ICN from Research to Commercialization

Keynote - ICN-WEN Workshop, Intel

Ravi Ravindran, Futurewei, June 19, 2018

My background

- **At Nortel for 10yrs**
  - Optical Networks, GMPLS - Routing and Signaling Protocols
  - MPLS, PseudoWires, PPVPNs
  - QoS/QoE in Networks
    - End-to-end Capacity planning of networks
    - WiMax/LTE Scheduling

- **Huawei for 8yrs**
  - Content Oriented Networking Architectures
    - Collaboration with PARC, UCLA, Winlab
    - ICN has been the main theme, CCN/NDN, MobilityFirst
    - 5G, IoT, Naming, Mobility, Routing/Forwarding

Agenda

- ICN Commercialization
  - Current Industry trends
  - Current state of ICN
  - ICN Selling features
- ICN for 5G
- ICN for IoT
- ICN Commercialization Opportunities
  - Edge Computing
  - IP-TV
  - incremental Ideas

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Current Industry Trends

- **Reduce CAPEX and Increase Flexibility and Scalability**
  - Network Function Virtualization
- **Programmability and Customization**
  - Commoditization of Network function's – CPU/GPU/FPGA/TPU based or White Box Solutions
  - Control Plane – SDN
  - Data Plane – P4/POF
- **Repurposing Infrastructure**
  - CORD
  - CloudRAN
- **Heterogeneous Wireless Connectivity**
  - 5G, mmWave etc (6Ghz ~ 100Ghz), LPWAN (Sigfox, LORA, NB-IoT etc.)
- **Need for more Resiliency and low latency**
  - URLLC use case in 5G
  - Deterministic networking (DETNET) WG in IETF.
- **Flatter Internet**
  - Cloud Inter-connect at POPs to CSP handover
  - Performance and probably economic reasons

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Current State of ICN

- **~10yrs in research now**
  - ICN Sigcomm, Workshops etc.
  - IETF/ICNRG, ATIS, ITU
  - Many ICN variants, CCN/NDN, MobilityFirst, NetInf etc.
- **Basic Tenet has been the same**
  - Make the network more Service-centric
  - Mobilityfirst uses GUIDs, CCN/NDN uses contextual Names
  - CCN/NDN is based on Interest/Data model, MF began with PUSH, later PULL primitive was also introduced
- **Multiple reasons for not taking off**
  - *Lack of Killer Purpose and Application*
    - Replacing as CDN deployments is difficult, as it has been engineered and shown to scale from cost and performance perspective
    - IoT is too heterogenous at the sensor networking level Zigbee, Zwave, BacNet etc, so ICN should show usefulness at the aggregation level above. In-Network compute has promise here.
  - *Privacy and Accountability Concerns*
    - So the scope now reduces to only trusted domains and end points.
    - IDEAS in IETF [1] was a Huawei effort, but faced significant opposition from privacy advocates
  - *Need for new deployment*
    - Software or Hardware
    - Community prefers incremental designs and standardization is required for third party interactions
  - *Huge paradigm shift*
    - Going from notion of hosts and devices to content is a big leap

[1] https://datatracker.ietf.org/wg/ideas/about/

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How SDN Evolved

- **Problem was to adapt the network to changing application requirements**
  - Distributed control plane network protocols with a programmable and centralized control plane
  - For operators it was reduce dependency on vendors and enable programmability
  - Drive networks to very high utilization, B4/SWAN from Google/Microsoft showed >90% utilization
  - Avoid the pain of standardization to enable new control protocol features
- **Reality Check**
  - SDN notions applied mostly in DC, **scoped to hosts and not in the network, .e.g. traffic shaping**
  - Scalability challenges and lack of killer SDN applications, many approaches for TE.
  - New control planes for increased simplicity, TE, flexibility and scalability, Segment Routing, BGP-LS etc.
  - Commoditization of SB interface e.g. NetConf and Yang data models
- **Current state**
  - Notion of Programmability has proven its usefulness
  - WAN Network Programmability being deployed in SD-WAN, SDN for Optical Networks
  - Very less deployment of OF, as originally anticipated.

Programmability was the big sell for SDN, what is it for ICN ?

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Many Good Features of NDN/CCN

- **Naming and Reusability of content objects**
  - Per CO based provenance, integrity and encryption if required.
  - Allows various link layer adaptations, such as in [1] for LTE
- **Per-hop Flow balance and Congestion Control**
  - Recent designs based on this proposed for DC, e.g. NDP, (Sigcomm 2018, won best paper award)
  - Also some generic versions coming out from Stanford
- **Multicasting**
  - IP multicasting only works in conditions where there is end-to-end network control and homogenous end points, e.g. IPTV, end-to-end error recovery or flow control big challenges.
  - Even having ICN state in the CO can help create a common platform for multicasting, e.g. among Settop boxes and Smart devices (more later)
- **Multi-homing**
  - 5g will operate over heterogeneous RATs, ICN is well positioned because of receiver oriented design
  - mmWave technology will work on beamforming with small cells, [1] KDDI has shown some ICN applicability using this technology
  - Wireless VR looking at 100Mbps to 1Gbps bandwidth, realizable over multi-beamed mmWave technology
- **Mobility**
  - Gateway based mobility, e.g. LTE, has too many drawbacks with inefficient routing and potential choke points because of traffic aggregation.
  - Flat architectures with in-build mobility helps with efficient routing, multiple ingress/egress points for the network.

[1] https://www.itu.int/en/ITU-T/Workshops-and-Seminars/201612/Documents/slides/52-KDDI_Research-Interplay_of_mmwave.pdf

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Need for PUSH Support

- NGMN and ITU’s IMT,2020 requires new networks such as 5G to support low latency and ultra reliable communications
  - Latency of 1-15ms, for Remote surgery, VR/AR, V2V, Robotic Control
- For immersive VR, a single control update should be able to push multiple content objects to keep the Motion-to-Photon (MTP) latency with 15-20ms
- PULL semantic may not be ideal for this as argued in [1]
  - When data produced is random and mission critical, hence almost no loss
  - 5G aims to cover 10^6 IoT devices per sq.km, e.g. for 5 data packets, we need $5 * 10^6$ outstanding interests.
- We proposed a Notification Semantic in CCN.
  - Breaks the flow balancing feature, but receiver oriented ideas as in [2] can be used to bring in flow and congestion control principals similar to Interest/Data paradigm

[1] Ravi Ravindran et al, “Support for Notifications in CCN”, IETF, ICNRG, 2017, https://tools.ietf.org/html/draft-ravi-icnrg-ccn-notification-01
[2] Chen, J., Arumaithurai, M., Fu, X., and KK. Ramakrishnan, "SAID: A Control Protocol for Scalable and Adaptive Information Dissemination in ICN.", ICN, Sigcomm 2016

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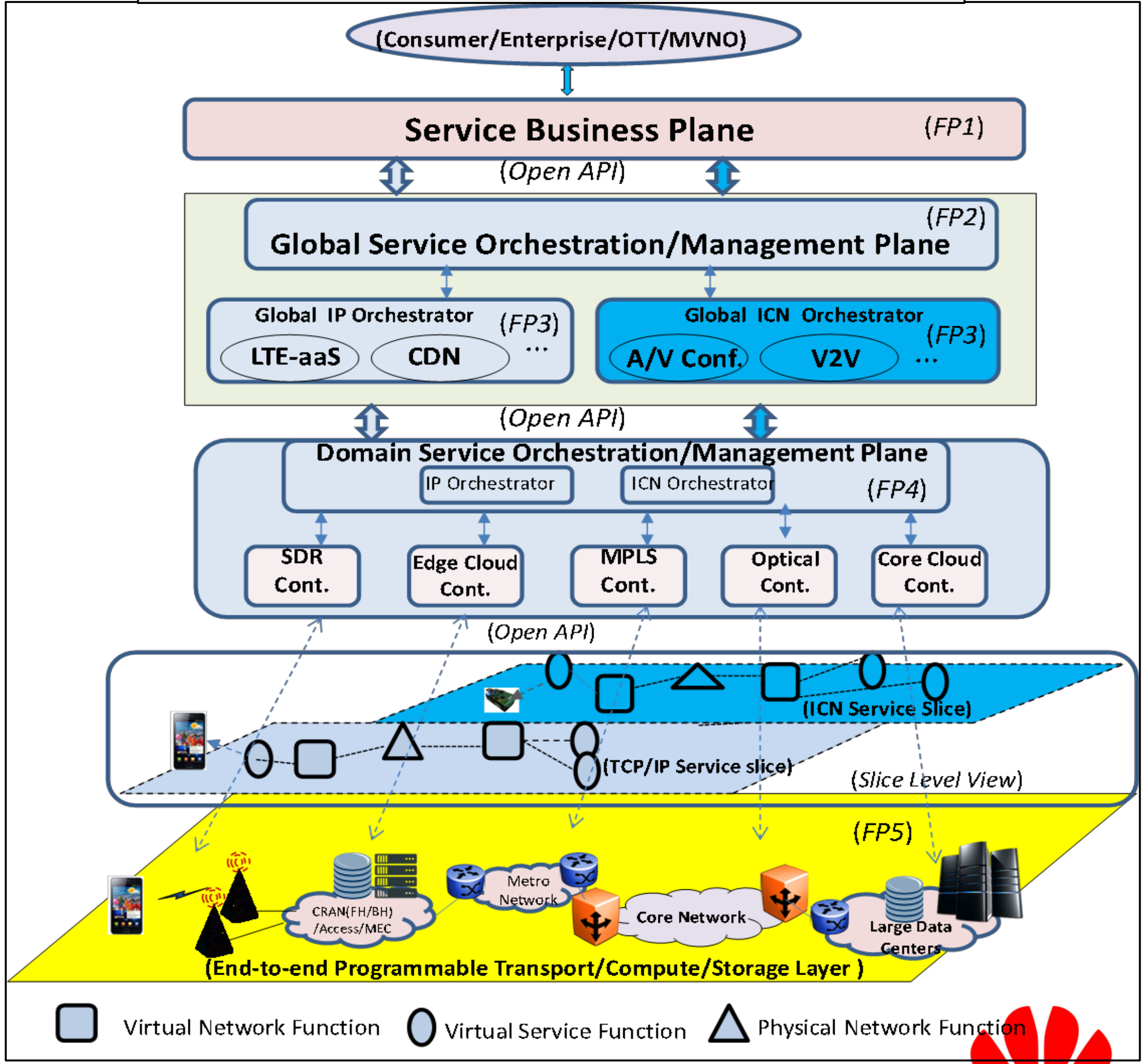
ICN in 5G

Realizing ICN as a Network Slice [1]

- **Realize end-to-end dedicated network for specific service scenario eMBB, URLLC, mMTC.**
  - Spans UE, RAT, Transport, Edge Clouds, DCs
- **Meet specific service objectives of Security, Latency, QoS, Reliability etc.**
- **End-to-end virtualization of Compute, Bandwidth, Storage, Data , Device resources.**
  - Virtualization allows resources to be efficiently flexibly managed among various slices.
- **Specialized Data/Control Plane and Service Control functions to enable rich services.**
  - Software Network Functions, P4/POF Platforms
  - Mobility-as-a-service, Security-as-a-service , Context Processing etc.
- **Creates scope for new network Architectures like ICN to address 5G Challenges**
  - **Multi-modal delivery connectivity: M2M, P2P, P2MP and MP2MP**
  - **Handle Mobility within the Slice**
  - **New APIs and Service Functions in the Network Architecture**

Network Slicing Framework



[1] R. Ravindran, Asit Chakraborti, Syed Obaid Amin, Aytac Azgin, G.Q.Wang, "5G-ICN: Delivering ICN Services over 5G Using Network Slicing," IEEE Comm., Mag., vol. 55, no. 5, May 2017, pp 101-107.
[2] ITU, FG, IMT 2020 Phase-1 – "Network Standardization Requirement for 5G"
http://www.itu.int/en/ITU-T/focusgroups/imt-2020/Documents/T13-SG13-151130-TD-PLEN-0208!!MSW-E.docx
[3] ITU, FG, IMT 2020 Phase-2 - Architecture and Technology enablers for Network Softwarization & Prototyping

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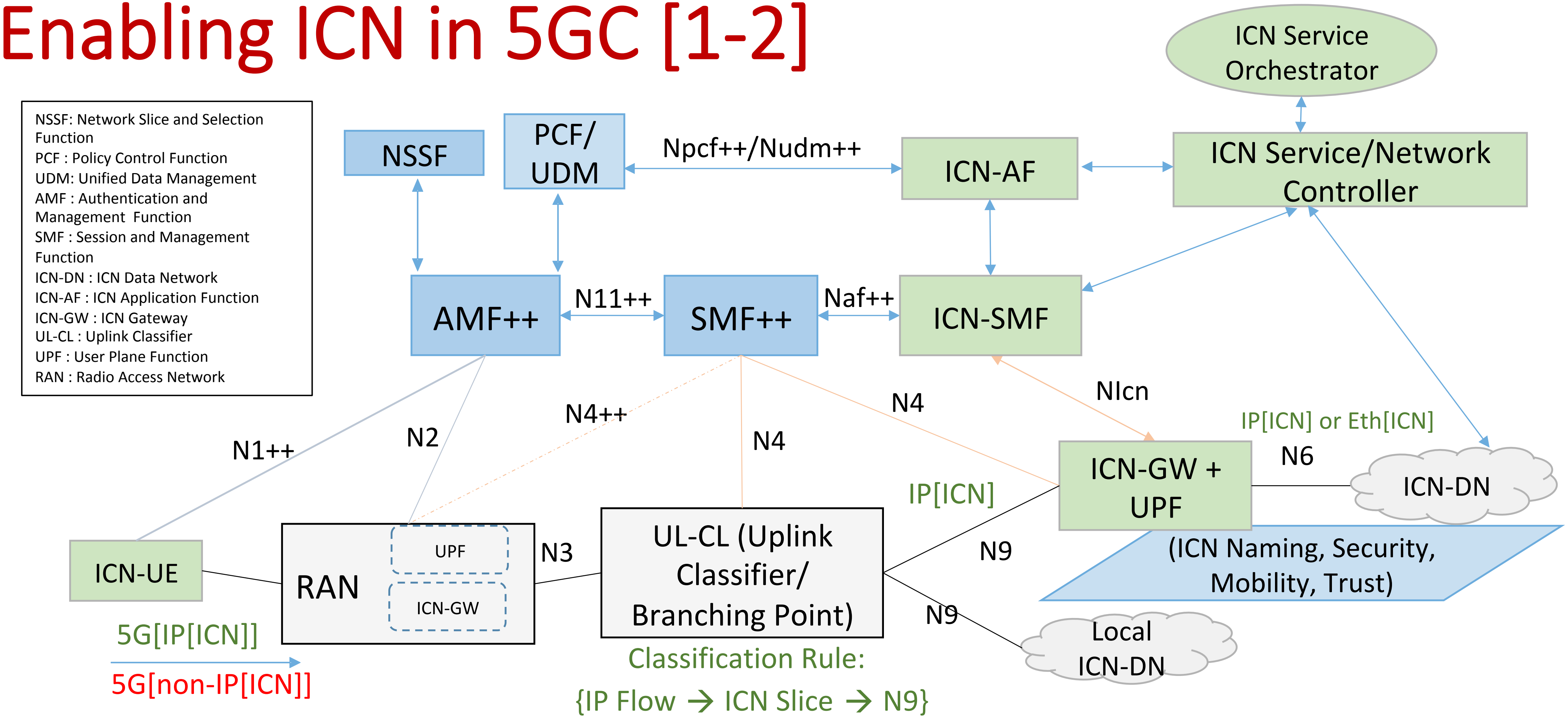
Enabling ICN in 5GC [1-2]



