IPoC: IP over CCN for seamless 5G mobility

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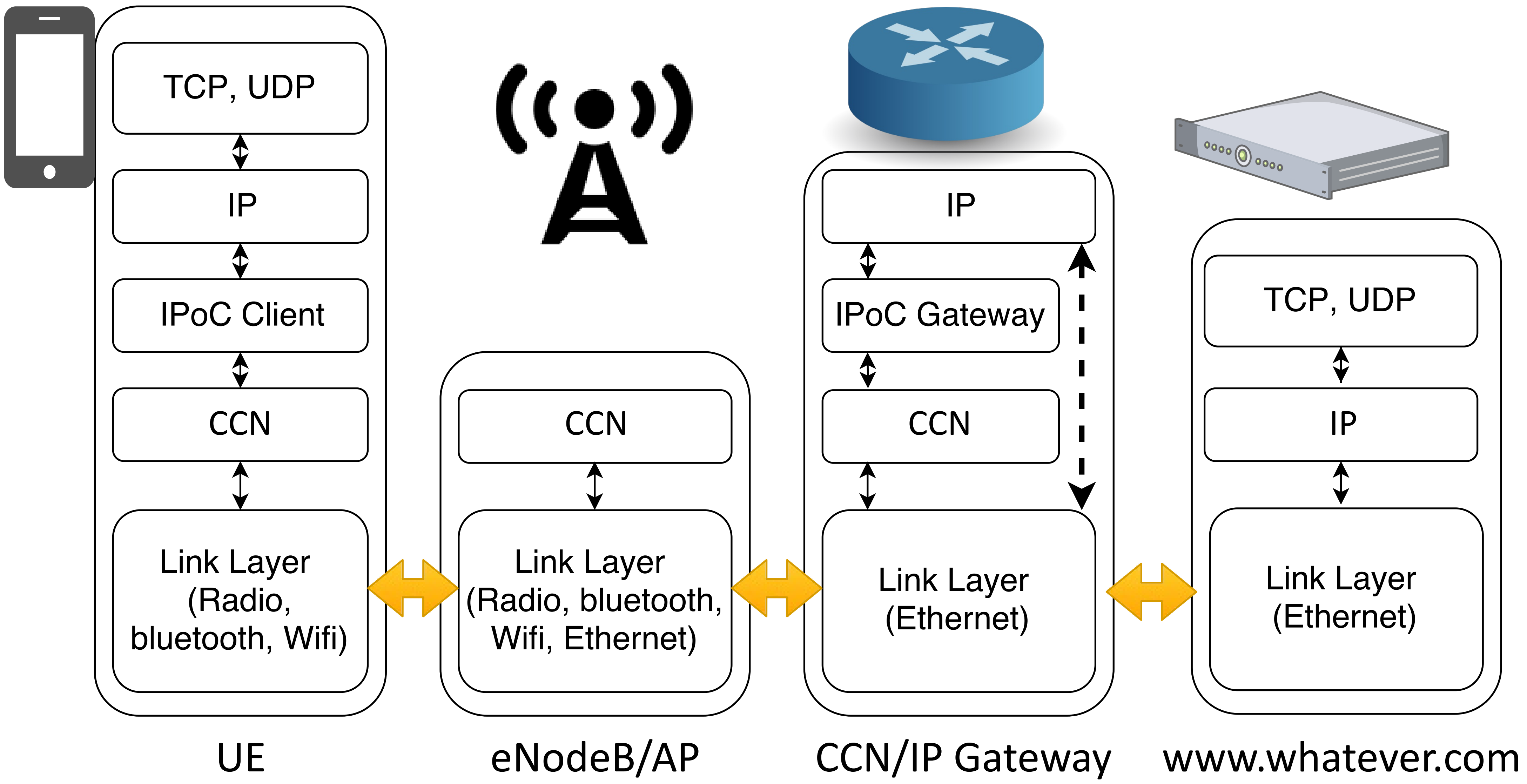
Background

- ICN seems attractive for mobile networking
  - Elegant consumer mobility via stateful forwarding
  - Multipath connectivity managed by the mobile device
  - In-network caching and processing
- How do we get there?
  - Network slicing? – and run two networks in parallel?
  - ICN over IP? – and lose the benefits above?

