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Mobility Management in Future Wireless Networks: Past, Present, and Future

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Outline of the Tutorial

- IP Mobility Management - Past
  - Mobility Problem and Requirement in the Internet
  - Existing Mobility Support Protocols
  - Applicability of Mobility Support Protocols
- Distributed Mobility Management - Present
  - Motivations
  - IETF Activities
  - Possible Approaches of Distributed Mobility Management
  - Comparisons and Challenges
- Mobility Management in ICNs - Future
  - Motivations and Overview of ICNs
  - Advantages and Challenges of Mobile ICNs
  - Survey on MM for ICNs

IP Mobility Management

- Technology enabling IP session continuity
- Standardized at the IETF

Distributed Mobility Management (DMM)

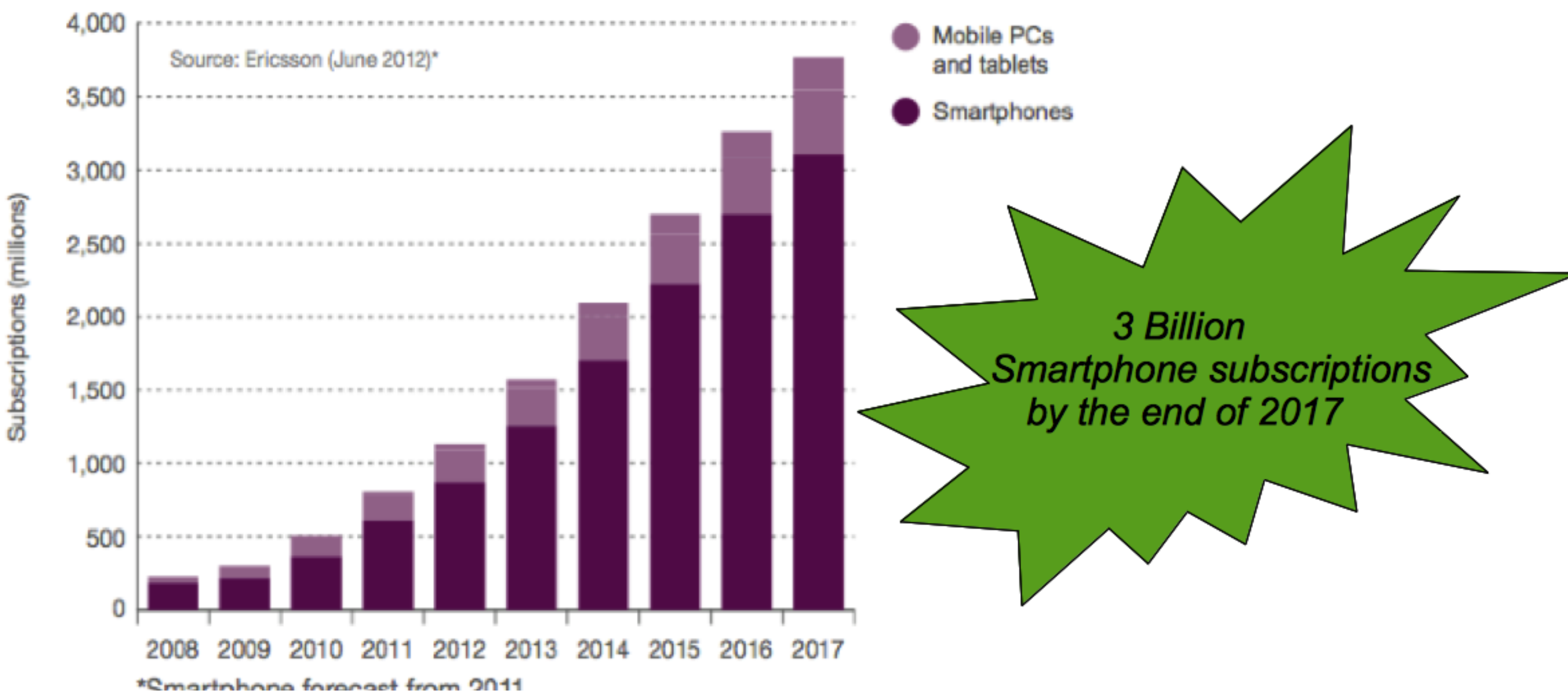
- New approach for enabling IP mobility in an explosion of mobile Internet traffic
- Being standardized at the IETF

Outline

- Motivations of Distributed Mobility Management
  - Explosion of mobile Internet traffic
  - Evolution from “hierarchical” to “flat” architecture
  - Centralized Mobility Management (CMM) is suffering
- Distributed Mobility Management (DMM)
  - IETF activities
  - Possible approaches of DMM
- Comparisons
- Challenges
- Conclusion remarks

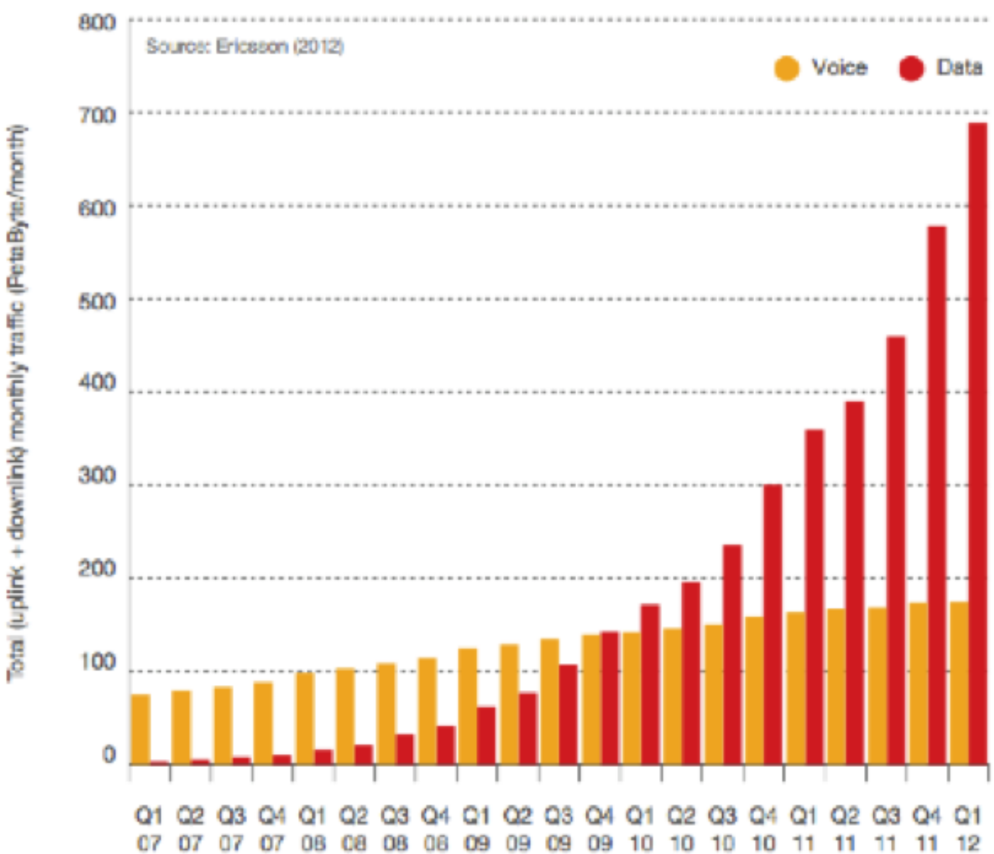
Motivations: Explosion of mobile Internet traffic (1/3)

- We are experiencing the explosion of mobile Internet traffic
  - Sparked by a wave of innovation in mobile devices



Motivations: Explosion of mobile Internet traffic (2/3)

- We are experiencing the explosion of mobile Internet traffic
  - Changed by digital content consumption habits



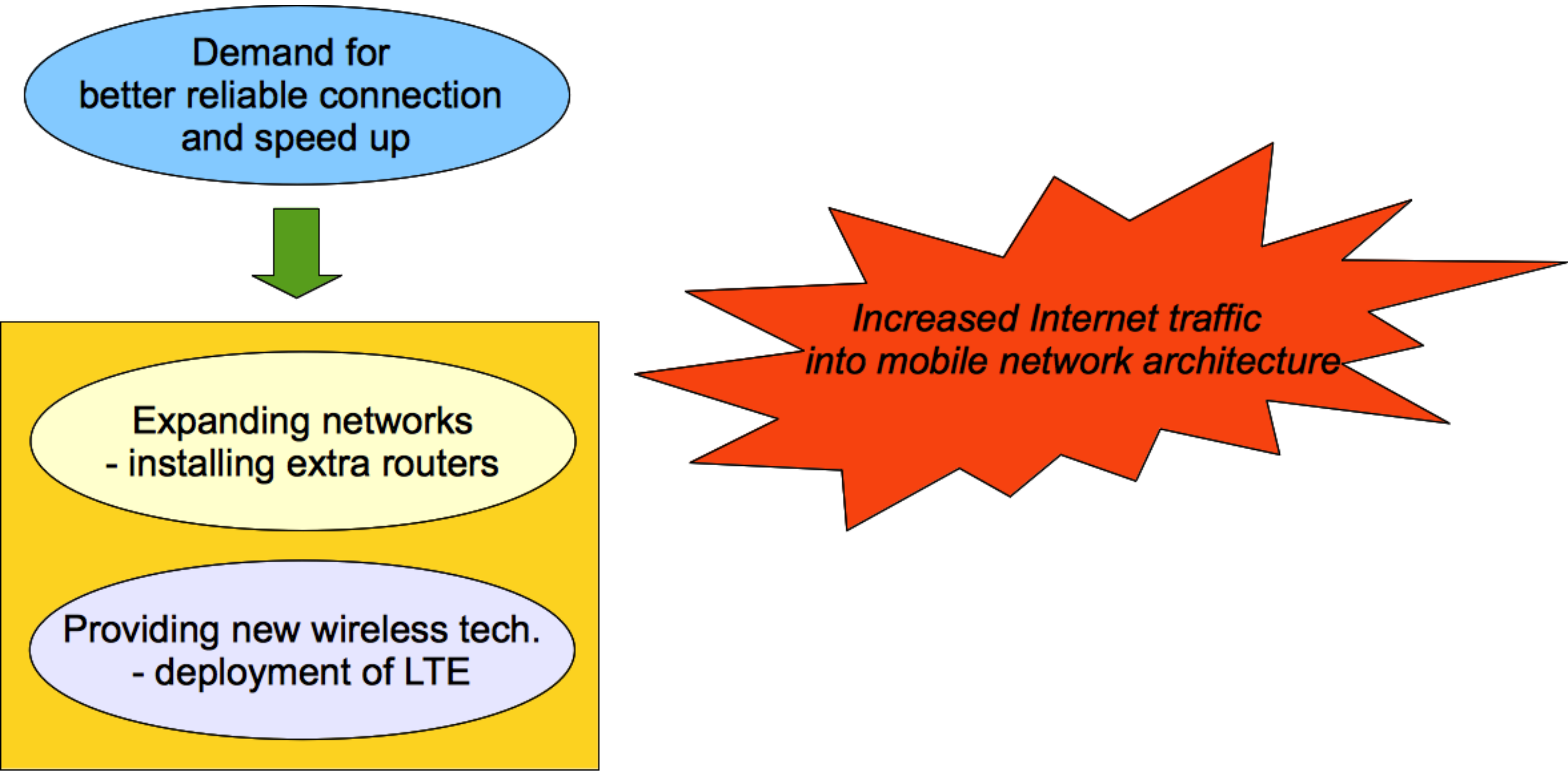
IP data traffic already overwhelms voice traffic

Data hungry mobile applications

- Mobile video streaming
- Mobile social networking

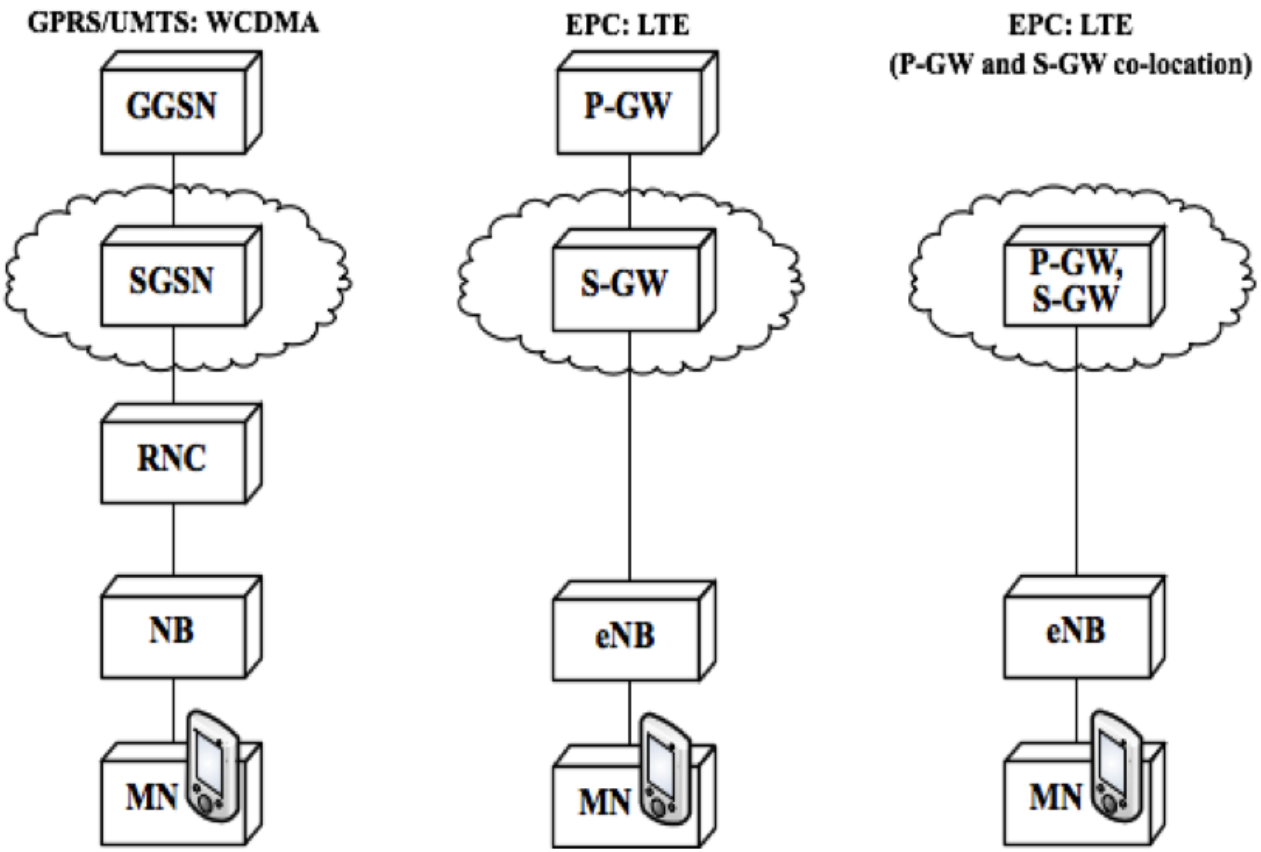
Motivations: Explosion of mobile Internet traffic (3/3)

- Mobile network operators are struggling with rapidly incr easing mobile Internet traffic