- **ICN can be transported over IP or as non-IP PDUs towards ICN-DN**
- **ICN-SMF handles session management of ICN-AP NF. AMF++/SMF++ enforce functions to allow UE subscription authentication to ICN DN, and provision rules in RAN, UL-CL and other intermediate UPFs to enable UE-ICN to anchor to ICN-AP.**
- **ICN-AF can push ICN PDU session requirements to PCF/UDM for slice selection or session management functions between the RAN and the ICN-AP**

[1] Ravi Ravindran et al, **“Enabling ICN in 3GPP’s 5GC Architecture”,** draft-ravi-icnrg-5gc-icn-01, IETF/ICNRG, 2018
[2] Ravi Ravindran, Prakash Suther, Asit Chakraborti, Syed Obaid Amin, Aytac Azgin, G.Q.Wang, “**Deploying ICN in 3GPP’s 5G NextGen Core Architecture**”, IEEE, 5G World Forum 2018 (Accepted for publication)

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Non-IP PDU Provision Considerations

- In this mode, the ICN-UE will operate without any IP configuration
- For maximum efficiency, the ICN-GW can be realized in the RAN.
  - Caching and Mobility can enabled in the RAN
- **Following are considerations to allow ICN as one of the non-IP PDU types which 5G can support.**
- **Attach Procedures/Control Plane for UE with non-IP PDN**
  - Extended Mechanisms required to authenticate/authorize ICN UEs at device or service level
  - This can be extended to authorize service access, as ICN is about networking services.
  - Mechanisms described in TS.23.501 using existing AUSF/UDM/PCF functions can be potentially extended towards this.
  - Can be extended to include ICN specific authentication function (ICN-AF)
    - AMF++/SMF++ and ICN-SMF functions to support non-IP PDU management
  - Current LTE identifies the connectivity type using PCO-IE, i.e. IP versus non-IP PDU, could be used for control plane session management
- **User Plane for UE with non-IP PDN**
  - Requires mechanism to identify ICN PDUs for policing, charging or legal interception
  - A flat ICN realization requires a distributed mechanism to handle these functions
  - ICN by design doesn’t include consumer identity, lower layer identities (e.g. PDCP/MAC) can be used towards this.
  - Further Slice-ID (from NSSAI) could be used in the UPF to map ICN flows to appropriate ICN slice

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Non-IP PDU Provision Considerations

- **Mobility Handling**
  - Involving IP networking between the RAN and the UPF is inefficient
  - Efficient handling by collocating ICN-GW with RAN
  - Requires integration with 5G and ICN CP/UP functions
- **Routing Considerations**
  - 5GC follows LTE’s centralized session management and routing approach using the SMF
  - Scalability challenges in a flat ICN realization where multi-source and multipath routing can be taken advantage of
  - Explore feasibility of distributed routing approaches within the 5GC framework
- **Mobile Edge Computing**
  - ICN level service orchestration to exploit services deployed in network or using in-network approach like NFN.
  - Routing challenge, to direct ICN service flows to closest service or in-network compute instance

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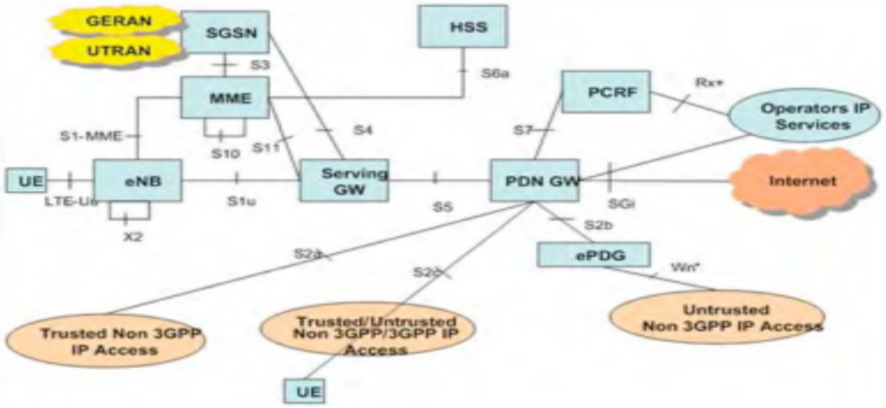
Seamless Mobility in ICN

Towards Next Generation flat Wireless Network Architecture.

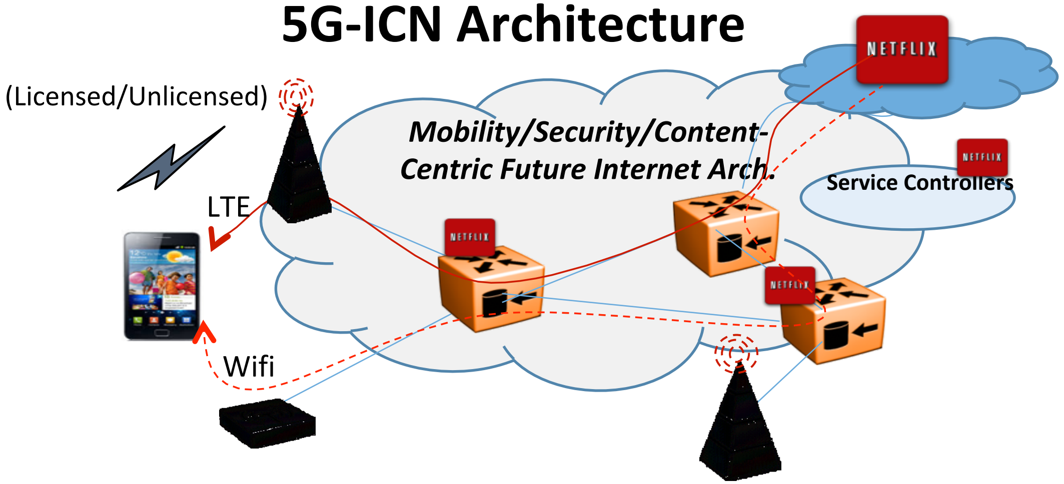
LTE Network Architecture



Current Architecture

- Hybrid 3GPP & IP Arch
- Disjoint Fixed and Cellular Access
- Complex Control interfaces.
- Technology Specific (2G/3G/4G)
- IP Tunneling in Data Path
- Gateways (…bottlenecks, sub optimal routing)

5G-ICN Architecture



5G-ICN Architecture [1]

✓Flat Information-centric Network Architecture.
✓ Cellular/Fixed Access Convergence
✓No Gateways or Tunnels
✓In-build Network Layer Mobility
✓In-build Security, Storage and Computing
✓Technology Neutral (any RAN/RAT)
✓Efficient Service Virtualization
✓Distributed Billing, Policy, Legal Intercept

[1] Shreyasee Mukherjee, Ravi Ravindran, D.Raychaudhuri, "**A Distributed Core Network Architecture for 5G Systems and Beyond**", (Accepted ACM, Sigcomm, NEAT Workshop, 2018)

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Seamless Mobility in CCN

- By default CCN handles Consumer Mobility using caching and Interest re-expression.
- Producer Mobility requires routing on names to resolve to current location.
  - Scalability challenge and Poor Throughput [1]
- Current Approaches can be classified as **Application or UE Based approaches**
  - *Anchor Based* : Traced and Tracing Interests, Security, Path Stretch and Naming Challenges [4]
  - *Anchorless Based* : New FIB structures and in-network signaling primitives [5]
    - Security, Signaling over head, Path Stretch and Routing Convergence Challenges
  - Main issue is cannot implement a "Make Before Break" mechanism

- **Our solution Network Based - AI/NI split, proposed Forwarding Label in [2][3]**
  - **Two features that help producer mobility are : Edge Name Resolution and Late Binding**
  - **Stable core routing based on NI**
  - **Limits Mobility Dynamics only to the network edge**
  - It allows edge CCN nodes to resolve Interest in a service and topologically aware manner.
  - A name resolution infrastructure required to map the two name spaces.
  - Current scope is for a single administrative domain, inter-domain name resolution can be realized using decentralized controller framework.

[1] Aytac Azgin, Ravi Ravindran, G.Q.Wang "Mobility Study in Name Data Networking in Wireless Access Networks", ICC, 2014. https://arxiv.org/pdf/1406.5521v1.pdf

[2] Aytac Azgin, Ravi Ravindran, G.Q.Wang, "Seamless Mobility as a Service in Information Centric Networks", 5G/ICN Workshop, ACM ICN Sigcomm, 2016, http://conferences2.sigcomm.org/acm-icn/2016/proceedings/p243-azgin.pdf

[3] IETF/ICNRG, "Forwarding Label Support in CCN Protocol", https://tools.ietf.org/html/draft-ravi-icnrg-ccn-forwarding-label-00

[4] H. Zhang, L. Zhang, "Kite: A Mobility Support Scheme for NDN", Y. Zhang, ACM ICN 2014.

[5] Jordan Auge et al, "Anchorless Producer Mobility in CCN", ICN Sigcomm, 2015

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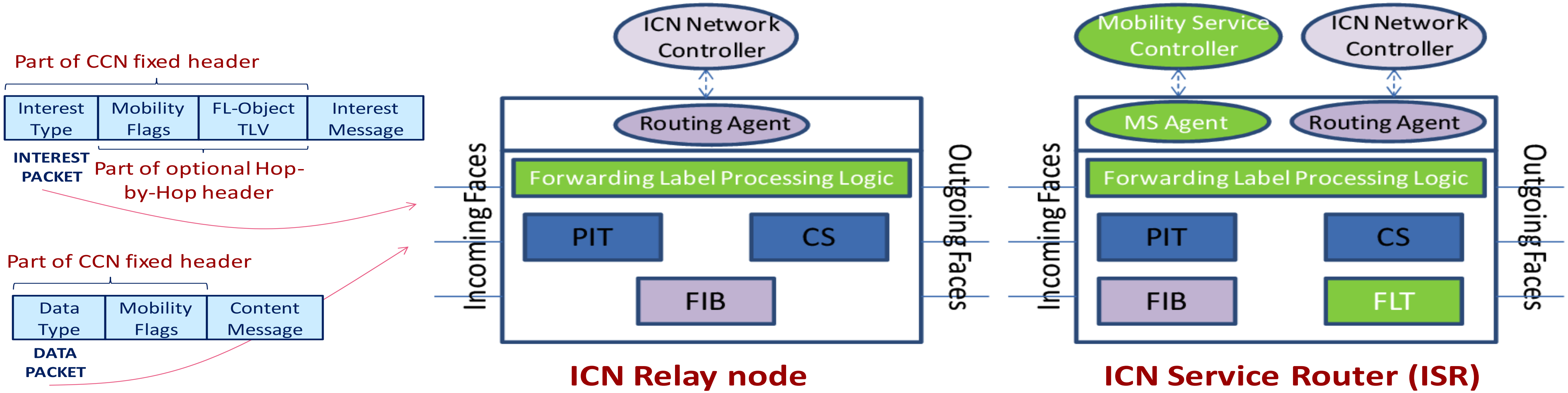
Seamless Mobility using Forwarding Labels in ICN



- We augment the Interest packet with FL-Object [1].
- FL-Object contains the forwarding label, along with optional security binding with name.
- The forwarders are enhanced to process the FL-Object.
- Late binding allows Interest flows to be re-routed to UE’s current location.

