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

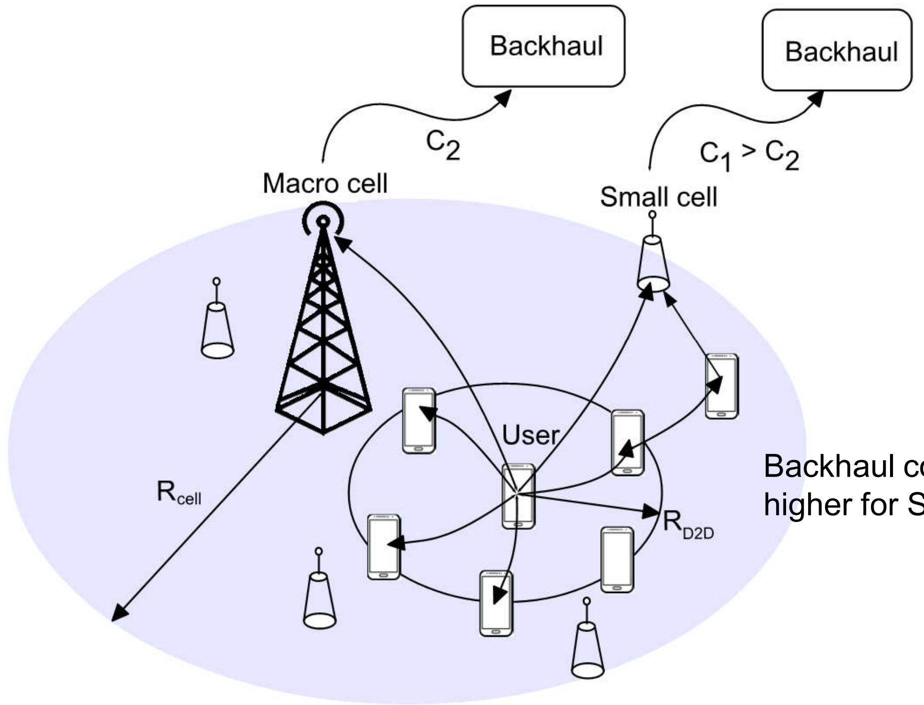
Universities: U. Massachusetts-Amherst, U. Wisconsin-Madison

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



Backhaul cost typically higher for SC connection

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)

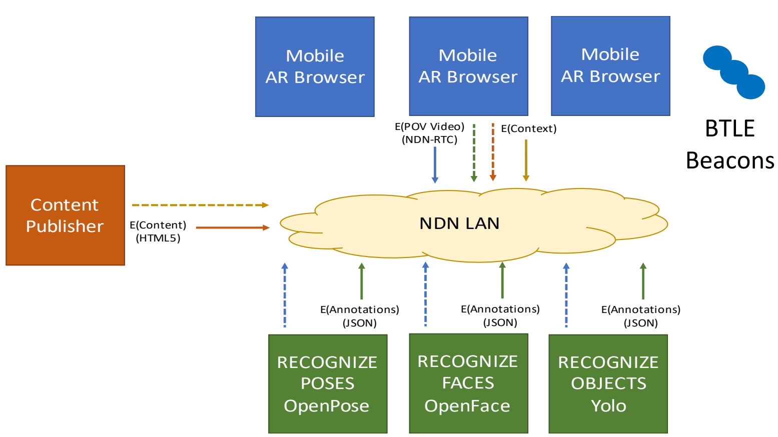
ALEX AFANASYEV, JEFF BURKE, JASON CONG, MARIO GERLA, SONGWU LU, JAY MISRA, LIXIA ZHANG

http://ice-ar.named-data.net/

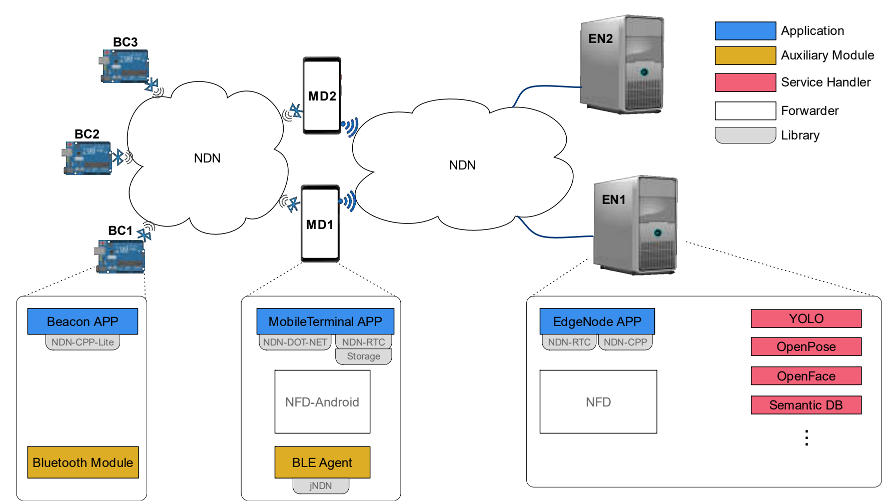
ICE-AR – Augmented Reality App

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.**
  - Mobile device (MD) publish POV video, stores in a local NDN repo
  - Edge service nodes (EN) consume video, generate/publish annotations using multiple ML modules.
  - MD fetches the resulting context annotations, re-associated with the frame (all in perceptual real-time for the end-user)
  - integration of BTLE beacons provides additional context for frames
  - 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
  - Further developed the NDN Common Name Library
    - **enable app developers to interact with NDN data without handling Interest/Data exchange details**.
  - **Improved real-time video conf. lib. (NDN-RTC) to support AR**
  - following the latest NDN protocol refinement

Accomplishment – Acceleration

- Objectives
  - Use FPGA in the edge node for acceleration.
  - Real-time processing with low energy cost.
- Achievements
  - Conducted study of **FPGA for network compression**
    - Compressed the network size by 70% with 2% of accuracy loss
  - Designed and implemented the FPGA accelerator for OpenPose algorithm based on the reduced network.
  - 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
  - faculty members
  - students
  - visitors

- Exploring **mechanisms for access control** for AR applications
  - 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
  - Performance optimizations as the main goal for codesign
  - Limited solution space: typical two layers for cross-layer design (e.g., transport & link, network & link)
  - Blackbox/graybox based design: Cannot reason whether it works or not in practice

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

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

Evaluation at two levels: what/how to measure

- **Qualitative benefits**
  - 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
  - Lack of access to lower layers
  - Existing wireless protocols unfit to ICN
  - 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
  - Bringing the power of ICN
  - 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