Concept

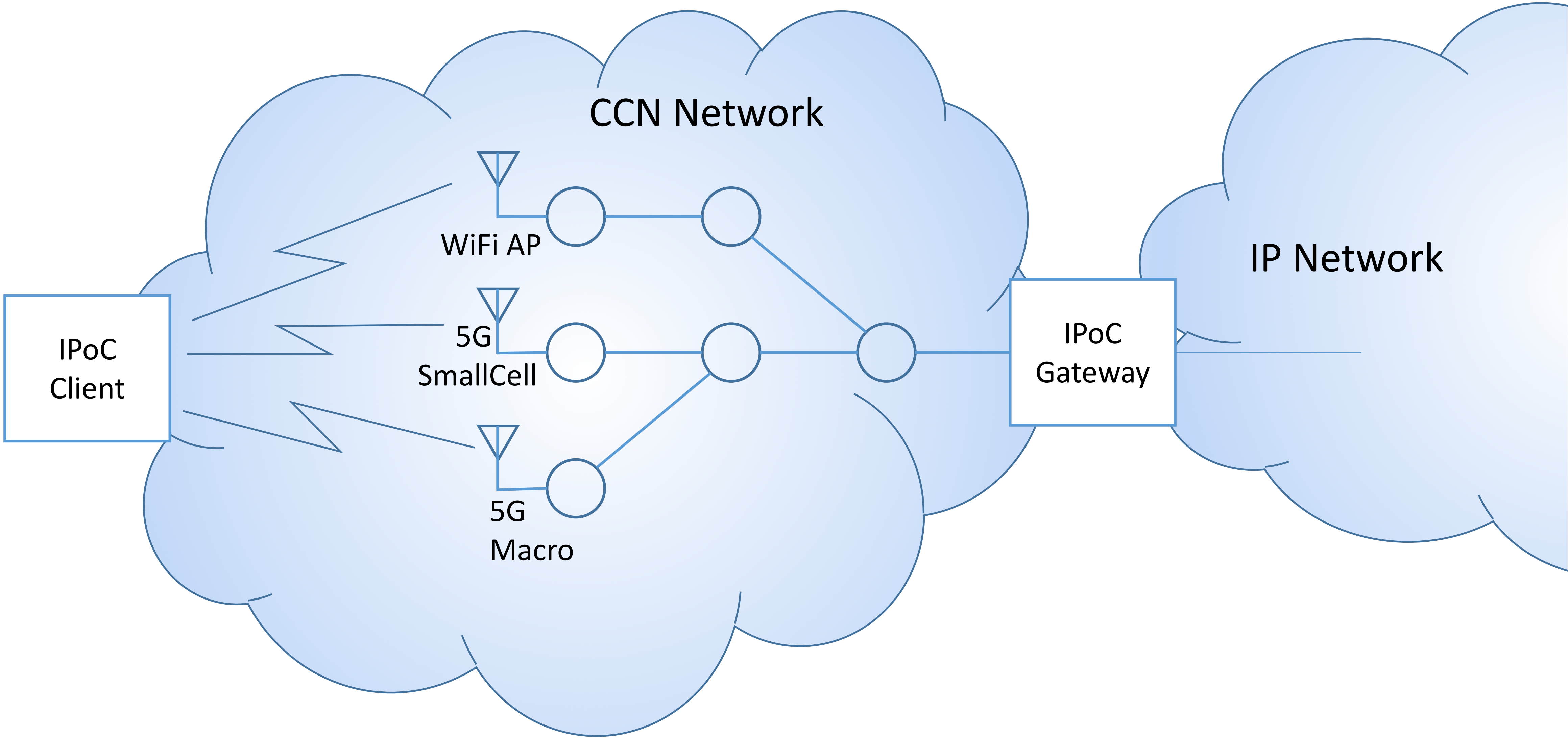
- Explore the idea of using CCN as THE forwarding plane for 5G
- Support existing IP services via an “IP over CCN” protocol – replacing LTE-EPC (GTP Tunnels) for IP Mobility
- Enable deployment of native CCN applications, preserving the benefits


TCP, UDP
IP
IPoC Client
CCN
Link Layer (Radio, bluetooth, Wifi)
CCN
Link Layer (Radio, bluetooth, Wifi, Ethernet)
IP
IPoC Gateway
CCN
Link Layer (Ethernet)
TCP, UDP
IP
Link Layer (Ethernet)
UE
eNodeB/AP
CCN/IP Gateway
www.whatever.com