[1] Ravi Ravindran, Asit Chakraborti and Aytac Azgin, “**Forwarding Label Support in CCN Protocol**”, https://tools.ietf.org/html/draft-ravi-icnrg-ccn-forwarding-label-02

[2] Aytac Azgin, Ravi Ravindran, “**Enabling Network Identifier in Information Centric Networks**”, IETF/ICNRG,

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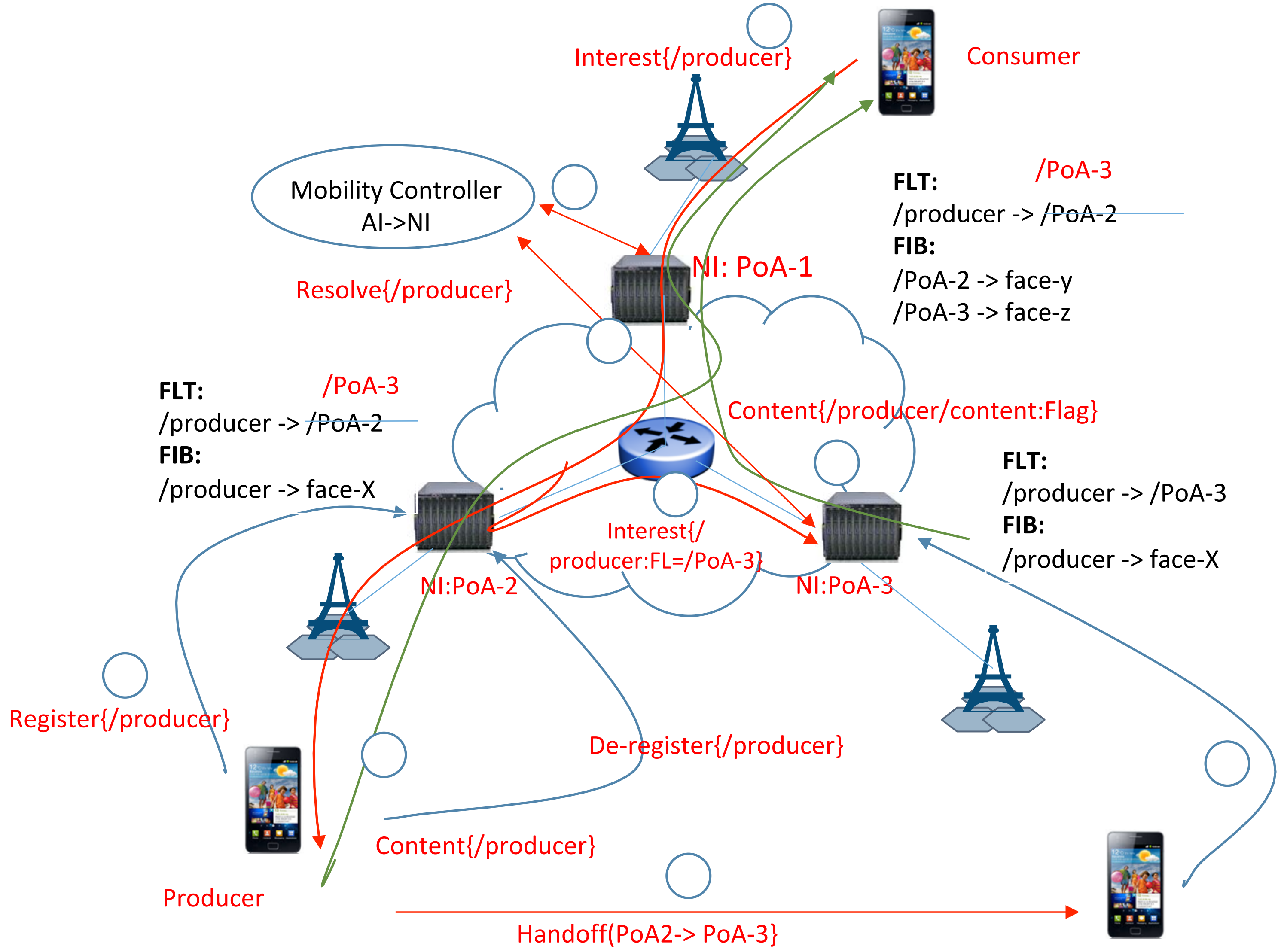
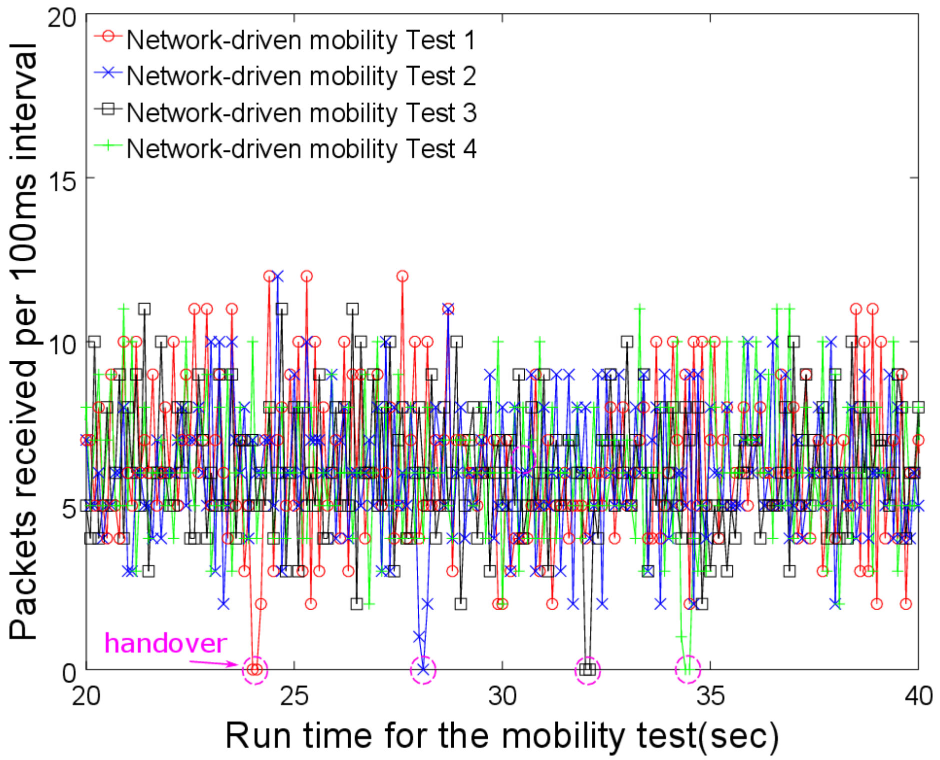
Seamless Mobility Through in CCN/NDN [1-3]





[1] Aytac Azgin, Ravi Ravindran, G.Q.Wang, "**Seamless Mobility as a Service in Information Centric Networks**", 5G/ICN Workshop, ACM ICN Sigcomm, 2016

[2] Aytac Azgin, Ravi Ravindran, "**Enabling Network Identifier in Information Centric Networks**", IETF/ICNRG,

[3] Ravi Ravindran , Asit Chakraborti, Aytac Azgin, "**Forwarding Label Support in CCN Protocol**", https://tools.ietf.org/html/draft-ravi-icnrg-ccn-forwarding-label-001

- **Seamless mobility with *Make-Before-Break* feature, ~100ms handover latency achievable.**
- **In Network based mobility, network provides the PoA information allowing proactive late binding after the de-registration from the UE**
- **If there is a candidate list of PoA, then the Interest can be multi-unicast to each one, until signaling from the new PoA**

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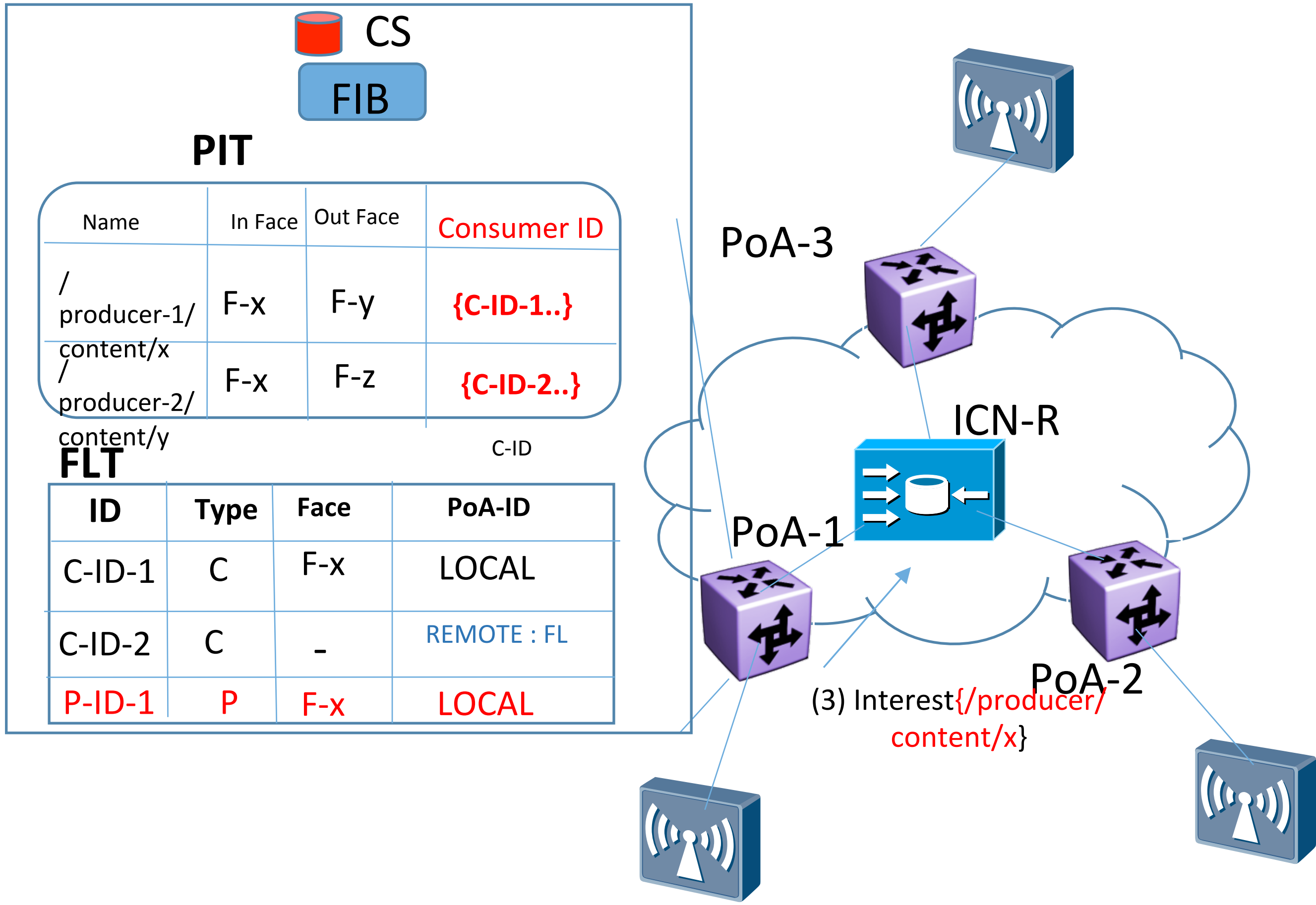
Using Forwarding Labels for Consumer Mobility [2]

- **We re-use the Forwarding Label cache Table [1] (FLT) to map the Consumer-ID to the local transport face and a forwarding label.**
  - FLT was proposed in [1] for producer mobility, the same table can be used for consumer mobility too.
  - Consumer-ID and Producer-ID can be the same, if mobility is handled at the device level.
  - The status stores the state of the device, as being Attached or Moved with a new FL.
- **The Interests from the consumer should include the consumer-ID.**
  - This has only local significance, i.e. it is not forwarded beyond the PoA.
- **The PIT is modified to store the set of C-IDs requesting the content.**



[1] Aytac Azgin, Ravi Ravindran, G.Q.Wang, "**Seamless Mobility as a Service in Information Centric Networks**", 5G/ICN Workshop, ACM ICN Sigcomm, 2016
[2] Ravi Ravindran, Aytac Azgin, "**Forwarding Label Support in CCN Protocol**", IETF/ICNRG, March, 2018 https://datatracker.ietf.org/meeting/interim-2018-icnrg-01/materials/slides-interim-2018-icnrg-01-sessa-revised-draft-forwarding-label-support-in-ccn-protocol-ravi-ravindran

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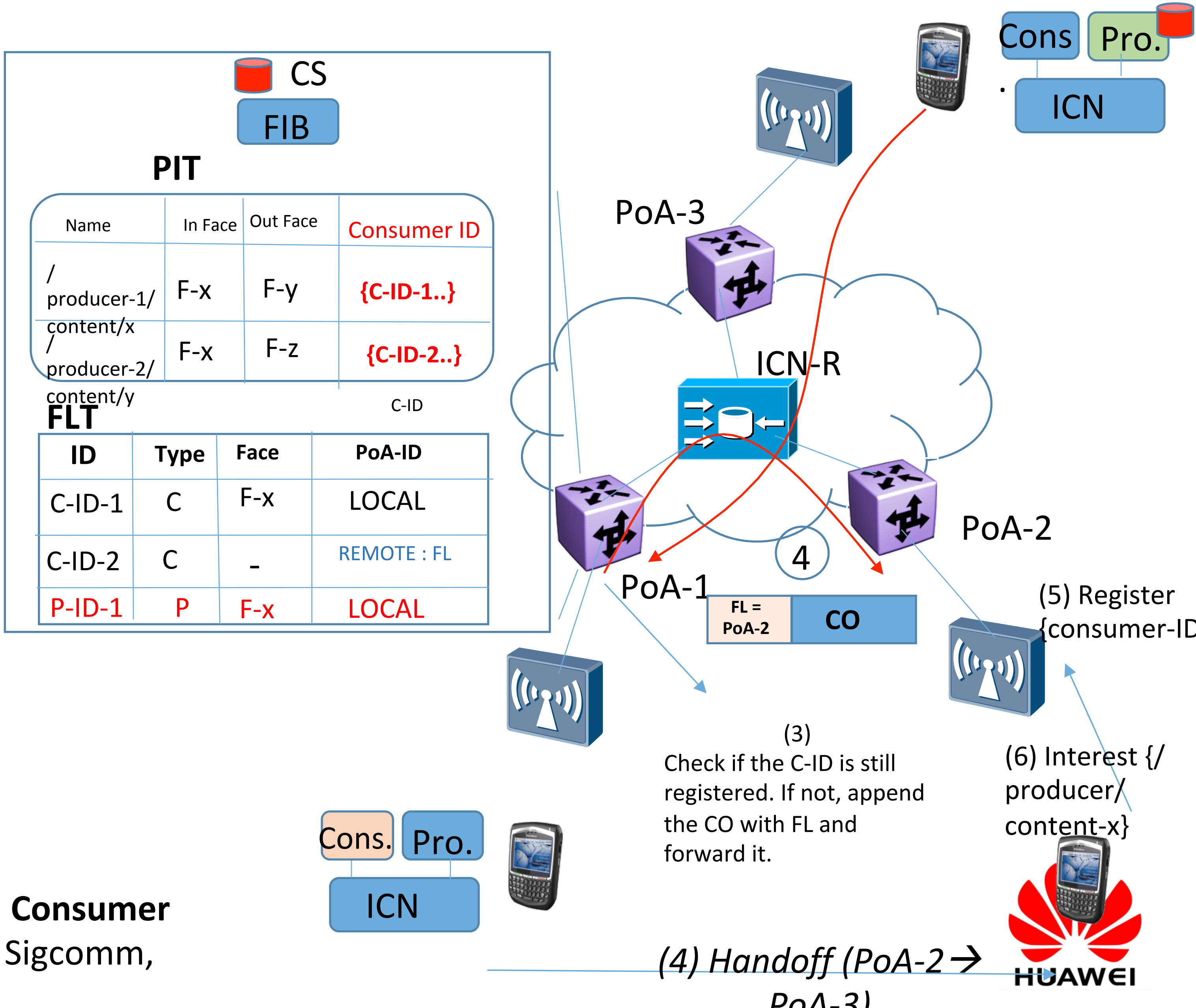
Using Forwarding Labels for Consumer Mobility

Network Handling of CO

- These POA forwarded COs are marked to be treated differently than the regular CO
- The ICN routers use the FL in the CO to forward the packets to the new POA
- At the new POA, the COs can be pushed to the UE, or cached to be pulled.