1. "DICE: Dynamic Multi-RAT Selection in the ICN-enabled Wireless Edge", MobiArch Workshop, July 2017.
2. "LASeR: Lightweight authentication and secured routing for NDN IoT in smart cities", IoT Journal, Feb 2018.
3. "Achieving Resilient Data Availability in Wireless Sensor Networks", ICN-SRA Workshop, May 2018
4. "Supporting Mobile VR in LTE Networks: How Close Are We?" ACM SIGMETRICS, June 2018.
5. "Towards Edge Computing Over Named Data Networking", IEEE International Conference on Edge Computing, July 2018.
6. "TACTIC: Tag-based Access ConTrol Framework for the Information-Centric Wireless Edge Networks" IEEE ICDCS, July 2018.
7. "Mobile Data Repositories at the Edge", USENIX HotEdge Workshop, July 2018.
8. "Supporting Augmented Reality: Looking Beyond Performance", ACM SIGCOMM 2018 Workshop on VR/AR Network, August 2018.
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
11. "An Overview of Security Support in Named Data Networking", IEEE Communication Magazine, special issue on ICN Security

ICE-AR - Other Papers

Tech reports

12. "NDN Automatic Prefix Propagation" NDN-0045, Feb 2018.
13. "VectorSync: Distributed Dataset Synchronization over Named Data Networking" NDN-0056, March 2018.
14. "NDN Device Secure Sign-On Protocol", in progress.
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

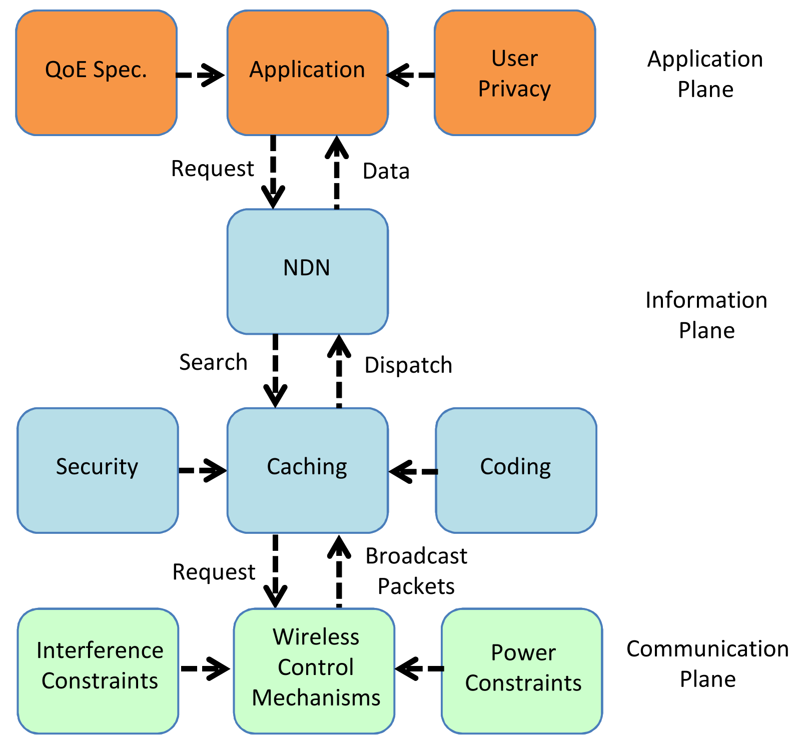
E. Bertino, R. Roy Choudhury, P. Crowley, A. Eryilmaz,
I-H. Hou, Y.C Hu, P.R. Kumar, S. Shakkottai, N. Shroff

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

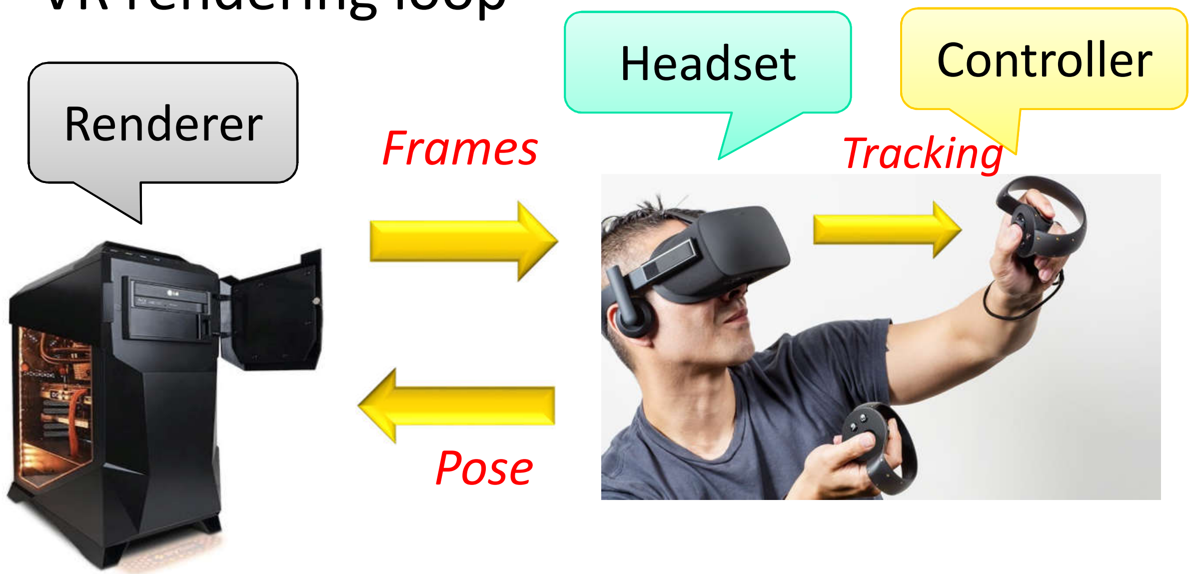
- **Wireless:** Platform to support scheduling/control mechanisms for latency/guarantees across multiple flows
- **Content caching**: Algorithms & protocols for predictive caching, coding and learning
- **NDN**: Integrate NDN natively into the wireless domain
- **Security/Privacy:** Develop practical 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?

VR rendering loop



- **Responsiveness:** motion-to-photon latency < 20 ms
- **High-quality visual effects:** rich & realistic scenes, FPS > 60
- **Untethered:** to provide ultimate VR experience, avoid tripping hazard

How to cut the cords?