Motivations: "hierarchical" to "flat" architecture

- Evolving mobile network architecture



Flatter structure can lead to better efficiency and cost reduction

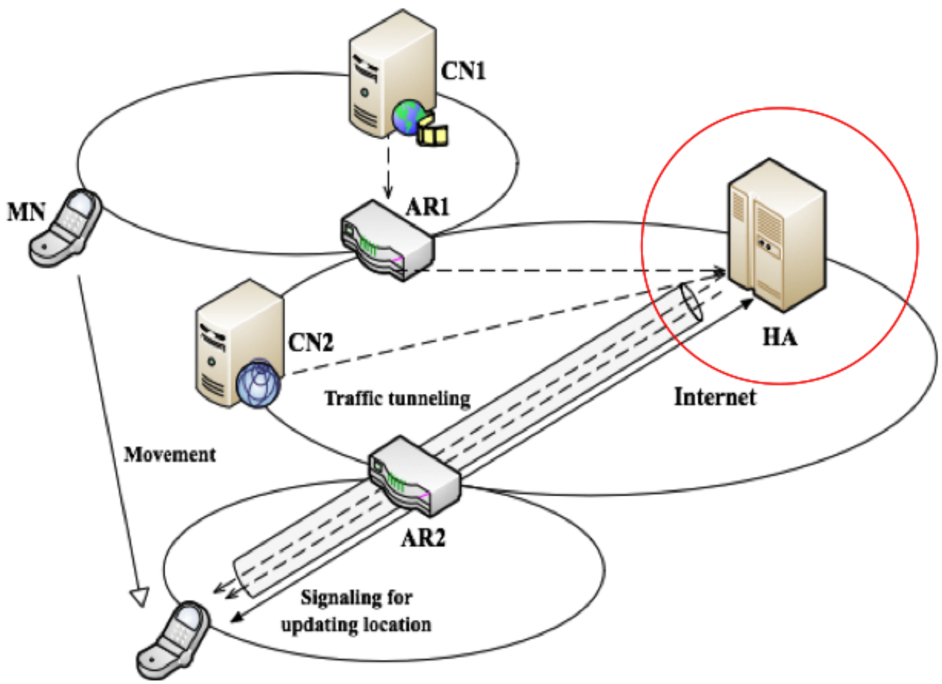
- e.g., 3GPP EPC architecture

Motivations: CMM is suffering (1/3)

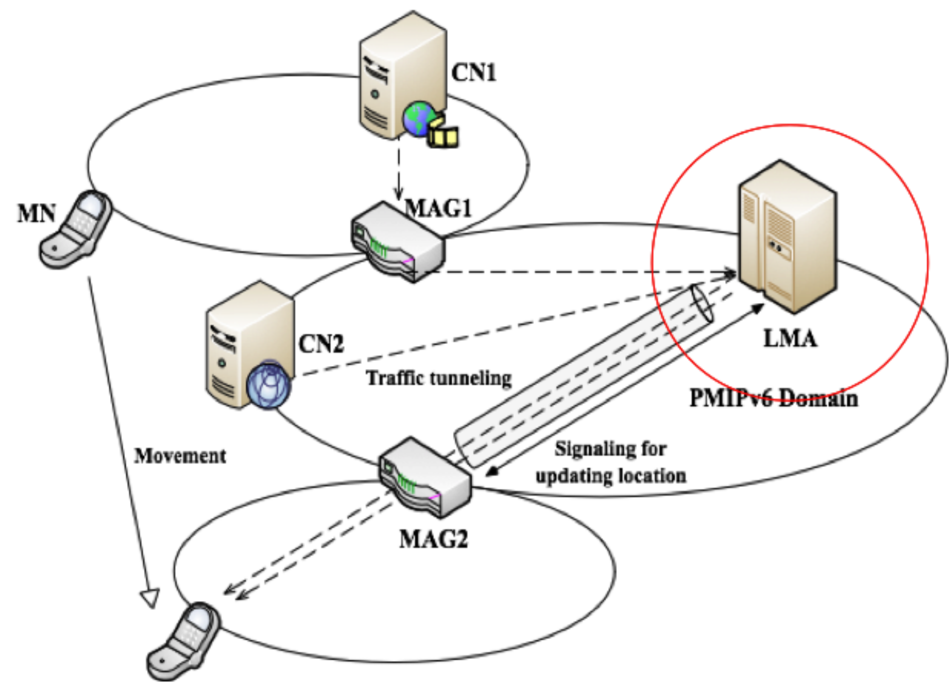
- How about IP mobility management?
  - Centralized Mobility Management (CMM) is suffering
    - Mobile IPv6 (MIPv6)
    - Proxy Mobile IPv6 (PMIPv6)
    - Developed for hierarchical mobile architecture
- Centralized mobility anchor
  - Home Agent (HA) of MIPv6
  - Local Mobility Anchor (LMA) of PMIPv6
  - Maintains mobility signaling and data traffic as well
    - Traffic concentration on a centralized mobility anchor

Motivations: CMM is suffering (2/3)

- Centralized Mobility Management (CMM)
  - Centralized mobility anchor



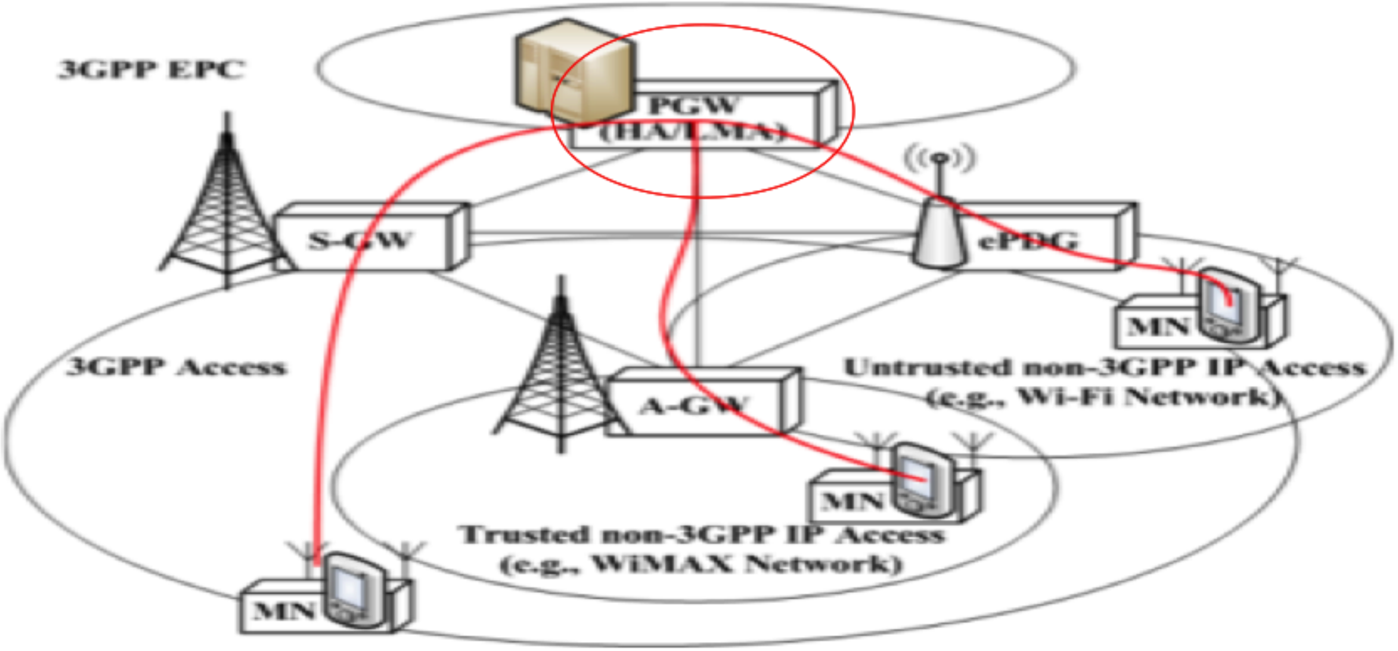
<Handover within MIPv6>



<Handover within PMIPv6>

Motivations: CMM is suffering (3/3)

- Deployment example of CMM in 3GPP EPC (LTE)



Centralized mobility anchor (HA/LMA)
- causes a long handover delay
- causes low end-to-end transmission performance
- becomes a traffic bottleneck
- becomes a single point of failure

DMM: IETF started off

- IETF DMM working group creation
  - DMM protocol aims at distributing traffic in an optimal way and not rely on centrally deployed mobility anchors to manage IP mobility sessions

- Work schedules
  - DMM solution requirement [chan2012]
    - draft-ietf-dmm-requirements-03
  - DMM practices and gap analysis
    - draft-ietf-dmm-best-practices-gap-analysis-00
  - DMM solution
    - Not yet started, but several proposals are available

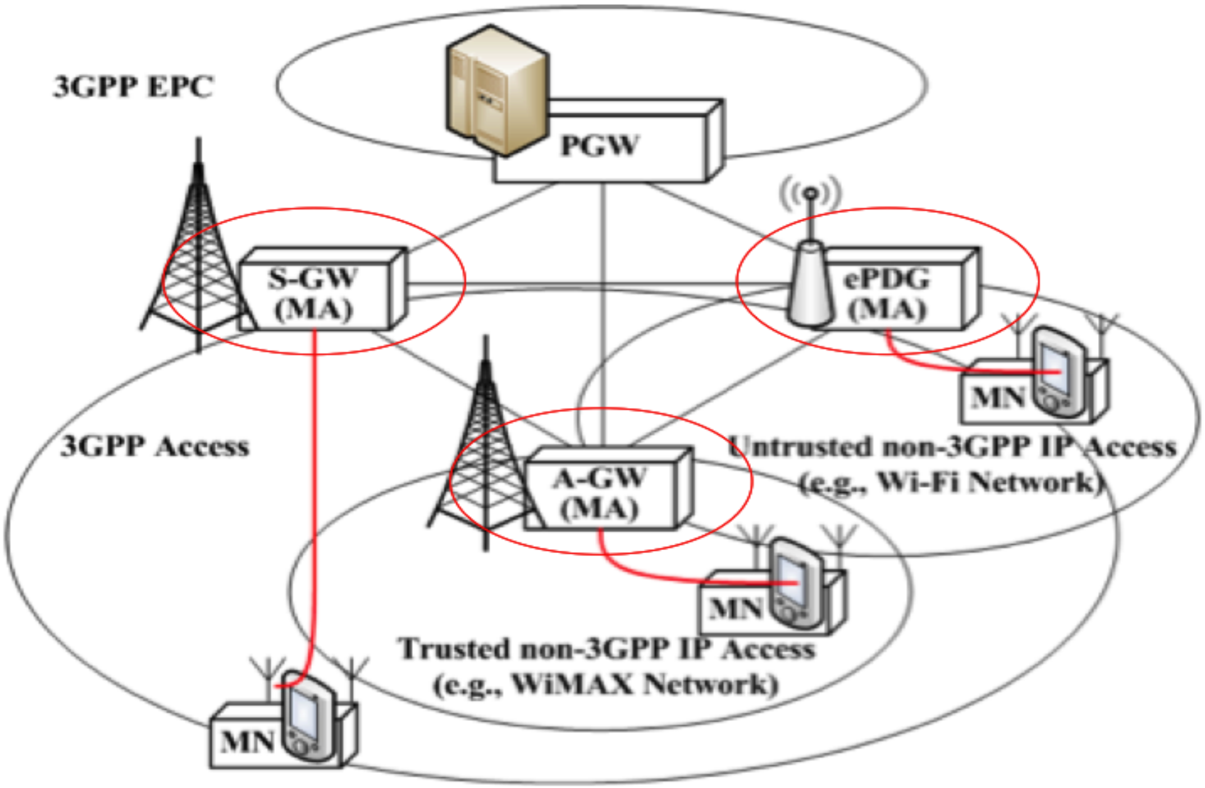
DMM: Possible approaches

- Consensus for development of DMM protocol is to utilize existing IETF IP mobility protocols
  - MIPv6 (host-based IP mobility protocol)
  - PMIPv6 (network-based IP mobility protocol)

- Distributing mobility anchors at access networks
  - For better performance
    - in terms of routing and scalability
  - For minimizing a single point of failure

DMM: Possible approaches

- Deployment example of DMM in 3GPP EPC (LTE)



Mobility Anchors (MAs) are distributed
at the access network level, e.g., at S-GW, A-GW, and ePDG

DMM: Possible approaches

- Host-based DMM [Lee2012]
  - Reuse and extend functionalities of MIPv6
  - Mobility signaling, i.e., binding update/ack.
  - Between a mobile node (MN) and a mobility anchor (MA)
  - Binding cache at the MA
  - Binding update list at the MN

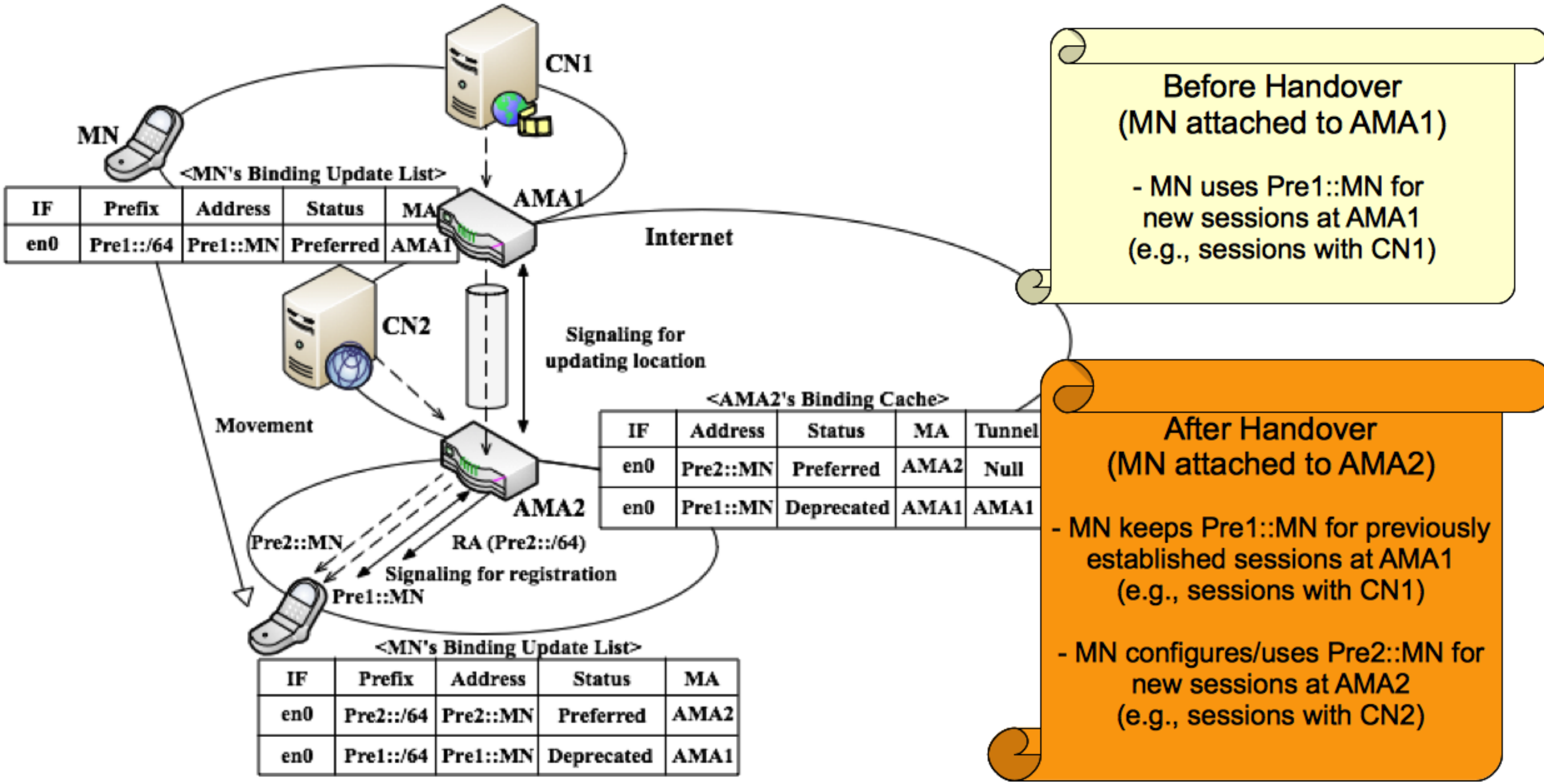
DMM: Possible approaches

- Host-based DMM
  - Introduction of a new mobility anchor
    - Access Mobility Anchor (AMA)
      - Extension of MIPv6's HA
    - Being distributed at the access network level

  - Introduction of new mobility signaling between AMAs
    - Access binding update (ABU) / Ack. (ABA)
      - To update mobility status of a given MN
      - To establish a bi-direction tunnel between AMAs for the MN