Caching Implications

- The CO will not be cached in the path from the intersection router to the old POA.
- It can be cached in the path segment between the intersection router and the new POA



PIT

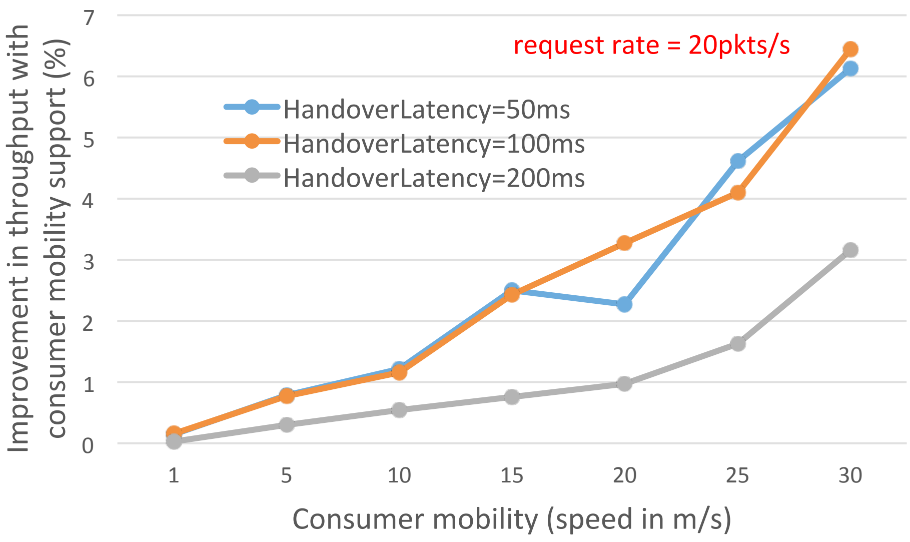
Name	In Face	Out Face	Consumer ID
/producer-1/content/x	F-x	F-y	{C-ID-1..}
/producer-2/content/y	F-x	F-z	{C-ID-2..}

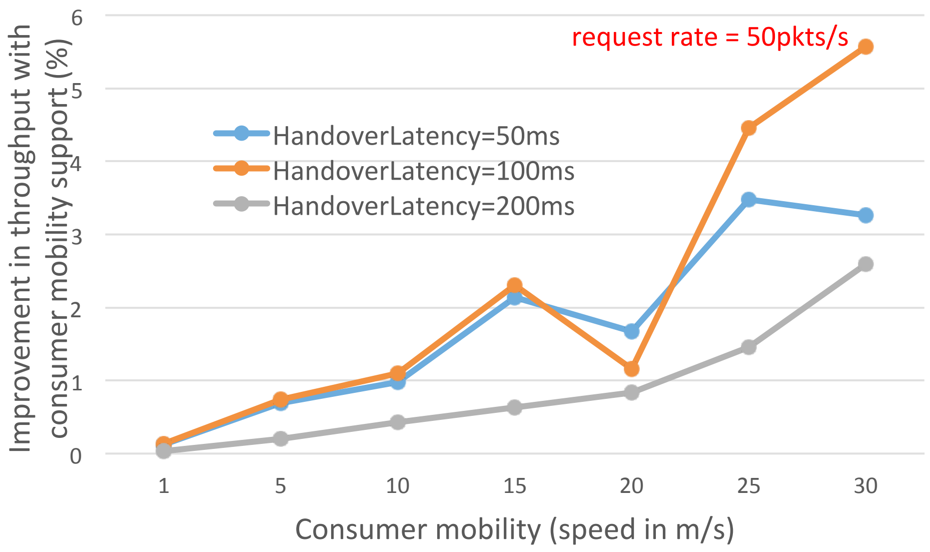
FLT

ID	Type	Face	PoA-ID
C-ID-1	C	F-x	LOCAL
C-ID-2	C	-	REMOTE : FL
P-ID-1	P	F-x	LOCAL

[1] Aytac Azgin, Ravi Ravindran, "**Network-assisted Consumer Mobility Support for ICN**", (Submitted to ACM ICN Sigcomm, 2018)

Simulation Results at different loads and handover latencies





- The main gain from the consumer mobility support architecture is to be able to receive data as soon it connects to the new PoA, as otherwise consumer may need to wait one RTT to start receiving data packets.

- Improvement may decrease at the highest handover latency (which would depend on the scenario), because the impact of lost requests during handover on the overall throughput at the consumer can increase.

- With 5G systems and beyond that aims to minimize handover latencies, the performance difference will be more severe.

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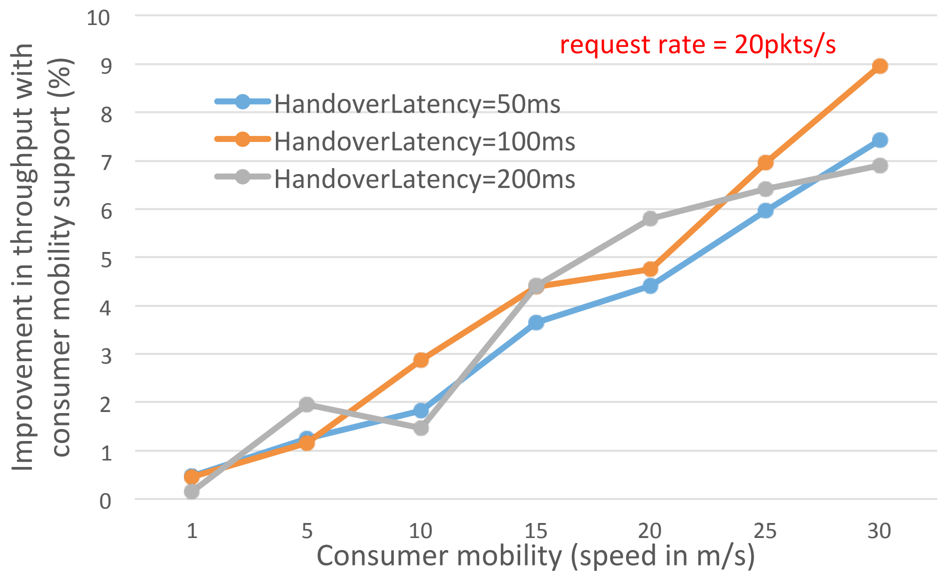
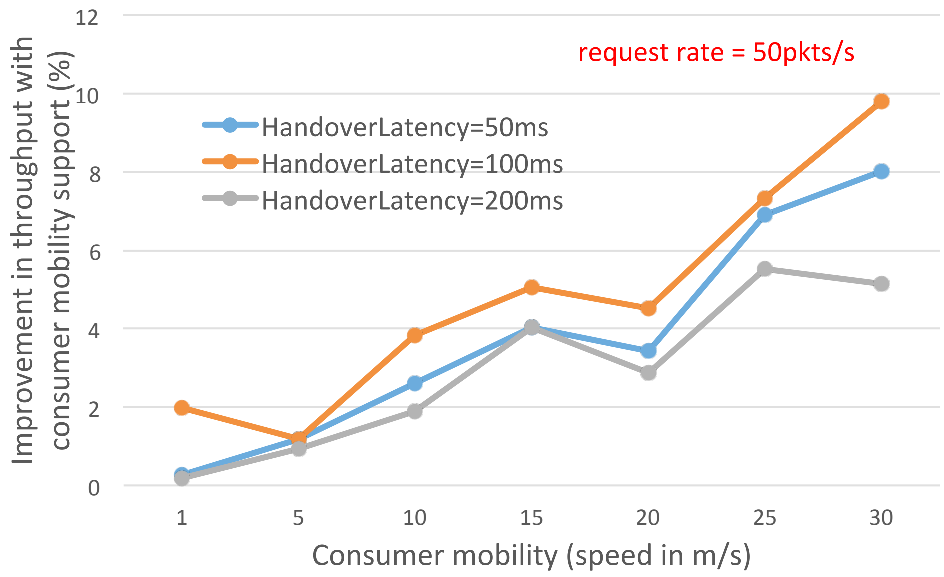
Simulation Results at different loads and handover latencies

We doubled the link latencies to increase the RTT time in-between end hosts





- Increasing RTT at the same request rate results in higher number of pending Interests at the access points or service routers.
- Such a case can degrade the performance as more packets would be lost during a handover, and needs to be recovered through retransmissions.
- Our solution limits the impact of those by delivering such Data packets to the new point of attachment.

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ICN-IoT

Design Considerations Draft.

Referred from "***Design Considerations for Applying ICN to IoT***", Ravi Ravindran, Yanyong Zhang, et al IETF/ICN-RG Draft. (WinLab/ Huawei/INRIA/UCLA) – "draft-irtf-icnrg-01"

→Considering 50B Things to be connected to the Internet (*Heterogeneous, physical things (assets), low power requirements, M2M, Mobile, Ad Hoc* etc.)

Inter-operability

- Unified Naming of Devices/Services/Content (IPv6 may not be sufficient)
- Flexible Naming (sensors, embedded devices, wearables, smart devices etc.)
- Naming (Persistent (Contextual), Secure, Human friendly)
- Open-API at all levels

Security , Privacy & Trust

- Access Control/Trust/Provenance/Data Integrity/Regulations
- Data Privacy/Secure Names

Scalability

- ID/Locator Split
- Enable Decentralized Communication (P2P)

Mobility

- Devices/Services accessible irrespective of Mobility or Migration

Reliability/Availability

- Storage and Caching (Sharing information, reducing upstream bandwidth, Processing)
- Disruption tolerance (QoS, Wireless, Redundancy, Flow Control, Opportunistic transmission)
- Near real-time requirements
- Multi-path & Multi-homing

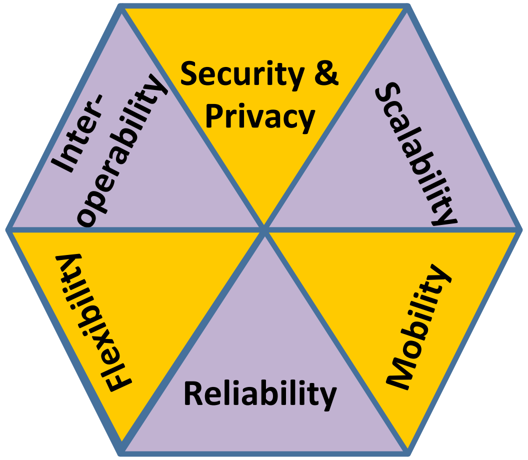
Flexibility

- **Heterogeneity (Lossy Radios; Traffic** (Push/Pull, Latency, Critical Events))
- **Contextual Communication** (Varies with IoT application, generally includes Location, Time, Policies etc.)
- **Self Organizing** (Edges, Simple Networking, Zero Configuration, Minimum Management)
- **Adhoc and Infrastructure Mode** (Topology /Service Discovery, Routing, Scalable Name Resolution)

Management

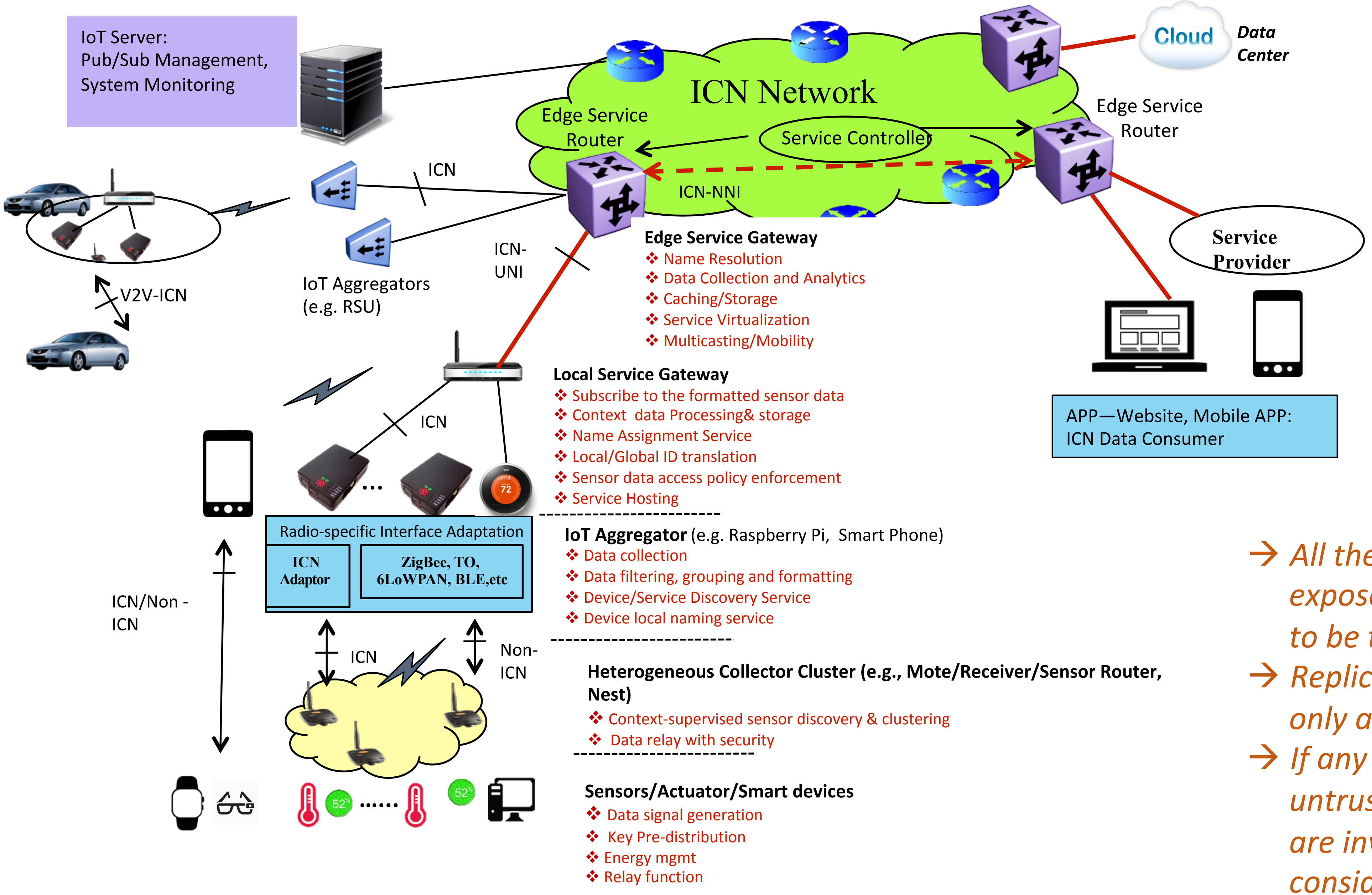
- FCAPS to IoT Services, Network , Devices, Protocols
- Scale to Large Number of Devices
- Requirements management of in-network Content, Services

IoT Requirements



Requirements vary with the Scenario such as Health Care/Smart Grid/Transportation/Home Networks/Industrial etc.