IP over CCN (IPoC) Goals

- Support all existing IP applications & transports without modification
  - Incl. TCP, UDP, SCTP, DCTCP, QUIC, BBR, etc.
  - …maybe not IP multicast.
- No change to IP stacks
- Leverage consumer mobility of CCN
- Support multipath connectivity
- High performance
- Low overhead
- Be a compelling replacement for EPC

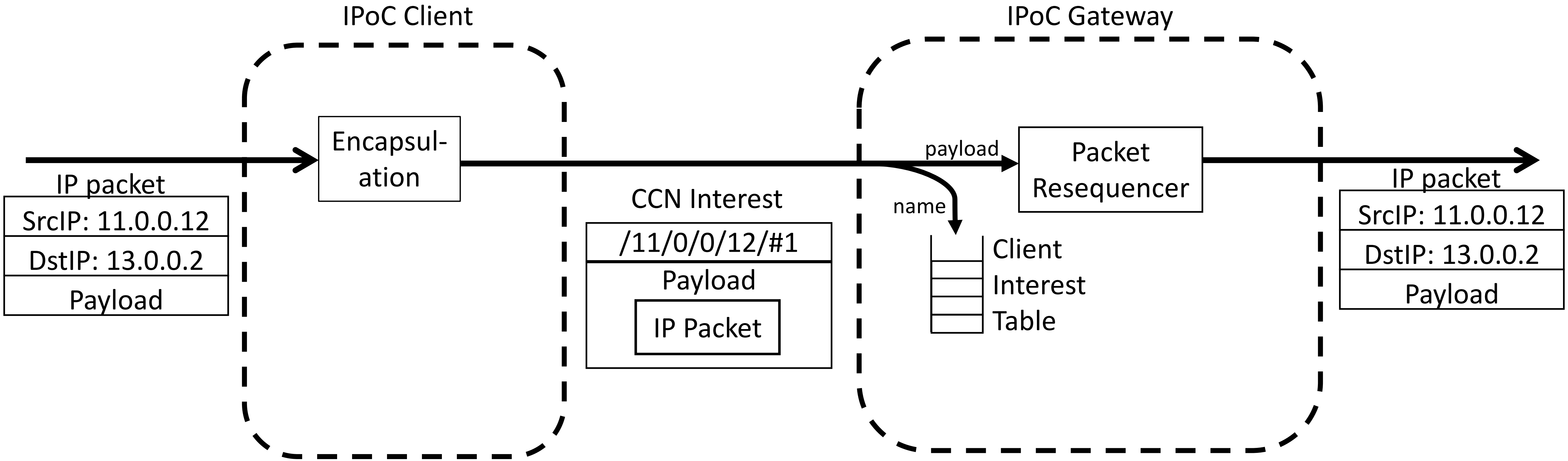
Architecture



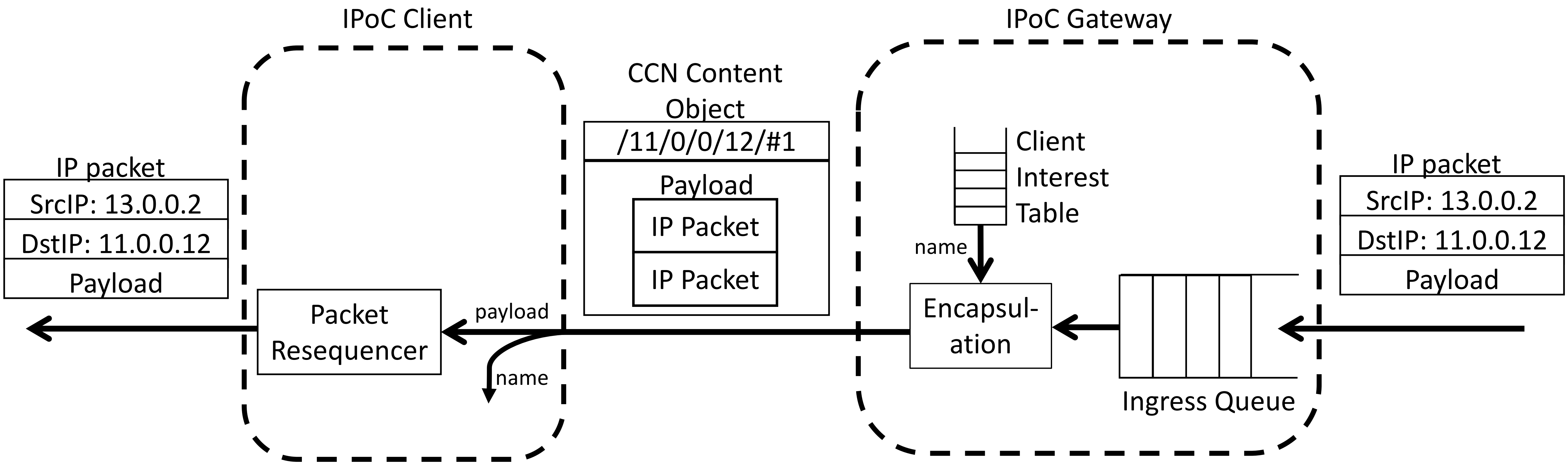
Leverage consumer mobility

- IPoC Client only sends Interest messages
  - “upstream” IP packets carried as Interest payloads
- IPoC Gateway only sends Content Objects
  - Containing “downstream” IP packets as payloads

“Upstream” (UE->Network) Packet Flow



“Downstream” (Network->UE) Packet Flow



IPoC Naming Convention

- ccnx:/ipoc/<hex_ipaddr>/<b64_seq>

- `hex_ipaddr:` Client IP address
  - for IPv4: four name segments each encoding (in hex) an octet of the IP address.
    - 192.168.1.100 -> "`c0/a8/1/64`"
  - for IPv6: RFC2737-sec.2.2,para.1 encoding, with colons replaced with name segment delimiters
    - 3ffe:1900:4545:3::fe21:67cf -> "`3ffe/1900/4545/3/0/0/fe21/67cf`"
- `b64_seq:` Interest Sequence Number
  - base64-encoded, monotonically increasing (with rollover)

CCN Routing

- Each IPoC Gateway on the CCN network supports connectivity and address assignment for one or more IP subnets.
- Each IPoC Gateway advertises routes within the CCN network for:
  - `ccnx:/ipoc/<ip4prefix>`
  - `ccnx:/ipoc/<ip6prefix>`
  - `ccnx:/ipoc/init`

Multiple prefixes can be advertised

IP Address Assignment

- Client sends Interest for: `ccnx:/ipoc/init/<nonce>`
- CCN network routes Interest to nearest IPoC Gateway
- Gateway responds with Content Object containing IP address configuration information (i.e. the DHCPv4 / DHCPv6 information)

Maintaining the CIT

- To avoid introducing downstream latency, the CIT needs to always contain at least one sequence number, ideally more than one in order to support a burst of downstream traffic

- Gateway has a target number of CIT entries that it seeks to maintain during idle conditions: min_CIT (e.g. 10)
  - This could be dynamically adjusted based on traffic expectations

- Client maintains an Interest Deficit Count
  - Upon CO arrival, Client increments IDC
  - Upon Interest transmission, Client decrements IDC
  - If IDC > 0, Client sends an “empty” Interest (no payload) – paced
  - IDC is bounded as: -IDC_limit <= IDC <= IDC_limit (e.g. 5)

Managing In-flight Count

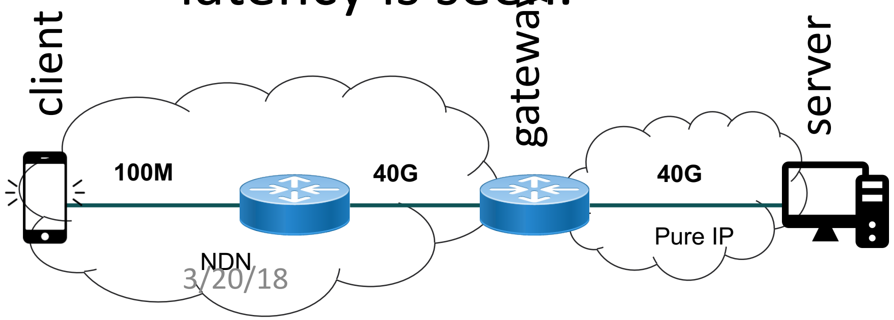
- Gateway can trigger an adjustment of the number of in-flight Interest Sequence Numbers (and hence CIT size)
  - Interest Deficit Report included in Content Object
  - Allowed IDR values: -1, 0, 1
  - Client adds IDR value to its Interest Deficit Count

