Advanced Internet and IoT Technologies

- Mobility Management in IPv6 -

Prof. Dr. Thomas Schmidt

http://inet.haw-hamburg.de | t.schmidt@haw-hamburg.de

Agenda

- Motivation
- Basic Mobile IPv6
- Protocol Improvements & Development
- Current Status, Conclusions & Future Trends

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- Motivation
  - Mobility Paradigm & Target Applications
  - Key Issues & Approaches
  - Limits of MIPv4
- Basic Mobile IPv6
- Protocol Improvements & Development
- Current Status, Conclusions & Future Trends

MIPv6 Released – Mobility on the Rise?

Historic: What we expected

Devices using Home Address while away

‘Workspaces’ roaming between local subnets

3GPP Mobiles operating IPv6 Data Service

+ Improvements on handover performance

+ Improved security protocols

+ Cheap availability of WLAN, WIMAX, DVB-IPDC

+ …

VoIP/VCoIP conferencing: real-time mobility

Streaming & group communication by Mobile Multicast

IP Mobility: Challenges & Terms

Objective:

Application persistence while roaming between IP subnets / providers

Preserve upper layer (L 4+) communication when changing IP subnets

Key Aspects:

- Mobile Node (MN) globally addressable: fixed Home Address (HoA)
- Home Agent (HA) to permanently represent MN at home network
- Mobile Node locally addressable: changing Care of Address (CoA)
- Sustain partner sessions: update Correspondent Nodes (CN)
- Enable efficient communication (route optimisation)

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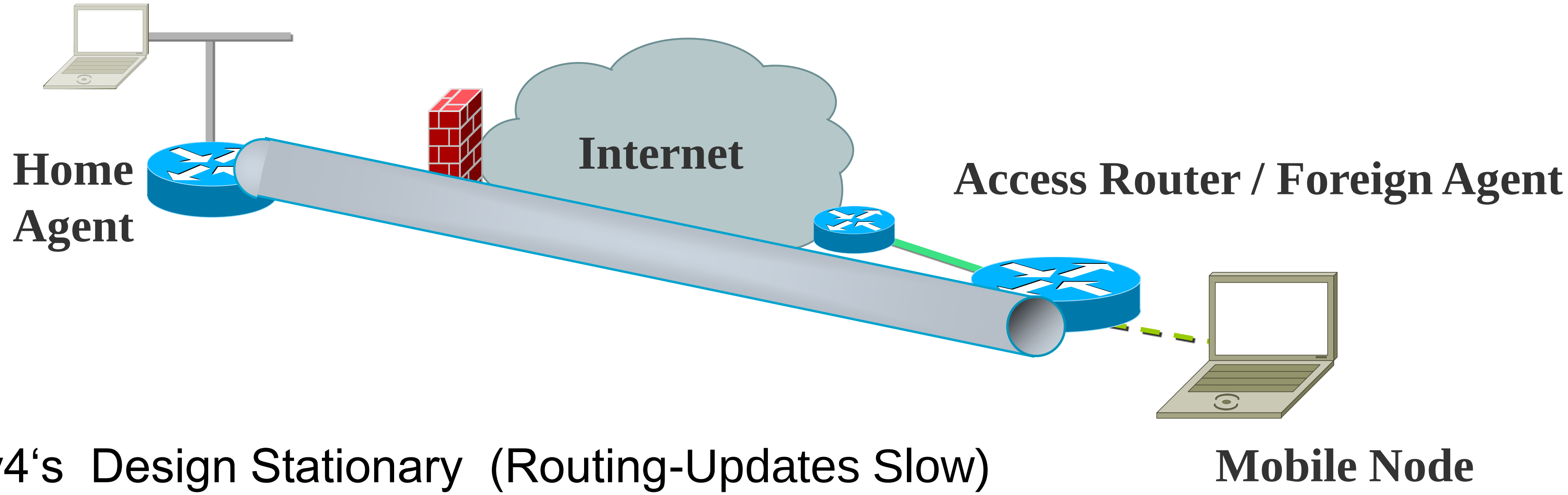
Key Mobility Approaches

- o Application: SIP Session Handover
  - SIP-server as application specific home agent
  - Requires mobility-aware applications
- o Transport Handover
  - Multipath capabilities to reconnect at changing interfaces
- o Mobile IP: Network-layer Handover
  - Stateless, transport transparent handover

    Mobile IPv4: IP Mobility Support for IPv4 (RFC 3344)

    Mobile IPv6: Mobility Support in IPv6 (RFC 3775, now 6275)

Limits of Mobile IPv4



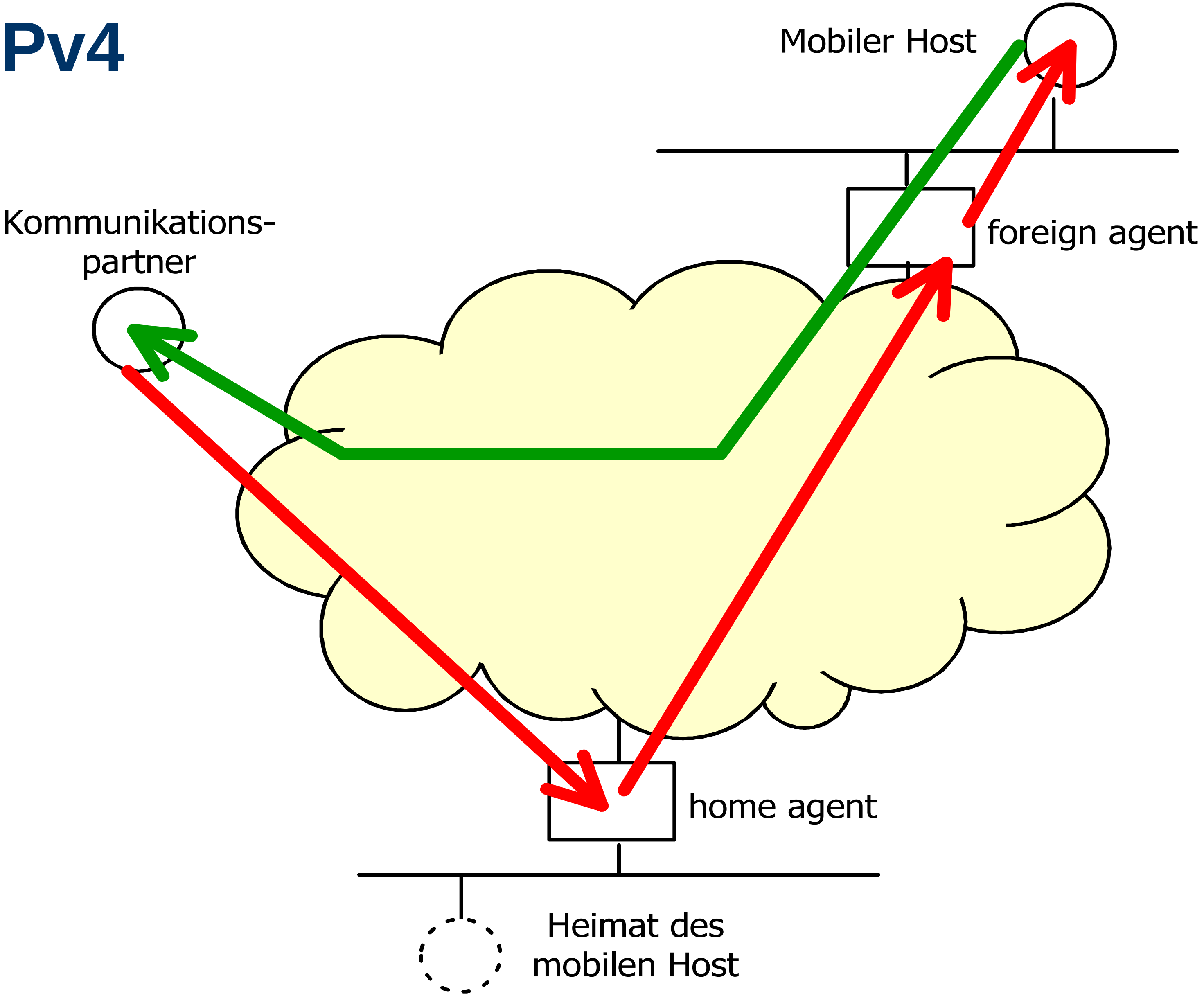
IPv4‘s Design Stationary (Routing-Updates Slow)

Implementation of Mobility Services: Tunnelling via Home Agent

IPv6 Potential:

- Several Addresses (2 for Mobile Node, many for Mobile Networks)
- Flexible, Extendable Architecture

Mobile IPv4


Mobiler Host
Kommunikations-
partner
foreign agent
home agent
Heimat des
mobilen Host

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  - Location & Handover Management
  - Basic Security
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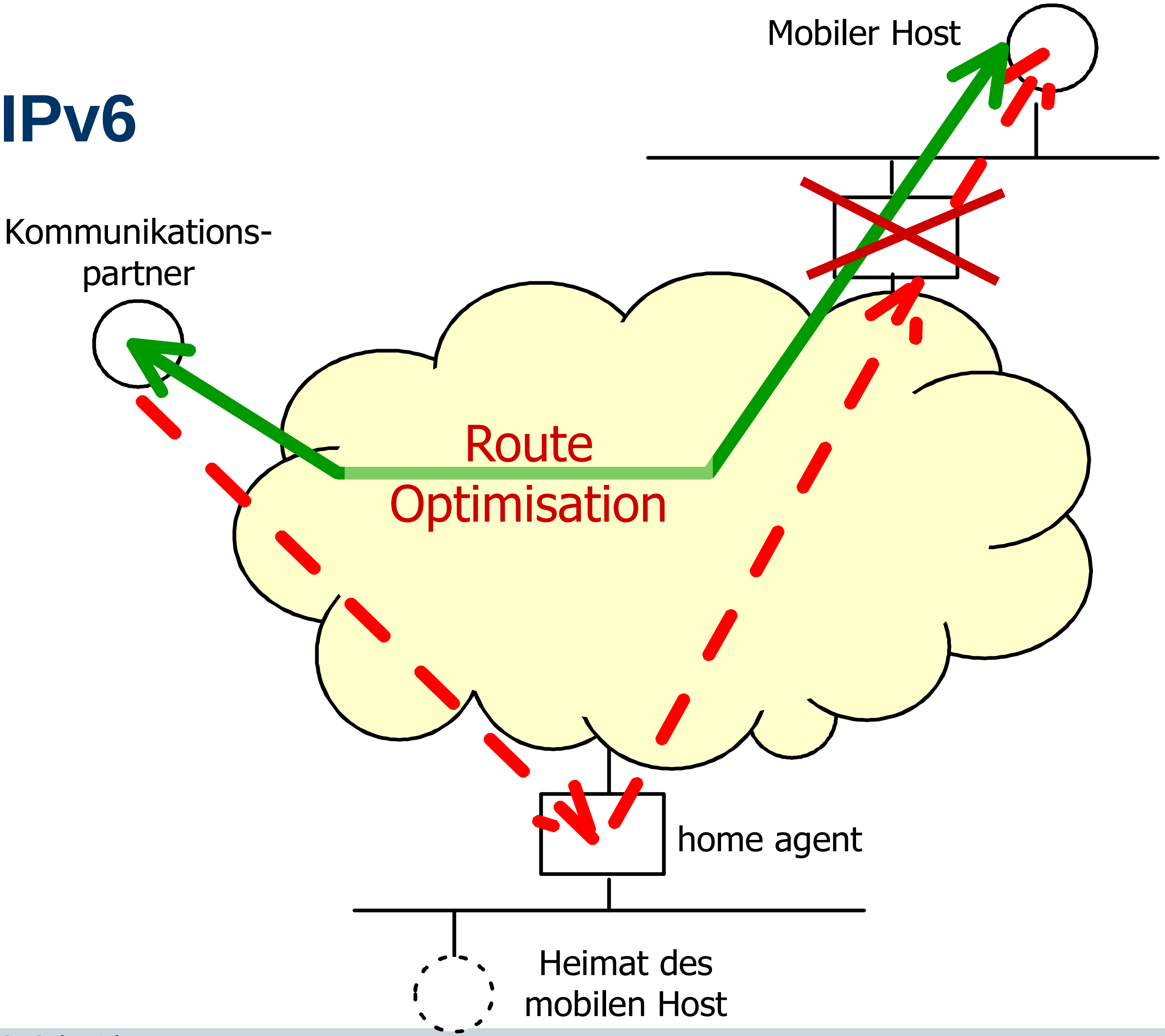
Mobile IPv6


Mobiler Host
Kommunikations-
partner
Route
Optimisation
home agent
Heimat des
mobilen Host

Basic Mobile IPv6

MN statelessly configures Care of Address in a foreign network and Binding Updates (BUs) with Home Agent (HA) and Correspondent (CNs).