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

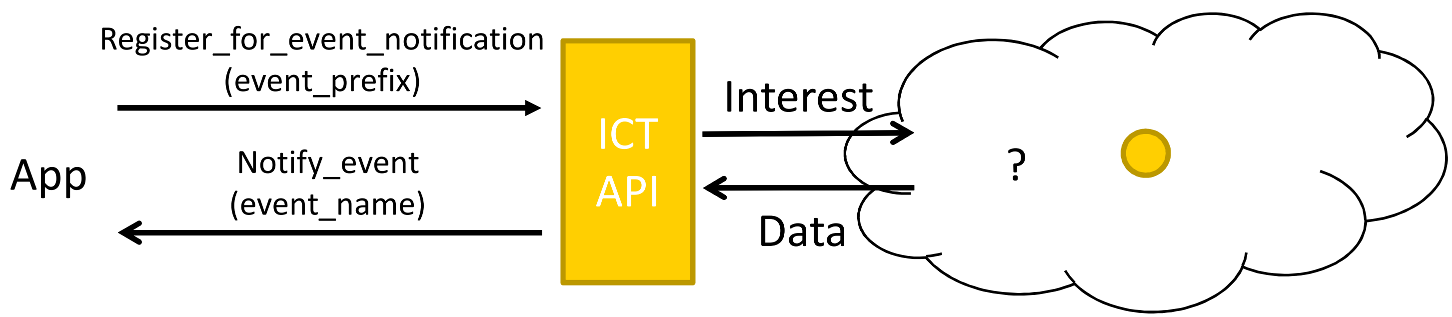
How to enable untethered VR applications?

- **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/



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]*

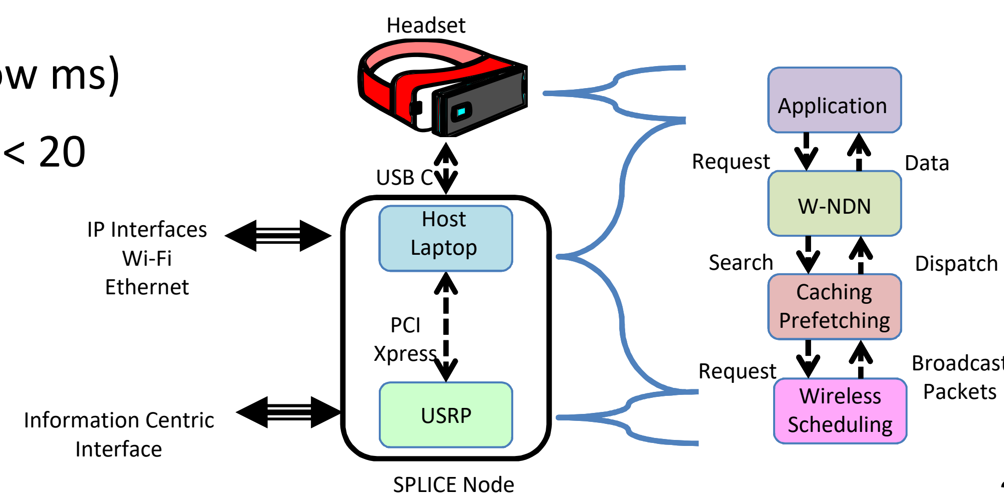
Security and Privacy

- 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'd 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



SPLICE Publication List – 1 of 3

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.
2. Han Deng and I-Hong Hou, “Optimal Capacity Provisioning for Online Job Allocation with Hard Allocation Ratio Requirement,” IEEE/ACM Trans. on Networking, vol.26, no.2, Apr 2018, pp.724–736.
3. PingChun Hsieh and I-Hong Hou, “A Decentralized Medium Access Protocol for RealTime Wireless Ad Hoc Networks With Unreliable Transmissions,” ICDCS, 2018.
4. Simon Yau, PingChun Hsieh, Rajarshi Bhattacharyya, Kartic Bhargav K. R., Srinivas Shakkottai, I-Hong Hou, P. R. Kumar, “PULS: Processor supported Ultralow Latency Scheduling,” ACM MobiHoc, 2018.
5. Jian Li, Srinivas Shakkottai, John C.S. Lui and Vijay Subramanian, "Accurate Learning or Fast Mixing? Dynamic Adaptability of Caching Algorithms", To appear in IEEE JSAC, 2018.
6. S. Wang and N. B. Shroff, “Towards FastConvergence, LowDelay and Low-Complexity Network Optimization,” Proceedings on Measurement and Analysis of Computing Systems (POMACS), 2017.

SPLICE Publication List – 2 of 3

7. X. Zhou, F. Wu, J. Tan, K. Srinivasan, and N. B. Shroff, “Degree of Queue Imbalance: Overcoming the Limitation of Heavytraffic Delay Optimality in Load Balancing Systems,” POMACS 2017.
8. X. Zhou, F. Wu, J. Tan, Y. Sun, and N. B. Shroff, “Designing Low Complexity HeavyTraffic DelayOptimal Load Balancing Schemes: Theory to Algorithms,” POMACS 2017.
9. F. Wu, Y. Sun, L. Chen, J. Xu, K. Srinivasan, and N. B. Shroff, “High Throughput Low Delay Wireless Multicast via MultiChannel Moving Window Codes,” IEEE INFOCOM'18, Apr. 2018.
10. S. Wang and N. B. Shroff, “Towards FastConvergence, LowDelay and Low-Complexity Network Optimization,” ACM Sigmetrics’18, Jun. 2018.
11. X. Zhou, F. Wu, J. Tan, K. Srinivasan, and N. B. Shroff, “Degree of Queue Imbalance: Overcoming the Limitation of Heavytraffic Delay Optimality in Load Balancing Systems,” ACM Sigmetrics’18.
12. X. Zhou, F. Wu, J. Tan, Y. Sun, and N. B. Shroff, “Designing LowComplexity HeavyTraffic DelayOptimal Load Balancing Schemes: Theory to Algorithms,” ACM Sigmetrics’18, June 2018.