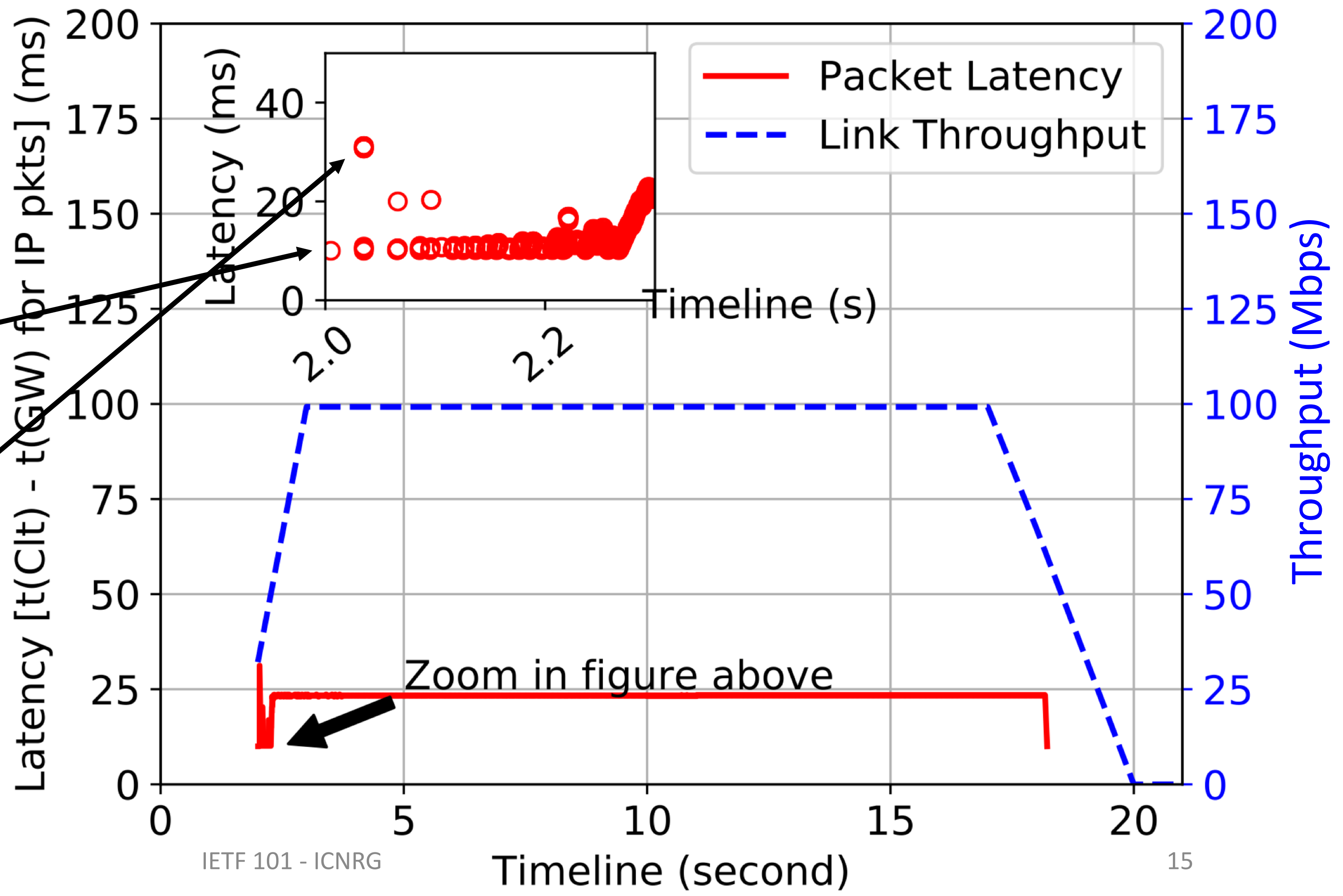
- IDR rules
  - Upon receipt of an Interest when the corresponding CIT is full
    - Gateway dequeues the head of CIT and sends empty CO with IDR = -1
  - When transmitting a CO, if the CIT size < min_CIT: Send IDR = 1

Throughput & Latency for Single File DL

- Link Rate = 100 Mbps
- IPoC RTT = 20ms
- Total RTT = 30ms
- Bottleneck Buffer = 15ms

- Baseline IPoC Latency = RTT/2 = 10ms
- When TCP initial cwnd arrives at GW, an additional IPoC RTT of latency is seen.





