.
  o Improved real-time video conf. lib. (NDN-RTC) to support AR
  o following the latest NDN protocol refinement
Accomplishment – Acceleration

◊ Objectives
  o Use FPGA in the edge node for acceleration.
  o Real-time processing with low energy cost.

◊ Achievements
  o Conducted study of FPGA for network compression
    † Compressed the network size by 70% with 2% of accuracy loss
  o Designed and implemented the FPGA accelerator for OpenPose algorithm based on the reduced network.
  o The current solution is estimated to achieve 3.2 FPS with 4.7x better energy efficiency than leading GPU
Accomplishments – Security development

◊ Creating a trust framework for diverse types of users in a campus setting
  o faculty members
  o students
  o visitors

◊ Exploring mechanisms for access control for AR applications
  o sharing content between mobile devices and edge servers

◊ Leveraging existing NDN trust and access control solutions, refine/enhance to meet ICN-WEN needs
Accomplishment – Wireless co-design

◊ **Overcome the barriers** of current wireless co-design
  o Performance optimizations as the main goal for codesign
  o Limited solution space: typical two layers for cross-layer design (e.g., transport & link, network & link)
  o Blackbox/graybox based design: Cannot reason whether it works or not in practice

◊ **Preliminary experimental characterizations**
  o AR/VR network traffic patterns, and
  o Deficiencies of 4G wireless for AR/VR [*SIGMETRICS’18*]

◊ **NDN-based approach to wireless co-design**
  o **Top-down** rather than bottom-up: from communication-driven wireless networking to app-driven networking
  o **Sharing app namespace across layers: enabler for cross-layer optimization**
    ♦ Cover both system performance and reliability aspects
  o **Built-in analytics** via NDN to learn what and reason why
Evaluation at two levels: what/how to measure

◊ **Qualitative benefits**
  o programmability, flexibility of application, ease of management, usability when applied at scale, robustness against attacks or failures, extensibility, composability, and so on.

◊ **Quantitative performance metrics**
  should be used to establish the benefits of a proposed scheme in the context of wireless network and device research
  o Lack of access to lower layers
  o Existing wireless protocols unfit to ICN
  o No plan on device research
Lessons learned

◊ Named, secured data enables integration of networking, storage, and processing into a coherent system

◊ Main challenge: NDN namespace ties together app, network, and security
  o Bringing the power of ICN
  o Making the design of each piece more challenging

◊ Ongoing effort: extracting general design guidelines through more experimentations

◊ App-driven architecture development works
ICE-AR - Recent publications

9. “Real-Time Data Discovery In Named Data Networking”, IEEE HotICN, August 2018
10. “AccConF: An access control framework for leveraging in-network cached data in the ICN-enabled wireless edge” Transactions on Dependable and Secure Computing, in press

6/19/18
ICE-AR - Other Papers

Tech reports
15. “NDN Host Multihoming”, in progress.

Under Submission
16. “Distributed Dataset Synchronization in Mobile Ad Hoc Networks over NDN”
17. “KITE: Producer Mobility Support in Named Data Networking”
18. “NDN Host Model”
SPLICE: Secure Predictive Low-Latency Information Centric Edge for Next Generation Wireless Networks

E. Bertino, R. Roy Choudhury, P. Crowley, A. Eryilmaz, I-H. Hou, Y.C Hu, P.R. Kumar, S. Shakkottai, N. Shroff
SPLICE Objectives

- **Go beyond per-packet QoS**
  - Provide guaranteed performance of information delivery – frequency, quantity, quality, and latency
  - Information is actionable and timely as needed by the applications

- **Embed ICN support in the Wireless Edge Network**
  - Exploit commonality/correlation of user information requirements
  - Exploit predictability of future demands
  - Enable distributed and seamless access to content (e.g., enable queries for content without need to ask where it is, which copy it is, whether it is a true copy...)
  - Security and performance must be built into design from start
SPLICE Architecture

- **Wireless**: Platform to support scheduling/control mechanisms for latency/guarantees across multiple flows
- **Content caching**: Algorithms & protocols for predictive caching, coding and learning
- **NDN**: Integrate NDN natively into the wireless domain
- **Security/Privacy**: Develop practical algorithms for content authentication, security, and privacy preservation
- **Applications**: Develop and integrate Virtual Reality apps into the SPLICE platform

A Sampling of Results...
Can NDN/5G enable high-quality VR on mobile?