SPLICE Publication List – 2 of 3

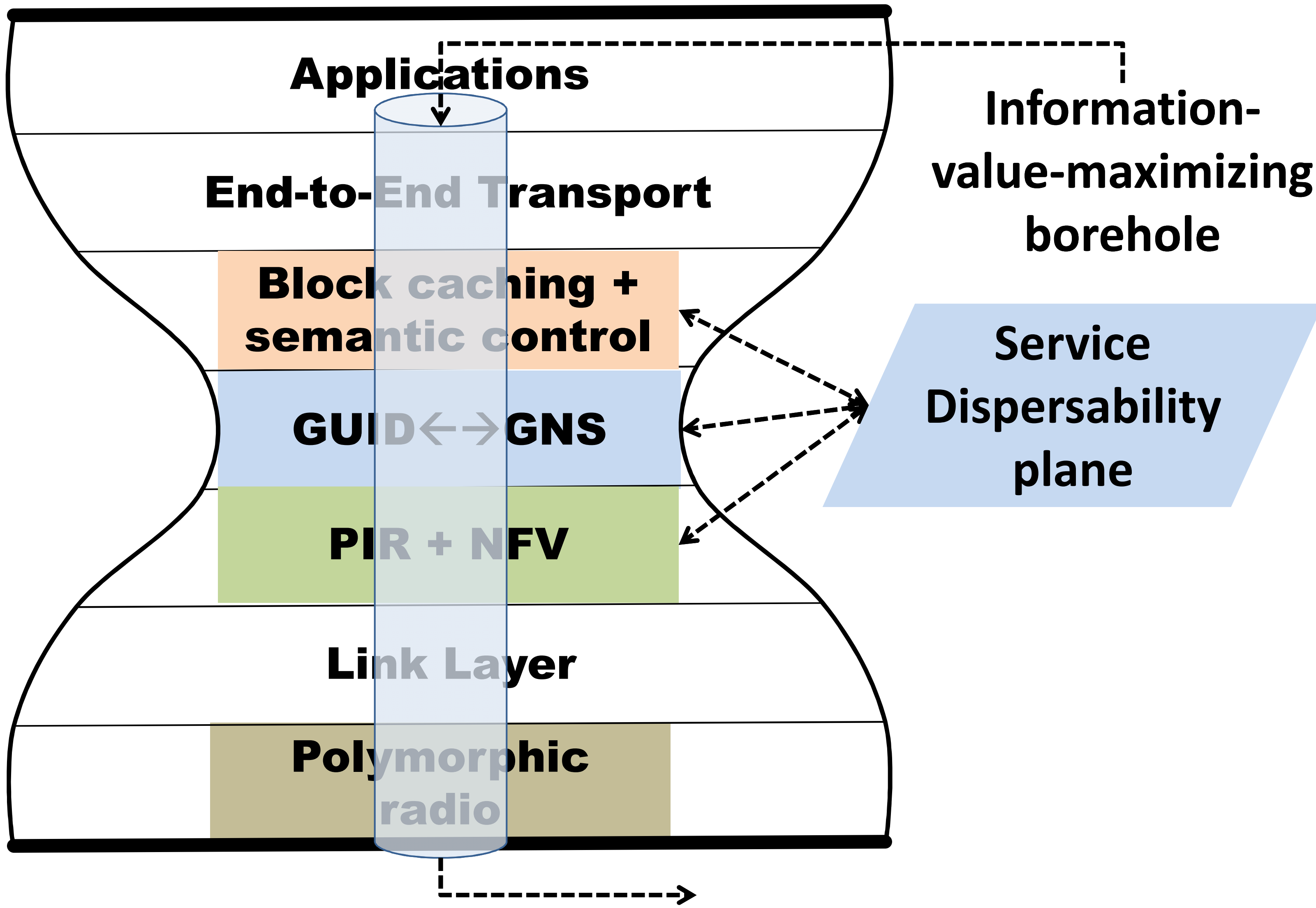
13. Altug Karakurt, A. Eryilmaz. C. E. Koksal, "Quick Discovery of Mobile Devices in ManyUser Regime Carrier Sensing or Simultaneous Detection?", Proceedings of WiOpt, May 2018. (**Best Paper Award**)
14. H. Gupta, A. Eryilmaz, R. Srikant, "LowComplexity, LowRegret Link Rate Selection in Rapidly TimeVarying Wireless Channels, Infocom, 2018.
15. Bin Li, Zai Shi, A. Eryilmaz, "Efficient Scheduling for Synchronized Demands in Stochastic Networks", Proceedings of WiOpt, May 2018.
16. Sheng Shen, Mahanth Gowda, Romit Roy Choudhury, "Closing the Gaps in Inertial Motion Tracking", ACM MobiCom 2018, Oct 2018.
17. S. R. Hussein, O. Chowdhury, S. Mehnaz, E. Bertino, "LTEInspector: A Systematic Approach for Adversarial Testing of 4G LTE", Proceedings of Network and Distributed Systems Security (NDSS) Symposium 2018.
18. E. Bertino, M. Nabeel, "Securing Named Data Networks: Challenges and the Way Forward", ACM SACMAT, June 2018.
19. Hila Ben Abraham, et al. "Decoupling Information and Connectivity via Information Centric Transport", to appear.

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

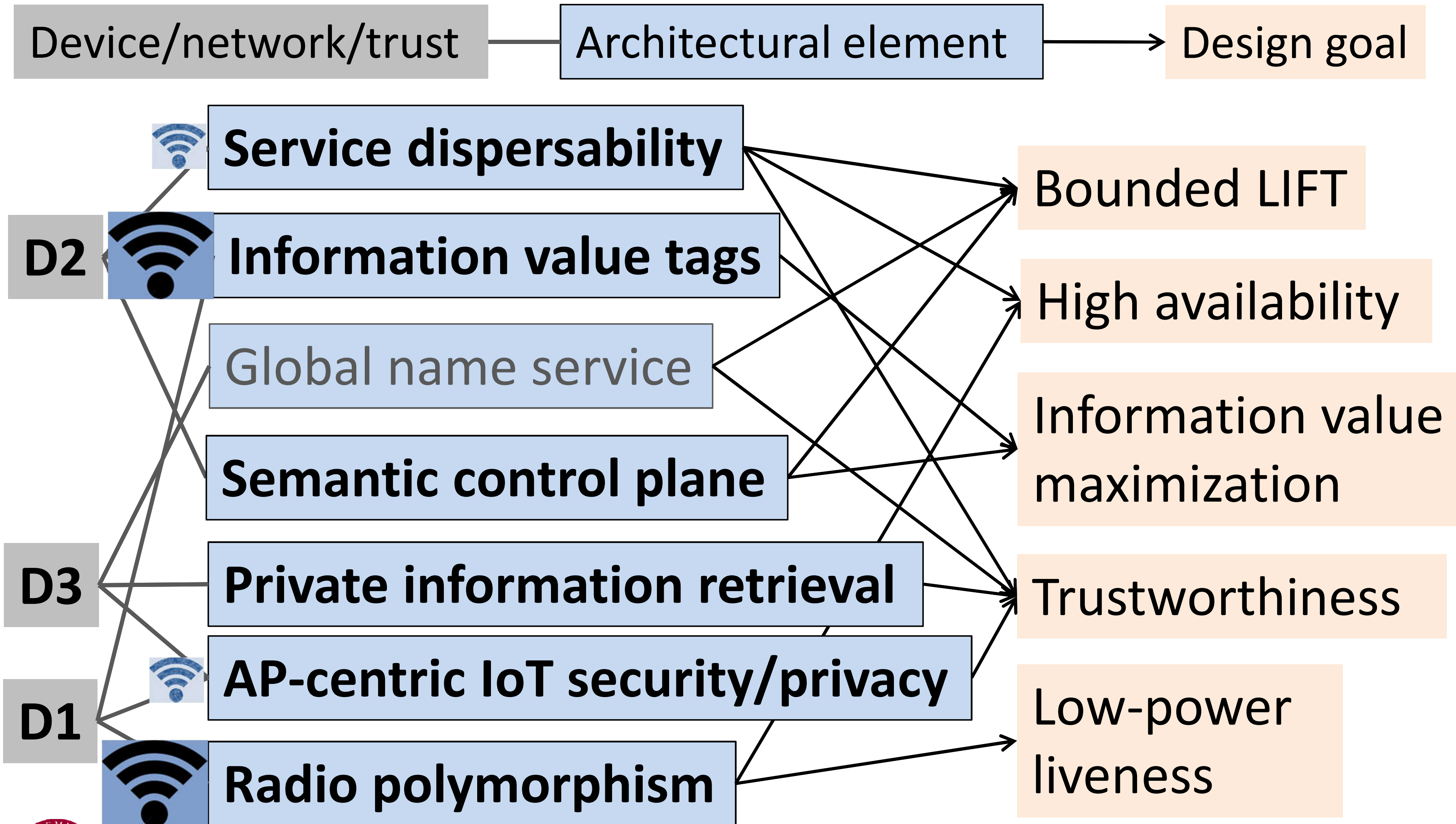
UMass Amherst (Ganesan, Gill, Houmansadr, Venkataramani)