ICN-IoT Middleware Architecture: Distribution of Functions

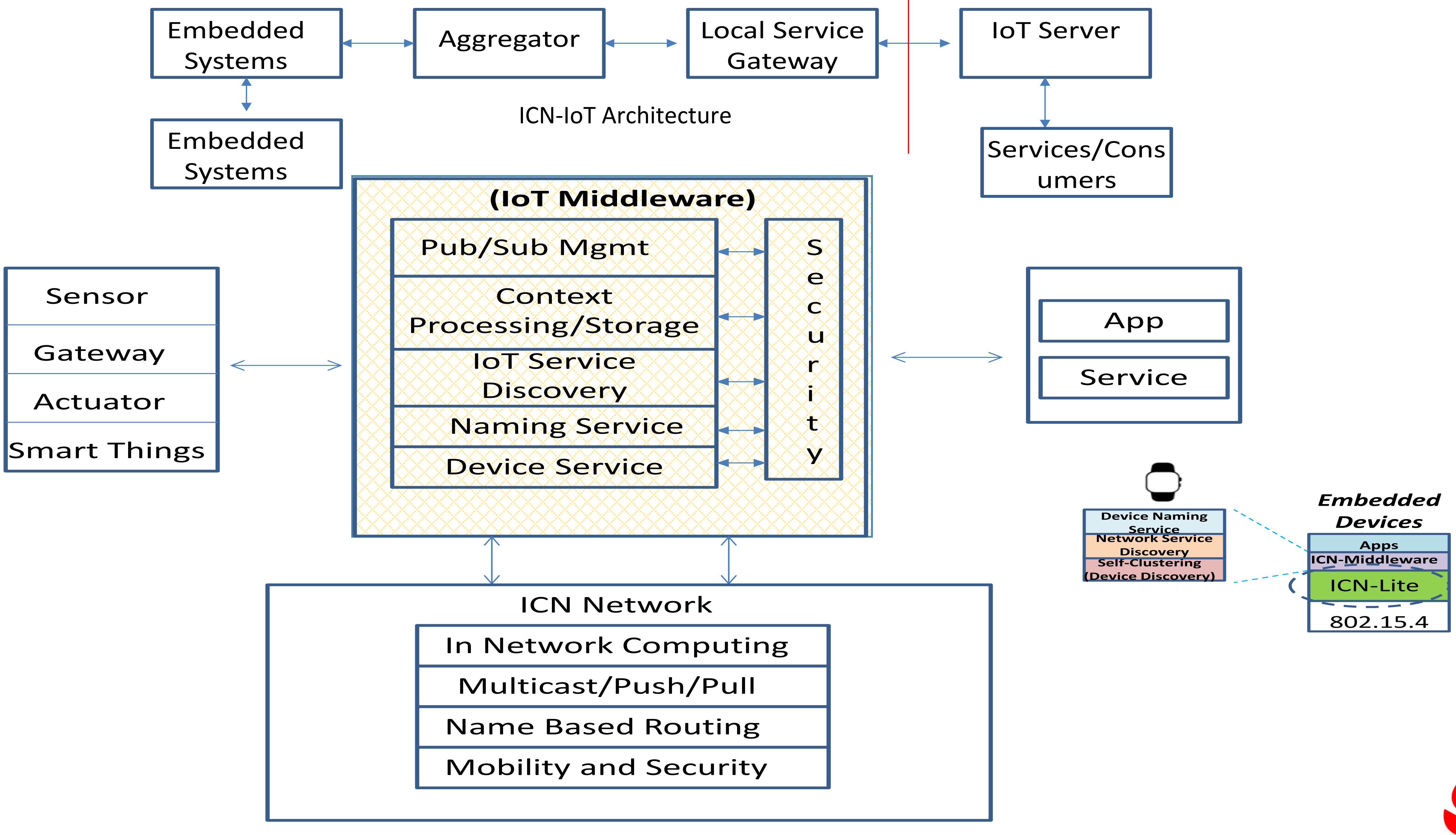


→ *All the points the data is exposed or processed has to be trusted.*

→ *Replication and processing only at trusted points.*

→ *If any intermediate untrusted ICN networks are involved, tunneling is a consideration.*

ICN-IoT Middleware Functions [1]



[1] Yanyong Zhang, L.Grieco, S.Misra, H.Liu , R.Ravindran, G.Q.Wang “ **ICN Based Architecture for IoT**”, https://tools.ietf.org/id/draft-zhang-icnrg-icniot-architecture-01.html

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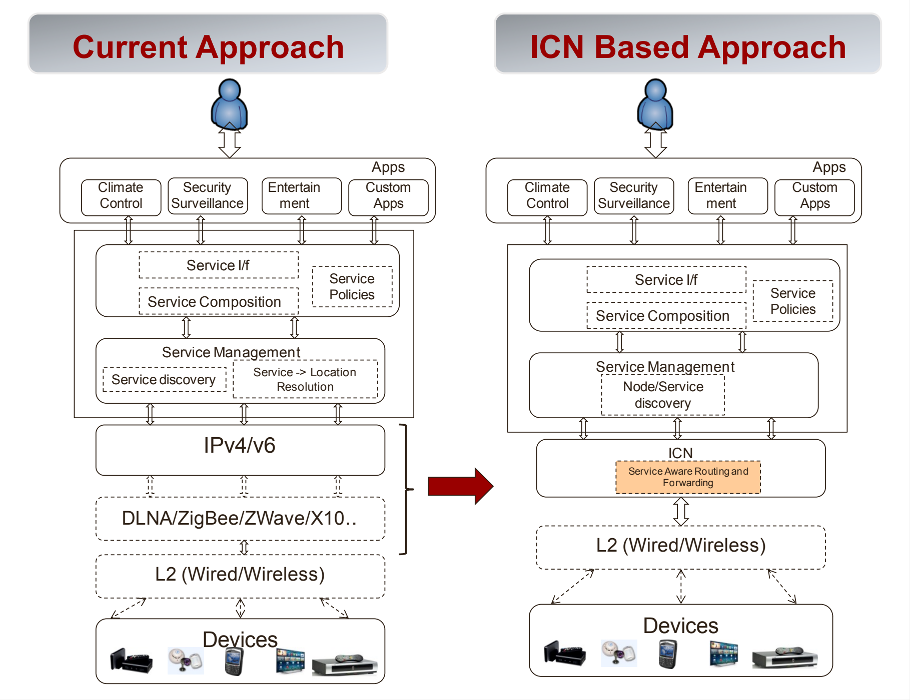
Information-Centric Smart Homes [1]

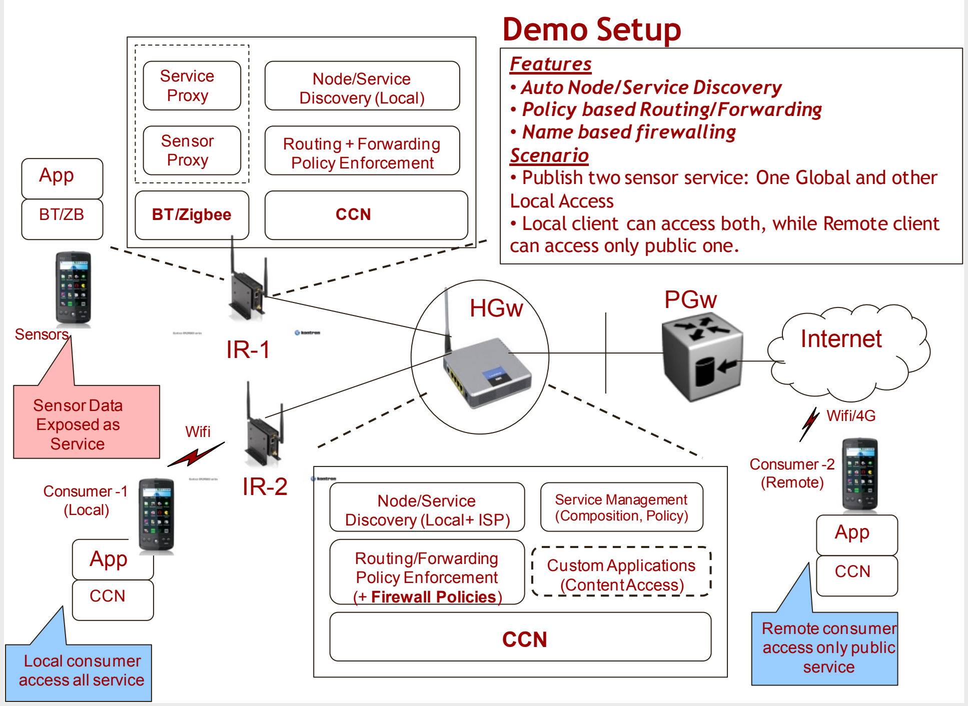
Key Smart Home Challenges

- Device and Protocol Heterogeneity
  - Lack Manageability (per device)
  - Lack Extensibility (plug-n-play)
- Lack Service Composition
- No Policy based Configuration (User groups, Access Control, Time..)
- Lack Adaptation to User/Device context

ICN Based HomeNets

- ✓ End-to-end ICN network Layer
- ✓ Zero Configuration
- ✓ Auto Node/Service Discovery
- ✓ Policy Aware Routing and Forwarding
- ✓ Mobility and Content Security
- ✓ Name based firewalling



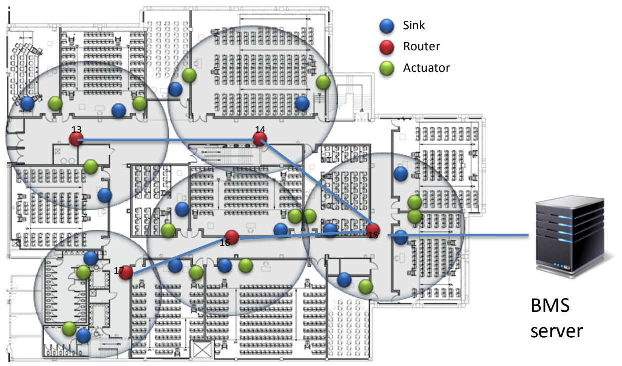


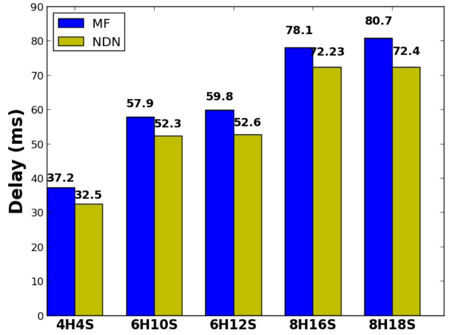
Acronyms: IR: Internal Router **HGw**: Home Gateway **PGw**: Provider Gateway **BT:** BlueTooth **ZB:** ZigBee

[1]Trisha Biswas, Asit Chakraborti, Ravi Ravindran, Xinwen Zhang, G.Q.Wang, "**Contextualized Information-Centric Home Networks**", SIGGCOMM, 2013 (Demo paper)

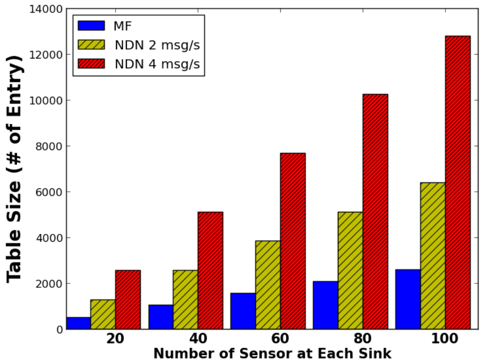
ICN-IoT Comparison of NDN and MobilityFirst [1]

- Compared the two protocol performance for BMS and Campus Mobility Scenario.
- Secure GUID versus Hierarchical Name, Push Vs Pull, Stateless versus Stateful, Mobility-Centric vs Content-Centric Arch.