Typically, a VR system contains three key components working together (rendering loop):

- **A Headset**: tracking your pose; seeing the virtual world in the display
- **A Controller**: tracking your gestures
- **A Renderer**: for rendering high-resolution VR contents
  - Workstation: In tethered solution (e.g., Oculus)
  - Phone: In untethered solutions

### Responsiveness
- **Responsiveness**: motion-to-photon latency < 20 ms

### High-quality visual effects
- **High-quality visual effects**: rich & realistic scenes, FPS > 60

### Untethered
- **Untethered**: to provide ultimate VR experience, avoid tripping hazard

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**How to cut the cords?**
How to enable untethered VR applications?

- **Single-player VR apps on mobile**
  - **Challenge:** data deluge overwhelms CPU/GPU, battery, network
  - **Furion** [Mobicom’17]
    - *A split architecture* utilizing pre-rendering, pre-fetching, H.264 encoding & parallel decoding to meet stringent QoE of high-res single-player VR apps
      - **Idea:** Break up into foreground (rendered onsite --- quickly changing) and background (rendered offsite --- static)
      - **Network requirement:** 130 Mbps avg throughput, 1-2ms RTT

- **Multi-player VR app experiments on mobile**
  - Prototyping on testbed novel techniques that max’ly leverage commonality among players ➔ ideal for NDN/caching/wireless mcast

- **Enable high accuracy Wireless Head Motion Tracking**
  - **Challenge:** Meet accuracy of AR/VR apps (mm level) w/out fixed HW
  - **IMU Based method** [Mobicom’18]
    - Inertial measurement using existing gyros ➔ combine with other methods to reduce errors further
How to enable VR over NDN?

- **Challenges** to enable Push over Pull-based NDN
  - Event-driven applications such as AR/VR applications rely on quick delivery of prediction/push notifications

- **Solution: Information Centric Transport (ICT)**
  - Simplifies applications by allowing them to stay in the “information plane,” and be agnostic to network mechanisms and characteristics (such as the type and number of links, forwarding strategies etc.)
  - Built a mechanism that allows apps to receive Push notifications