UWisconsin-Madison (Akella, Banerjee, Kim)

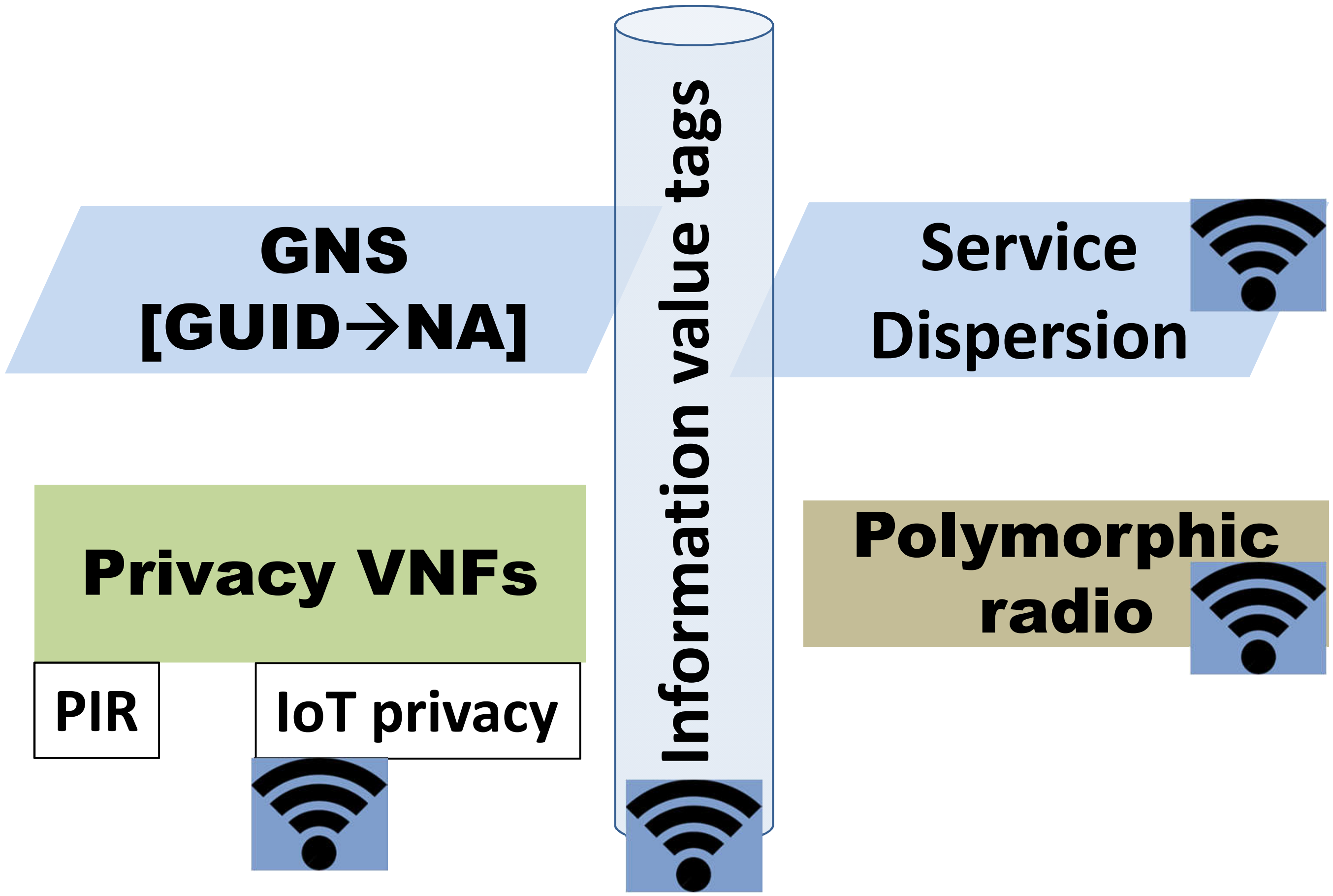
LSN functional stack



LSN novel architectural elements



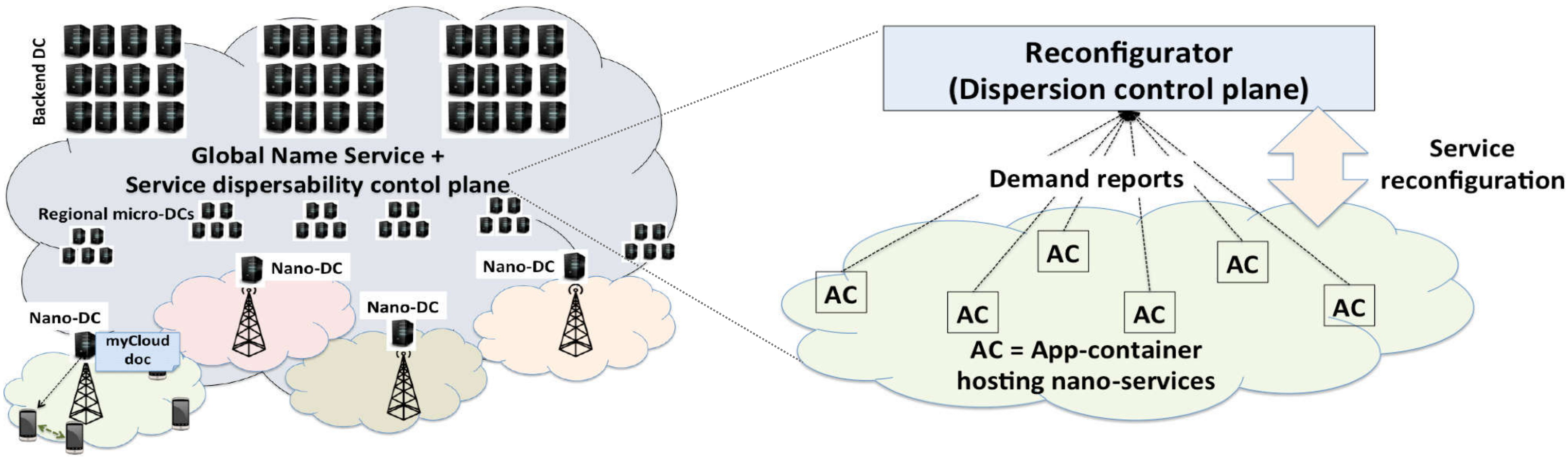
LSN architectural components



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



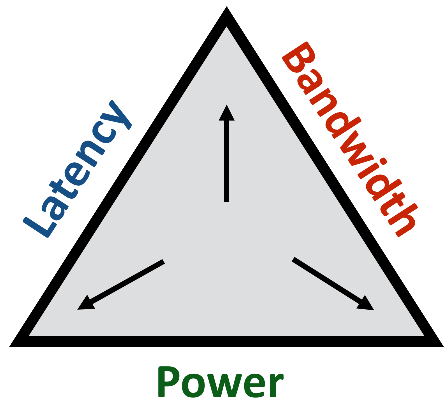
- <u>Service dispersability</u>
  - Feasibility and proof-of-concept of *GigaPaxos* core to enable dispersability of third-party services *(under submission)*
- <u>ICN architectural comparison</u>: comparison of name-based ICN architectures based on mobility support *(Infocom'18)*
- <u>Radio polymorphism</u>:
  - 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

1. Hermes: A Real Time Hypervisor for Mobile and IoT Systems. Neil Klingensmith, Suman Banerjee, ACM HotMobile, February 2018.
2. Augmenting Self-Driving with Remote Control: Challenges and Directions. Lei Kang, Wei Zhao, Bozhao Qi and Suman Banerjee, ACM HotMobile, Feb 2018.
3. Practical Driving Analytics with Smartphone Sensors.
   Lei Kang, Suman Banerjee, IEEE Vehicular Networking Conference, Dec 2017.
4. A Vehicle-based Edge Computing Platform for Transit and Human Mobility Analytics. Bozhao Qi, Lei Kang and Suman Banerjee, ACM/IEEE Symposium on Edge Computing, October 2017.
5. Younghyun Kim and Yongwoo Lee, "CamPUF: Physically Unclonable Function based on CMOS Image Sensor Fixed Pattern Noise," Proc. Design Automation Conference (DAC), pp. 66:1-66:6, San Francisco, CA, 2018
6. **Best Demo Award.** Yongwoo Lee, Kyuin Lee, and Younghyun Kim, "CamPUF: Physically Unclonable Function based on CMOS Image Sensor Fixed Pattern Noise," SIGDA University Demonstration at DAC 2018, San Francisco, CA, 2018.