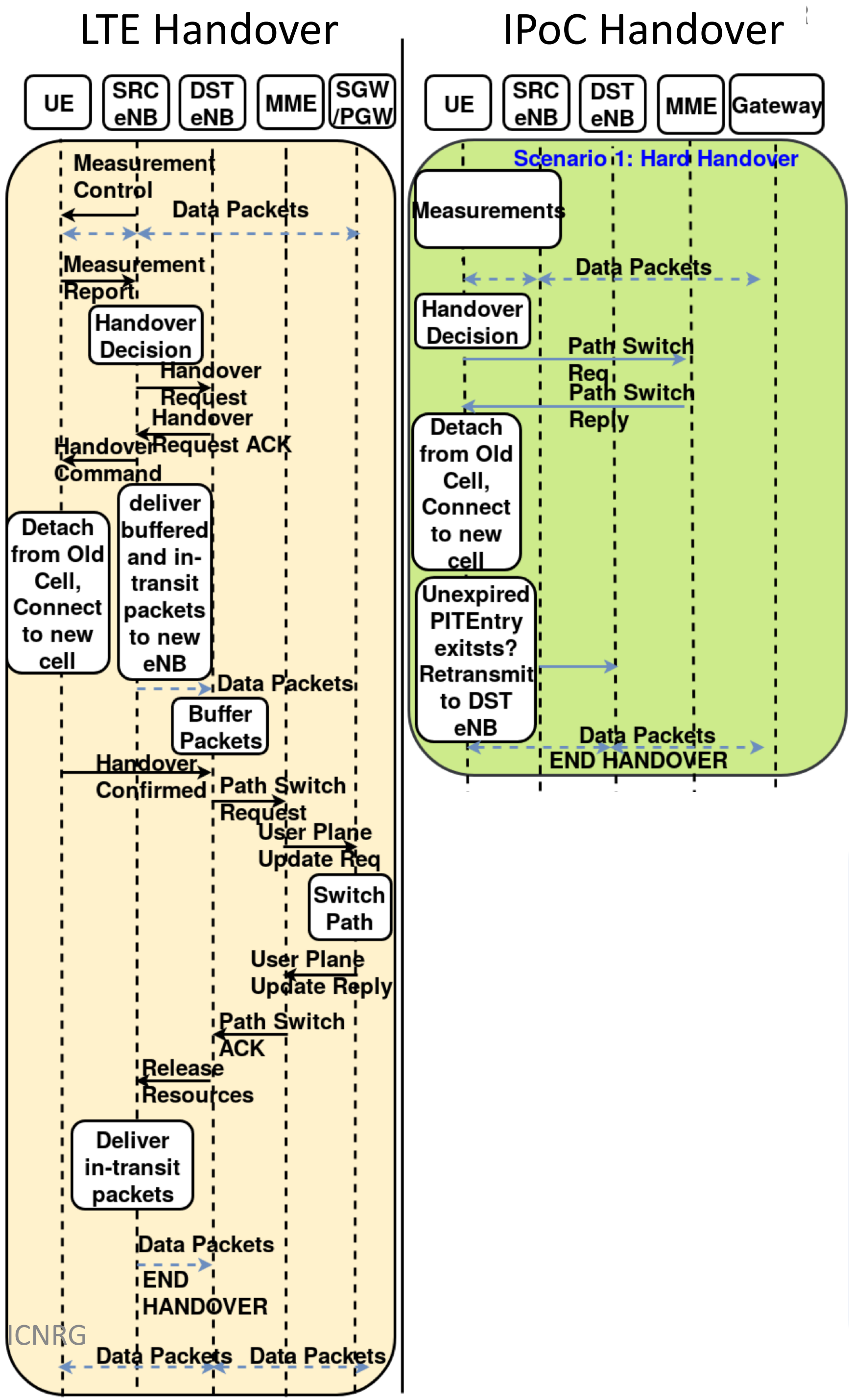
PIT Entry Lifetimes

- It is expected that PIT entries in intermediate nodes will have finite lifetimes
- Gateway calculates a CIT Lifetime after which it considers a CIT entry to be stale
- When head-of-queue CIT entry times out, Gateway sends an "empty" Content Object
  - If CIT size < min_CIT: IDR = 1
  - If CIT size == min_CIT: IDR = 0
  - If CIT size > min_CIT: IDR = -1