MN, CN & HA keep Binding Cache Tables.

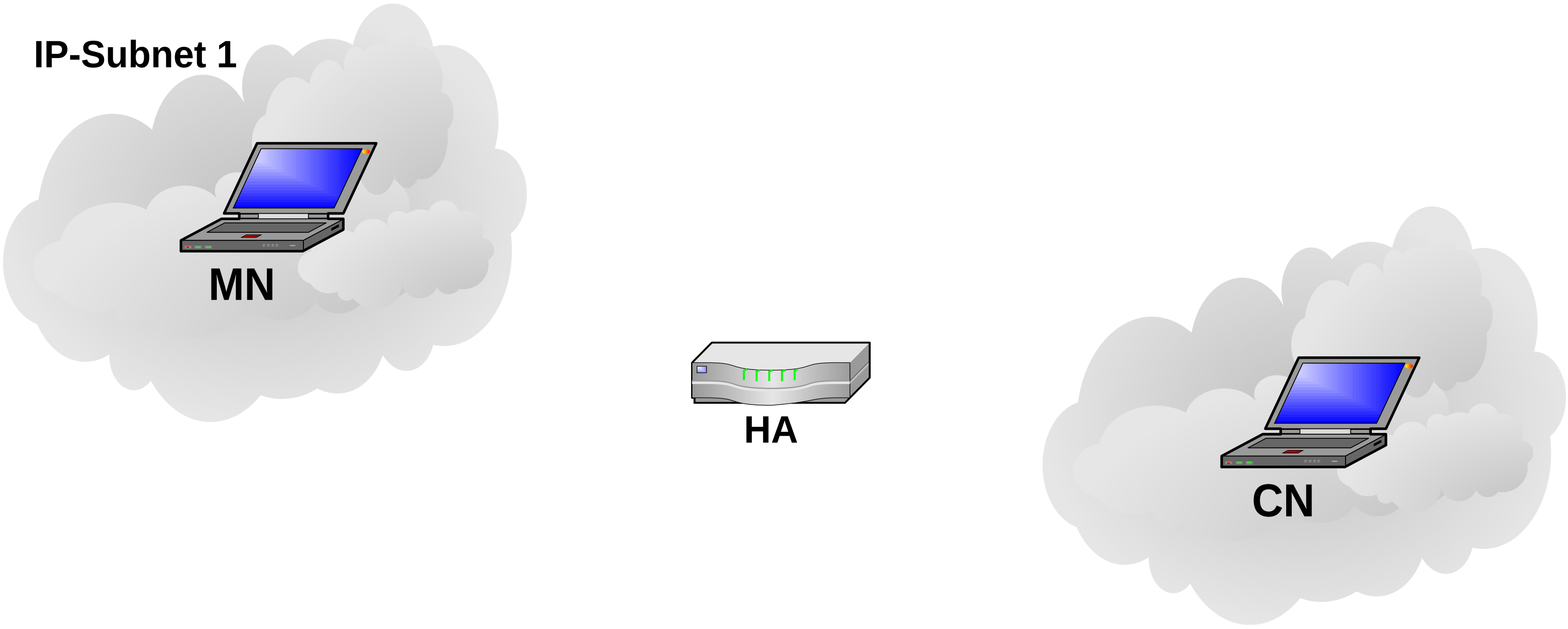
Home-Agent needed as Address Dispatcher.

MIPv6 transparently operates address changes on IP layer by:

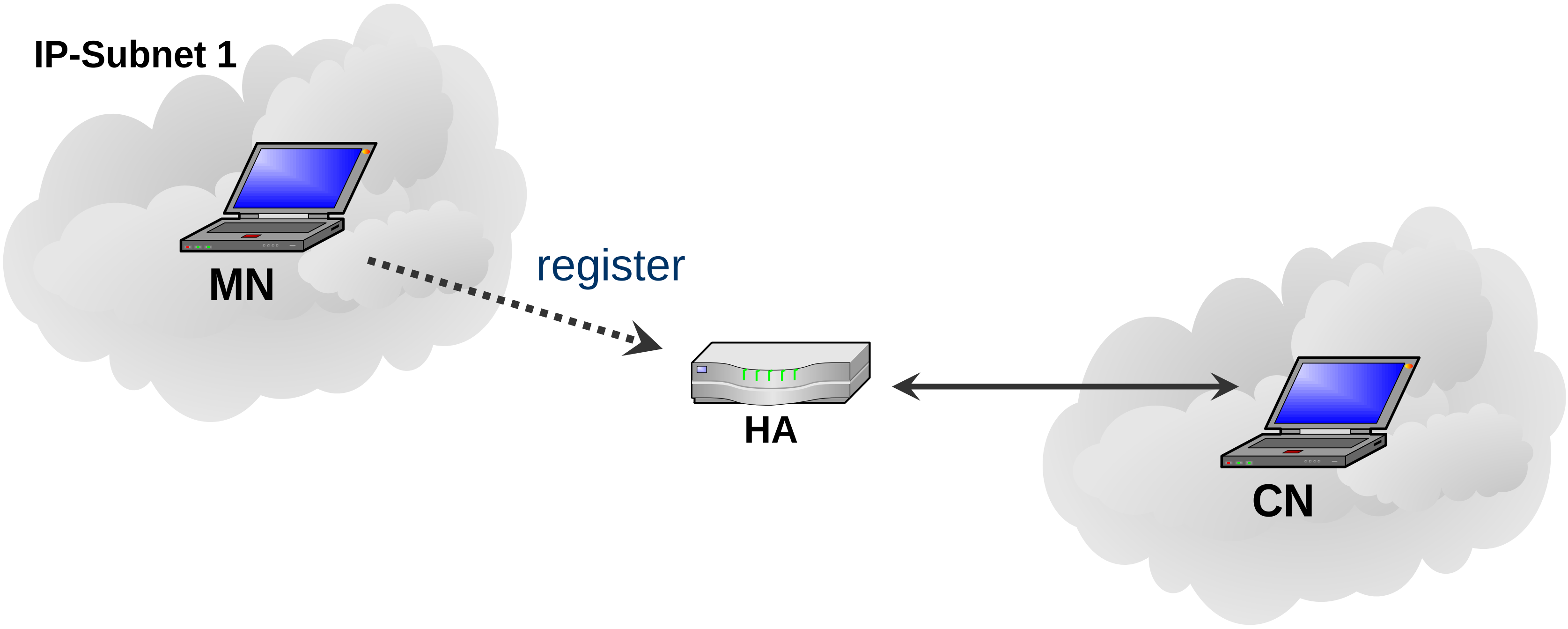
MN continues to use its original Home Address in a Destination Option Header, thereby hiding different routes to the socket layer.

CNs continues to use Home Address of the MN, placing it in a Routing Header (Type 2) as Source Route via the current CoA .

Mobile IPv6 Signaling



Mobile IPv6 Signaling



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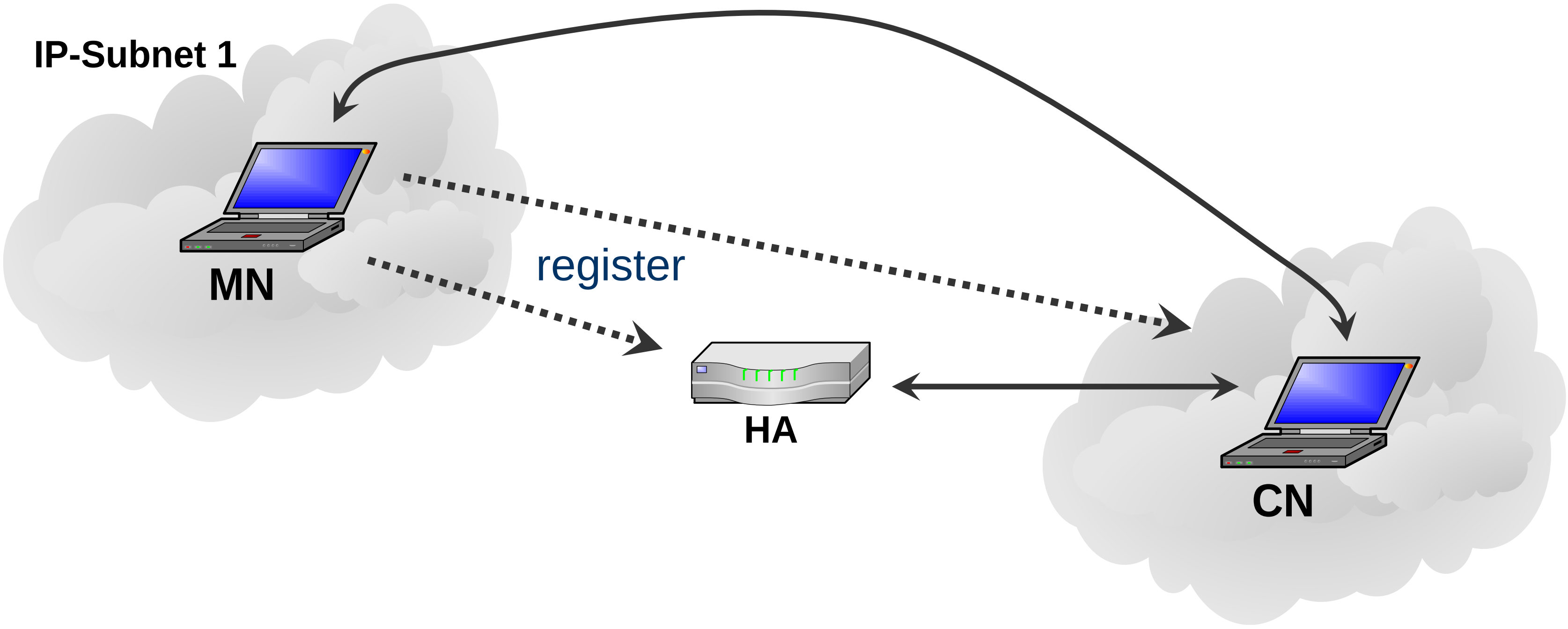
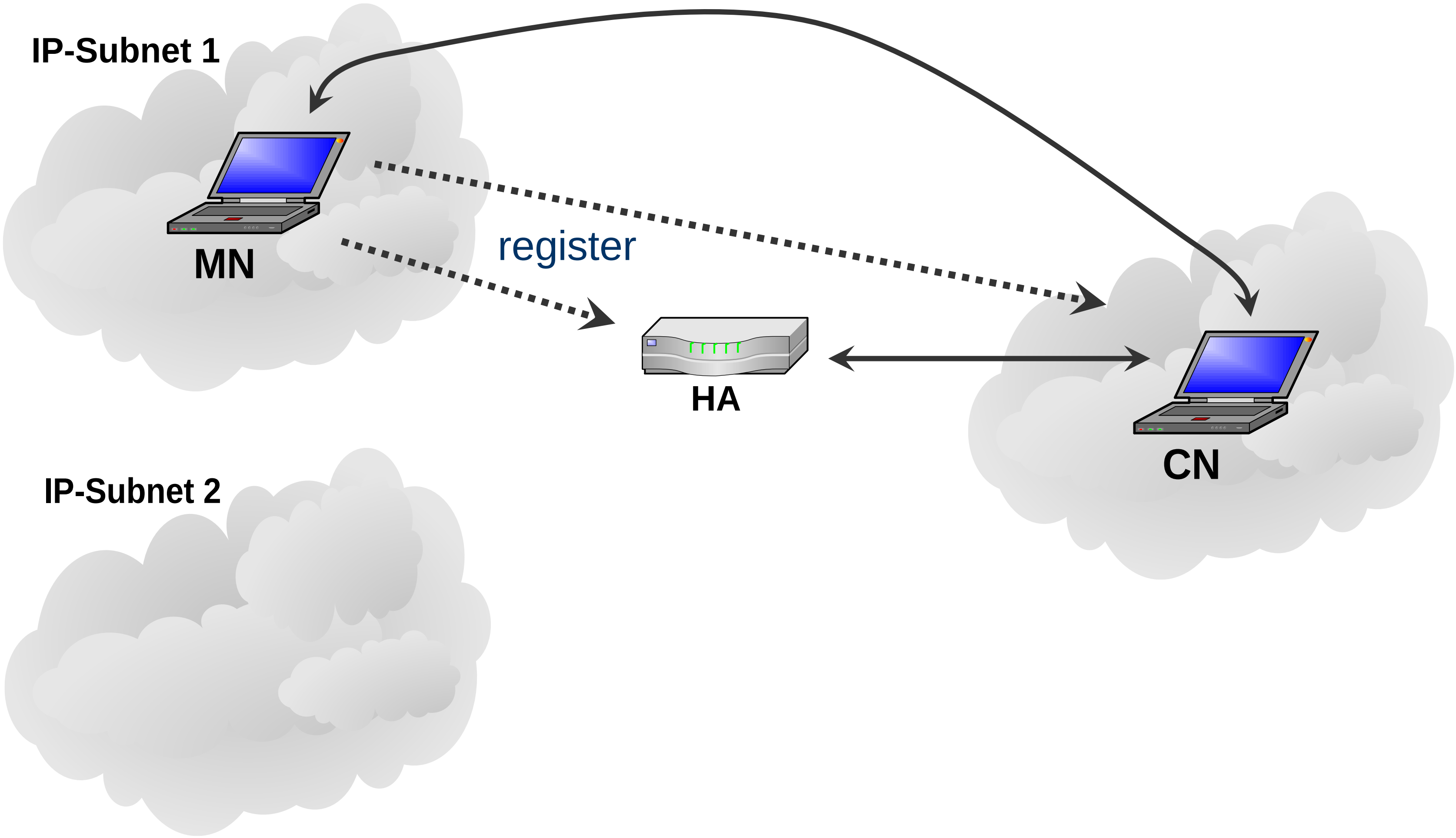
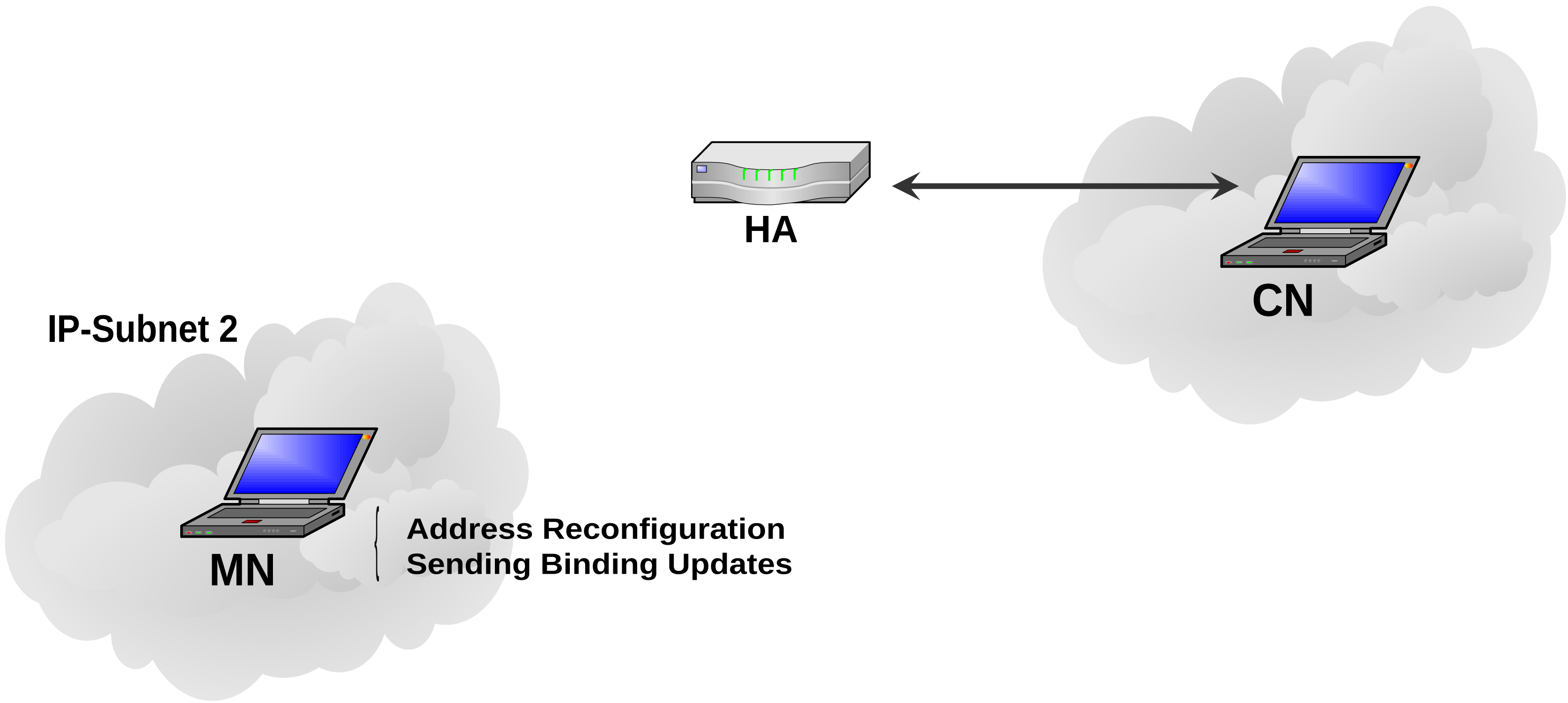