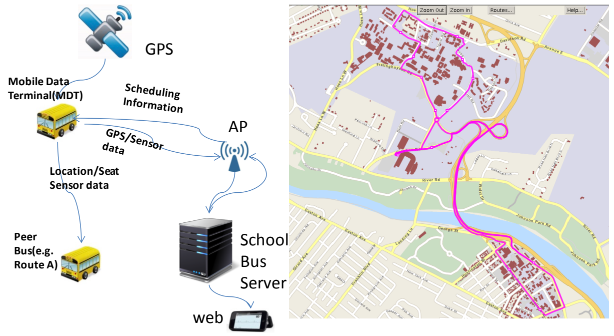


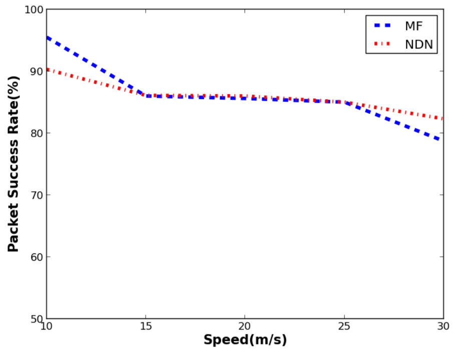


Average delay from sink to actuator

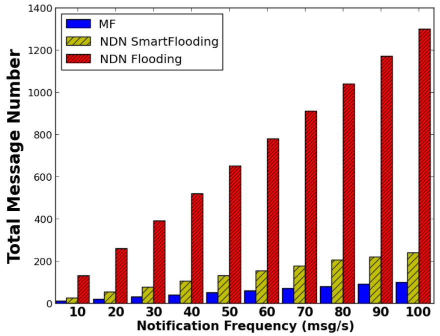


Total PIT size in the network





Packet success rate against speed



Data Plane overhead

[1] Sugang Li, Yanyong, Dipankar Raychaudhuri, Ravi Ravindran "**A Comparative Study of MobilityFirst and NDN based ICN-IoT Architecture**", ICN, Qshine, 2014

CDMA Based IoT Services with Shared Band Operation of LTE

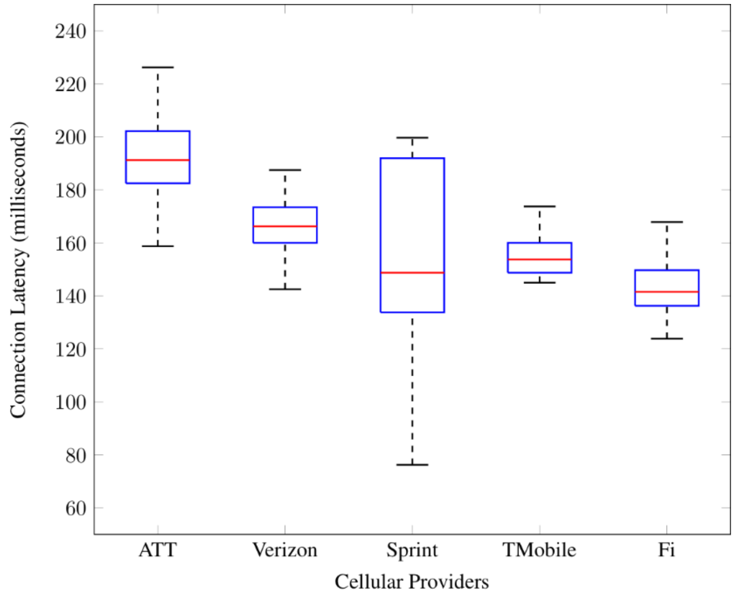


Fig 1: Connection Latency for different providers.

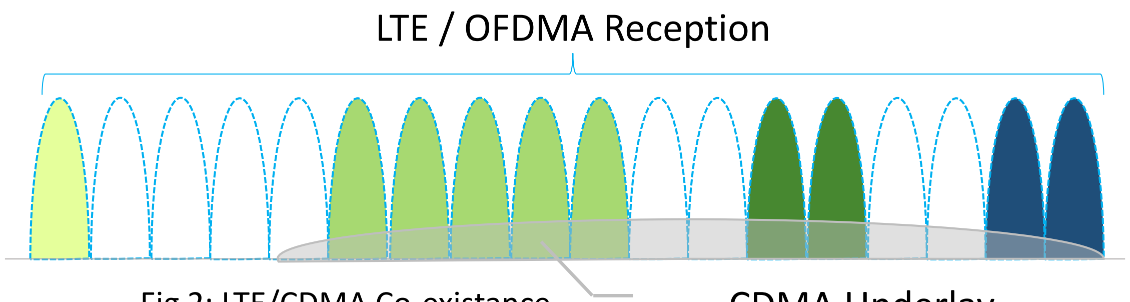
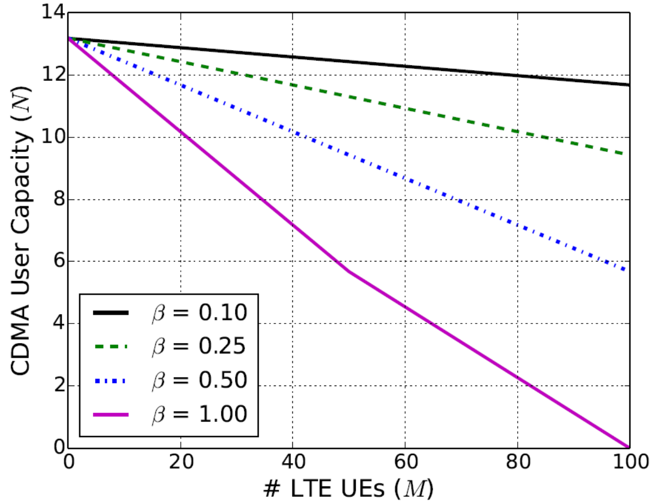
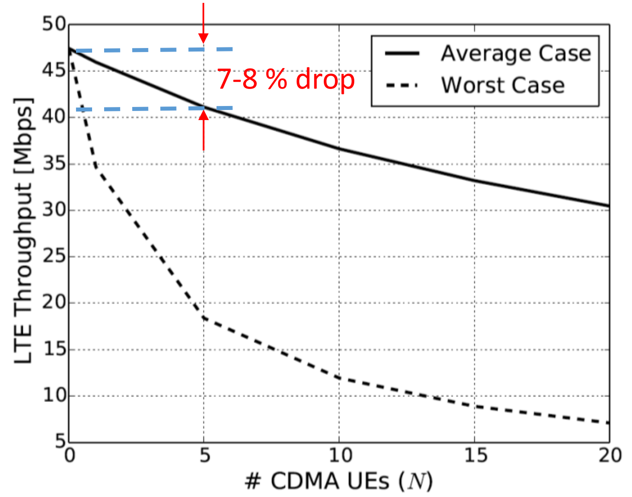


Fig 2: LTE/CDMA Co-existance

CDMA Underlay overlapping partial or complete with LTE transmission





Observations: We can sustain N=5 simultaneous users with a known 7-8 % degradation of LTE Throughput

- The goal was to allow IoT devices opportunity to randomly transmit leveraging CDMA radio, allowing low latency tx.
- The paper provided capacity estimation on number of IoT transmitters and degradation to LTE transmissions during co-existence.

[1] Shweta S Sagari, Siddarth Mathur, Dola Saha, Syed Obaid Amin, Ravishankar Ravindran, Ivan Seskar, Dipankar Raychaudhuri, and Guoqiang Wang, "**Realization of CDMA-based IoT Services with Shared Band Operation of LTE in 5G**", ACM, Sigcomm, MECOM, Workshop, 2017.

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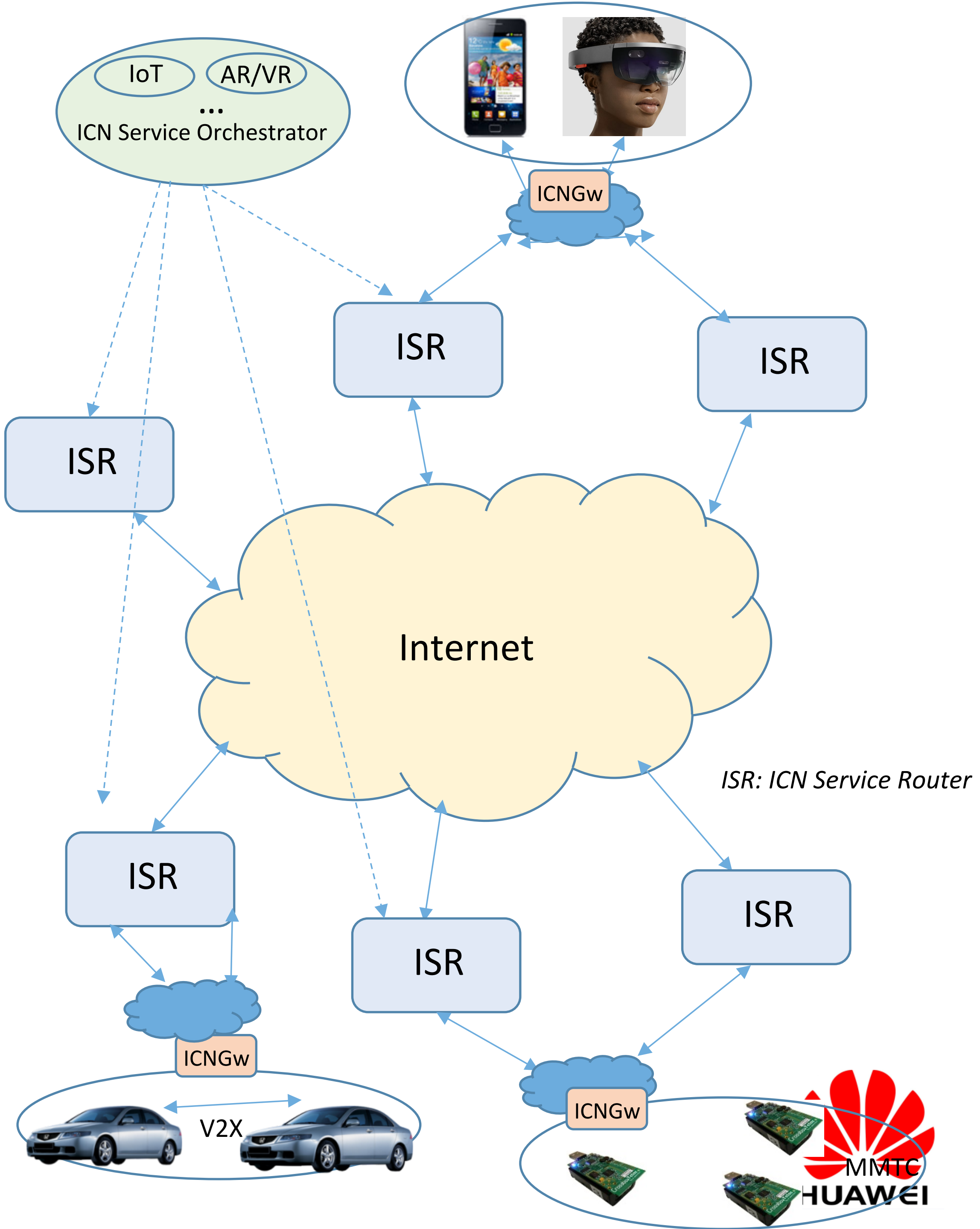
Commercialization Opportunities

ICN in the Edge

- **ICN makes lot of sense in the edge**
  - Edge is where you define in ICN..
  - Seamless contextual networking platform to connect heterogeneous devices, applications with edge compute, cache and storage resources.
  - Need for contextual routing to service points
    - E.g. DNS would have scalability problems in a decentralized edge.
  - Edges have limited resources, so need for contextual computing, e.g. NFN, moving functions in the network.
  - Reusing shareable data via location independent caching both upstream and downstream
  - Receiver oriented Communication – Multihoming, Mobility and Multicasting
  - Challenges, as it will be overlaid, interconnecting ICN instances, discovering services, privacy, security, data accountability



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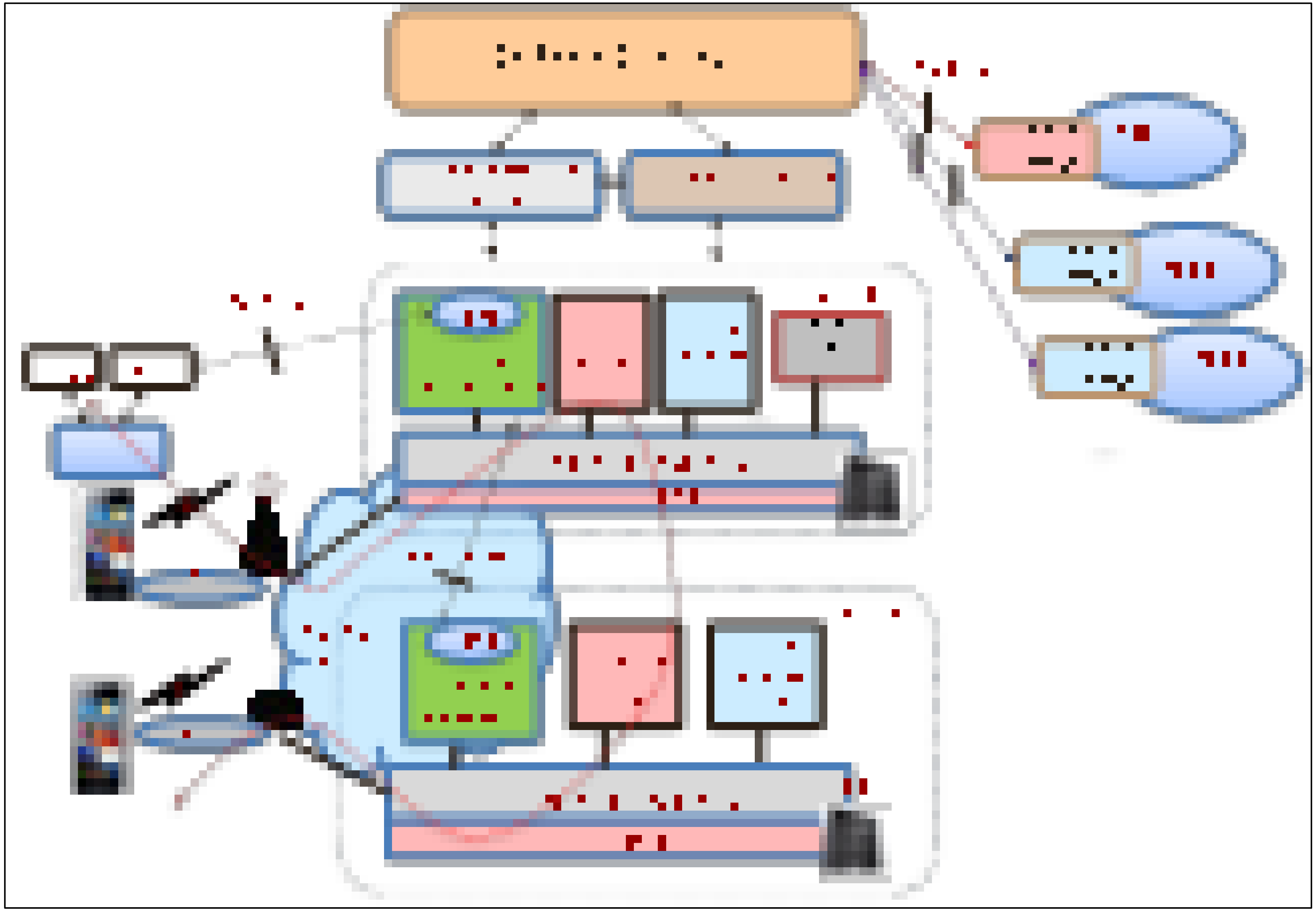
Virtual Service Edge Router (VSER) Architecture [1]