If no traffic, this drains the CIT down to ~min_CIT entries

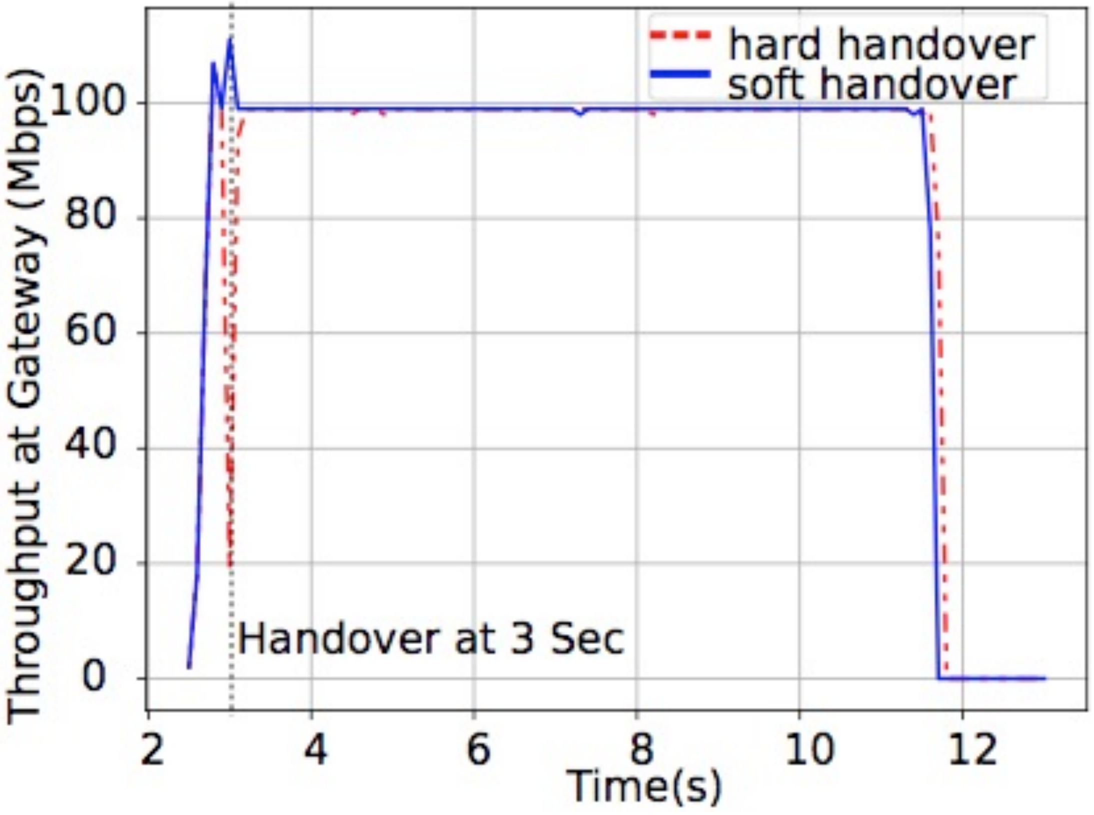
LTE Handover vs. IPoC Handover

- IPoC significantly simplifies handover compared to LTE-EPC
- No S1 tunnel manipulation to orchestrate
- No X2 tunneling/hairpinning
- Less capacity utilization in core
- UE simply detaches from old link, establishes new link, and resends unexpired PIT entries (without payload).
- No handover-specific functions in GW, eNodeB/gNodeB, or network routers
- Role of MME is simplified
- Soft handover & multipath connectivity are simple
- Operation in HetNets (WiFi/LTE/5G) is straightforward