Mobile IPv6 Signaling



Mobile IPv6 Signaling



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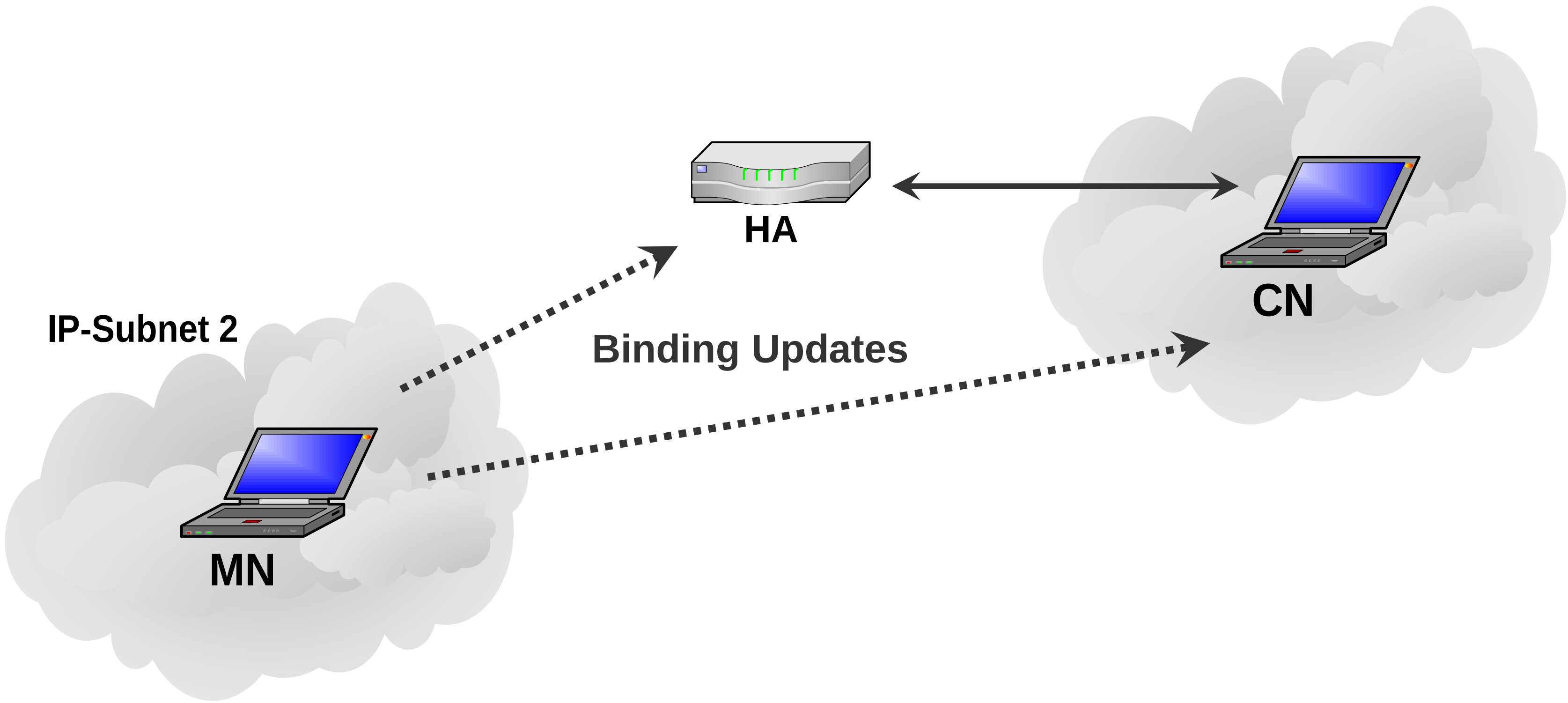

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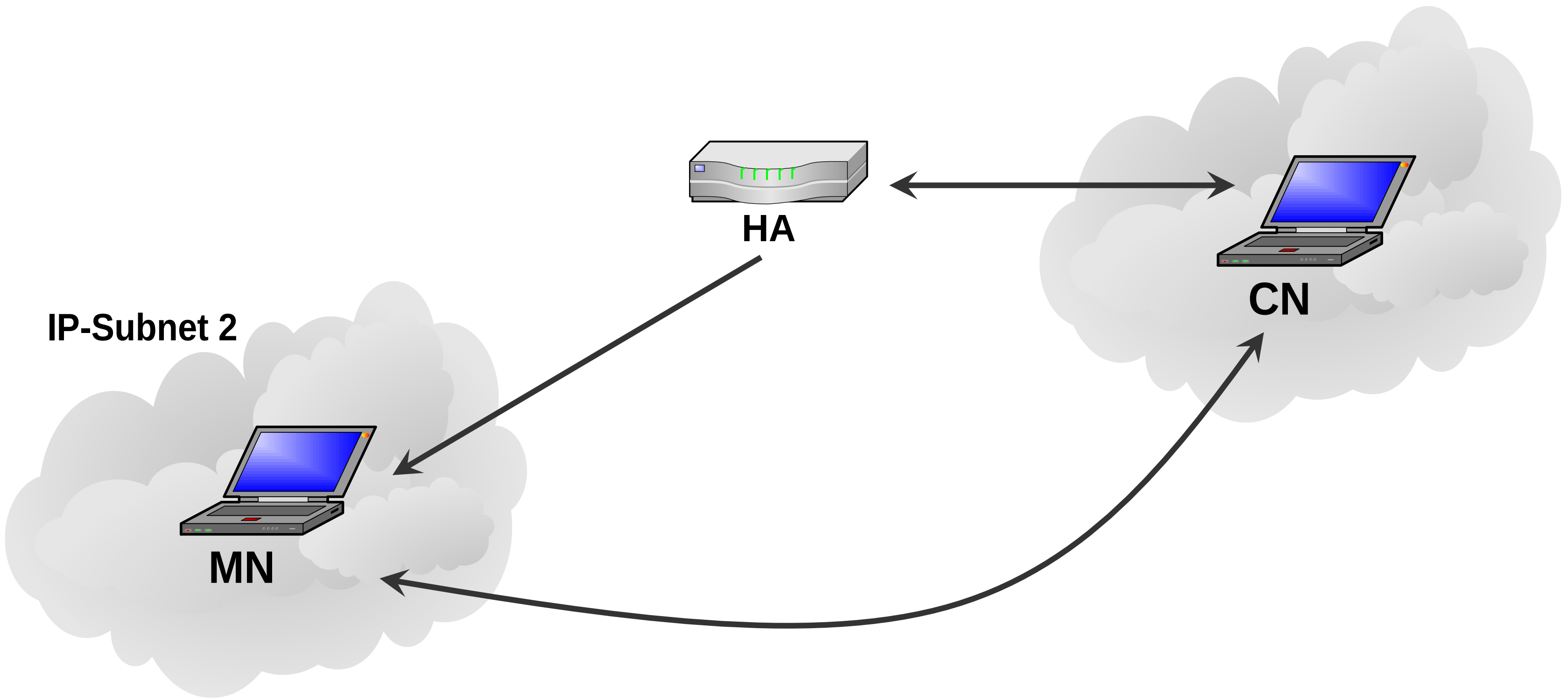