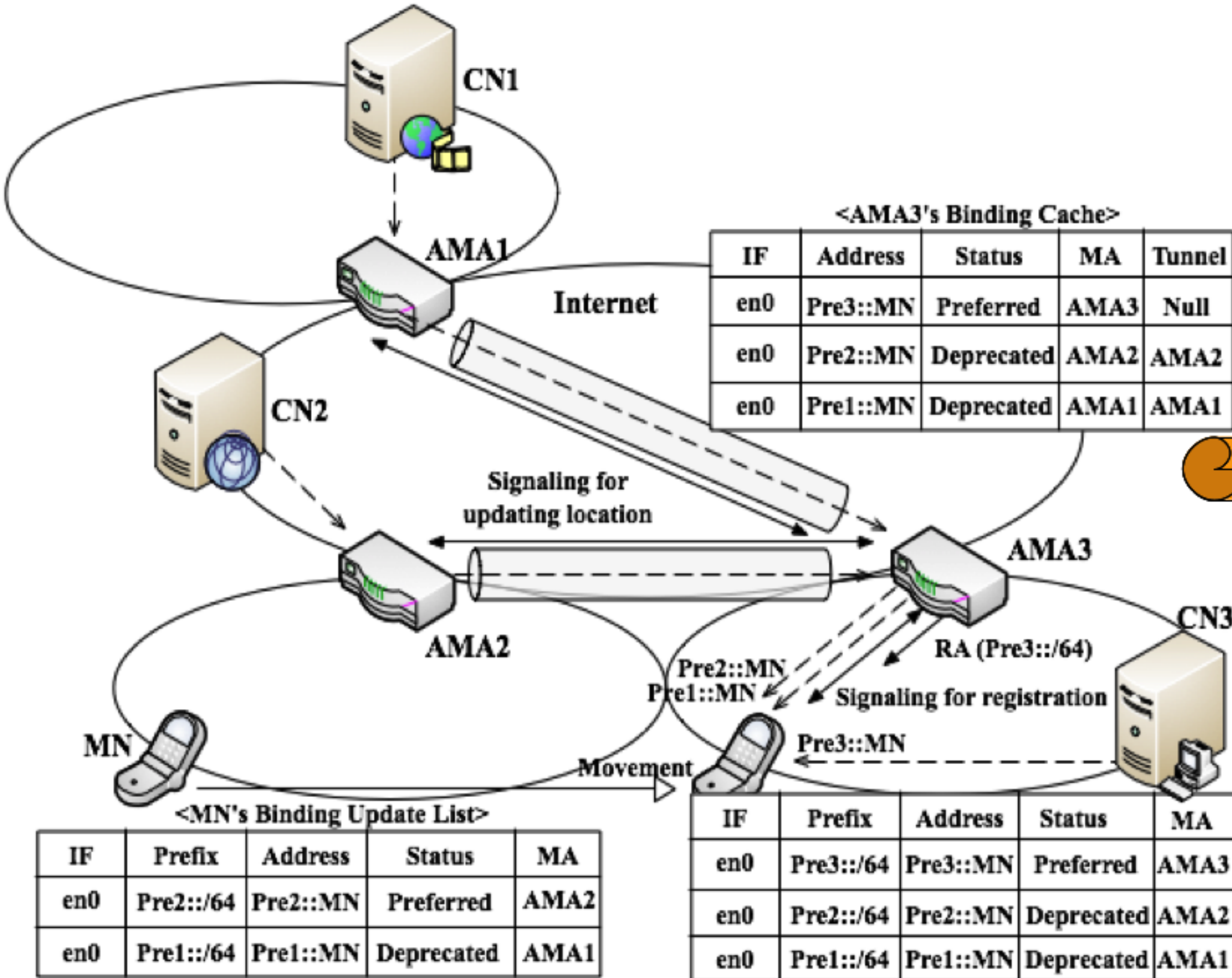
DMM: Possible approaches

- Host-based DMM: Handover from AMA1 to AMA2



DMM: Possible approaches

- Host-based DMM: Handover from AMA2 to AMA3



<AMA3's Binding Cache>

IF	Address	Status	MA	Tunnel
en0	Pre3::MN	Preferred	AMA3	Null
en0	Pre2::MN	Deprecated	AMA2	AMA2
en0	Pre1::MN	Deprecated	AMA1	AMA1

<MN's Binding Update List>

IF	Prefix	Address	Status	MA
en0	Pre2::/64	Pre2::MN	Preferred	AMA2
en0	Pre1::/64	Pre1::MN	Deprecated	AMA1

IF	Prefix	Address	Status	MA
en0	Pre3::/64	Pre3::MN	Preferred	AMA3
en0	Pre2::/64	Pre2::MN	Deprecated	AMA2
en0	Pre1::/64	Pre1::MN	Deprecated	AMA1

Before Handover
(MN attached to AMA2)

- MN keeps Pre1::MN for previously established sessions at AMA1 (e.g., sessions with CN1)
- MN uses Pre2::MN for new sessions at AMA2 (e.g., sessions with CN2)

After Handover
(MN attached to AMA3)

- MN keeps Pre1::MN and Pre2::MN for previously established sessions (e.g., sessions with CN1 and CN2)
- MN configures/uses Pre3::MN for new sessions at AMA3 (e.g., sessions with CN3)

DMM: Possible approaches

- Network-based DMM [Seite2013]
  - Reuse and extend functionalities of PMIPv6
    - Mobility signaling, i.e., proxy binding update/ack.
      - Between mobility anchors (MAs)
    - Binding cache at the MA

DMM: Possible approaches

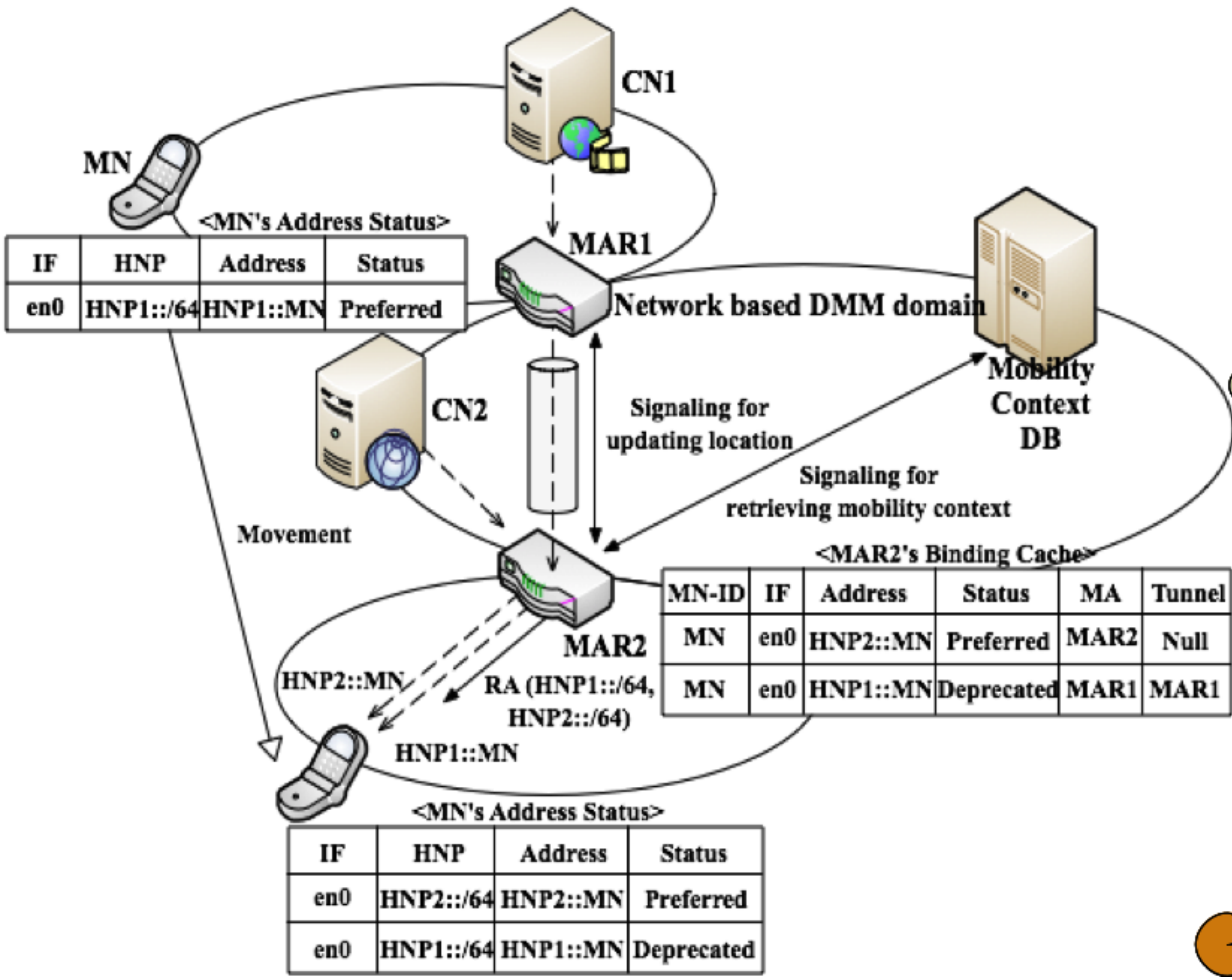
- Network-based DMM
  - Introduction of a new mobility anchor
    - Mobility capable Access Router (MAR)
      - Extension of PMIPv6's LMA
    - Being distributed at the access network level
  - Introduction of a centralized mobility context database
    - Mobility context for all MNs is maintained
      - Only mobility context; not involved in routing
      - Decoupling mobility signaling and data traffic
    - Semi-distributed mobility management
      - Taking advantages of the centralized access and control

DMM: Possible approaches

- Network-based DMM
  - Introduction of new mobility signaling between MARs
    - MAR binding update (MBU) / Ack. (MBA)
      - To update mobility status of a given MN
      - To establish a bi-directional tunnel between MARs for the MN
  - Introduction of new mobility signaling between MAR and centraliz ed DB
    - Mobility Context Request (MCReq) / Response (MCRes)
      - To obtain mobility context for a given MN

DMM: Possible approaches

❖ Network-based DMM: Handover from MAR1 to MAR2



<MN's Address Status>

IF	HNP	Address	Status
en0	HNP1::/64	HNP1::MN	Preferred

<MAR2's Binding Cache>

MN-ID	IF	Address	Status	MA	Tunnel
MN	en0	HNP2::MN	Preferred	MAR2	Null
MN	en0	HNP1::MN	Deprecated	MAR1	MAR1

<MN's Address Status>

IF	HNP	Address	Status
en0	HNP2::/64	HNP2::MN	Preferred
en0	HNP1::/64	HNP1::MN	Deprecated

Before Handover
(MN attached to MAR1)

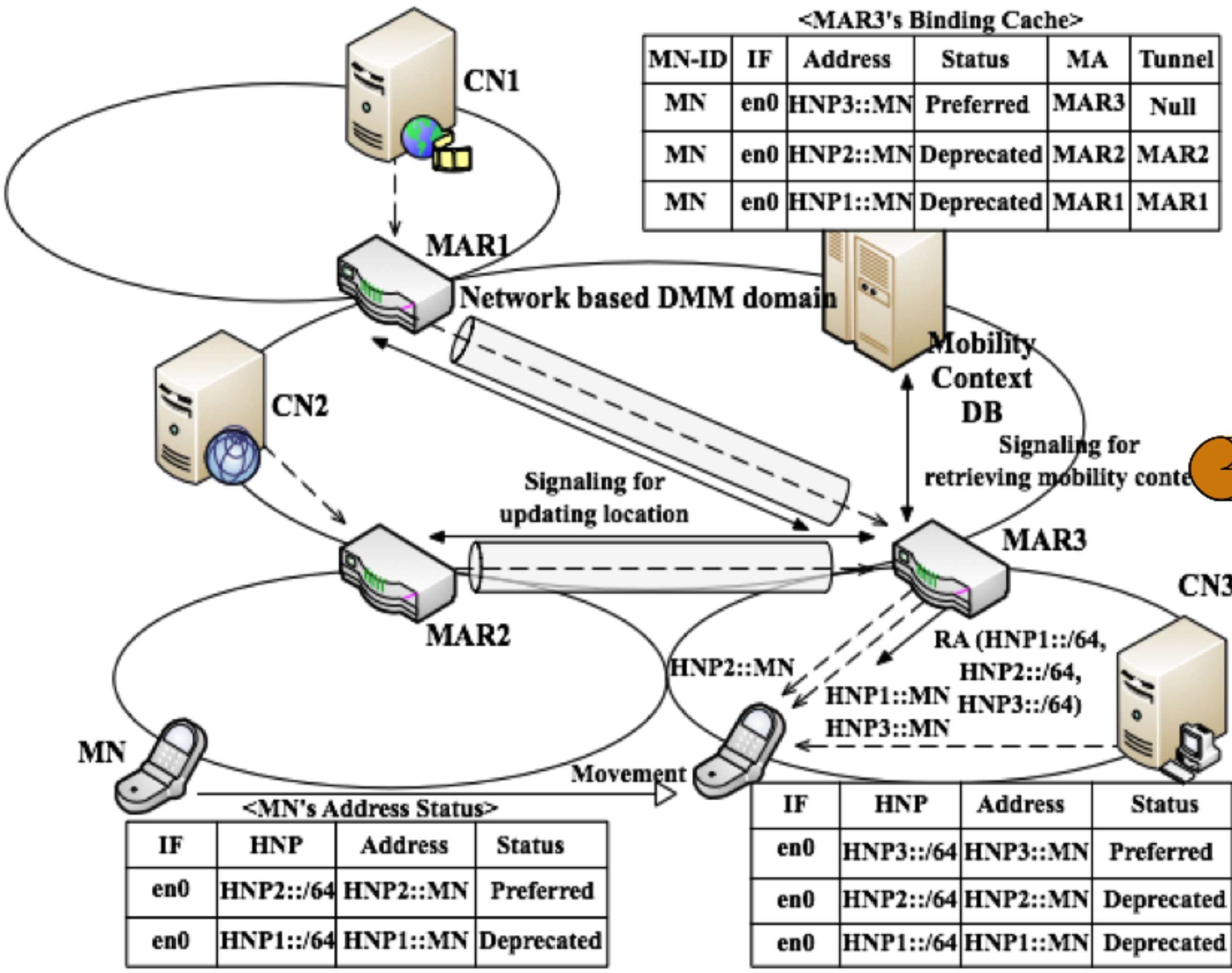
- MN uses HNP1::MN for new sessions at MAR1 (e.g., sessions with CN1)

After Handover
(MN attached to MAR2)

- MN keeps HNP1::MN for previously established sessions at MAR1 (e.g., sessions with CN1)
- MN configures/uses HNP2::MN for new sessions at MAR2 (e.g., sessions with CN2)

DMM: Possible approaches

- Network-based DMM: Handover from MAR2 to MAR3



<MAR3's Binding Cache>

MN-ID	IF	Address	Status	MA	Tunnel
MN	en0	HNP3::MN	Preferred	MAR3	Null
MN	en0	HNP2::MN	Deprecated	MAR2	MAR2
MN	en0	HNP1::MN	Deprecated	MAR1	MAR1

<MN's Address Status>

IF	HNP	Address	Status
en0	HNP2::/64	HNP2::MN	Preferred
en0	HNP1::/64	HNP1::MN	Deprecated

IF	HNP	Address	Status
en0	HNP3::/64	HNP3::MN	Preferred
en0	HNP2::/64	HNP2::MN	Deprecated
en0	HNP1::/64	HNP1::MN	Deprecated

Before Handover
(MN attached to MAR2)

- MN keeps HNP1::MN for previously established sessions at MAR1 (e.g., sessions with CN1)

- MN uses HNP2::MN for new sessions at MAR2 (e.g., sessions with CN2)

After Handover
(MN attached to MAR3)

- MN keeps HNP1::MN and HNP2::MN for previously established sessions (e.g., sessions with CN1 and CN2)

- MN configures/uses HNP3::MN for new sessions at MAR3 (e.g., sessions with CN3)

Comparisons: Qualitative analysis (1/2)

	MIPv6	FMIPv6	HMIPv6	PMIPv6	FPMIPv6	Host-based DMM	Network-based DMM
Mobility management type	Host-based	Host-based	Host-based	Network-based	Network-based	Host-based	Network-based
Mobility scope	Global	Local	Local	Local	Local	Global	Local
Required infrastructure	HA	HA, enhanced AR	HA, Mobility Anchor Point (MAP)	LMA, MAG	LMA, enhanced MAG	AMA	MAR, Mobility DB
MN modification	Required	Required	Required	Not required	Not required	Required	Not required
Addressing model	Shared-prefix model	Shared-prefix model	Shared-prefix model	Per-MN-prefix model	Per-MN-prefix model	Shared-prefix model	Per-MN-prefix model
MN address	Home address (HoA), Care-of address (CoA)	HoA, CoA	HoA, Regional CoA, On-link CoA	HoA	HoA	IP address(es) configured at the access network(s)	IP address(es) configured at the access network(s)
# of MN addresses associated	2	2	3	1	1	*n*	*n*