https://openscholarship.wustl.edu/cse_research/1169/

```
App

Register_for_event_notification (event_prefix)

Notify_event (event_name)

ICT API

Interest

Data

?```

https://openscholarship.wustl.edu/cse_research/1169/
NDN Caching & Wireless Communications

- **Proactive Multicast:**
  - Developing new proactive multicasting algorithms that *exploit the shape of the popularity distribution* [Infocom 2018]
  - **Key Insights:**
    - Significant delay reduction even w/ small caches & mis-aligned content requests
    - New moving window codes substantially improves performance over traditional rateless codes
    - Feedback mechanism only requires very small (constant) overhead

- **Custom MAC Scheduling: Longest-Deficit First (LDF)**
  - Current MAC does not provide latency guarantees (AR/VR < 5ms)
    - To service *bounded flows*, developed “PULS: Processor-Supported Ultra-Low Latency Scheduling”, [MobiHoc 2018]
Security and Privacy

- Developed & evaluated **Block-chain based Public Key Infrastructure (PKI) for IoT [under submission]**
  - Significantly reduces both cost and time of adding a new certificate at the server and IoT device

- Designed an initial approach for a **privacy-preserving attribute-based access control for NDN** based on a broadcast group key management scheme (BGKM) [*ACM SACMAT 2018*]

- **LTEInspector [NDSS 2018]**
  - **Vulnerability discovery of 4G.** Developed a model based testing approach for analyzing the security of privacy of 4G LTE standard. Uncovered 10 new attacks, ID’ed 8 prior. Next: analyze other protocols.
  - **Identify fake base stations.** Developed a *lightweight and offline-online signature generation based broadcast authentication* of the bootstrapping signals in cellular network
How to design the SPLICE testbed?

- **Goal**: construct a testbed of Nodes that can instantiate a Secure Predictive Low-Latency Information Centric Edge

- **Challenges**:
  - Support for high throughput PHY + low-level MAC (currently ~ 500 μs/pkt)
  - Support for low latency (< 5 ms) & high throughput flows (currently MAC scheduling decision ~ 100 μs)
  - Support for caching, coding, prefetching (low ms)
  - Support for NDN (retrievals in low ms)
  - Support for VR scene rendering (< 20 ms)
  - Platform Security

- **SPLICE Node** consists of a host computer (laptop) and a software defined radio (USRP with FPGA)
  - Currently 8 nodes
- USRP (plus FPGA)
  - PHY and low-level MAC
- Host (Windows)
  - High-level MAC
  - Coding/prefetching
  - NDN, caching
  - App Rendering
- Integration with VR headset
1. Tao Zhao, Korok Ray, and I-Hong Hou, “A Non Monetary Mechanism for Optimal Rate Control Through Efficient Cost Allocation,” accepted for IEEE/ACM ToN.


Light-Speed Networking:
*Refactoring the Wireless Network Stack to Dramatically reduce Information Response Time*

UMass Amherst (Ganesan, Gill, Houmansadr, Venkataramani)

UWisconsin-Madison (Akella, Banerjee, Kim)
LSN functional stack

Applications

End-to-End Transport

Block caching + semantic control

GUID <-> GNS

PIR + NFV

Link Layer

Polymorphic radio

Information-value-maximizing borehole

Service Dispersability plane
LSN novel architectural elements

Device/network/trust → Architectural element → Design goal

- Service dispersability
- Information value tags
- Global name service
- Semantic control plane
- Private information retrieval
- AP-centric IoT security/privacy
- Radio polymorphism

- Bounded LIFT
- High availability
- Information value maximization
- Trustworthiness
- Low-power liveness
LSN architectural components

- GNS [GUID → NA]
- Privacy VNFs
  - PIR
  - IoT privacy
- Information value tags
- Service Dispersion
- Polymorphic radio
LSN in a nutshell

- An ICN that leverages edge clouds to
  - Drive down information response times (msec → usec)
  - Drive down power consumption (mwatts → uwatts)
  - Improve trustworthiness

- Adopts MobilityFirst global name service (GNS)
  - GUID: Self-certifying globally unique identifier (one-way hash of public key) for all endpoint principal
    - Interface, device, service, content, group of names, etc.

- Access point - critical edge cloud placement point
Progress overview

- **Service dispersability**
  - Feasibility and proof-of-concept of GigaPaxos core to enable dispersability of third-party services *(under submission)*

- **ICN architectural comparison**: comparison of name-based ICN architectures based on mobility support *(Infocom’18)*

- **Radio polymorphism**:
  - Completed hardware design of polymorphic radio to switch between active/passive with early results showing 5-10x power improvement
  - Developing edge-cloud based learning to leverage polymorphism
Progress overview (cont’d)

- **Private information retrieval (PIR):**
  - Designed first asymmetric PIR protocol suitable for LSN applications compared to symmetric state-of-the-art
  - Designing two new PIR approaches with variable-sized content to trade privacy slightly to improve bandwidth cost

- **AP-centric IoT privacy:** Limiting PI leakage

- **Information value:** Developed ParaDrop WiFi edge computing platform with deployment in vehicular setting *(ACM/IEEE Symposium on Edge Computing 2017)*

- **Semantic control plane:** Developed Iron for container isolation *(NSDI’18)*; StreamNF for stateful NF chain management *(paper under submission)*
Polymorphic radio architectures

§ **Polymorphic radios:** Combine active and passive building blocks to tradeoff power, latency, and bandwidth.

- Achieve *ultra-low latency interaction with* the edge cloud while operating at *very low power*
- Enable IoT data analytics be split between the IoT devices & edge cloud

§ **Status**