LSN Publications – 2 of 3

7. Younghyun Kim, "Miro- and Nano-Sensors for IoT Security," US-Korea Forum on Nanotechnology, Seoul, Korea, 2018, invited poster presentation. **Poster Award.**
8. Polymorphic Radios: A New Design Paradigm for Ultra-Low Power Communication, Mohammad Rostami, Jeremy Gummeson, Ali Kiaghadi, Deepak Ganesan, ACM SIGCOMM 2018.
9. A cross-architectural quantitative evaluation of mobility approaches**,** Vasanta Chaganti, Jim Kurose, Arun Venkataramani, IEEE INFOCOM 2018.
10. Scalable Fine-Grained Reconfigurable Replica Coordination, Arun Venkataramani, Zhaoyu Gao, Tianbo Gu, Karthik Anantharamu, UMass CICS Technical Report, www.cs.umass.edu/~arun/papers/gigapaxos.pdf
11. Iron: Isolating Network-based CPU in Container Environments, Junaid Khalid, *UW-Madison;* Eric Rozner, Wesley Felter, Cong Xu, and Karthick Rajamani, Alexandre Ferreira*,* Aditya Akella, USENIX NSDI 2018.
12. StreamNF: Performance and Correctness for Stateful Chained NFs**,** Junaid Khalid, Aditya Akella, CoRR abs/1612.01497 (2016).

Prior Related LSN Publications – 3 of 3

- ParaDrop: Enabling Lightweight Multi-tenancy at the Networks Extreme Edge. Peng Liu, Dale Willis, Suman Banerjee. ACM/IEEE Symposium on Edge Computing, October 2016.
- Low Cost Video Transcoding at the Wireless Edge. Jongwon Yoon, Peng Liu, Suman Banerjee. ACM/IEEE Symposium on Edge Computing, October 2016.
- Greening the Video Transcoding Service with Low-Cost Hardware Transcoders. Peng Liu, Lance Johnson, Suman Banerjee. USENIX Annual Technical Conference, June 2016.

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

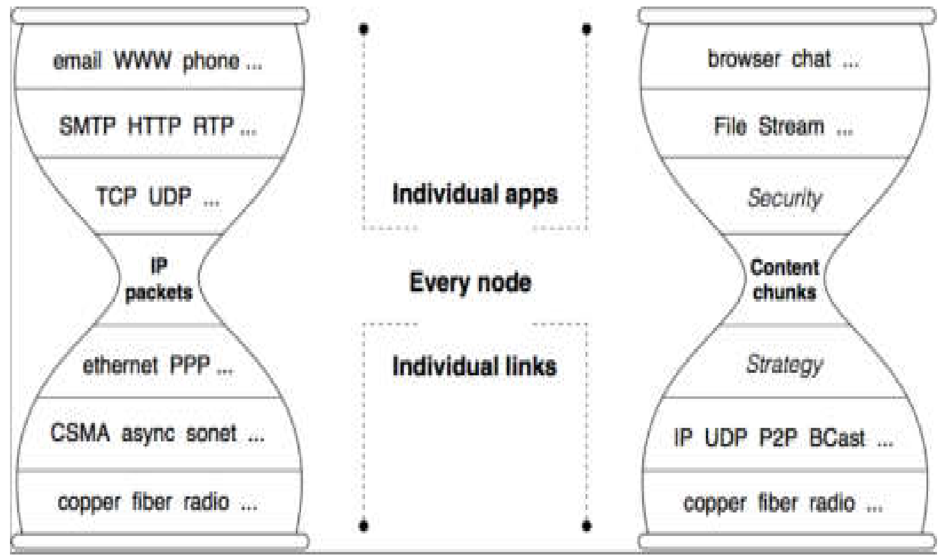
Srikathyayani Srikanteswara
Jeff Foerster
Intel Labs (IL)