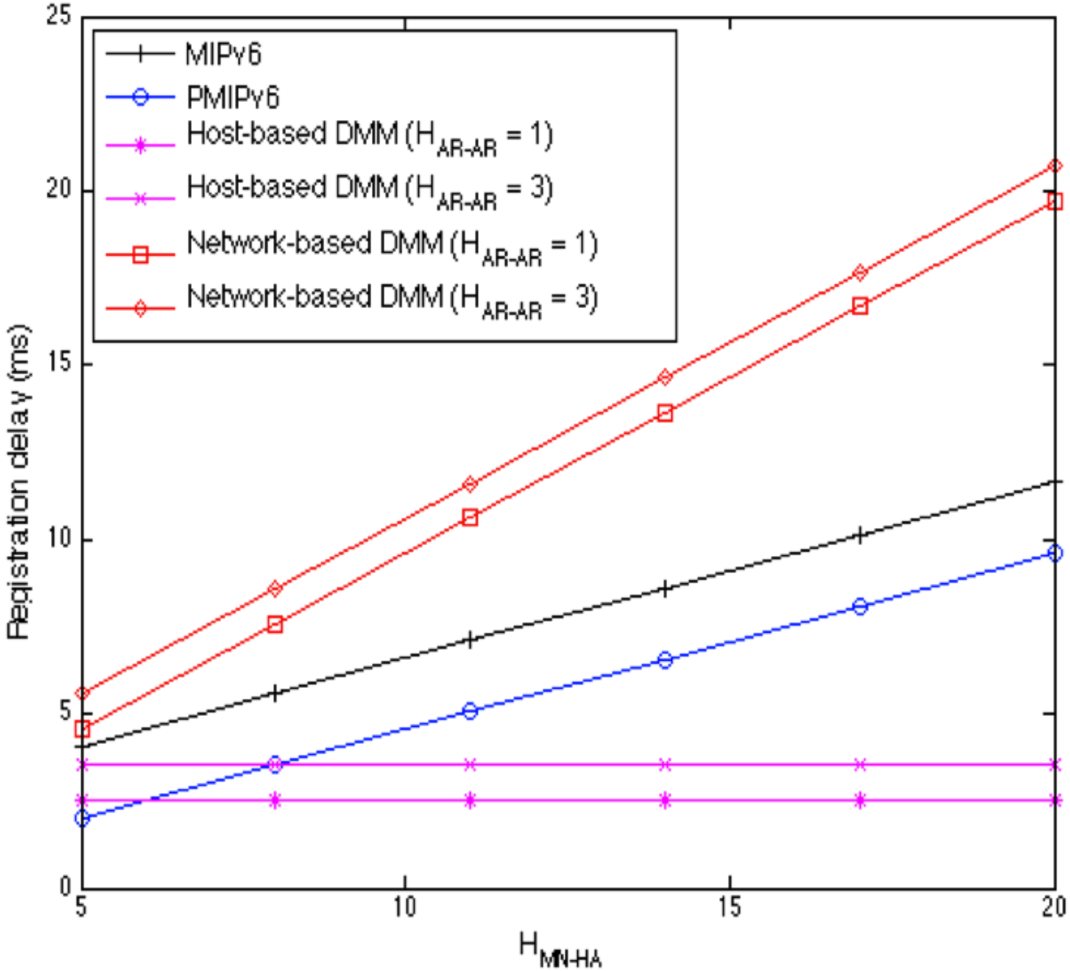
Comparisons: Qualitative analysis (2/2)

	MIPv6	FMIPv6	HMIPv6	PMIPv6	FPMIPv6	Host-based DMM	Network-based DMM
Signaling message over wireless link	BU/BA between MN and HA	BU/BA between MN and HA, RtSolPr/ PrRtAdv/ FBU/ FBack between MN and pAR, UNA between MN and nAR	BU/BA between MN and HA, Local BU/BA between MN and MAP	Not required	Not required	Not required	Not required
Required tunneling	HA-MN tunnel	HA-MN tunnel, pAR-nAR tunnel	HA-MN tunnel, MAP-MN tunnel	LMA-MAG tunnel	LMA-MAG tunnel, pMAG-nMAG tunnel	Origin AMA(s)-Serving AMA tunnel	Origin MAR(s)-Serving MAR tunnel
# of tunneling per MN	1	2	2	1 (shared with other MNs)	2 (shared with other MNs)	$n-1$ (shared with other MNs)	$n-1$ (shared with other MNs)
Tunneling over wireless link	Required	Required	Required	Not required	Not required	Not required	Not required
Supported link type	Any type of link	Any type of link	Any type of link	Point-to-point link	Point-to-point link	Any type of link	Point-to-point link

Comparisons: Quantitative analysis (1/4)

- Comparison of the proposed DMM protocols with MIPv6 and PMIPv6 in terms of
  - Registration delay
    - Required time to register mobility context of an MN
  - Signaling overhead
    - Registration overhead in units of bytes * hops per second
  - Traffic intensity
    - Amount of ongoing communication sessions concentrated on a mobility anchor

Comparisons: Quantitative analysis (2/4)



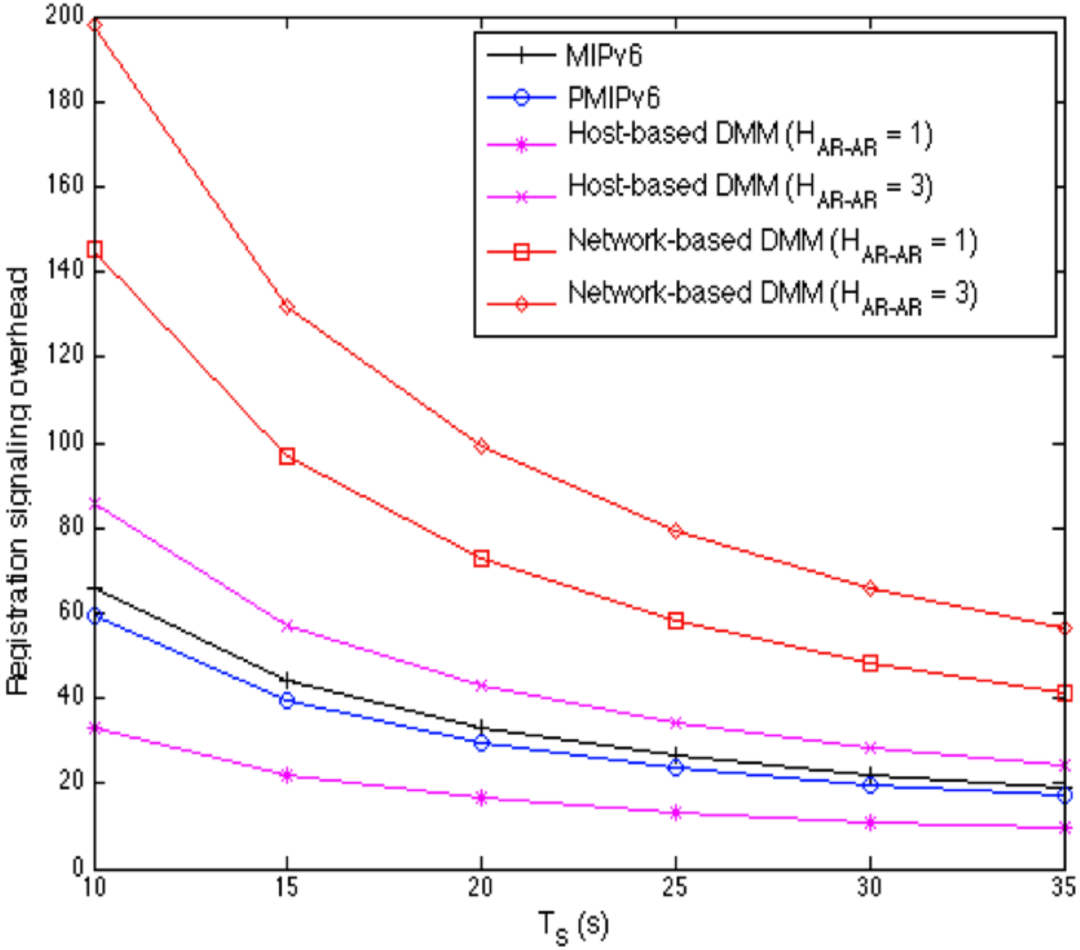
Registration delay as the function of number of hops between the MN and the HA (i.e., mobility anchor/mobility context DB)

In this result, we confirm:

1. The DMM protocols require an additional registration delay to origin mobility anchors that depends on the number of hops between neighbor ARs

2. The network-based DMM requires the largest registration delay due to the involvement of mobility context DB

Comparisons: Quantitative analysis (3/4)



Registration signaling overhead as the function of resident time in a subnet

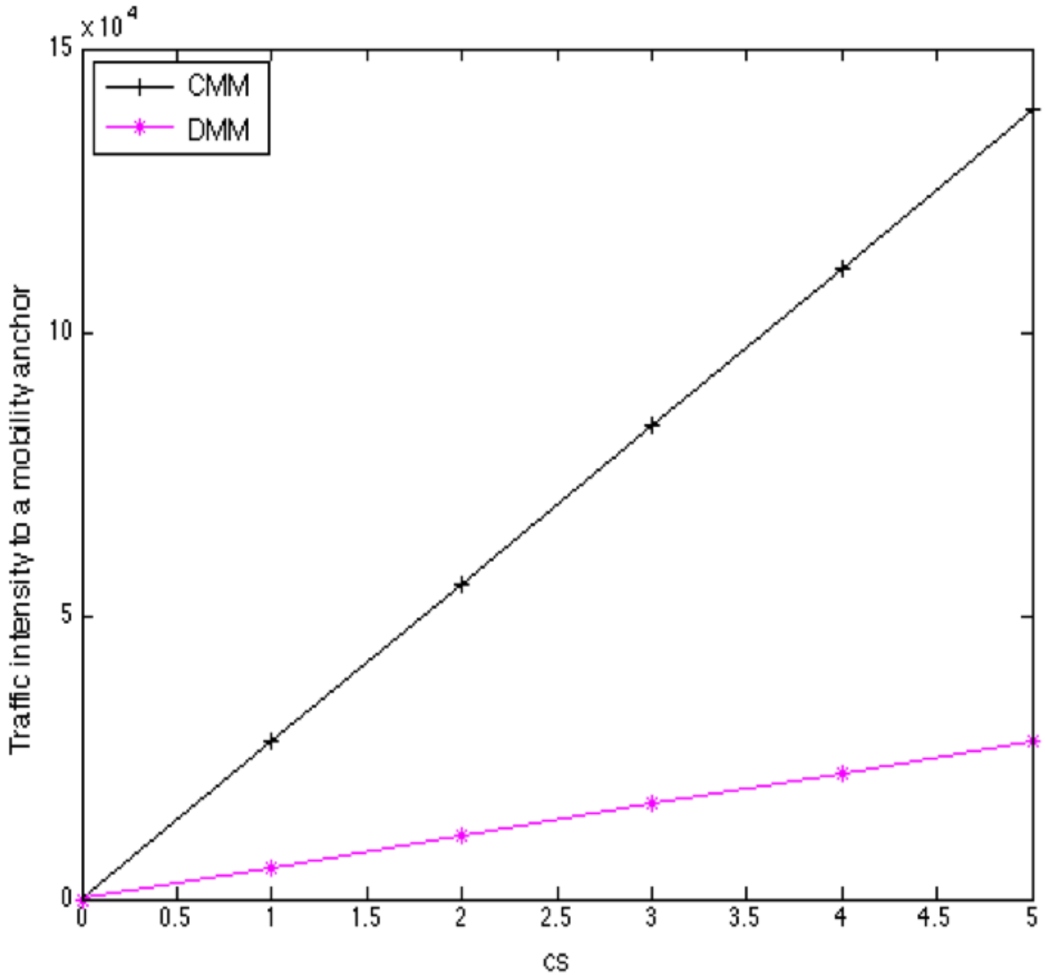
In this result, we confirm:

1. As the resident time increases, the signaling overhead of all protocols decreases and converges to the same level

2. The network-based DMM has the largest signaling overhead due to extra signaling involvements to the mobility context DB

3. When the number of hops between the neighbor ARs is small, the host-based DMM has the smaller signaling overhead than others. It means that the network topology configuration largely affects to the signaling overhead

Comparisons: Quantitative analysis (4/4)



Traffic intensity as the function of number of MN's communication sessions

In this result, we confirm:

1. As the number of ongoing communication sessions increase, the traffic intensity of CMM (i.e., MIPv6, PMIPv6) dramatically increase due to the deployment of centralized mobility anchor such as HA/LMA

2. On the other hand, DMM mitigates the traffic intensity as it employs the distributed mobility anchors that avoid the user traffic's concentration to a single point

Challenges in DMM development (1/4)

- Address and tunneling management
  - As an MN may configure a new address while keeping its previous addresses, the number of addresses (*n*) and the number of bidire ctional tunnels (*n* - 1) associated to the MN increases
  - A design of efficient address and tunneling management scheme i s thus required
  - One can be expected: a session activity for each address is check ed periodically (by the MN or serving mobility anchor) and a given address is concluded as an address not being used if no session ac tivity for the given address has taken place for a predefined peri od time.

Challenges in DMM development (2/4)

- Registration delay and signaling overhead
  - As the number of bidirectional tunnels associated to MNs is incre ased, signaling messages to establish and manage the tunnels betw een the serving mobility anchor and origin mobility anchors are re quired.
  - Even if the mobility anchors manage those signaling messages, it c auses additional registration delay and signaling overhead compare d to CMM.
  - In addition, if a semi-DMM approach (i.e., the introduced network -based DMM) is deployed, extra delay and overhead are required between mobility anchors and a centralized agent managing mobili ty context of registered MNs

Challenges in DMM development (3/4)

- Network configuration and resource management
  - Unlike CMM in which a centralized control is possible, network con figuration and resource management such as self-configuration, s elf-optimization, and QoS provision are required in a distributed way.
  - This challenge comes with the DMM's benefits such as scalability and may influence a design choice between semi-DMM and fully-D MM

Challenges in DMM development (4/4)

- Security consideration
  - Access network security and end-to-end security are required to protect DMM services. For access network security, EAP based a uthentication can be used, while IPsec can be used for end-to-end security
  - However, unlike CMM, frequent tunnel establishments at the acce ss network level are required for session continuity and efficient security associations between mobility anchors thus are required

DMM: Conclusion Remarks

- We have been experiencing
  - Ever-increasing mobile Internet traffic over mobile networks
  - Evolution of mobile network architectures
    - From "hierarchical" to "flat"
  - Current IP mobility protocols are suffering
    - Centralized Mobility Management
- In order to cope with such challenges
  - Research on Distributed Mobility Management has been started r ecently

DMM: References

- [Chan2012] H. Chan (Ed.), "Requirements of distributed mobility management", draft-ietf-dmm-requirements, July 2012.
- [Seite2013] P. Seite, P. Bertin, and J.-H. Lee, "Distributed Mobility Anchoring", draft-seite-dmm-dma, January 2013.
- [Lee2012] J.-H. Lee, J.-M. Bonnin, and X. Lagrange, "Host-based distributed mobility management support protocol for IPv6 mobile networks", In Proc of *IEEE WiMob 2012*, October 2012

Mobility Management in ICNs

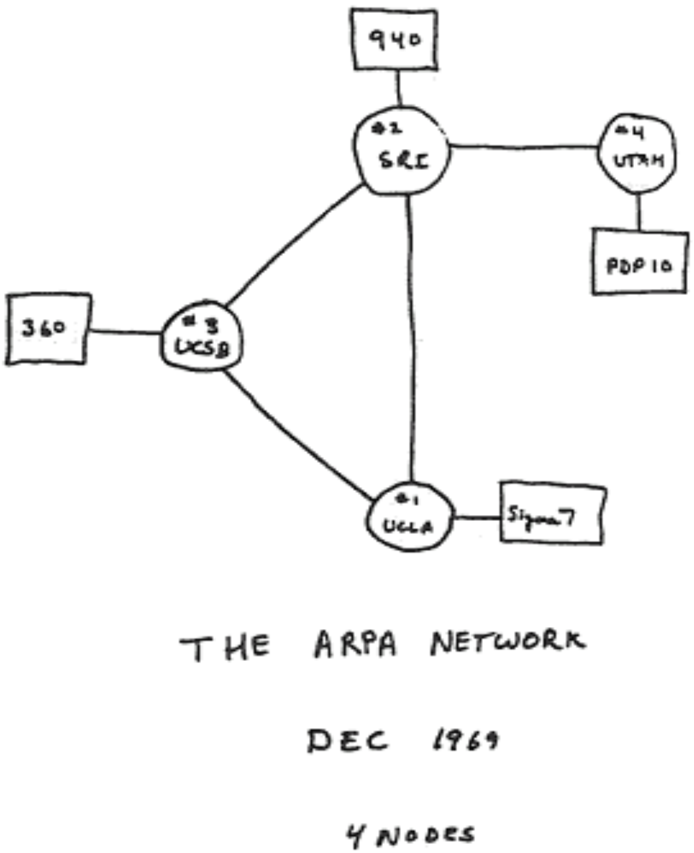
- Revolutionary network architecture for information/contents/data-centric networking
- Hottest research area in Future Internet
- New challenges in mobile ICNs

Outline

- Information Centric Networks (ICNs)
  - Motivation and overview
  - Two representative ICNs: DONA and CCN
- Advantages of Mobile ICNs
- Challenges of Mobile ICNs
- Survey on Provider/Consumer Mobility
- Conclusion remarks

Introduction (1/2)

- (Origin) Internet
  - Internet was designed for host-to-host communications
    - Remote login, file transfer, …
  - Internet (TCP/IP) architecture is well-suited for communications between two stationary hosts



Conceptual Sketch of Orignal Internet

Introduction (2/2)

- (Today) Internet
  - Majority of Internet usage is data retrieval and service access
  - Users care about the contents and are oblivious to location
- This usage pattern does not fit comfortably within the host-to-host communication model
- A new paradigm for contents/information-centric from host-centric architecture!