- **Designed preliminary architecture** & protocol stack with ability to switch between active and passive transmitter/receiver.
- **5-10x power improvement** over a traditional low-power radio for short-range interaction w/out sacrificing latency.
- Developed demo with polymorphic radio **integrated with wearable eyeglass for real-time eye tracking.**
- Developing edge-cloud based machine learning methods that leverage polymorphic radios.
LSN Publications – 1 of 3


Prior Related LSN Publications – 3 of 3


Some Interesting Questions Raised

• Is there an Art to Naming and Namespace Design?

• What constitutes information centrism and how to measure its benefits?

• To realize Quality of Experience (QoE) and Quality of Service (QoS), isn’t there a need for greater sharing of (meta-data) information across the “layers” in the system architecture? All the way from the App to the MAC and back again?
Questions?
ICN-WEN

Information Centric-Networking in Wireless Edge Networks

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Internet of Things Group (IoTG)

March 30, 2017
Outline

• Backstory
• ICN-WEN Program
• Next Steps
• Bigger Picture

“Thin waist of the Internet”
Intel Backstory: ICN for IoT

- Deployed ICN at the network edge
  - Within edge administrative domain
  - Sidestepped global deployment
- Built, evolved early IoT PoCs: ICN as a trusted data bus
  - Smart home – *Pub-sub & security APIs*
  - Smart neighborhood – *Data-centric privacy*
  - Massive IoT software updates – *Scalability*
  - Edge computing – *Move the compute to the data*
- Supplied user vs. router insights
- Grew partnership between Labs & IoTG
NSF-Intel ICN-WEN Program: $6.5M over 3 years, 2-3 projects to be awarded

• Focus on Wireless Edge Networks
  • Ultra low-latency and massive IoT applications
• ICN approach to 3 dimensions:
  • wireless device endpoints
  • wireless network infrastructure and architecture
  • wireless data security and privacy
• Clean-slate design
• Research goals: NSF 16-586
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ICN and 5G+ Networks

• ICN over wireless a natural next step
• 5G+ use cases very different from traditional ones
  • High bw and support for large #s of devices
  • AR/VR, autonomous vehicles, dense IoT, robotics, drones, etc.
• New usage models where source-dest model falls short
  • Source is inaccessible: *e.g.*, *in sleep mode, offline, encounters congestion, mobility or interference*
• IoT Data
  • Data often originates and is processed at the Edge
    • May (not) flow back to the core
  • ICN enables access to data within the network
    • With less application dependence
Translating to 5G Requirements: 
*ITU's IMT Vision*

**Peak:** 10-20 Gbps  
**User:** 100Mbps/1Gbps  
**Spectral Efficiency:** 3-5x

**Latency:** 1ms  
**Reliability:** 99.999%

**Connection Density:** $10^6$/km²  
**Energy Efficiency:** 10x

**New metrics and wide variety and variability of Services**
Likely ICN-over-Wireless Benefits?

- Wireless Edge Networks with dynamic reconfigurations and data requirements
  - Flow of data cannot be programmed during net setup
  - Benefits in routing and data management
- Data access benefits in Non-star topologies
  - Not simple Cellular and WiFi
  - Wireless mesh networks
- Liberation of meta-data
  - Use of contextual info in the lower layers w/out app dependence
- Support for reverse data flows
  - Combines routing with caching/storage ... & processing
Challenges and Hard Problems

• Producer mobility
• Security and Privacy
  • End user devices may have limited resources to implement complex encryption
  • How to establish trust?
• Bridging ICN islands with each other and with IP networks
• Modifications to ICN architecture to directly implement over wireless MAC layer
• Wireless co-design with ICN
  • Make ICN wireless-aware
  • Make wireless ICN-aware
Why is Intel interested in ICN?

• ICN has potential, but is it ready for prime time?
  • Develop practical ICN use cases
  • Develop ICN implementations that can be commercialized & standardized for industry adoption

• What is improved if we use ICN instead of IP?

• Evaluate potential for...
  • Being an industry solution
  • Implementing 5G+ networks
  • Meeting ultra low-latency requirements and massive IoT solutions
  • Enabling Edge/Fog computing...
Next Steps

Awardees to be announced Mid-May of 2017!
Bigger Picture
Data Inversion Problem: IoT Edge data flows upstream
Cloud functionality migrating to be more proximate to the data

“By 2018, 40% of IoT-created data will be stored, processed, analyzed, and acted upon closest to, or at the edge of the network.”
12/2014
Problem:
*Legacy clouds fall short ... or are unusable*

When the IoT data generated is
- Delay-sensitive
- High-volume
- Trust-sensitive
- (Intermittently) Disconnected

Countless examples
- Both near term & further out

**Video Analytics**
- Smart Camera (24.7 Mbps)
- 20K wys (24x7)
- Legacy Cloud (~1.6 Tbps)

**Augmented Reality**
- Data heavy
- Compute intensive
- **Response times <30ms**
- Small form factor
- Low power
Need for Edge and Fog Computing

A Multi-tier Cloud of Clouds

Use ICN for rCDNs (reverse CDNs)?
Reverse data flows combining routing with storage and processing
Bigger Picture:
From Cloud to Edge to Fog Computing

• IoT Data causing disruption ...
  • What’s the network+compute+storage architecture needed?
  • What’s the impact on privacy, security, trust models?
  • How/where to put the control?

• Liberation of data and meta-data
  • Accessible anywhere? Safeguarded everywhere?

• ICN’s role in and/or relationship to...?
  • Fog data flows - Intra-cloud, E/W and N/S (rCDNs)
  • Smart data/object frameworks
  • Data naming, lineage and interoperability
  • “Organically-grown” Trust