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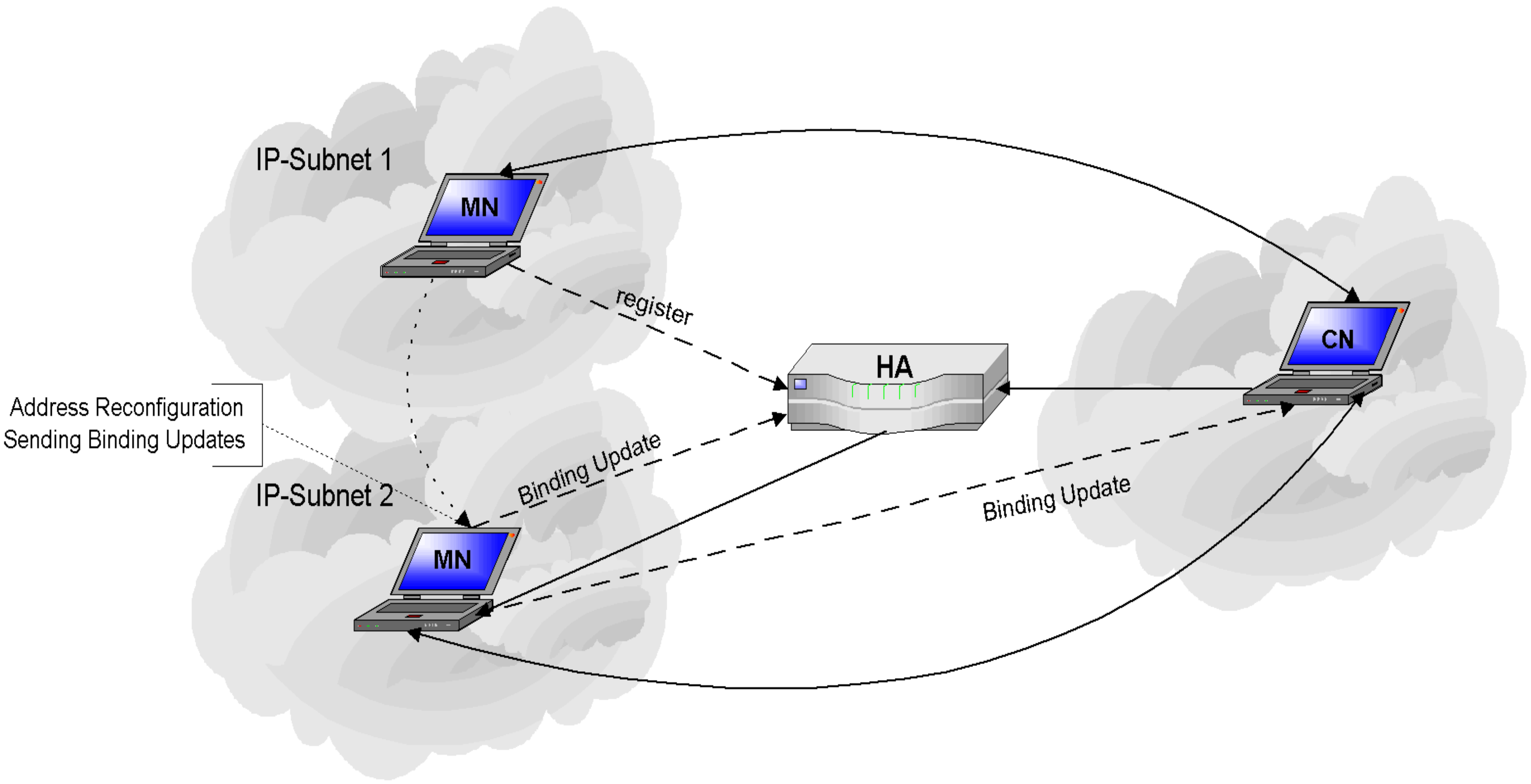
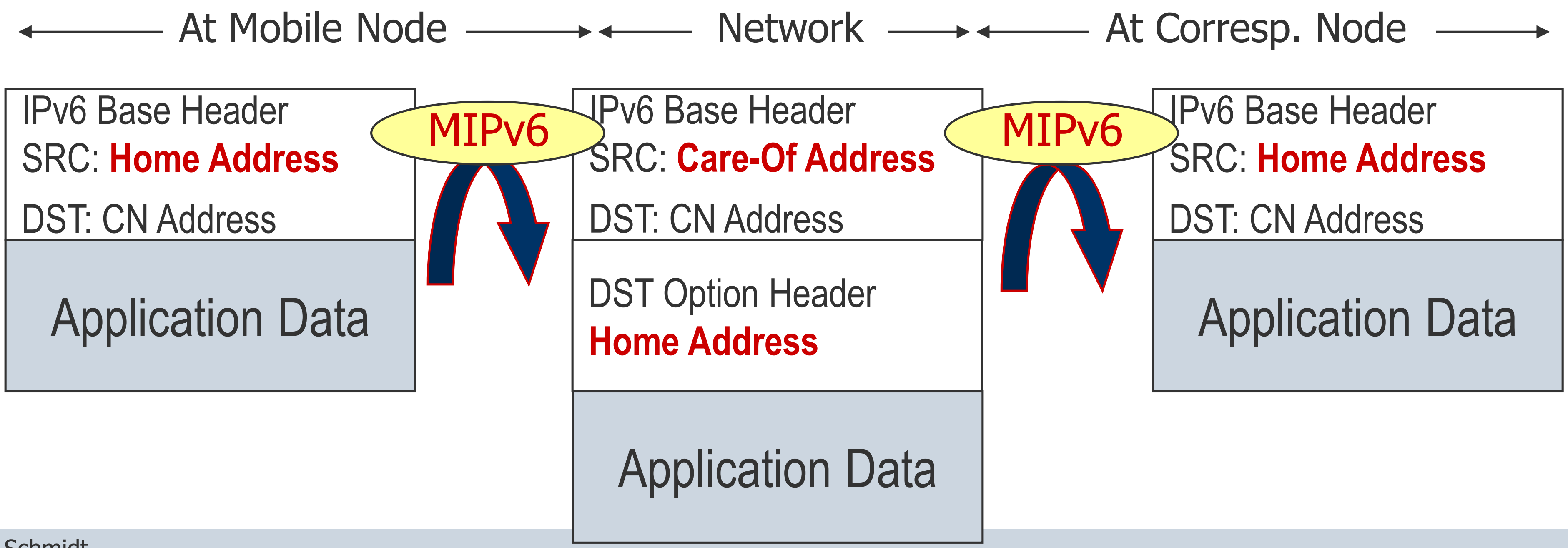


MIPv6 Transparent Communication MN → CN

Application persistence requires continuous use of HoA

Infrastructure requires use of topologically correct source address: CoA

MIPv6 stack moves HoA to Destination Option Header

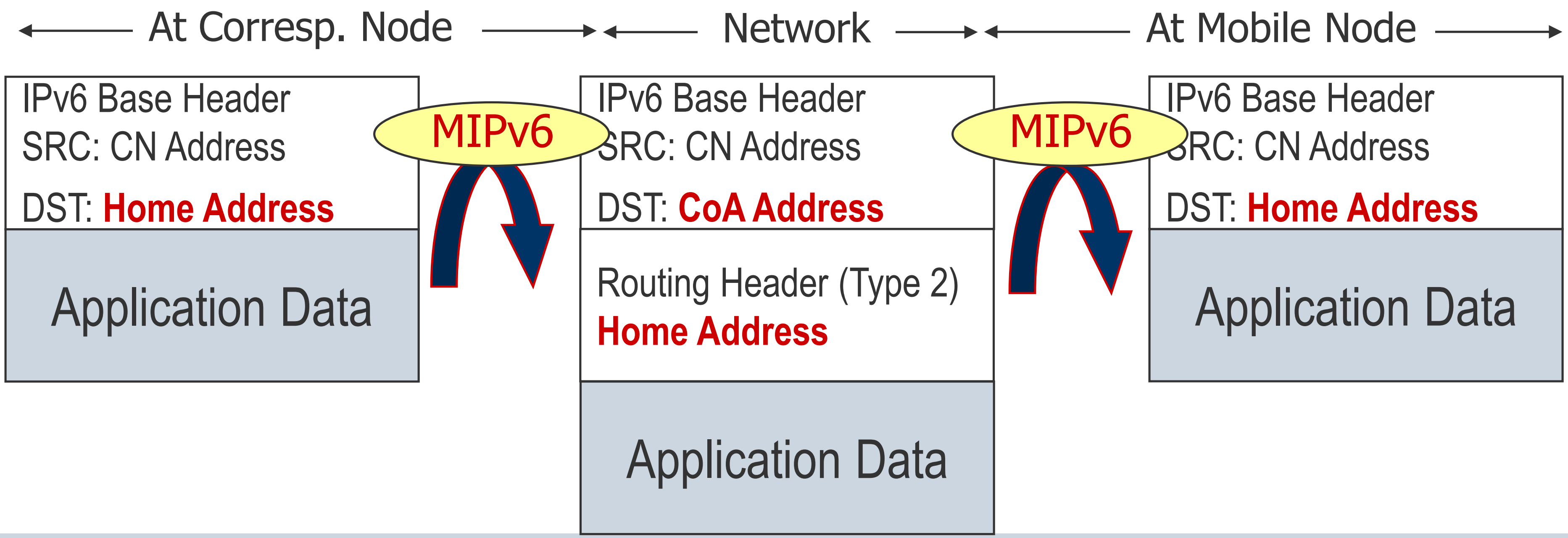


MIPv6 Transparent Communication CN → MN

Application persistence requires continuous use of HoA

Route optimisation operates with CoA

MIPv6 extracts CoA from Binding Cache and initiates source routing to HoA via CoA



Handover Security

Binding Udates place a severe security challenge:

MN must provide strong authentication

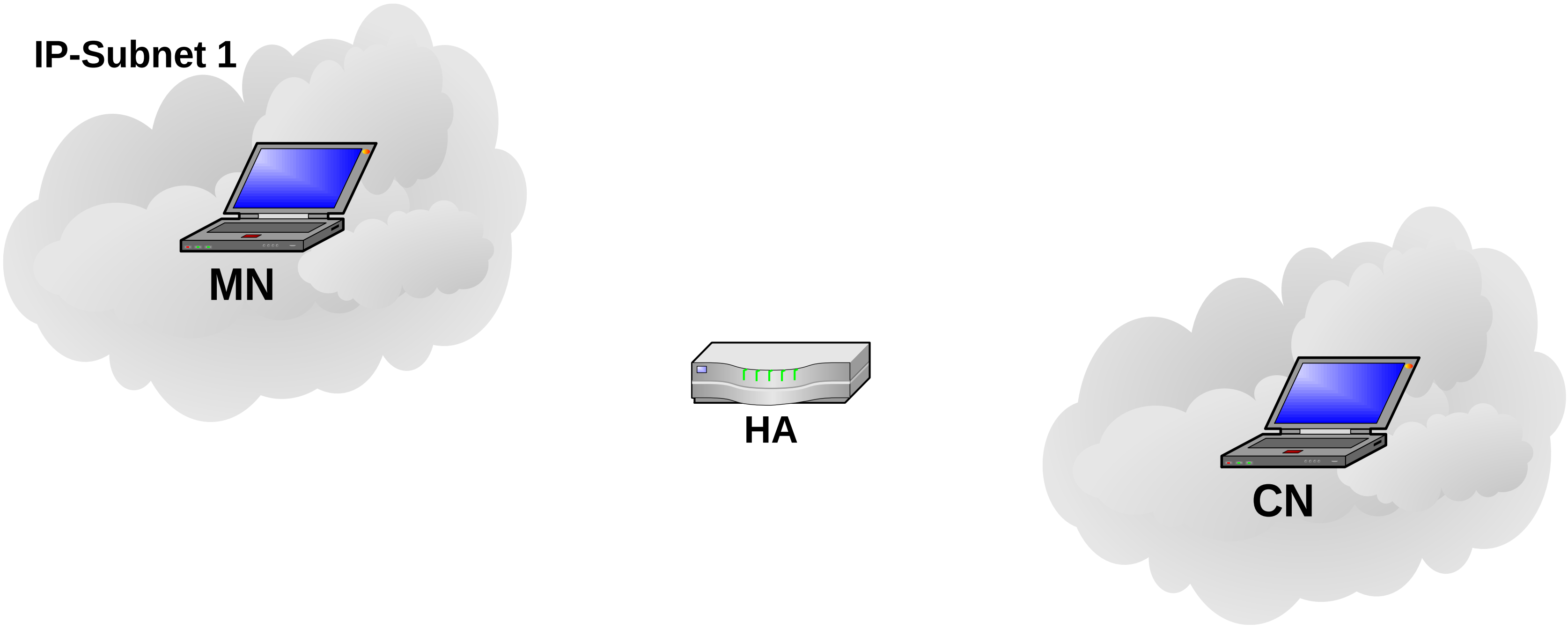
BU with HA: IPSec ESP Security Association (strong coupling)

BU with CN: Return Routability Procedure (lightweight coupling)

to test correctness of MN's HoA and CoA

- HoTI/HoT: MN(Cookie) $\rightarrow$ HA $\rightarrow$ CN (HToken, Cookie) $\rightarrow$ HA $\rightarrow$ MN
- CoTI/CoT: MN (Cookie) $\rightarrow$ CN (CToken, Cookie) $\rightarrow$ MN
- Finally do BU with Hash(HToken, CToken) invertable by CN