ICN: Motivation

- Information Centric Network (ICN)
  - Let's build a new network architecture suited for Internet usage!
  - One of hottest research topics in Future Internet

SIGCOMM 2013 Hong Kong

The 3rd ACM SIGCOMM Workshop on Information-Centric Networking (ICN 2013)

To be held in Hong Kong, China

IEEE Communications Magazine

July 2012, Vol. 50, No. 7

www.comsoc.org

·Information-Centric Networking

computer communications

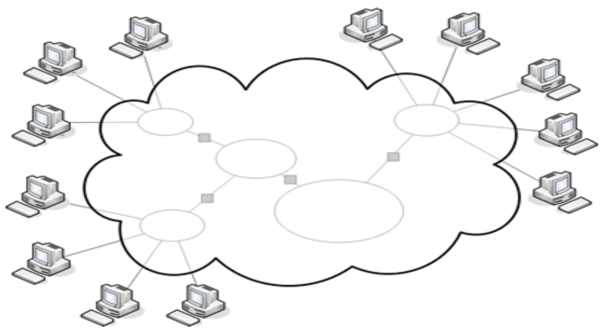
Call for Papers
Special Issue on Information-Centric Networking

IRTF

Information-Centric Networking Research Group (ICNRG)

ICN: Brief Idea

- Current Internet
  - Host-to-host communications
  - Node-centric design



- ICN
  - Contents access/retrieval and Data-centric design
  - Don't worry about location (or address)!

Different ICN Architectures

- Data oriented network architecture (DONA)
  - http://radlab.cs.berkeley.edu/wiki/DONA
- Content centric networking (CCN)
  - http://www.ccnx.org/ (http://www.named-data.org/)
- Publish-subscribe Internet routing paradigm (PSIRP)
  - http://www.psirp.org/
- Network of Information (NetInf)
  - http://www.netinf.org/
- See [AHL12] for survey

DONA vs. CCN

- Data-Oriented Network Architecture (DONA)
  - The first ICN approach by UC Berkeley
  - Flat naming and (logically) hierarchical network archi tecture
- Contents-Centric Networking (CCN) (or Named Data Network (NDN))
  - By Xerox PARC (Dr. V. Jacobson) and UCLA (Prof. L. Zhang)
  - Hierarchical naming and flat network architecture

DONA: Overview

- Key idea
  - Replace contents names with flat, self-certifying names!
  - Replace contents/data name resolution with a name-based anycast primitive!
- Features
  - Flat and invariant names
  - Route-by-name paradigm
  - Self-certifying names: easy authentication

DONA: Naming

- Each datum or any other named entity is associated with a principal; each principal is associated with a public-private key pair
  - Can verify the data by checking the public key hashes into principal and validating the signature corresponds to the public key
- Challenge is how to resolve the flat name into the appropriate location

DONA: Name Resolution

- Route-by-name paradigm for name resolution
  - Resolution infrastructure consists of resolution handlers (RH)
  - each domain will have one logical RH
- Name resolution is accomplished through the use of two basic primitives:
  - FIND(P:L): data request
  - REGISTER(name): set up the state for the RHs to route FINDs effectively

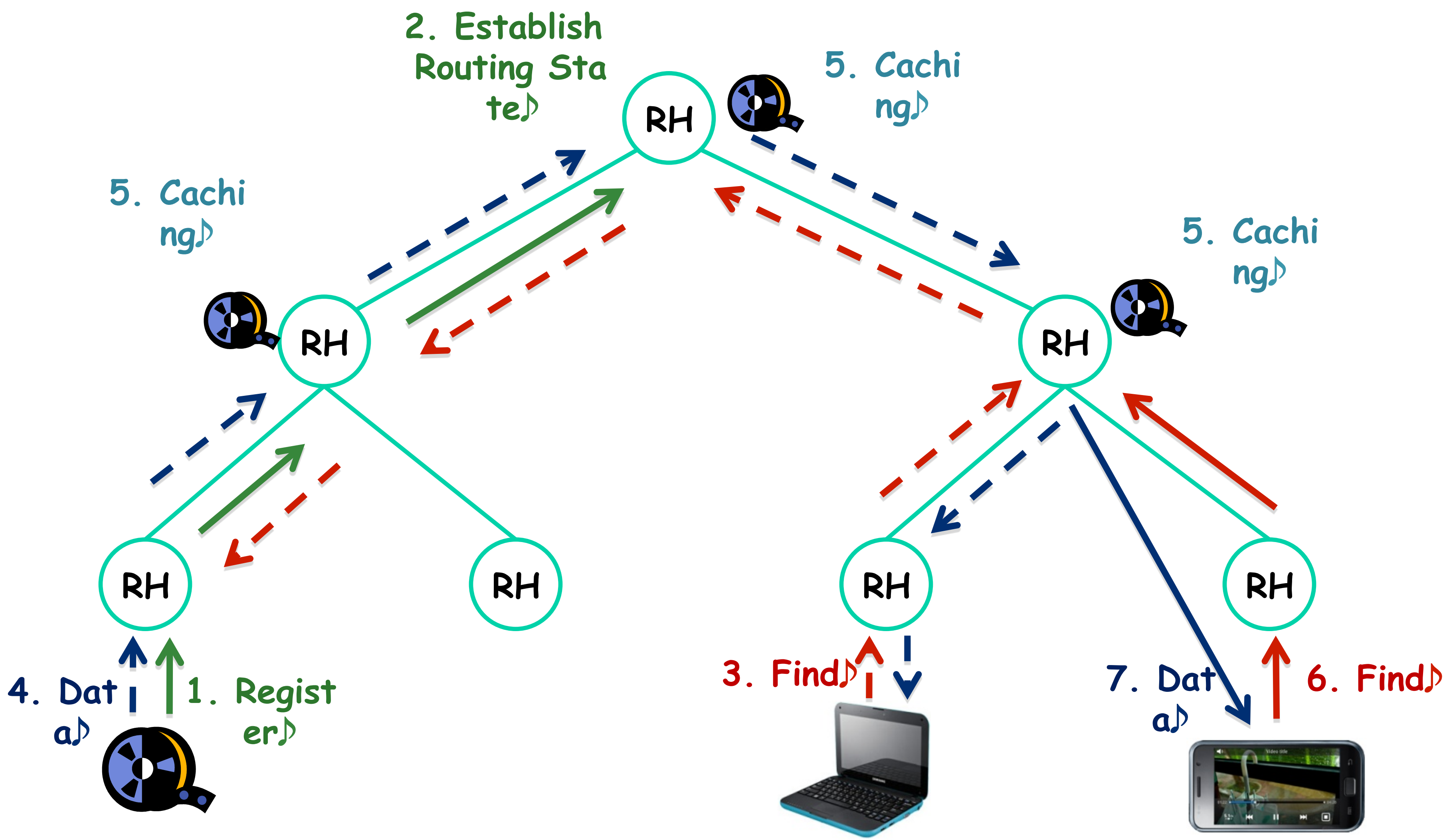
DONA Operation: REGISTER

- A node to serve P:L sends a REGISTER(P:L) to its first-hop RH
- RH maintains a registration table that maps a na me to both a new-hop RH and the distance to the copy
  - REGISTERs from child to both peers and parents
  - REGISTERs from peers optionally to parents/peers

DONA Operation: FIND

- When FIND(P:L) arrives at a RH
  - use RH hierarchy to guide routing
  - if there is an entry in the registration table
    - FIND to nearest data by sending to the next-hop RH
    - RHs respond to FIND if data is in cache
  - if there is no entry
    - RH forwards the FIND towards to its parent

DONA: Example

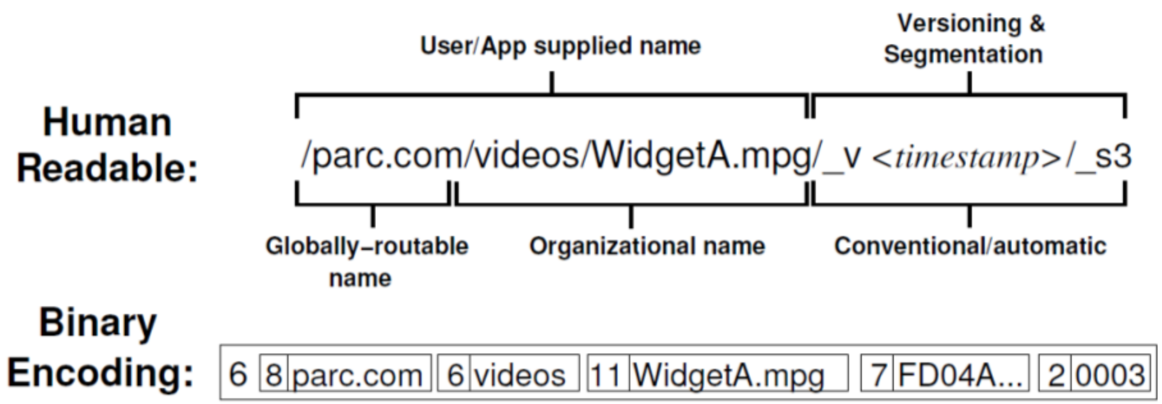


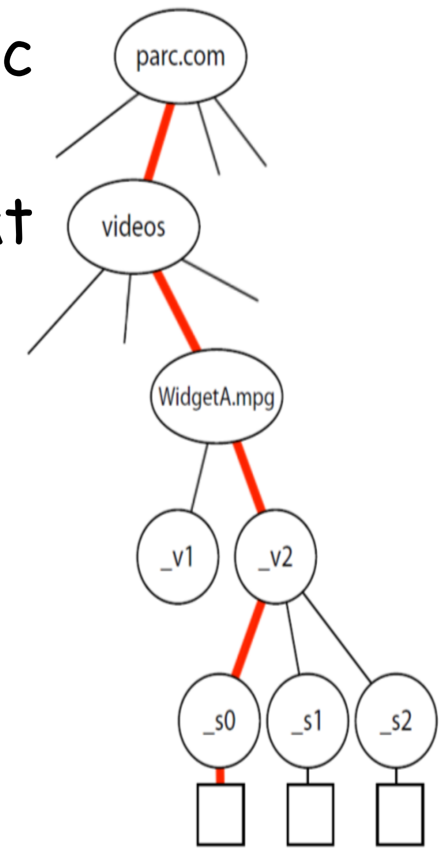
CCN: Overview

- Key idea
  - Send a query with contents name and receive the corre sponding contents from nearby nodes
    - Similar to Directed Diffusion in wireless sensor networks
- Features
  - Hierarchical name (cf. URL): name aggregation
  - In-network caching
  - External trust source is needed for integrity

CCN: Naming

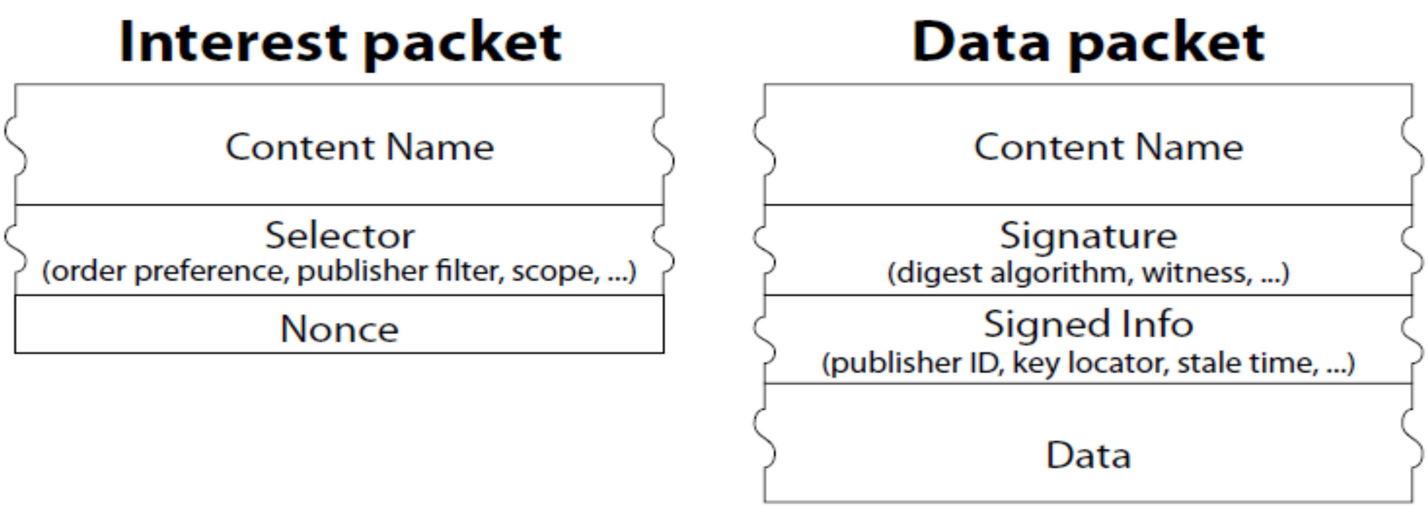
- Hierarchical name
  - Consumers are requesting individual pieces from large collection of data
  - Many recipients may share the same data packets: caching effect