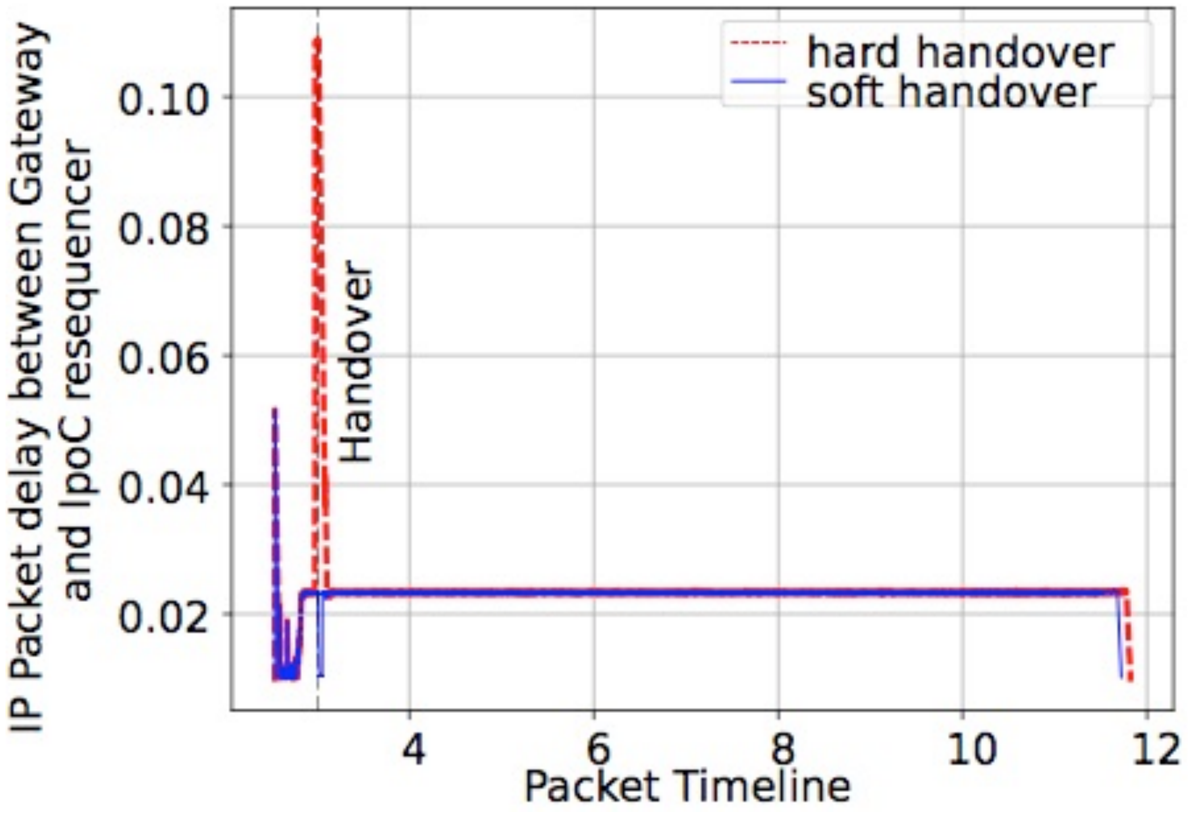


Hard vs Soft Handover Simulation

Throughput



Delay



Open Source Implementations

- Linux/MacOS implementation on Metis (ca. 2016)
- ndnSim implementation

- Neither is posted publicly yet.

Backup Slides

“Upstream” IP packet handling

- Client: Upon receipt of one or more IP packets from the local stack:
  - Send an Interest message
    - Name formed by client’s IP address and next sequence number
    - Body contains entire IP packet(s)
- Gateway: Upon receipt of an Interest message
  - De-encapsulate IP packet(s) and add to resequencer for forwarding to IP network
    - Resequencer ensures in-order delivery
  - Add Sequence Number to the “Client Interest Table”

Client Interest Table (CIT)

- The CIT is a FIFO queue maintained by the gateway
- CIT contains received Interest Sequence Number and Arrival Time tuples
- One CIT per active client IP address

“Downstream” IP packet handling

- Gateway:
  - Arriving IP packets are queued on a per-client-IP basis*
  - Queues are serviced in a round-robin manner
  - Queue blocks when its CIT is empty
  - Packet(s) are dequeued to form a Content Object
  - CIT entry is dequeued to form CO name
  - CO includes a CO Sequence Number (monotonically increasing, with rollover)
    - CO Sequence Number space is independent of Interest Sequence Number space
- Client: Upon receipt of a Content Object
  - De-encapsulate IP packet(s) and add to resequencer for delivery to IP stack

*more sophisticated queuing, e.g. AQM/L4S could also be used