Securing Binding Updates: Return Routability



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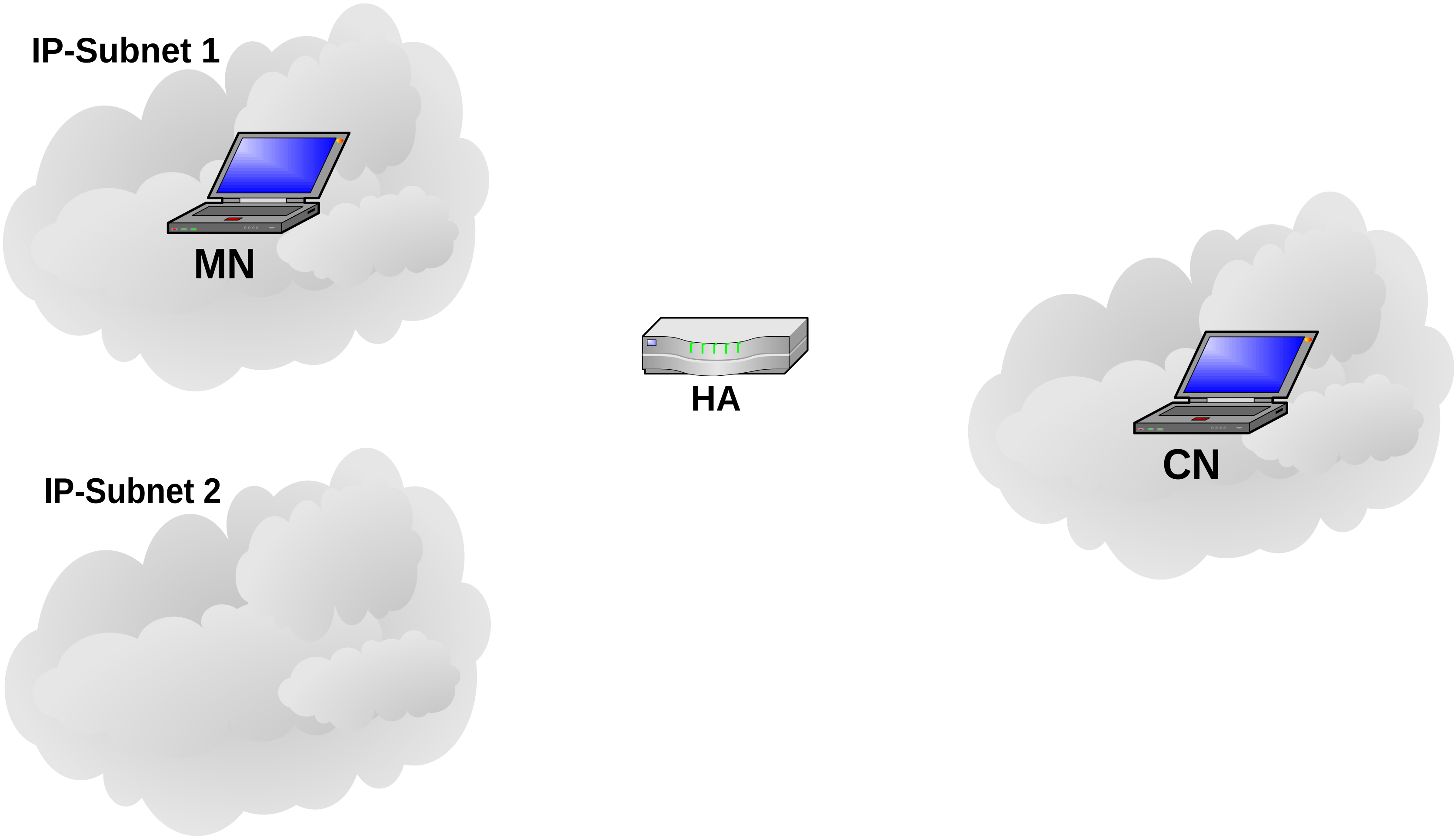

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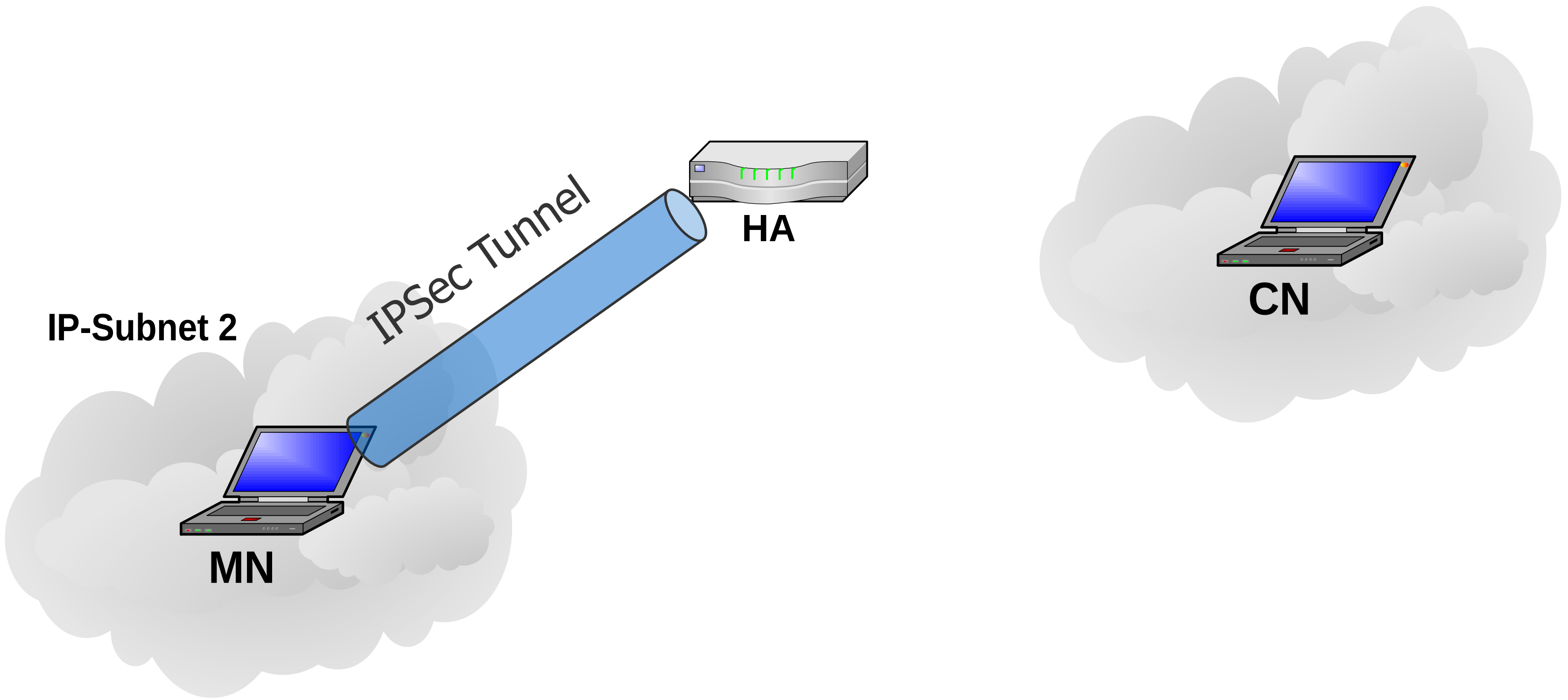
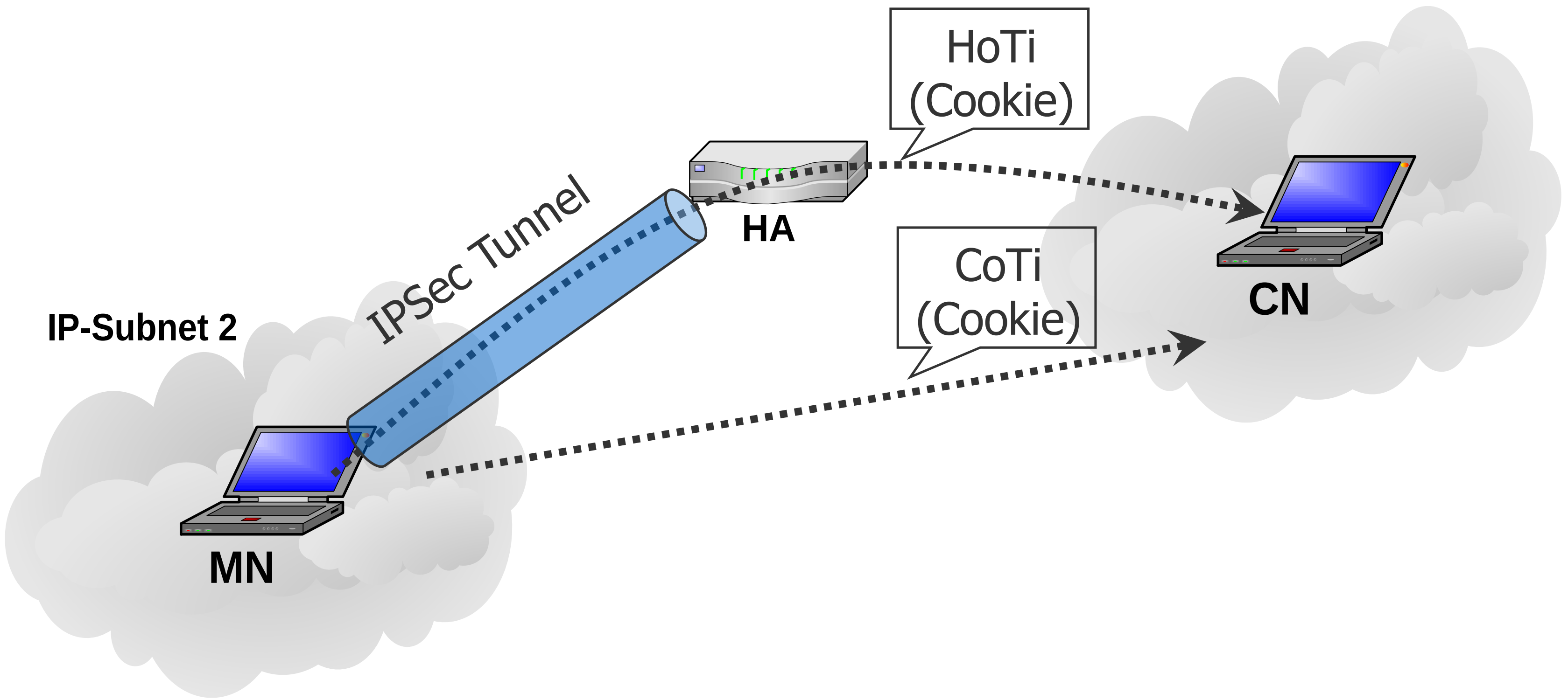
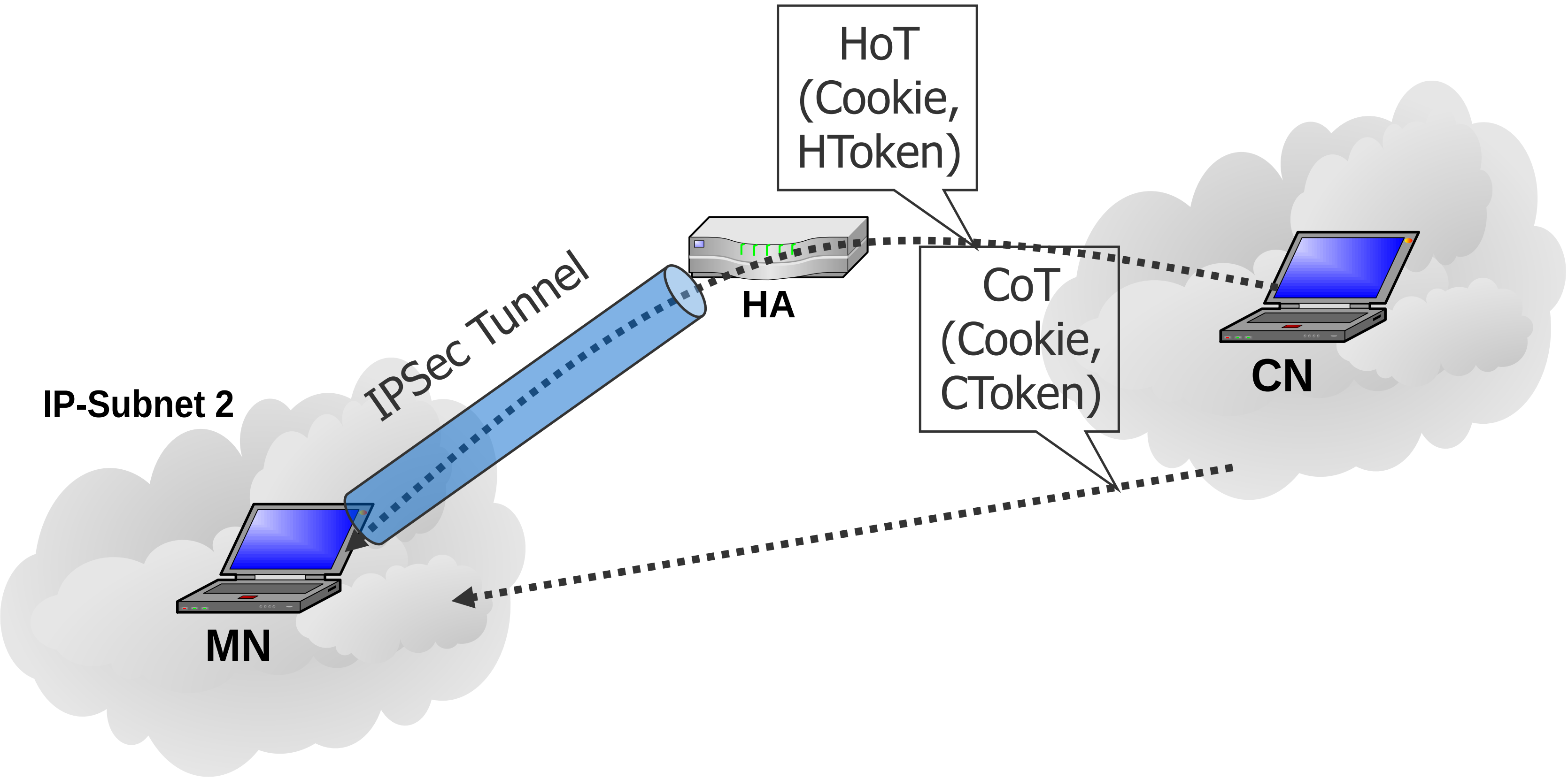