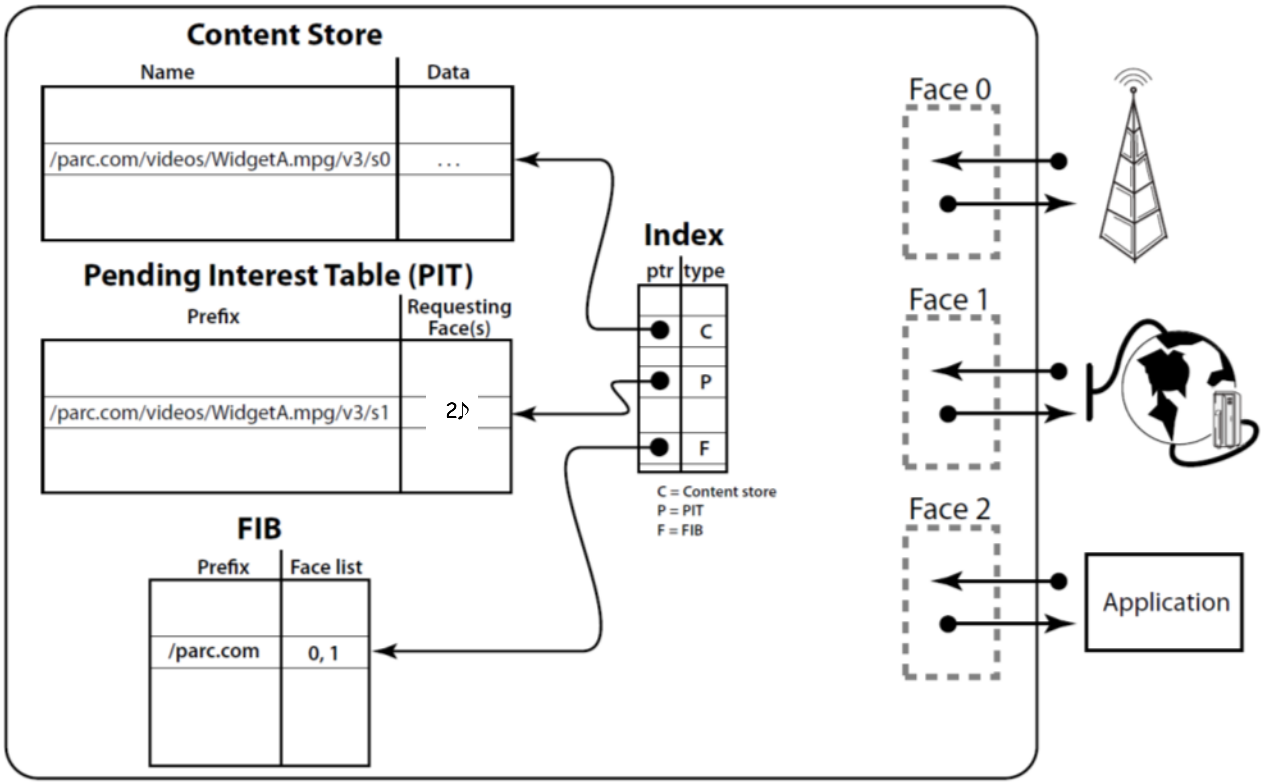


CCN: Interest and Data Packets

- Interest packet
  - Similar to http "get"
- Data packet
  - Similar to http "response"

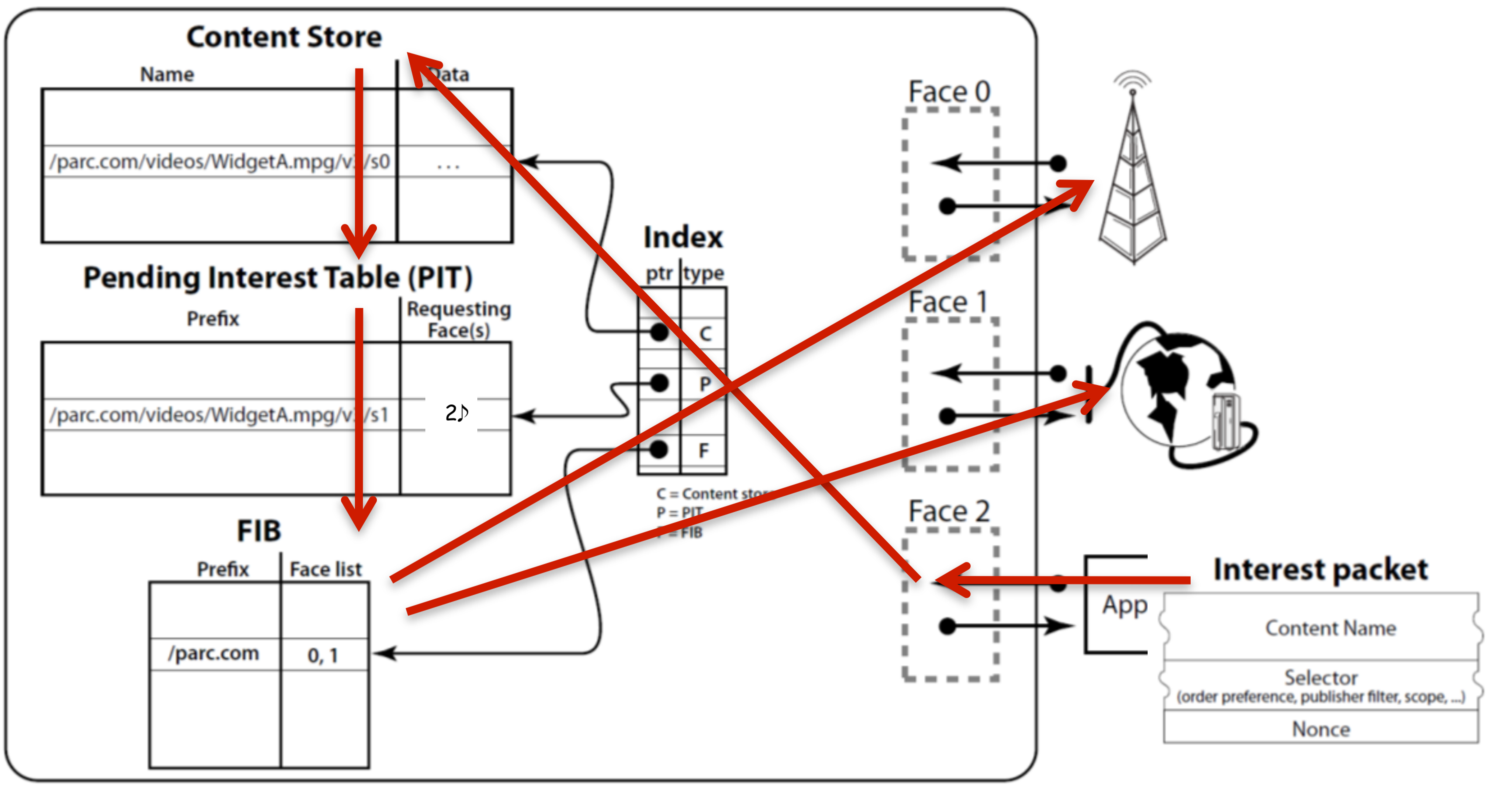


CCN Router

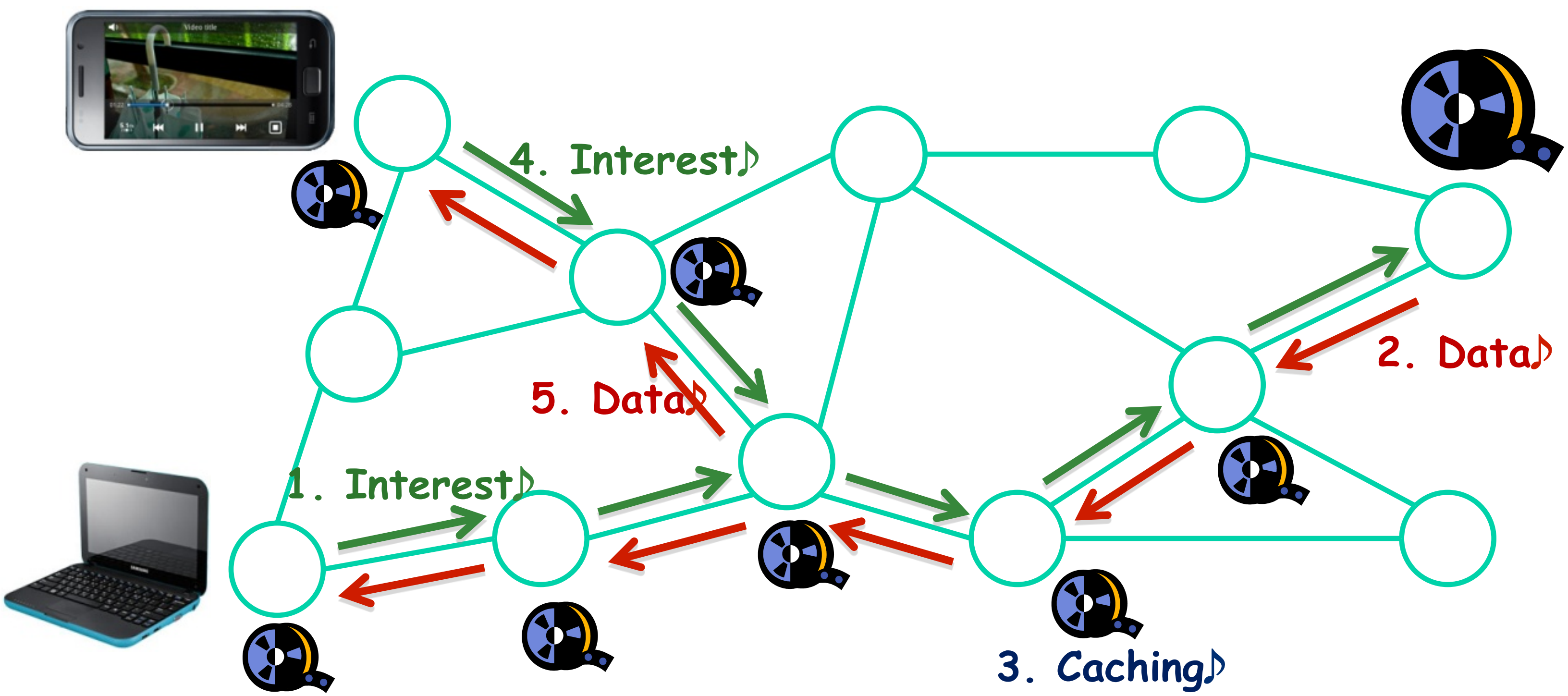


Content Store
Name
Data
/parc.com/videos/WidgetA.mpg/v3/s0
...
Pending Interest Table (PIT)
Prefix
Requesting Face(s)
/parc.com/videos/WidgetA.mpg/v3/s1
2
FIB
Prefix
Face list
/parc.com
0, 1
Index
ptr
type
C
P
F
C = Content store
P = PIT
F = FIB
Face 0
Face 1
Face 2
Application

CCN Forwarding Example

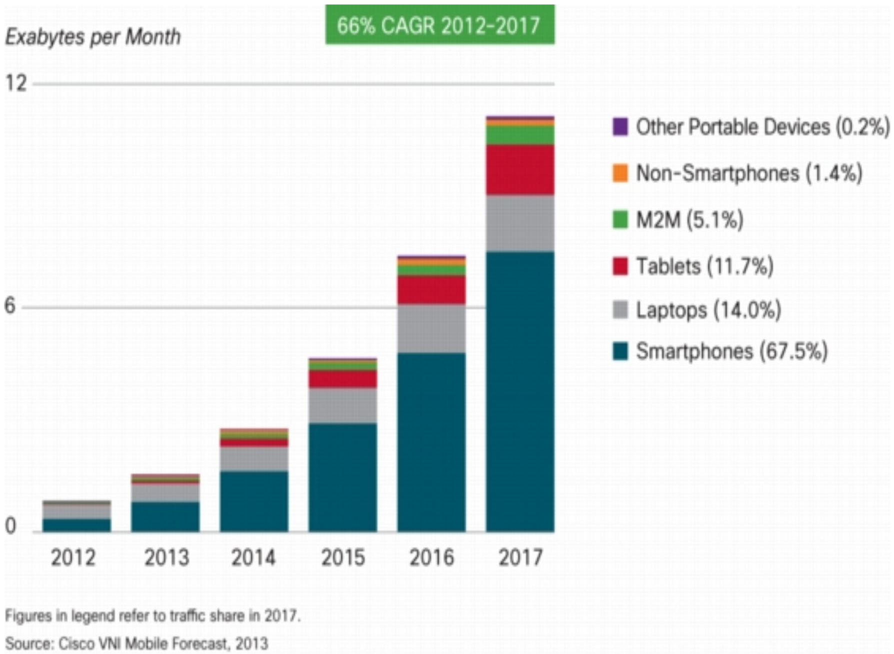


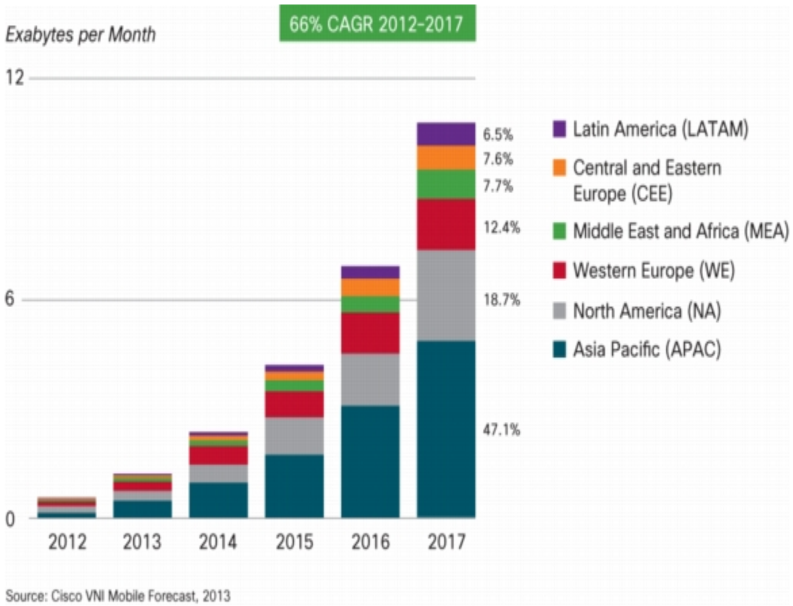
CCN Routing Example



In-Network Caching (1/3)

- Observation #1
  - IP traffic explosion (especially in mobile networks)
  - [CISCO Visual Networking Index 2012]





In-Network Caching (2/3)

- Observation #2
  - Many redundant traffic
- Observation #3
  - Storage is too cheap
  - But, communication fee is still expensive (at least in Korea)
- Observation #4
  - Access latency is heavily affected by RTT
    - So, CDN is very popular

Akamai

In-Network Caching (3/3)

- Hence, in-network caching is the most effective ways to reduce the contents access delay and the traffic!

- All of ICNs adopt in-network caching

- In-network caching can be benefit in terms of mo bility support

Now, let's move to mobile ICNs

Advantage of ICN

- Faster contents access
  - In-network caching (multi-path or anycast)
- Security
  - Integrated with the content itself
  - Spam protection by receiver-driven model
- Mobility
  - Contents are not bound to location
  - But, for nomadic not seamless

Advantage of Mobile ICN (1/4)

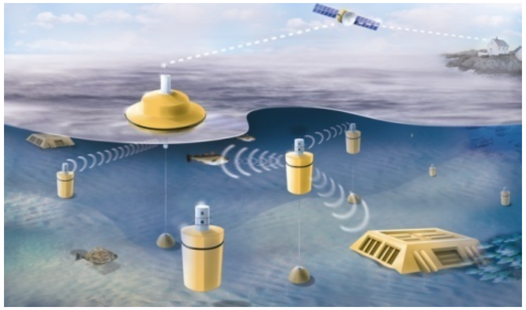
- Host Multihoming (vs. Uni-homed)
  - No binding between a flow with a specific interface
    - Application concerns only data item of its interest
    - A request can be multiplexed over different interfaces (e.g., 3 G and WiFi)
  - Multihomed ICN node can seamlessly exploit different interfaces without any knowledge of active interface
    - Seamless handover, bandwidth aggregation, etc.