- *ICN Service Orchestrator*
  - Service Abstraction to Services
  - Service Graph and Resource Abstraction
- *ICN Service Function Controller*
  - ICN Service and Network Function Life Cycle Manager
- *ICN Network Controller*
  - ICN Network Virtualization
  - Name based Routing Virtualization
- *ICN Service Hypervisor*
  - Host ICN Agent to manage Service and Network functions
  - Interface to ICN Network and Service Controller
- *Service Access Point (SAP)*
  - Service Discovery and ICN Service Gateway Discovery
- *Service Access Layer (SAL)*
  - UE service agent fore Service Discovery for local applciations

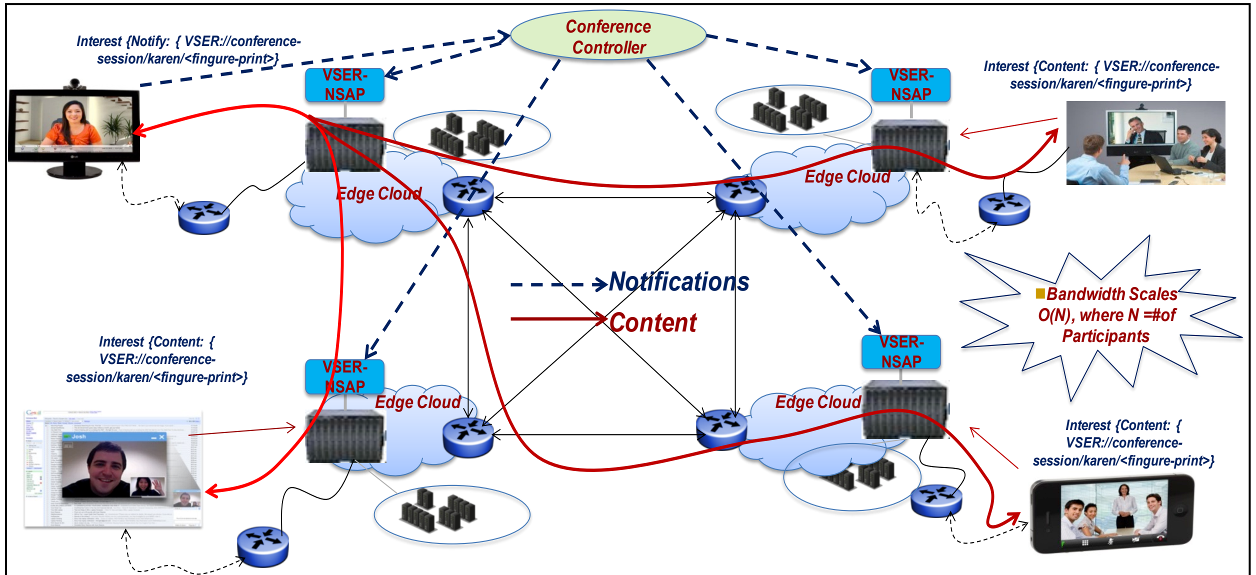
- **VSER platform allows to create Service Slices leveraging features such as Name Based Routing, Seamless Mobility Support, Caching, Multicasting and Multihoming.**

[1] Ravi Ravindran et al, "**Towards Software defined ICN based Edge Cloud Services**", IEEE, CloudNet, 2012

[2] Asit Chakraborti, Ravi Ravindran et al, "**Multi-party Conference over Virtual Service Edge Router (VSER) Platform** " ICN Sigcomm, 2015

Serverless Scalable Audio-Video Conferencing over VSER [1-3]

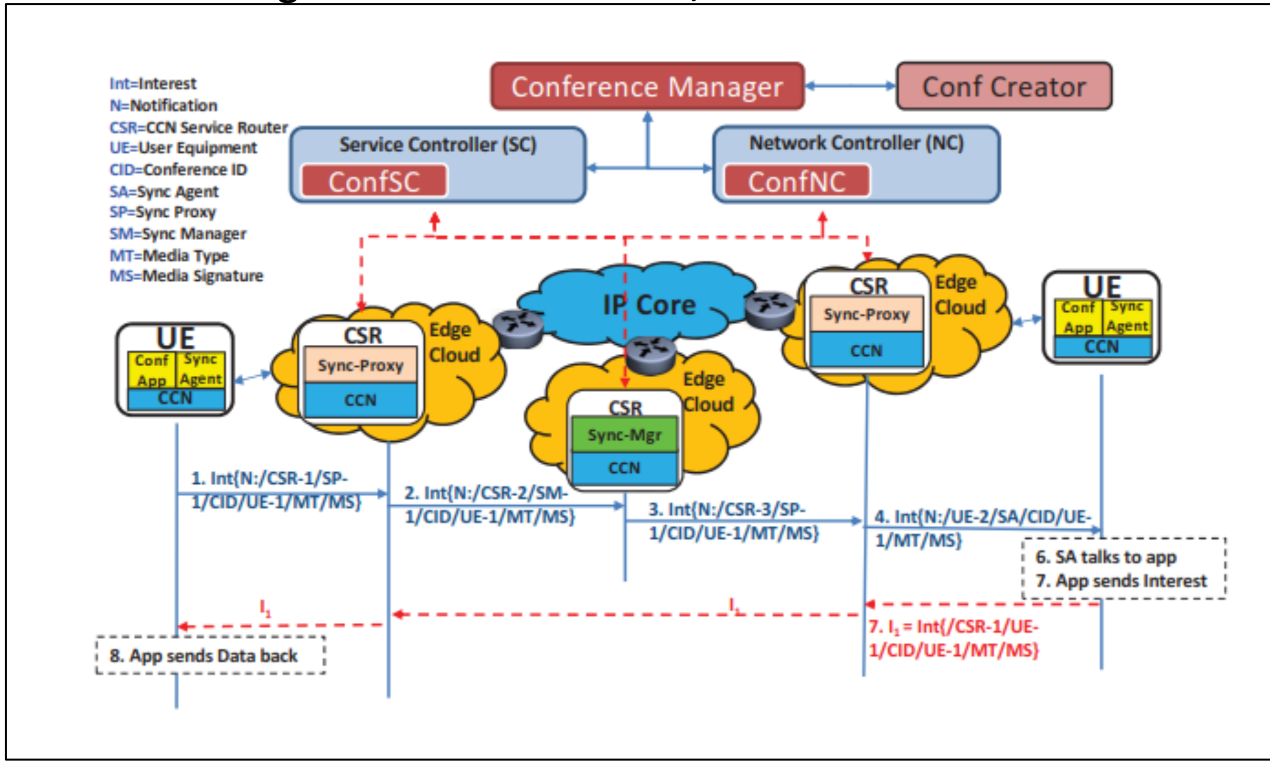
Edge Cloud based ICN A/V Deployment



Conference Controller Functions

- Enable MP-2-MP Connectivity
- Conference Level Virtualization : *Multiple Simultaneous Conferences , Service Scaling, Dynamic Name Based Routing, Conference Monitoring and Management.*
- Context level Adaptation

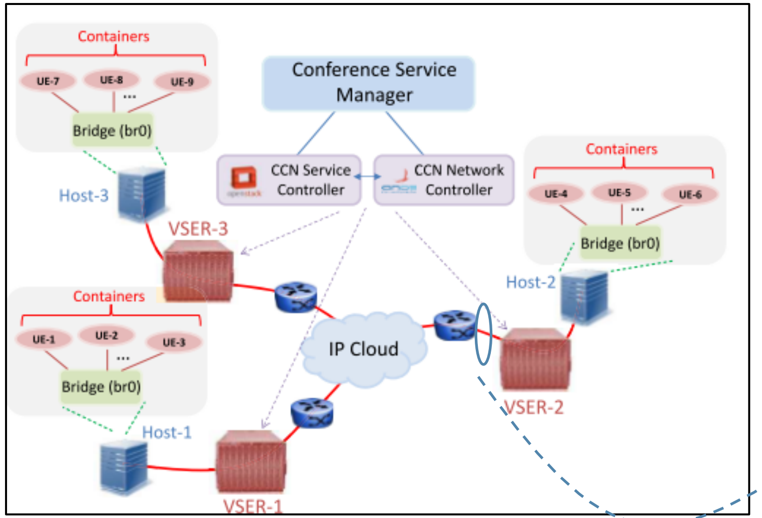
Edge Cloud based ICN A/V Solution



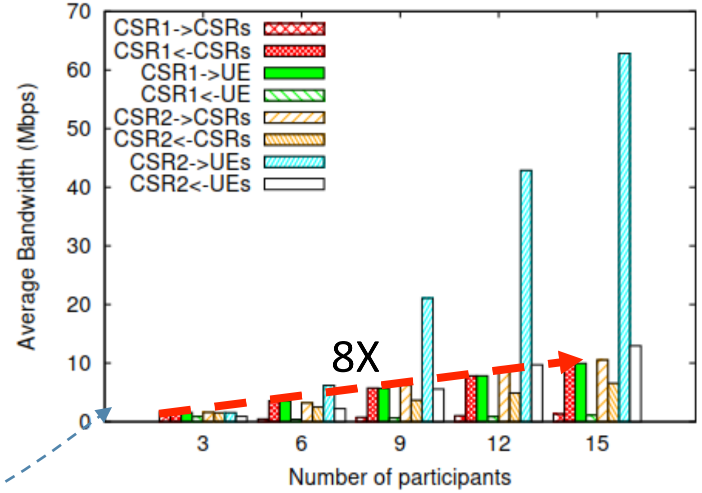
- Current solutions such as Skype, Goto-Meeting, Webex follows a client-server model and are made to scale restricting the number of active producers of media.
- CCN/NDN has to emulate PUSH behavior to meet realtime application requirements.
- Ad hoc participant joint requires immediate synchronization among producers and consumers
- The bottleneck in our design is the VSER because of unicast towards the participants and consumer due its producer state tracking algorithms

[1] Asit Chakraborti Syed Obaid Amin, Aytac Azgin, Ravi Ravindran, G.Q.Wang,, "**ICN Based Scalable Audio/Video Conferencing over Virtual Service Edge Router (VSER) Platform** " ICN Sigcomm, 2015
[2] Anil Jangam, Asit Chakraborti, Ravi Ravindran et al, "**Realtime Multi-Party Video Conferencing Service over Information-Centric Network**", Workshop on Mutimedia Streaming in ICN (MuSIC), 2015
[3] Asit Chakraborti et al, "**Design and Evaluation of a Multi-source Multi-destination Real-time Application on Content Centric Network**", HotIcn, 2018.

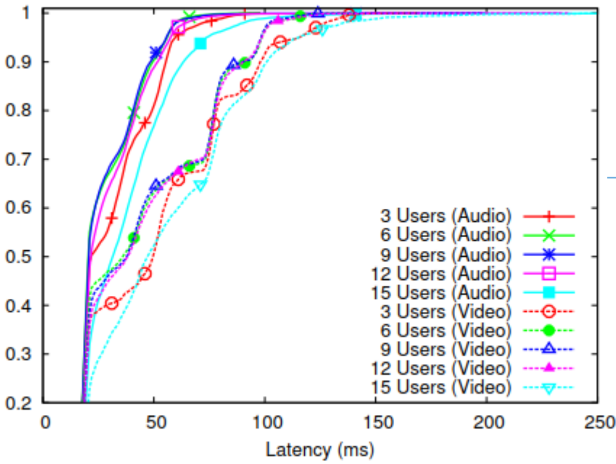
ICN A/V Conferencing Evaluation



Test Bed for Evaluation

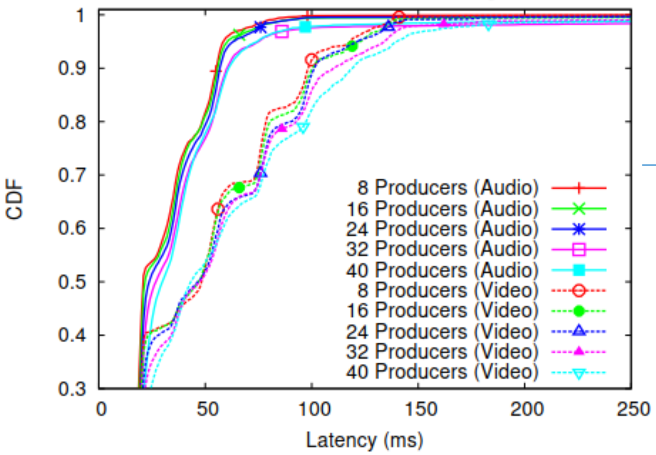


(b) Bandwidth utilization



(a) Audio/video latency performance

→ For 15 All Party Conferencing mostly < 150ms and 250ms for Audio/Video



(a) Audio/video latency performance

→ For 40 producers and I Consumer Conferencing mostly < 150ms and 250ms for Audio/Video

Set Up:

- 3 VSER and Host Nodes (*Intel – i7 family*)
- Participants emulated in Containers
- End-to-end IP Latency (15)ms

O(*N*) growth instead of O(*N*^{2})

From 3 → 15 Participants :

~1 → 8 Mbps

(8X Instead of 25X)

[1] Asit Chakraborti et al, "**Design and Evaluation of a Multi-source Multi-destination Real-time Application on Content Centric Network**", (Submitted to HotICN, 2018).