Securing Binding Updates: Return Routability

Binding Update Init: Return Routability Procedure

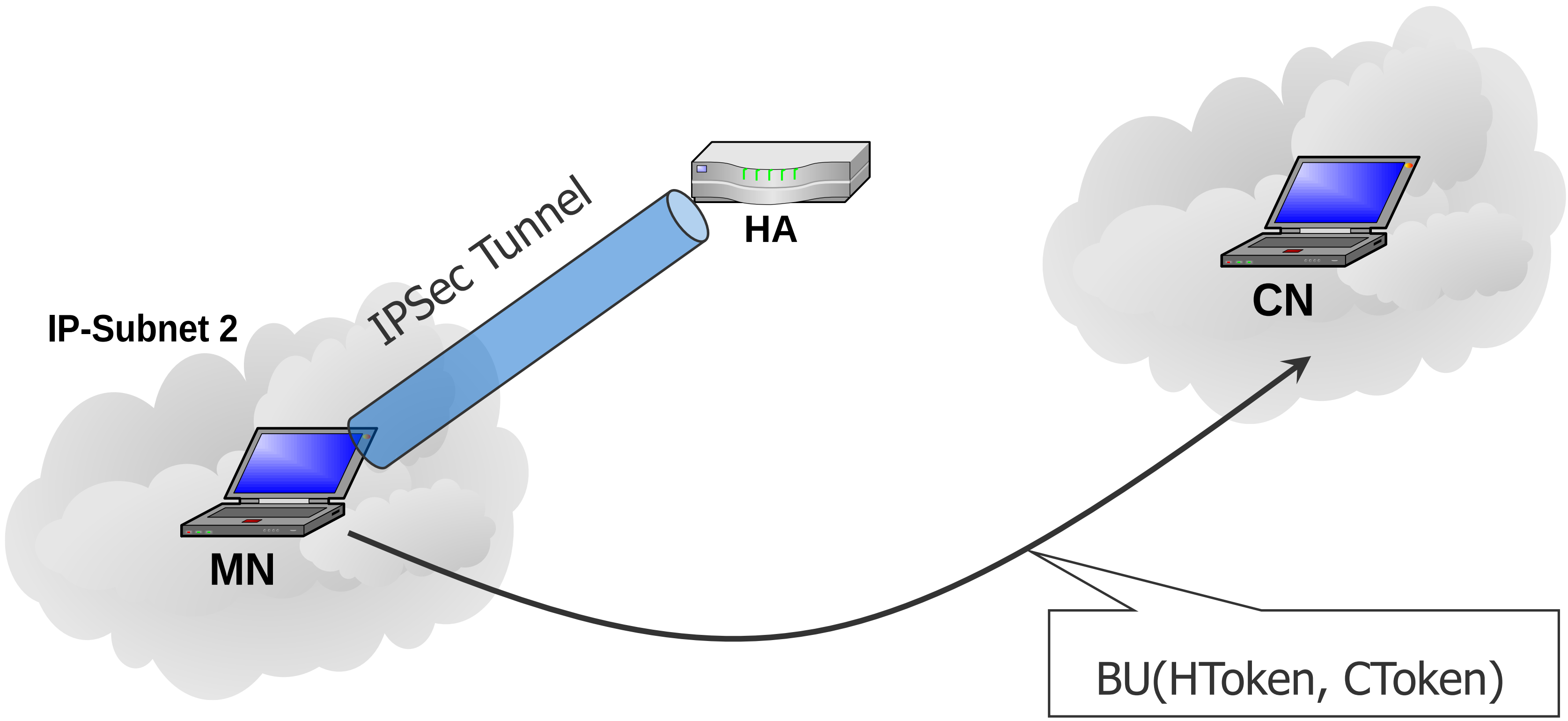


Securing Binding Updates: Return Routability



Securing Binding Updates: Return Routability

Binding Update CN



Agenda

- Motivation
- Basic Mobile IPv6
- Protocol Improvements & Development
  - Transparent Mobility: PMIPv6
  - Handover Acceleration: HMIPv6 & FMIPv6
  - Predictive versus Reactive: Analysis of Handover Performance
  - Secure Enhancement of Route Optimisation
  - Multicast Mobility Extensions
- Current Status, Conclusions & Future Trends

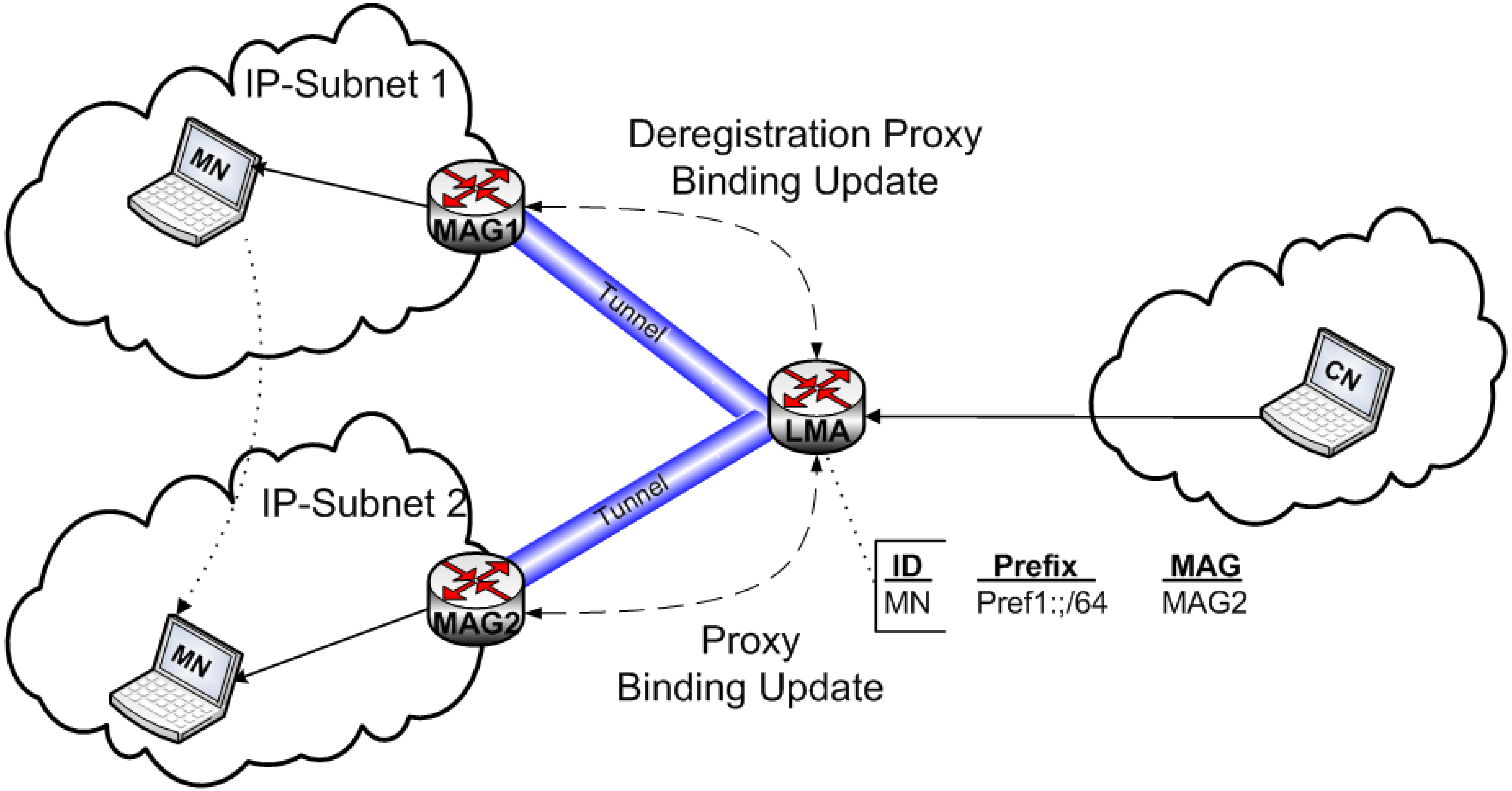
Transparent Mobility: Proxy Mobile IPv6 (RFC 5213)

Objective: Support IPv6 Mobility without Client Support nor Client Implementation

Approach: Network-operated Tunnel Management – PMIPv6

- Local Mobility Anchor (LMA ↔ HA) and Mobile Access Gateway (MAG ↔ AR) make tunnel follow the MN
- IP address of MN remains unchanged at handovers
- Routing twisted: MAG uses policy-routing based on MNs ID
- LMA attains role of regional gateway like in 3/4GPP telco networks

Proxy Mobile IPv6 (RFC 5213)



Performance: Handover Steps

1. Link Layer Handover
2. L3 Movement Discovery
3. Local Addressing: Form a New CoA
4. Duplicate Address Detection
5. Binding Update with Home Agent
6. Binding Update with Correspondent Node