Advantage of Mobile ICN (2/4)

- Connectionless operation (vs. TCP)
  - ICN is based on network (or packet)-level contents delivery
  - No need to maintain persistent session information at contents provider/consumer
  - Relocation of a host does not require the re-establishment of a connection
    - But, ASAP attachment to PoA is needed
    - Retransmission of request may be also needed

Advantage of Mobile ICN (3/4)

- In-network caching (vs. conventional router)
  - No binding between contents and location; contents can be retrieved *any* nodes (e.g., nearby router with in-network cache)
  - Replication of local copies can improve resilience in contents access
    - More powerful in dynamic mobile environments (e.g., delay/disruption tolerant networks (DTN))



Advantage of Mobile ICN (4/4)

- ID and locator separation (vs. IP)
  - Application can *abstractly* publish or consume the contents without concern of location (or network address)
  - Can solve access control problem and non-optimal path problem in CDN
    - CDN typically select nearby replica based on IP
    - Some contents at www.naver.com cannot be access in foreign countries due to access control using IP

Challenges in Mobile ICN (1/5)

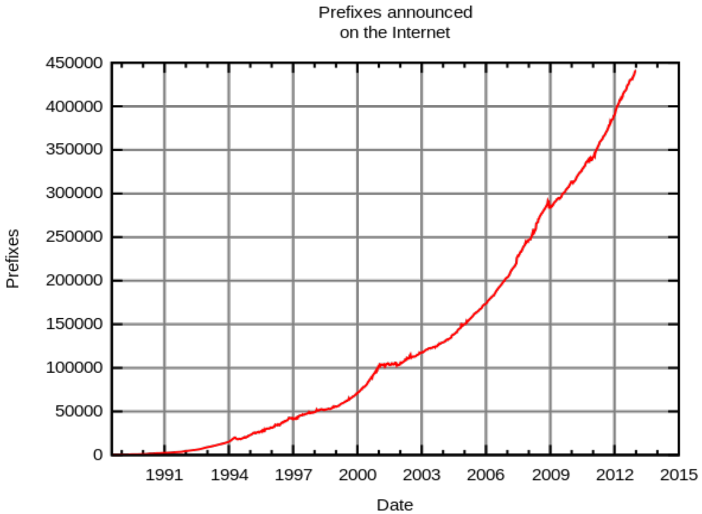
- Provider Mobility (vs. Consumer Mobility)
  - Consumer mobility can be (relatively) easily handled du e to consumer (receiver)-driven nature
  - However, for provider (contents source) mobility
    - To route a request to contents provider properly, routing consi stency even during/after provider mobility should be satisfied
  - More serious for unpopular contents
    - Popular ones can exploit the benefits of caching or replication

Challenges in Mobile ICN (2/5)

- Request Staleness
  - During mobility, the previously requested data can be routed to old PoA not new PoA
  - Hence, we need
    - To forward the buffered data from old PoA to new PoA
      - Similar to FMIP
      - The forwarding requires knowledge of locations and topology, which can violate the philosophy of ICN
    - To retransmit request at new PoA
      - What is the optimal retransmission timer?

Challenges in Mobile ICN (3/5)

- Scalability
  - Flat names are not fundamentally scalable
  - Consider hierarchical contents name in CCN
    - Without mobility, forwarding entries can be aggregated
      - korea.ac.kr/mov/scene1 and korea.ac.kr/mov/scene2
    - With mobility, forwarding entries cannot be aggregated
      - korea.ac.kr/mov/scene1 and ubc.ca/mov/scene2
  - Same problem in BGP router



Challenges in Mobile ICN(4/5)

- Asymmetric wireless link
  - In most ICNs, it is assumed that the requested data can follow the reverse path that the request follows (e.g., PIT in CCN)
  - However, this assumption may not be valid in dynamic mobile environments
    - Same problem in MANET routing

Challenges in Mobile ICN (5/5)

- Security and Privacy
  - Dynamic association in mobile environments leads to ne w security problems
  - In mobile ICNs, a malicious node can publish incorrect contents information, which can pollute forwarding ent ries
    - Authentication for forwarding entries is strongly needed

Survey on Consumer and Provider Mobility

Contents Consumer Mobility

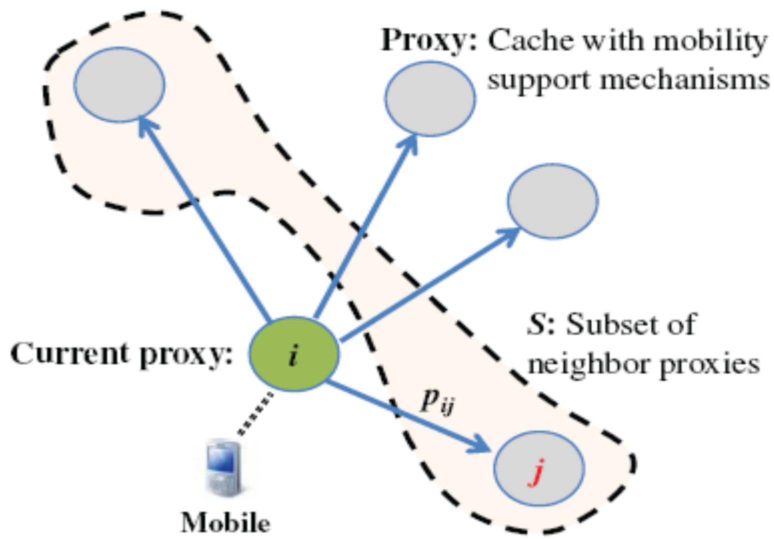
- Approach I
  - Complete handover ASAP and resend request
  - Cross-layer optimization for handover (e.g., FMIP) and optimal timer setting for request retransmission
- Approach II
  - Exploit local cached content
  - Cross-over or adjacent routers

Proactive Selective Neighbor Caching [VAS 12] (1/2)

- The original idea was reported in
  - S. Pack, H. Jung, T. Kwon, and Y. Choi. "SNC: A Selective Neighbor Caching Scheme for Fast Handoff in IEEE 802.11 Wireless Networks," *ACM Mobile Computing and Communications Review, 9(4):39–49*, October 2005.
- *Select an appropriate subset of neighbor **proxies** that minimize the mobility costs in terms of expected average delay and caching costs*

Proactive Selective Neighbor Caching [VAS 12] (2/2)

- Target cost function
  - $P_{hit}(S) \cdot C_{hit} + (1 - P_{hit}(S)) \cdot C_{miss} + N(S) \cdot C_{cache}$
    - $P_{hit}(S)$: the probability to move a proxy in S
    - N(S): number of proxies in S
    - C_{hit}, C_{miss}, C_{cache}: the delay cost for each case



Contents Provider Mobility (1/2)

- Not easy!
- *How to maintain routing consistency during conte nts provider's movement*

- Indirection point (permanent anchor)
  - Approaches I, II, and III (+V)
- Forwarding table change
  - Approaches IV and V

Contents Provider Mobility (2/2)

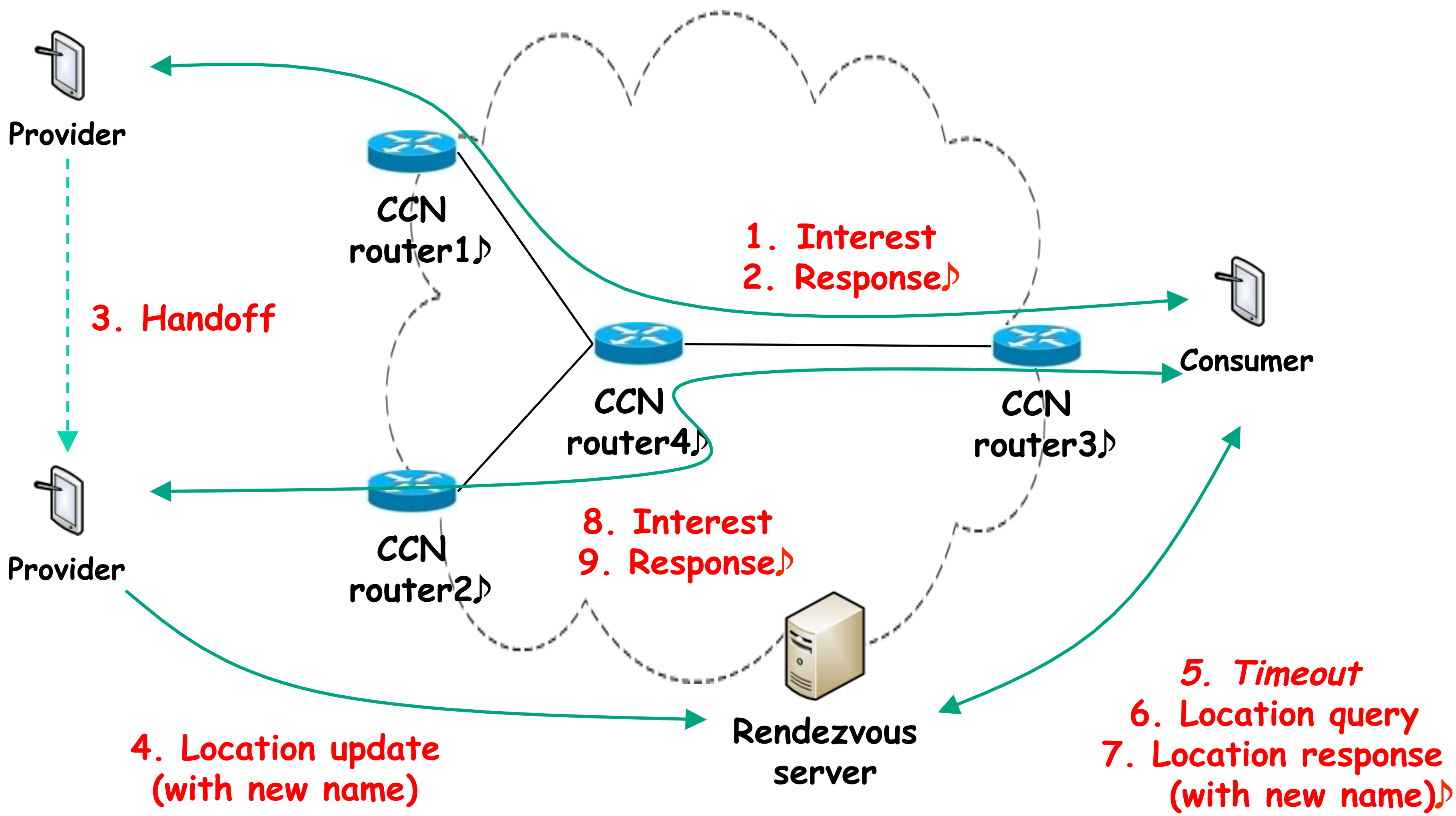
- Approach I: Rendezvous Point [KIM12]
- Approach II: Indirection Point [HER11]
- Approach III: Tunnel-based redirection [LEE12]

- Approach IV: Interest Forwarding [KIM12]
- Approach V: Interest Forwarding + Indirection P oint [HAN12]

Rendezvous Point [KIM12] (1/2)

- Rendezvous Point
  - A location management server for ICN mobility
  - Naming resolution service between contents name and l ocator
  - Higher latency for new name update/query and FIB est ablishment
  - Not well-matched with the philosophy of ICN
    - Just a reference model

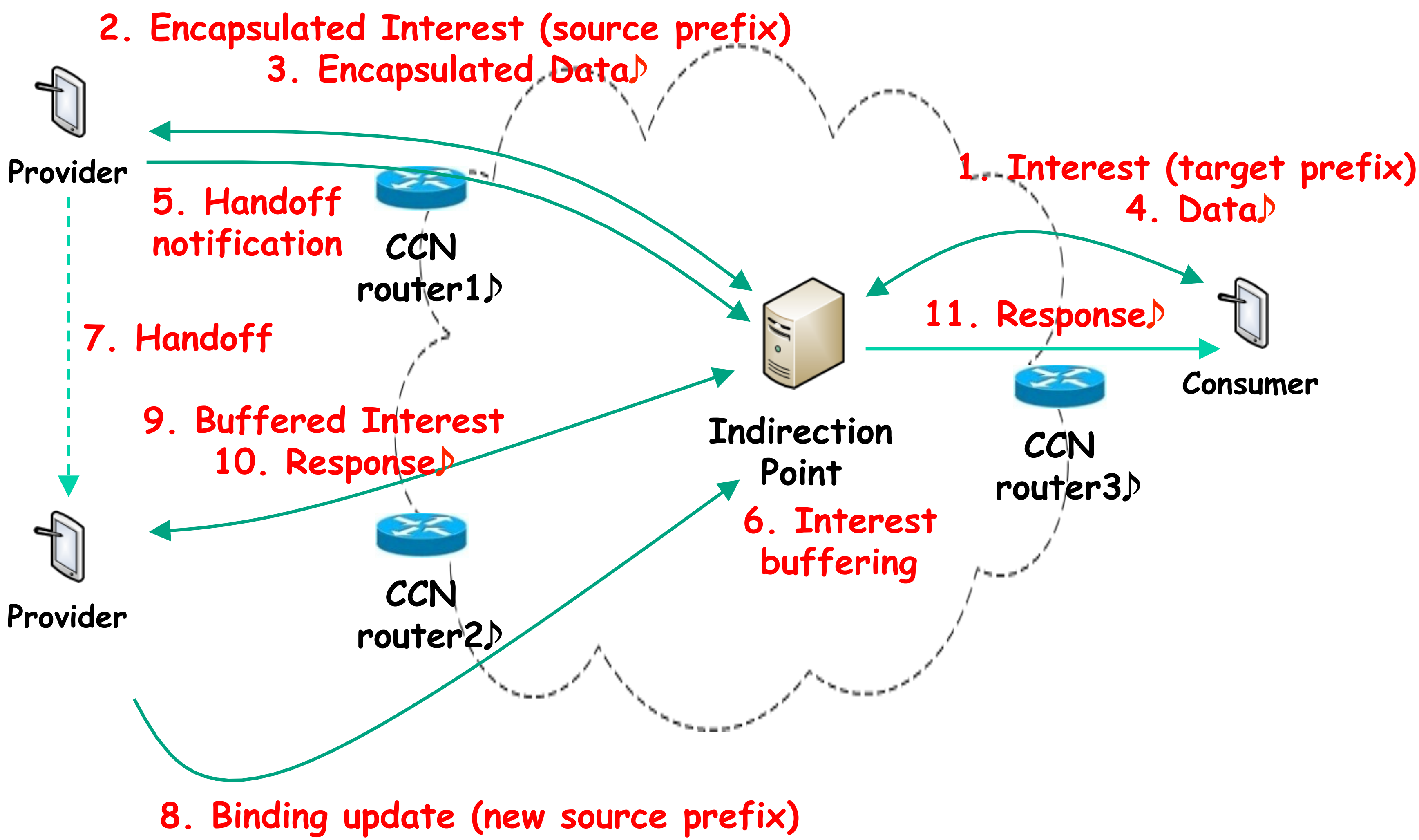
Rendezvous Point [KIM12] (2/2)



Indirection Point [HER11] (1/2)

- Indirection point
  - A permanent server that maintains a set of bindings be tween target prefix (name) and source prefix (name)
    - Target prefix: a prefix that a provider wants to serve data (i. e., persistent name or HoA)
    - Source prefix: a prefix that a provider can currently receive i nterests (i.e., temporary name or CoA)
  - All interests for contents provider first arrive at the permanent server, which encapsulates the original inte rest with the temporary name and tunnels it to the ne w location (similar to MIP)
  - How to implement interest encapsulation in CCN?
  - Indirection point can be a single point of bottleneck