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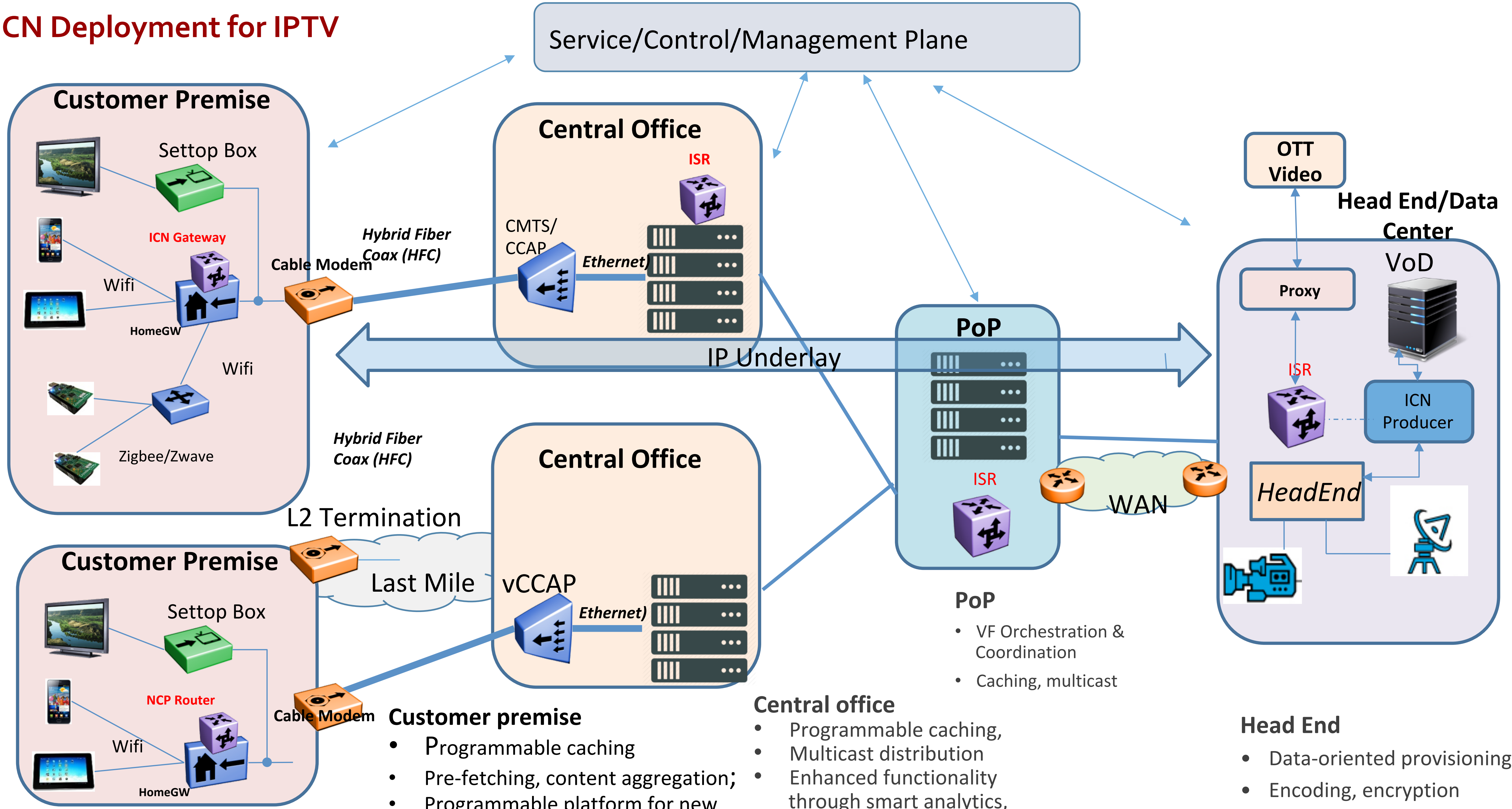
ICN Deployment for IPTV



PoP

- VF Orchestration & Coordination
- Caching, multicast

Customer premise

- Programmable caching
- Pre-fetching, content aggregation;
- Programmable platform for new applications (IoT, AR)

Central office

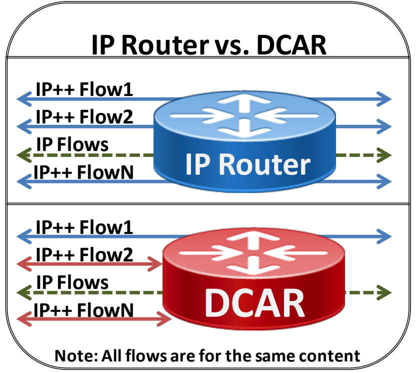
- Programmable caching,
- Multicast distribution
- Enhanced functionality through smart analytics, prediction etc.

Head End

- Data-oriented provisioning
- Encoding, encryption
- Root of multicast distributi

DCAR(Dual-mode Content Aware Router)[1-2]

- **DCAR leverages the proposed IP primitives and understands both ICN and IP flows**
- **Understands ICN content abstraction**
- **Transparent Caching using flat hash-IDs**



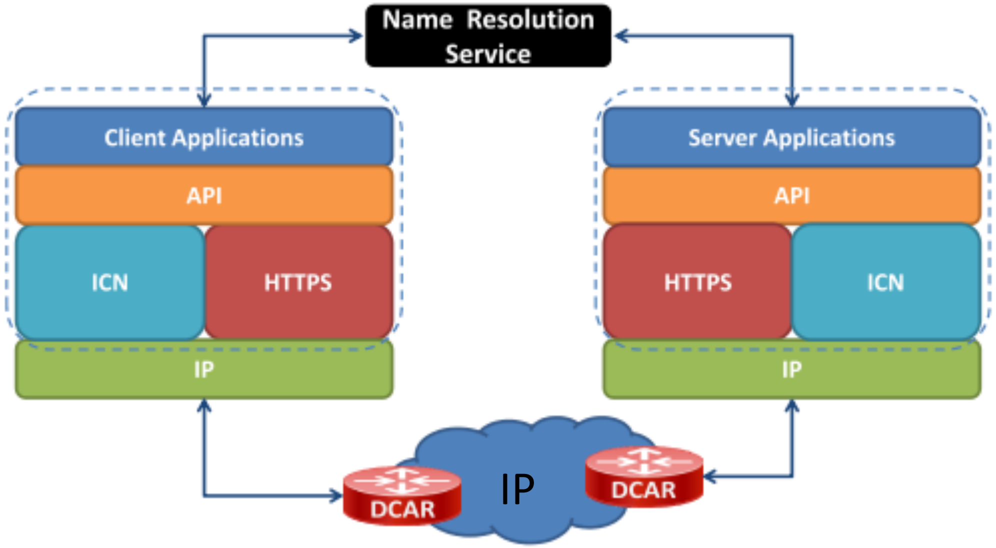


Fig. 1 : Incremental IP Network Architecture

Fig. 2: IP ToS Bits for identify IP-I/IP-C flows

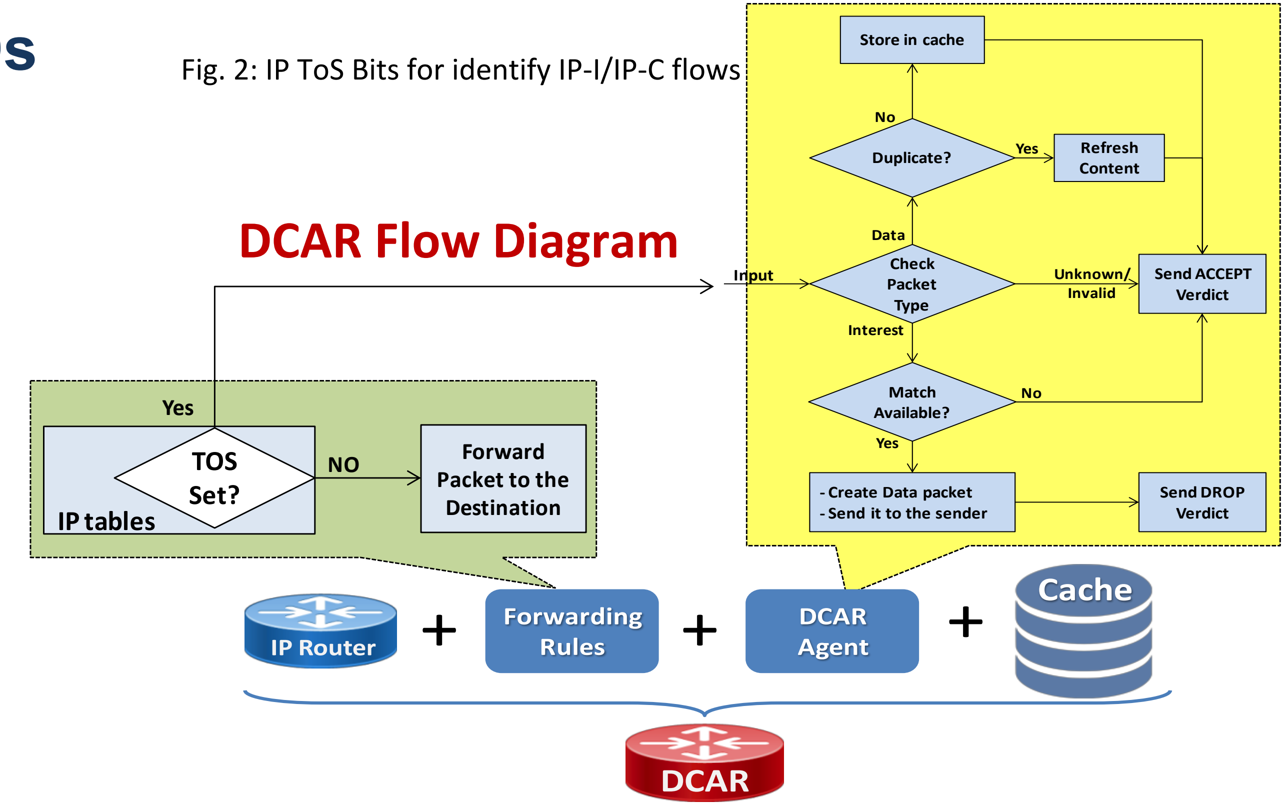


Fig. 3: IP ToS Bits for identify IP-I/IP-C flows

***ACCEPT** = handle the packet according to default forwarding rules,
DROP = DCAR Agent can handle the packet, do not forward it further.

[1] Syed Obaid Amin, Qinji Zheng, Ravi Ravindran, G.Q.Wang,"**Leveraging ICN for Secure Content Distribution in IP Networks**", ACM, Multimedia, 2016 (Demo Paper)
[2] Syed Obaid Amin, Ravi Ravindran, G.Q.Wang, "**DISCS: Secure Content Distribution in IP using ICN**", IEEE, Fog World Congress, 2017

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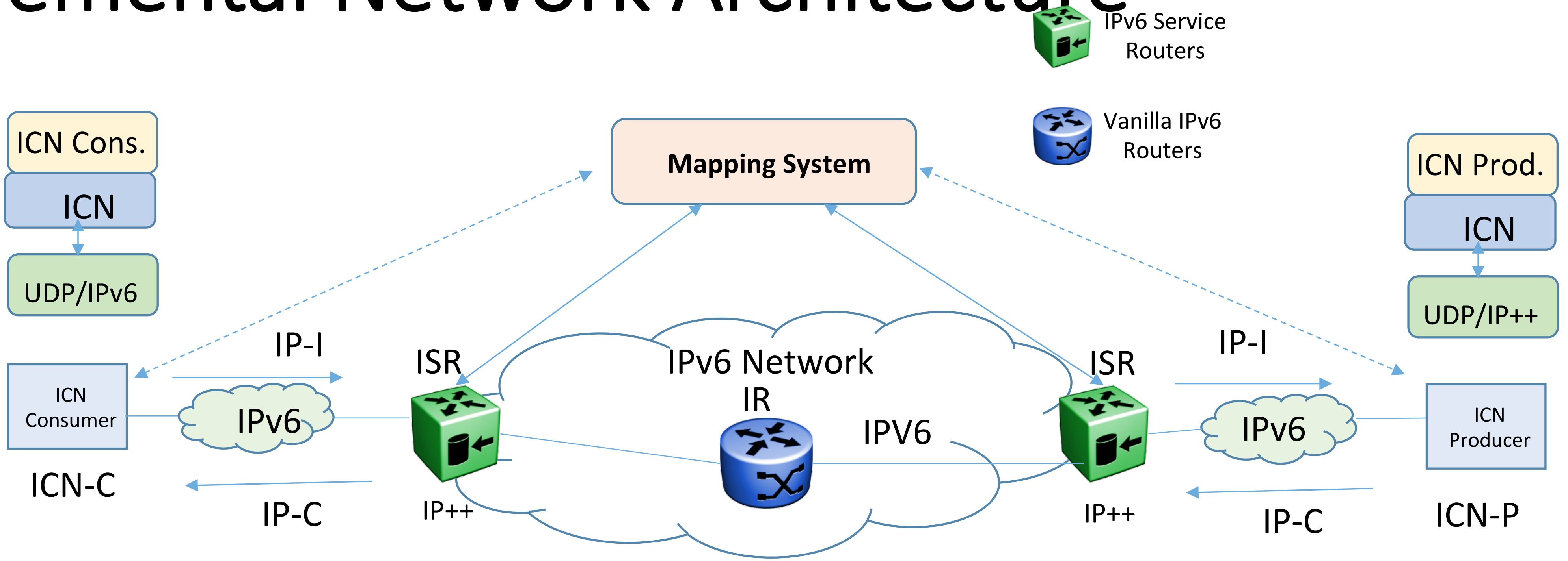
Incremental Network Architecture



Key Functional Components

- **ICN End points**
  - ICN Consumers and Producers over ICN stack over UDP/IPv6 stack.
  - Minimal, if possible no changes to end point Linux/Android stack
- **ISR**
  - IPv6 Service Router with IP++ stack, which is enhanced to process IP-I and IP-C flows
  - ISR has an interface to a mapping system that maps content names to IP locators.
- **IR**
  - Are regular IPV6 router that has no ICN based processing logic in it.
- **Mapping system**
  - Maps the content names to the ICN-P Locators.

IPv6 Dest: ISR
IPv6 Src: Consumer-IP
TC: Interest[0xf0]]
IPv6 Extension header (Flat ICN Name) [Code ?]
UDP
ICN Interest

IP Interest (IP-I) packet on the wire

IPv6 Dest: ISR
IPv6 Src: Producer-IP
[TC: Data[0xf1]]
IPv6 Extension header (Flat ICN Name) [Code ?]
UDP
ICN Data

IP-Content (IP-C) packet on the wire

→ Compared to HICN we don't use names in IP headers, addressing routing scalability problem.

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Key Takeaways

- All new technologies created a inflection point offering something that didn't exist earlier, which attracts more research and investment.

- ICN/CCN/NDN has to find killer purpose and applications to make it compelling for industry adoption.

- Be realistically grounded considering emerging application requirements, e.g. suitability to low latency scenarios

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Thanks !