VoIP/VCoIP
Real-Time Requirements

! Latency ≈< 100 ms

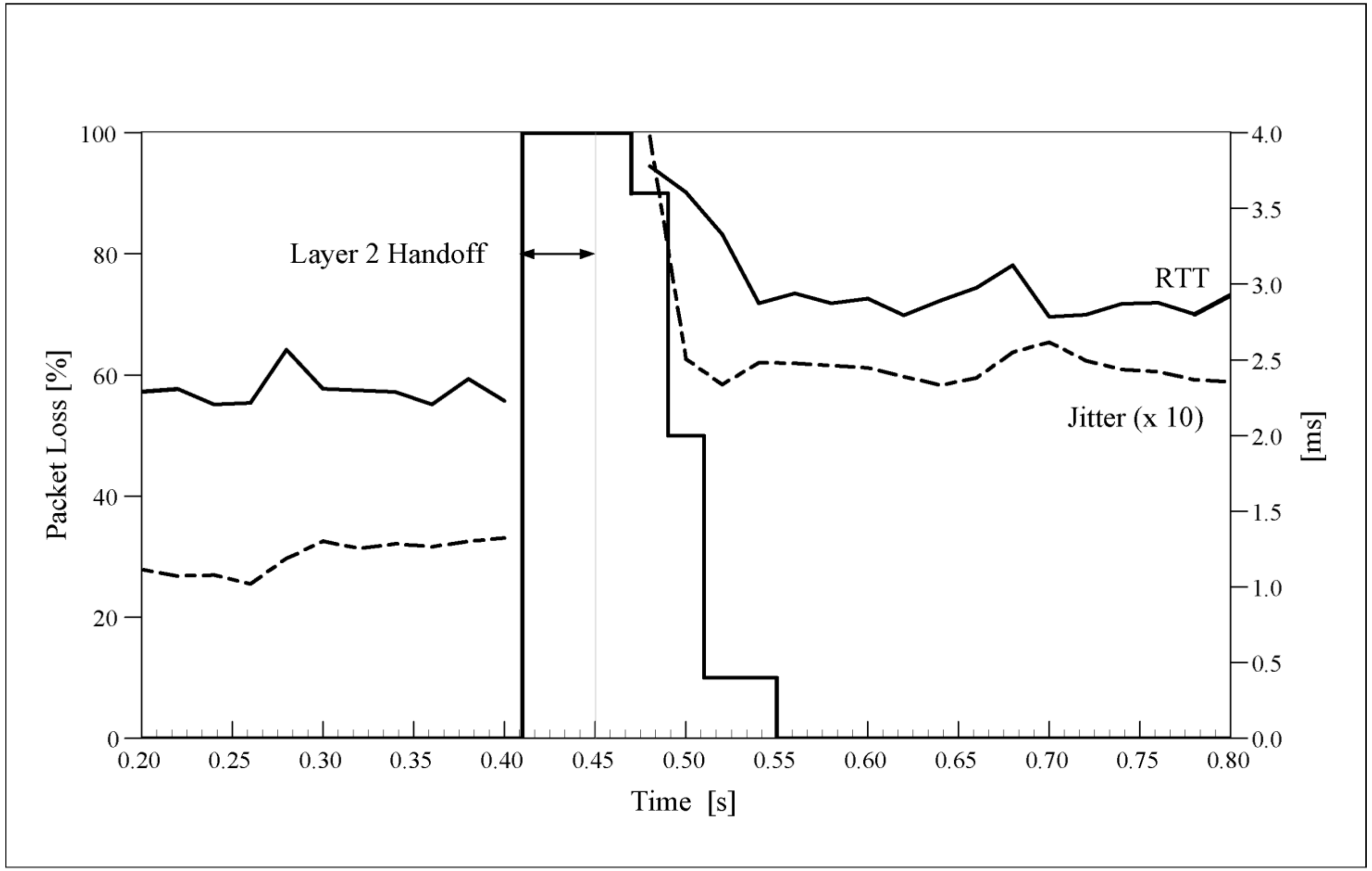
! Jitter ≈< 50 ms

! Packet loss ≈< 1 %

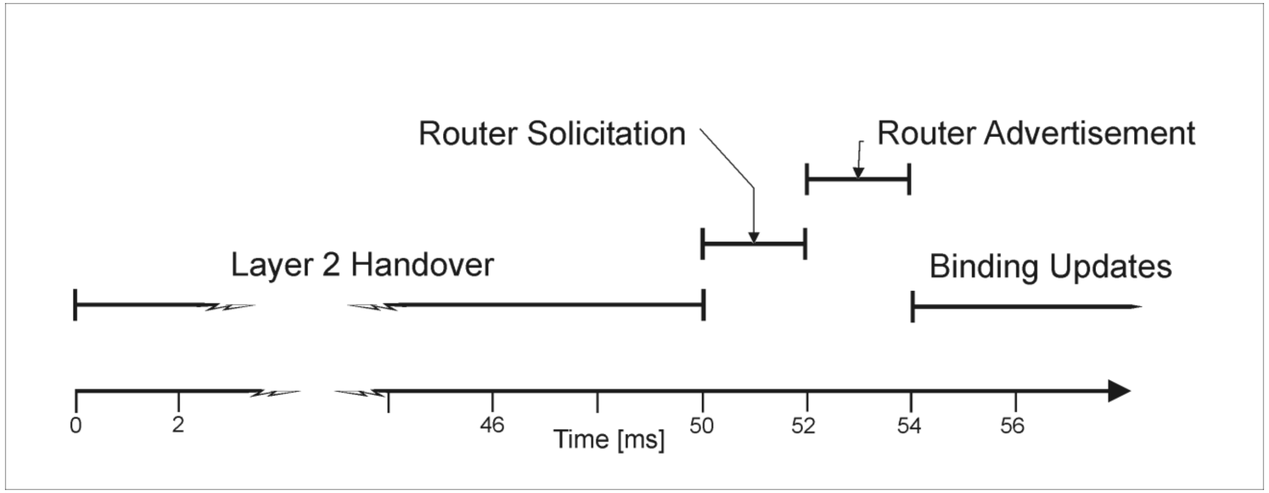
! Interruption: 100 ms ≈ 1 spoken syllable

→ 100 ms are critical bound

Local Handover Measurements: Empirical Results on WiFi



Local Handover Acceleration: L2-Trigger & DAD Suppression



IP-Config: Reduce

- MAX_RA_DELAY_TIME ≈ 1 – 5 ms
- MAX_RTR_SOLICITATION_DELAY ≈ 1 – 5 ms

Problem:

Binding Updates are strongly topology dependent

MIPv6 Handover: Topology Problem

- Generally HA and CN are at Significant Distance
- Handover Time: (t_X is RTT MN $\leftrightarrow$ X)

$$t_{handoff} = t_{local} + t_{BU-of-HA} + t_{BU-of-CN}$$

$$\approx t_{local} + \frac{3}{2} t_{CN} + 2t_{HA}$$

- Jitter Enhancement: $$\frac{Jitter_{handoff}}{Jitter_{stationary}} \approx \frac{t_{HA} + t_{CN}}{t_{CN}}$$

- Essential: Eliminate HA/CN RTT Dependence

Handover Acceleration: HMIPv6 & FMIPv6

Hierarchical Mobile IPv6

Mobility Anchor Points (MAPs) as domain wise HA proxies

- MN communicates via bi-dir tunnel with MAP
- Intra-domain (micro-)mobility invisible to outside world

Inter-domain HO requires regular BUs via MAPs

Fast Mobile IPv6

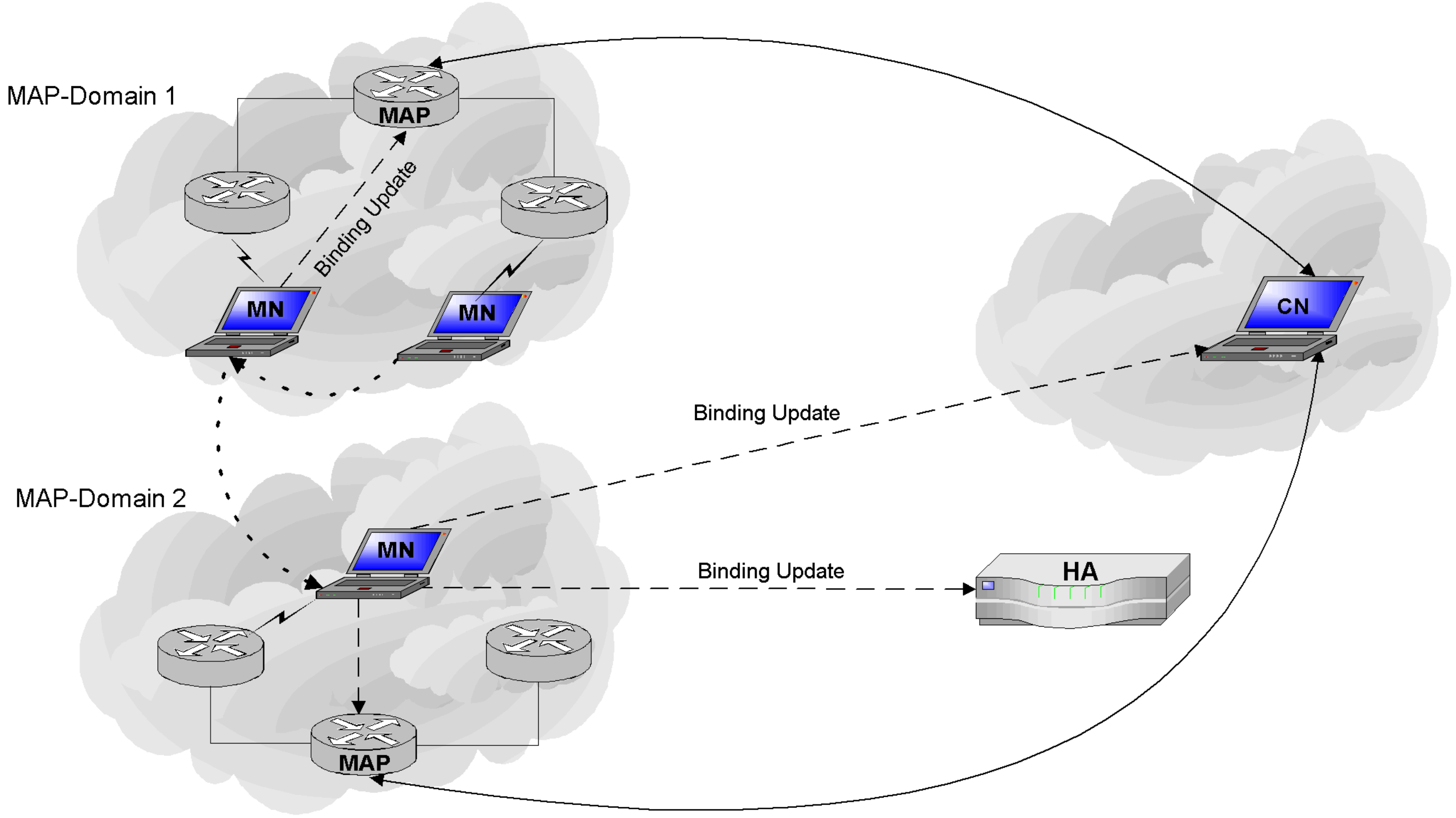
Handover Management at Access Routers

- Predictive HO based on L2:L3 topology map, pre-configures New CoA
- Reactive HO as fallback

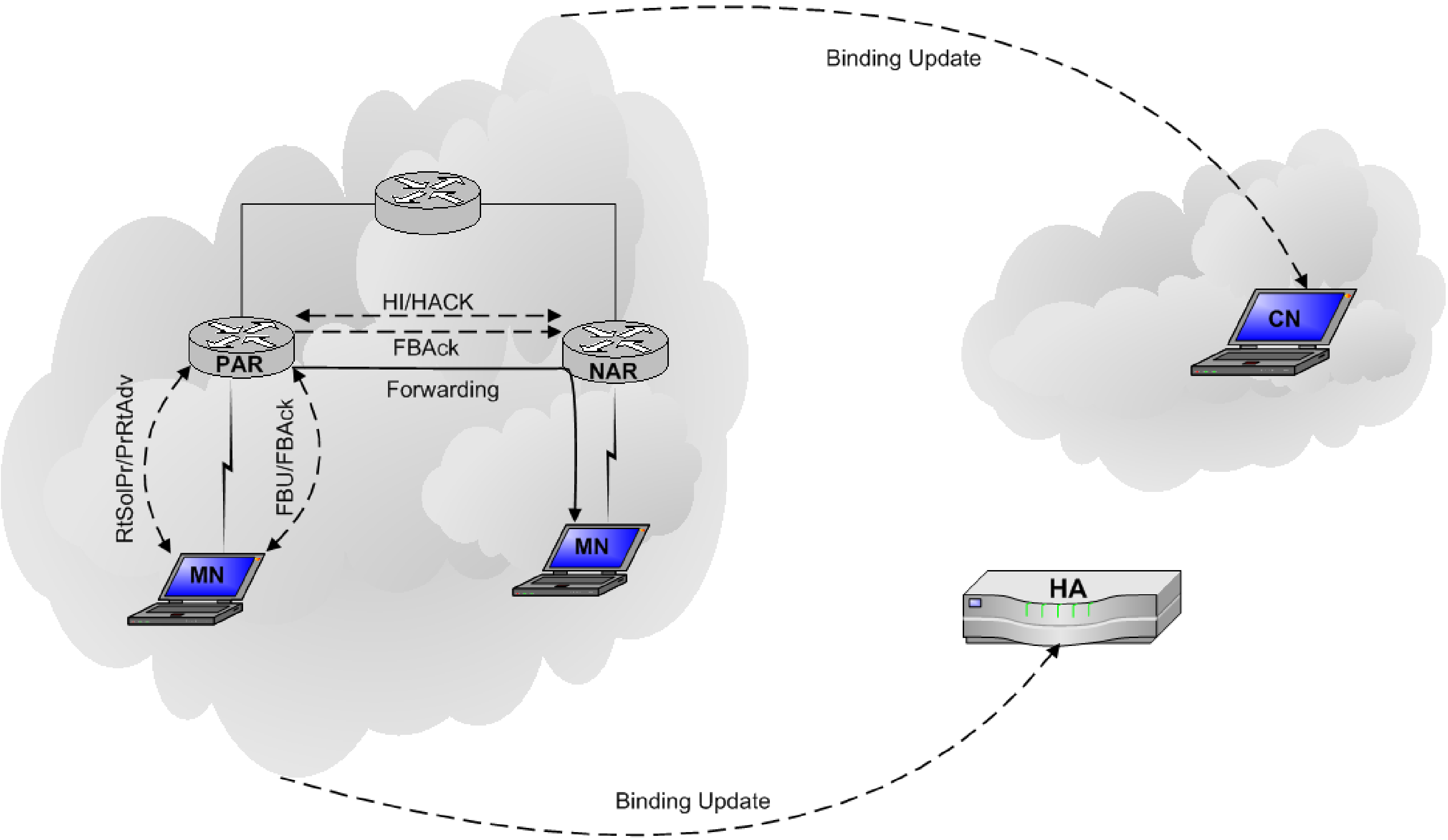
BUs operated asynchronously

Both approaches resolve topological dependences

Micro-Mobility with HA Proxies: Hierarchical MIPv6 (RFC 5380)