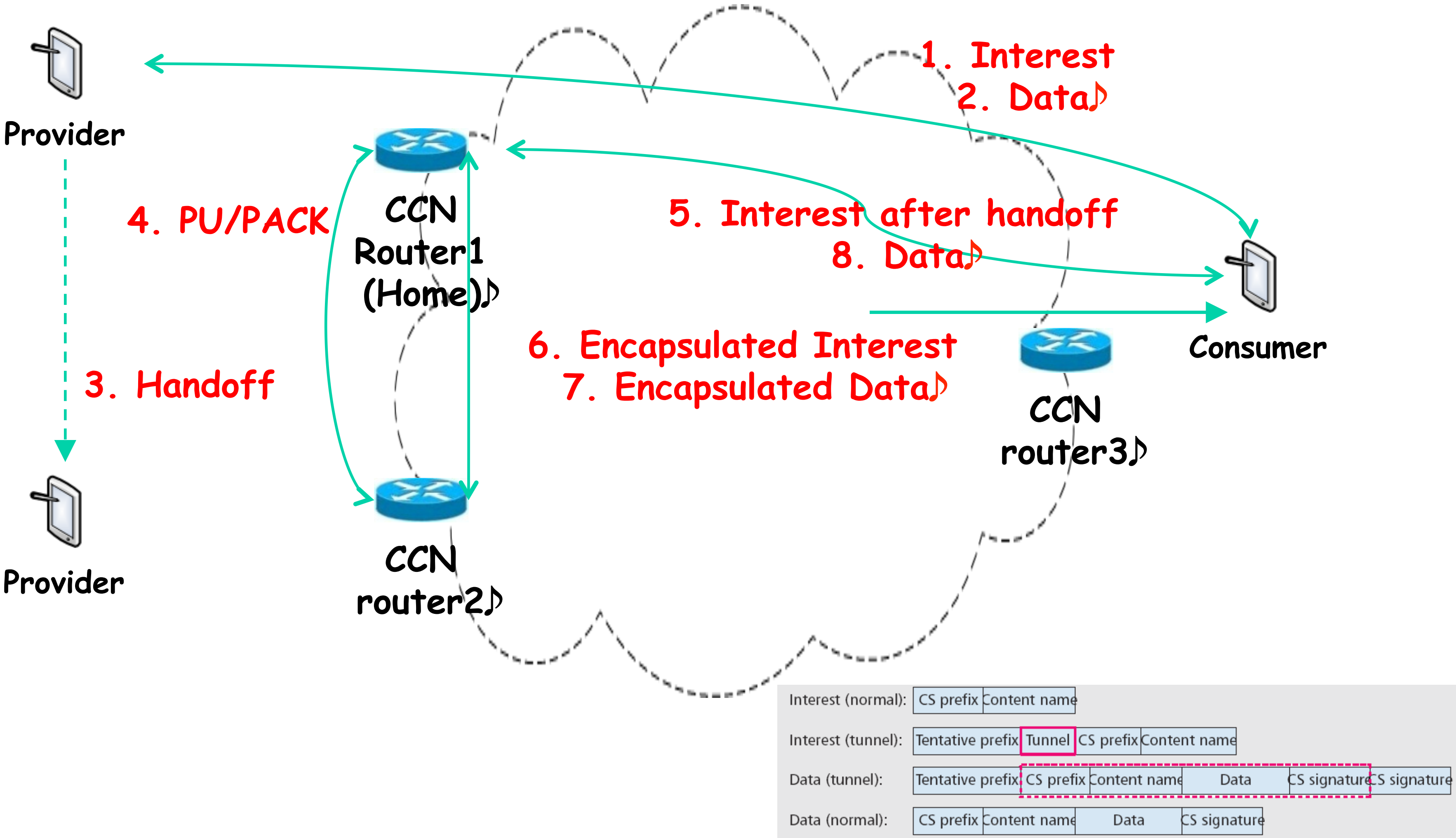
Indirection Point [HER11] (2/2)



Tunnel-Based Redirection [Lee12] (1/2)

- Similar to indirection point
  - Home router (instead of indirection server)
  - Two messages and encapsulation formats
    - Prefix update (PU): from new PoA to home router
    - Prefix update acknowledgement (PACK): from home router to new PoA
  - Contents provider updates sends a PU message after handoff. Then home router encapsulates and forwards incoming interests, and decapsulates tunneled data and forward data to consumer

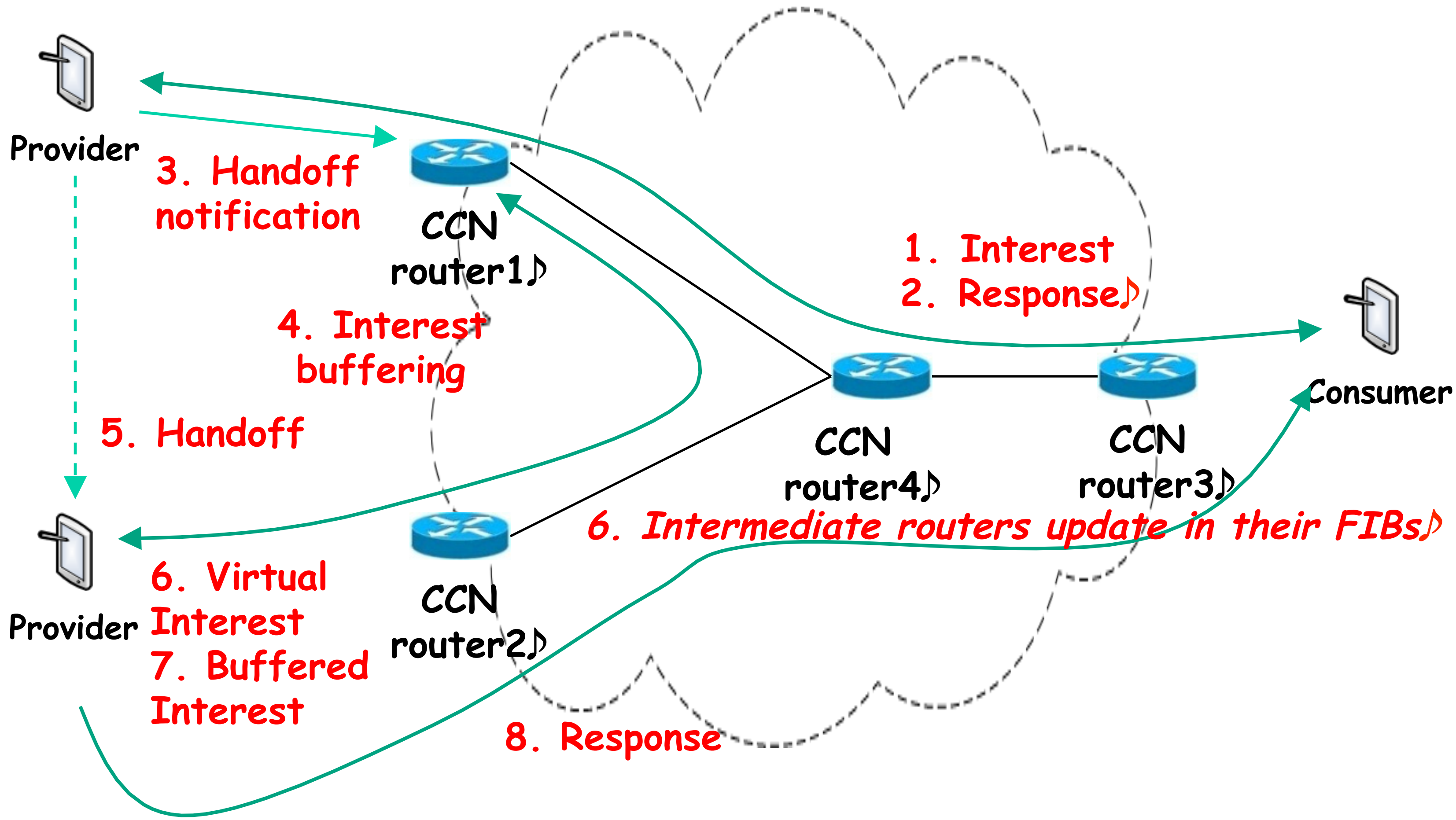
Tunnel-Based Redirection [Lee12] (2/2)



Interest Forwarding [KIM12] (1/2)

- Interest Forwarding
  - No need of a new hierarchical name
  - A virtual interest with the original contents name is transmitted to the previous router
    - Intermediate routers receiving the virtual interest update their forwarding entries in order to forward packets to a new location
    - For the buffered interests, a flag is set to indicate retransmission to avoid interest discard
    - A forwarding entry created by virtual interest has a lifetime to prevent radical increment

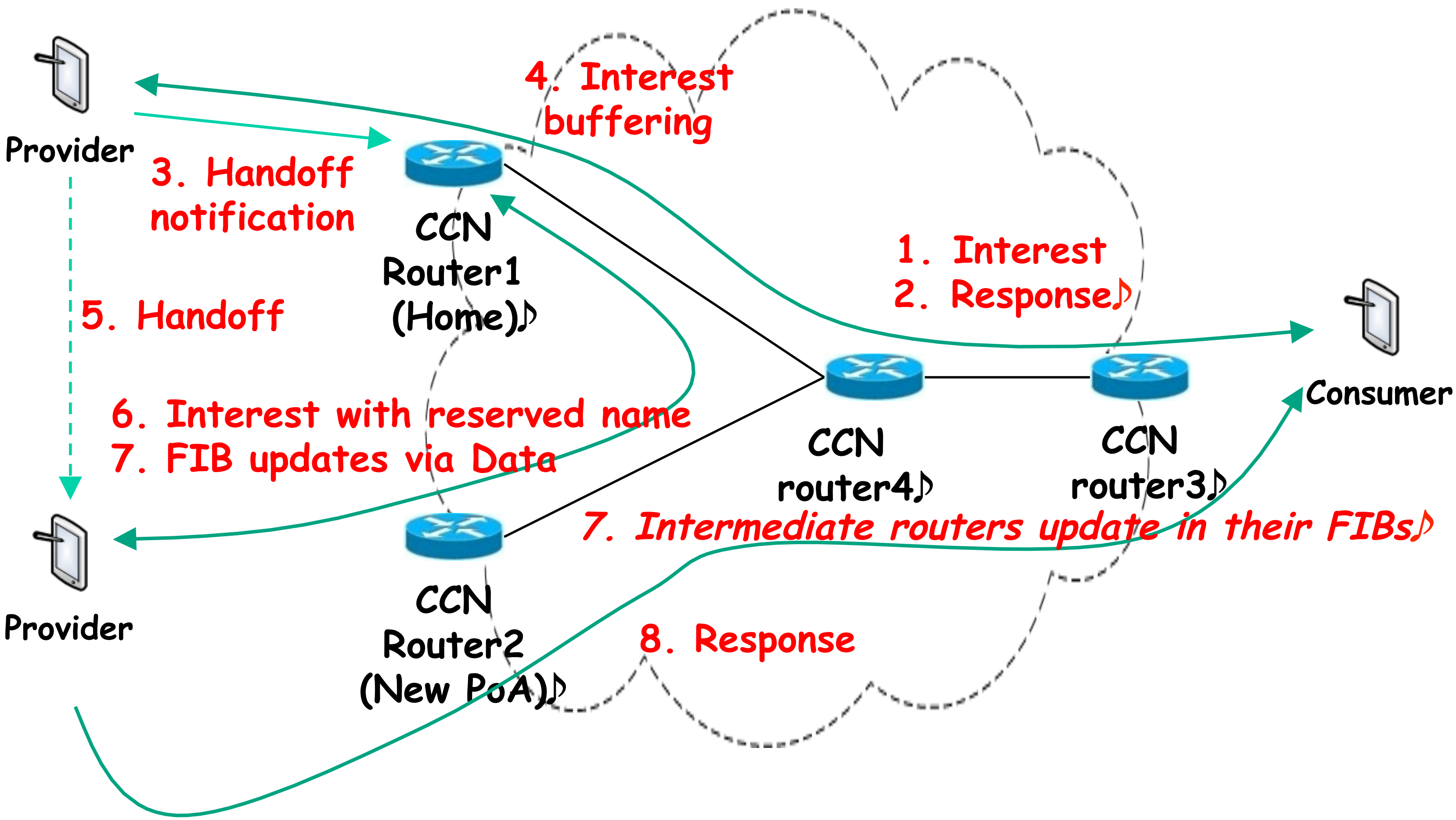
Interest Forwarding [KIM12] (2/2)



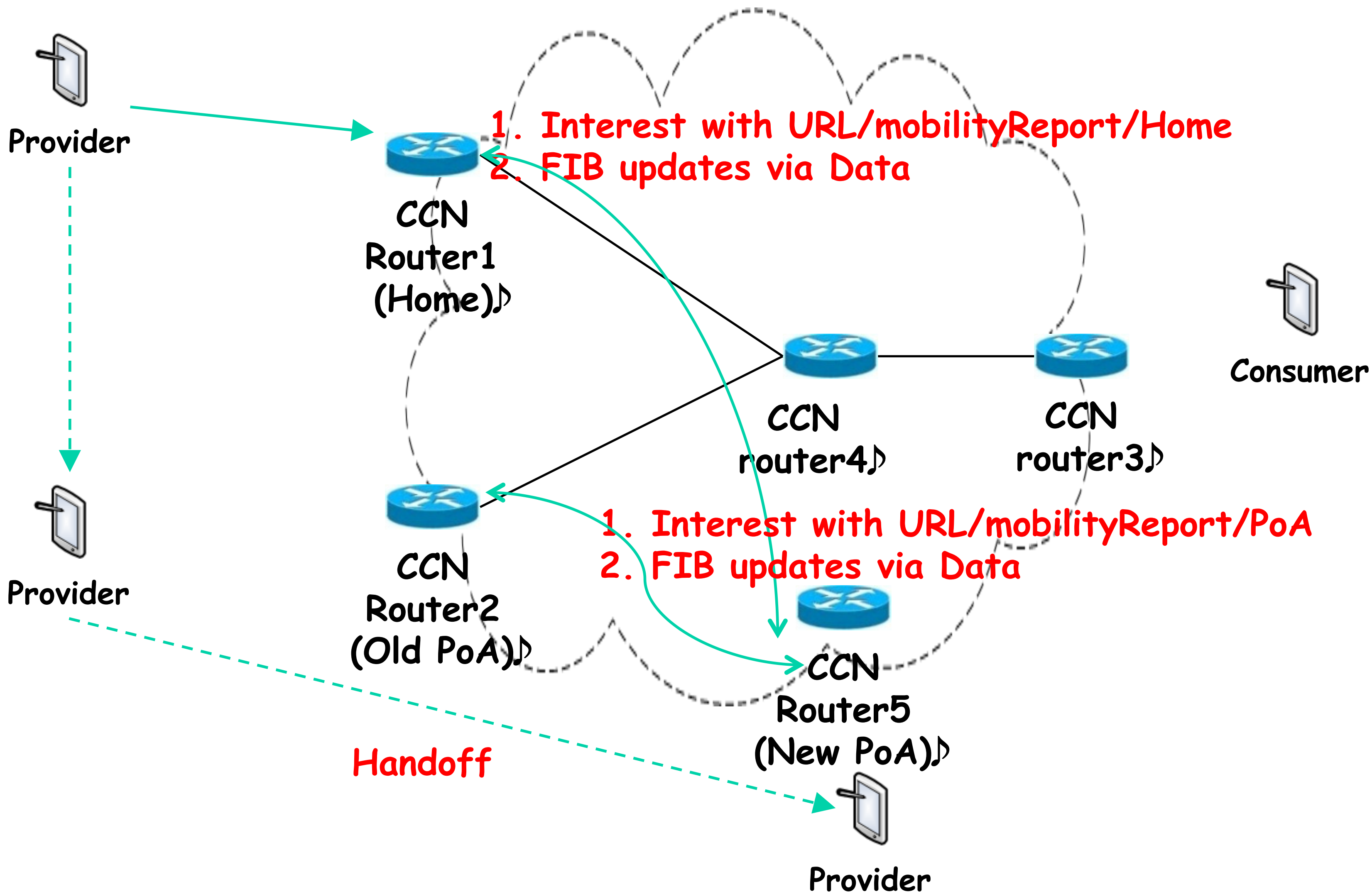
Interest Forwarding + Indirection Point [HAN12] (1/3)

- Interest Forwarding + Indirection Point
  - Two reserved names
    - *Provider's URL/mobilityReport/Home*
      - To keep the home updated with the path information to the provider
    - *Provider's URL/mobilityReport/PrevPoA*
      - To make a path from the previous PoA to the new PoA and to receive the missing interest packets arrived at the previous PoA while the provider is moving
- Why home updates?

Interest Forwarding + Indirection Point [HAN12] (2/3)



Interest Forwarding + Indirection Point [HAN12] (3/3)



Comparison

	Rendezvous Point	Indirection Point	Tunnel-based redirection	Interest Forwarding	Interest Forwarding + Indirection Point
Handoff latency	High	High	Medium	Low	Medium
Routing path	Optimal	Triangular path	Triangular path	Near optimal	Near optimal
Additional entity	Yes	Yes	Partially	No	Partially
Modification of CCN routing	No	No	Partially	Yes	Yes

MM for ICNs: Concluding Remarks

- Mobile ICNs introduce new research challenges
  - In particular, mobility management in ICNs is at initial stage and more researches are strongly needed!

  - No analytical and experimental studies
  - No unified framework for mobility management
  - No standard yet; you can contribute more!

MM for ICNs: References (1/2)

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- [KIM12] D. Kim, J. Kim, Y. Kim, H. Yoon, and I. Yeom, "Mobility Support in Content Centric Networks," in *Proc. ACM ICN 2012*, August 2012.

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- [HAN12] D. Han, M. Lee, K. Cho, T. Kwon, and Y. Choi, "PM C: Publisher Mobility Support for Mobile Broadcasting in Content Centric Networks," in *Proc. AsiaFI 2012 Summer School*, August 2012.