Eve Schooler
Internet of Things Group (IoTG)

March 30, 2017

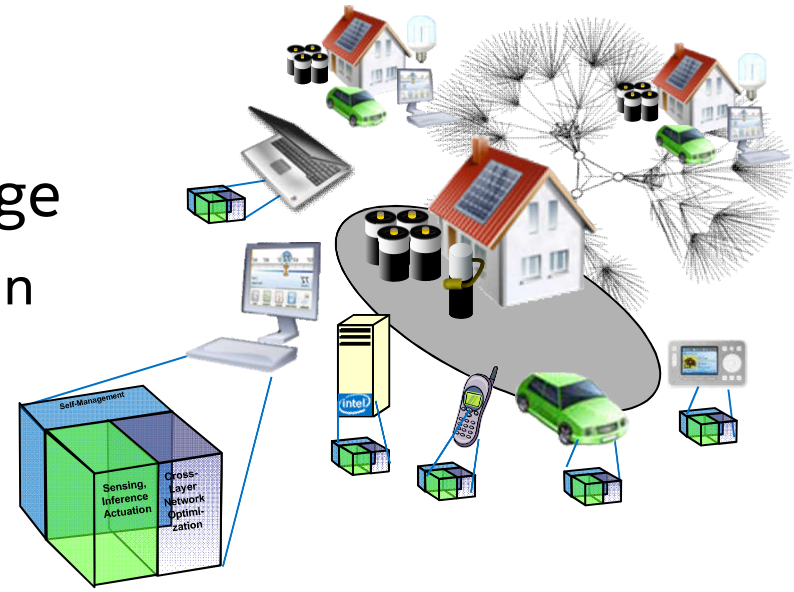
Outline

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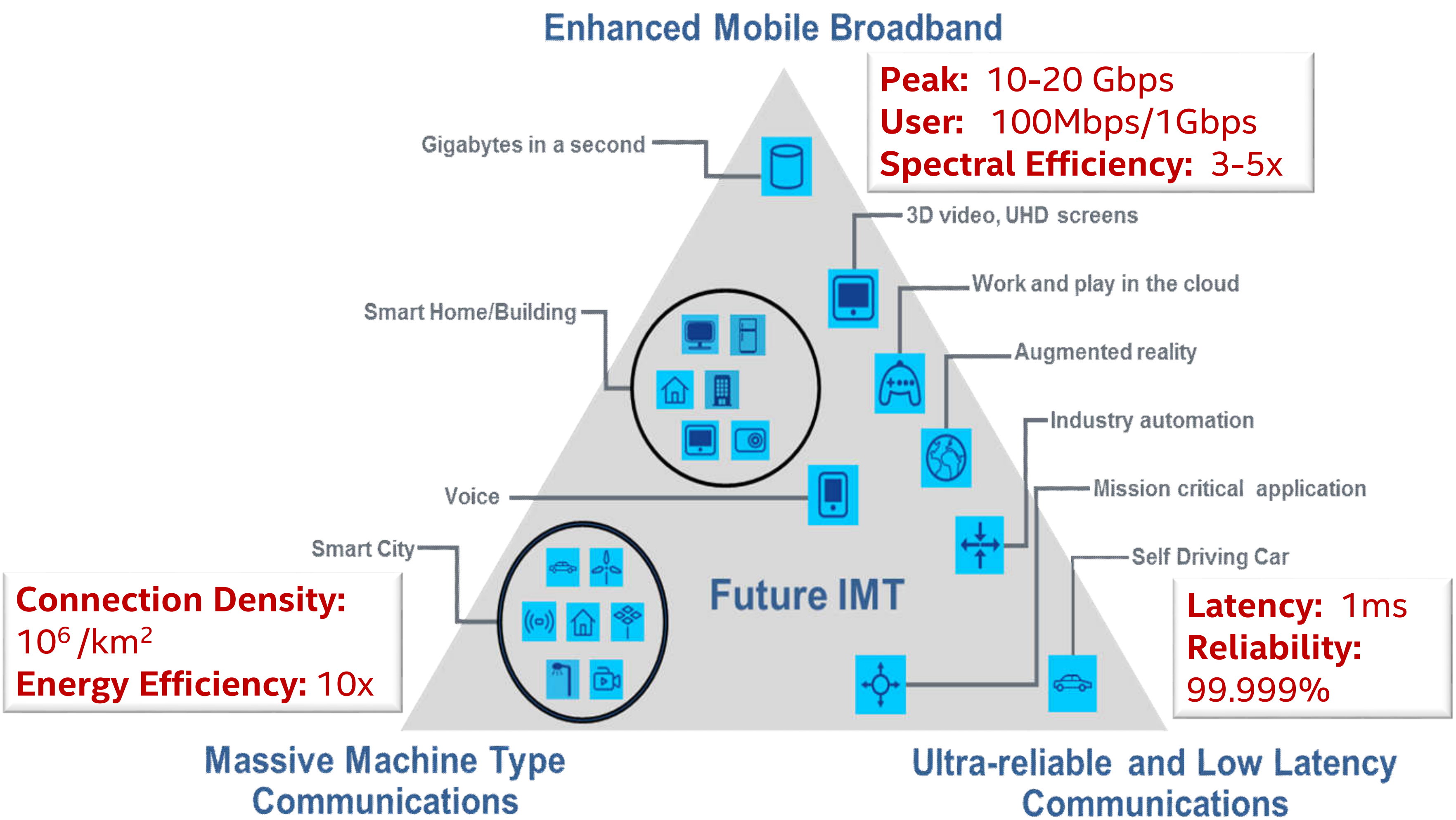
- Focus on Wireless Edge Networks
  - Ultra low-latency and massive IoT applications
- ICN approach to 3 dimensions:
  - wireless device endpoints
  - wireless network infrastructure and architecture
  - wireless data security and privacy
- Clean-slate design
- Research goals: NSF 16-586
  - Create new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

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



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!

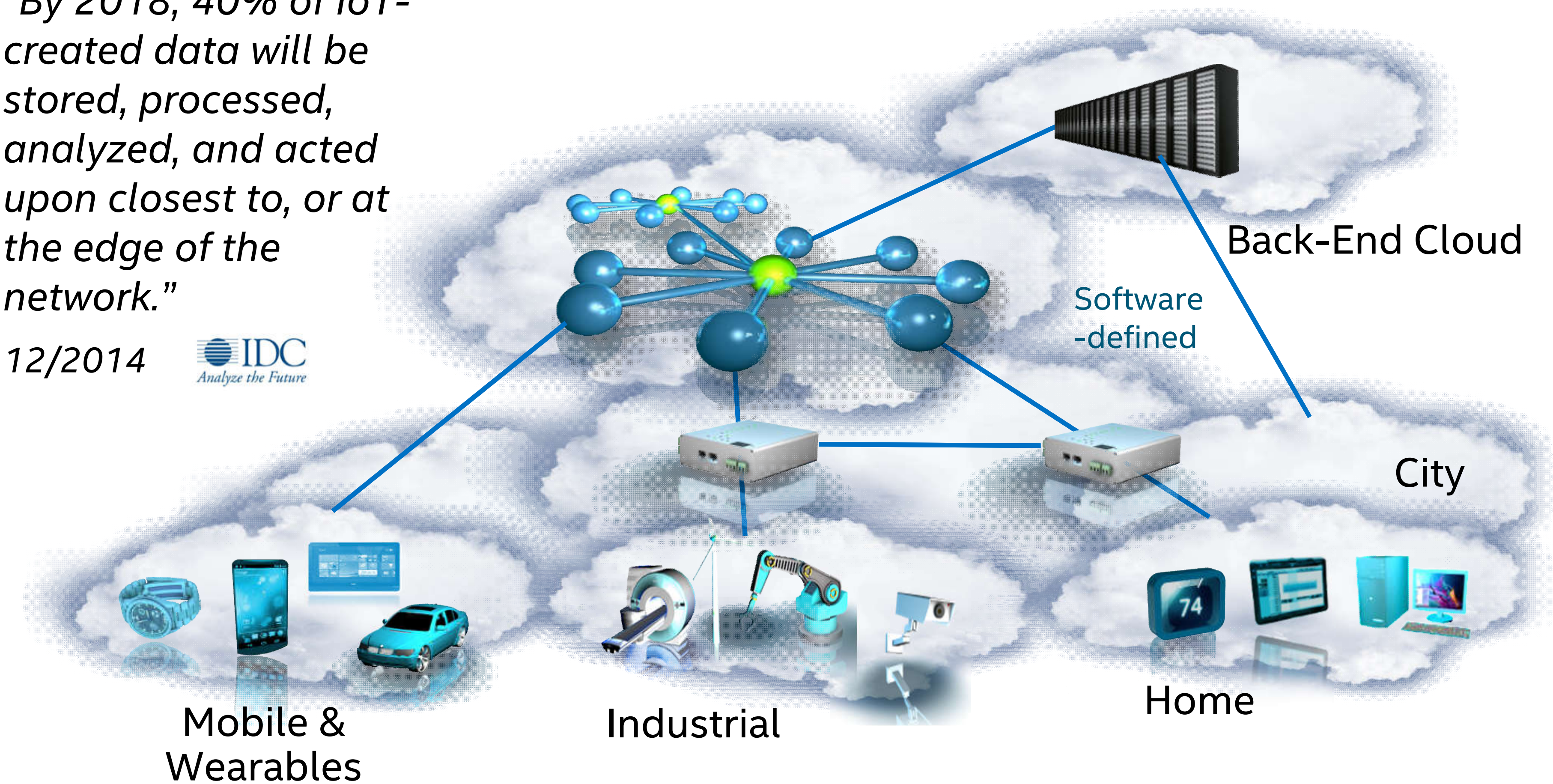
Bigger Picture

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 IDC Analyze the Future



Problem:
Legacy clouds fall short …or are unusable

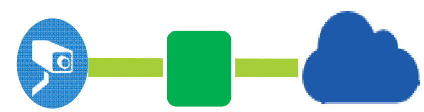
When the IoT data generated is

- Delay-sensitive
- High-volume
- Trust-sensitive
- (Intermittently) Disconnected

Countless examples

- Both near term & further out

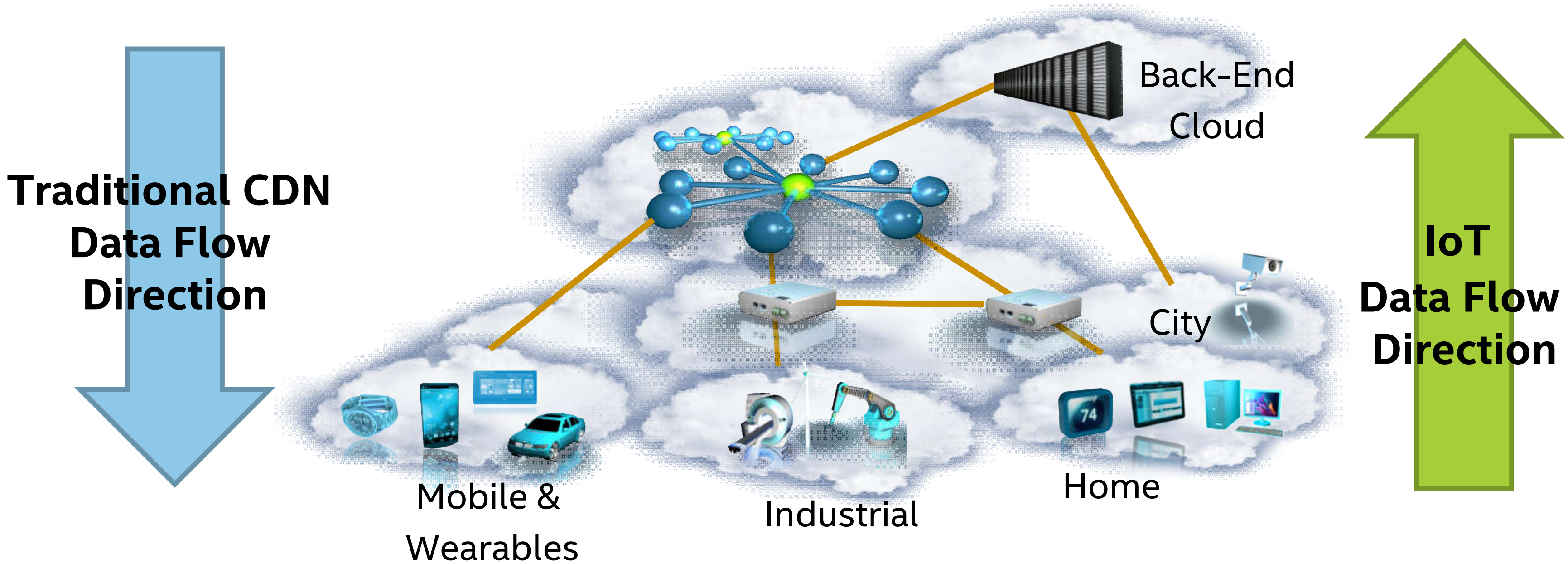
Video Analytics



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 <u>network+compute+storage</u> 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