Edge Handover Management: Fast MIPv6 (RFC 5568)

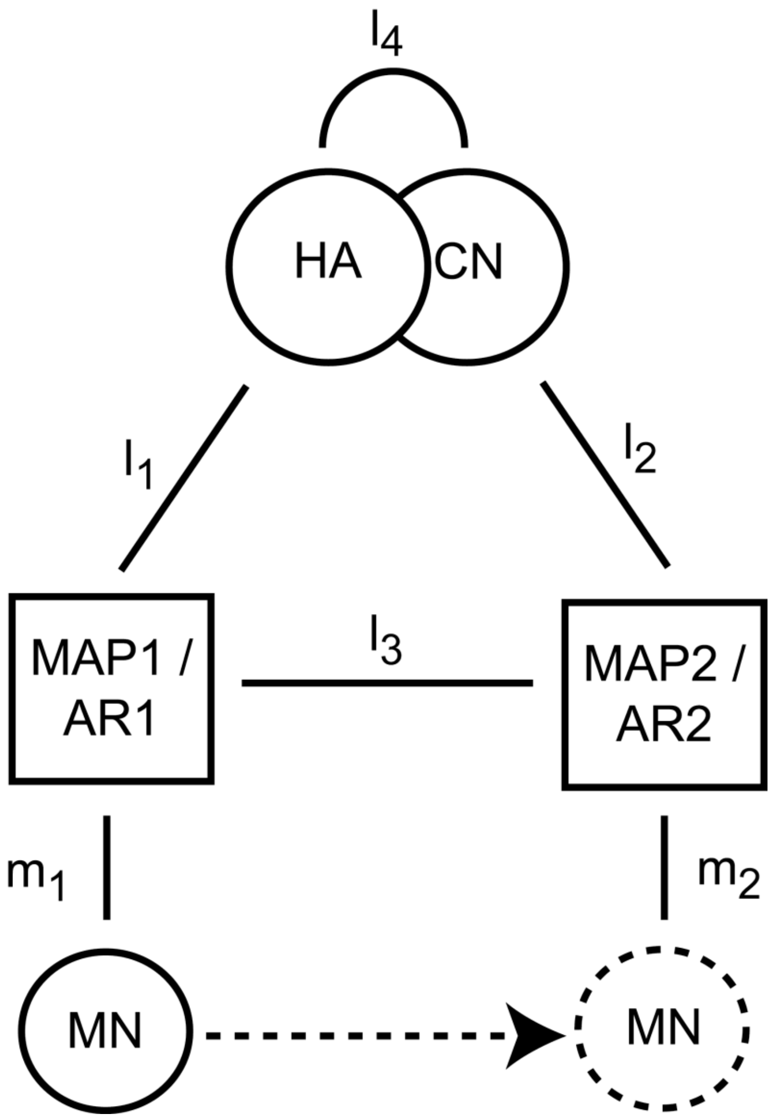


Handover Analysis:
Predictive versus Reactive

Relevant metrics

- Handover performance: packet loss, delay + jitter
- Number of performed handovers
- Number of processed handovers
- Robustness
- Handover Costs

Handover Performance



Simple analytical model:

- Compare reactive vers. predictive handover
- Characteristic to problem: Router distance t_{l3}
- Charac. to predictive HO:

$$(t_{Ant} - 2t_{l3}) + (t_{L2} - t_{l3})$$

- Charac. to reactive HO:

$$t_{l3} + t_{L2}$$

More detailed …

Reactive Handover:

$$\text{Packet loss} \propto t_{L2} + t_{local-IP} + t_{m_2} + t_{l_3}$$

$$\text{Additional arrival delay} = t_{l_3} + t_{m_2} - t_{m_1}$$

Predictive Handover (successful):

$$\text{Packet loss} \propto \Delta^{-}t + \max(\Delta t + t_{L2} + t_{m_2} - t_{l_3}, 0)$$

$$\text{Additional arrival delay} = t_{l_3} + t_{m_2} - t_{m_1}$$

where

$$\Delta^{\pm}t = \max(\pm t_{Ant} \mp 2t_{l_3} \mp t_{m_1}, 0), \text{ and}$$

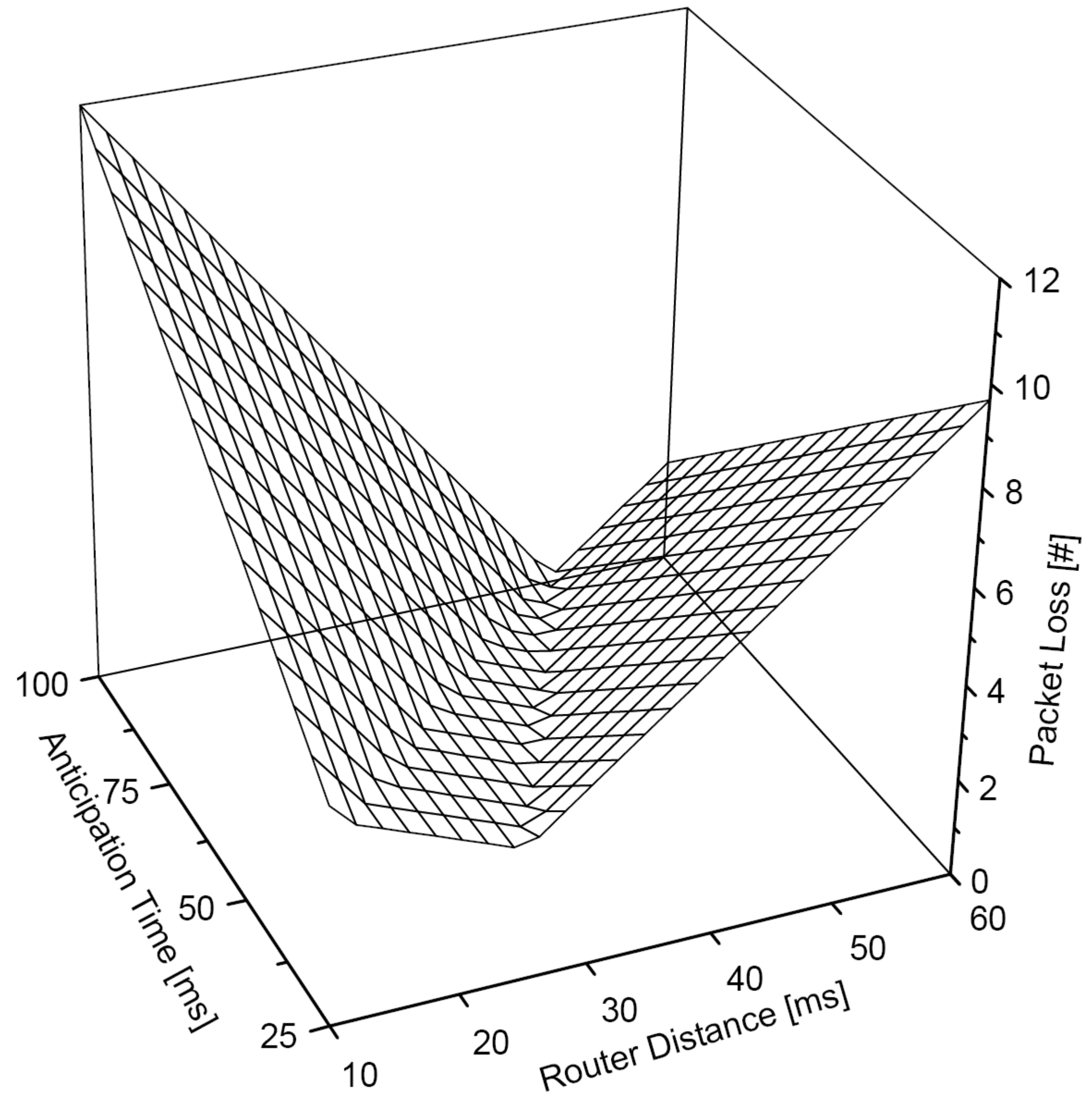
$$\Delta t = \Delta^{+}t - \Delta^{-}t.$$

Packet Loss Function

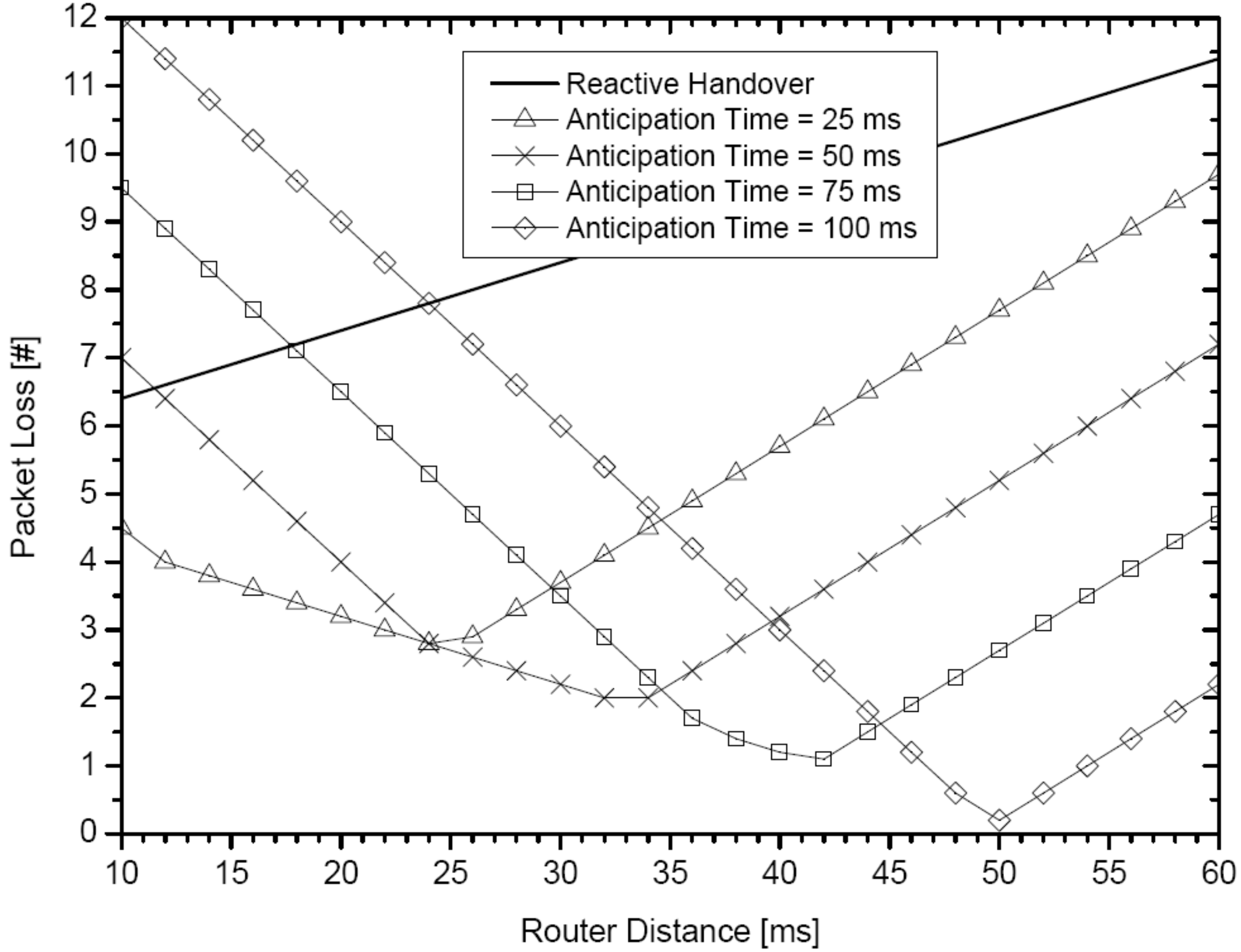
L2 Delay: 50 ms

Traffic:

CBR at 1 Pkt/10 ms



Comparative Samples



Packet Loss: Stochastic Simulation

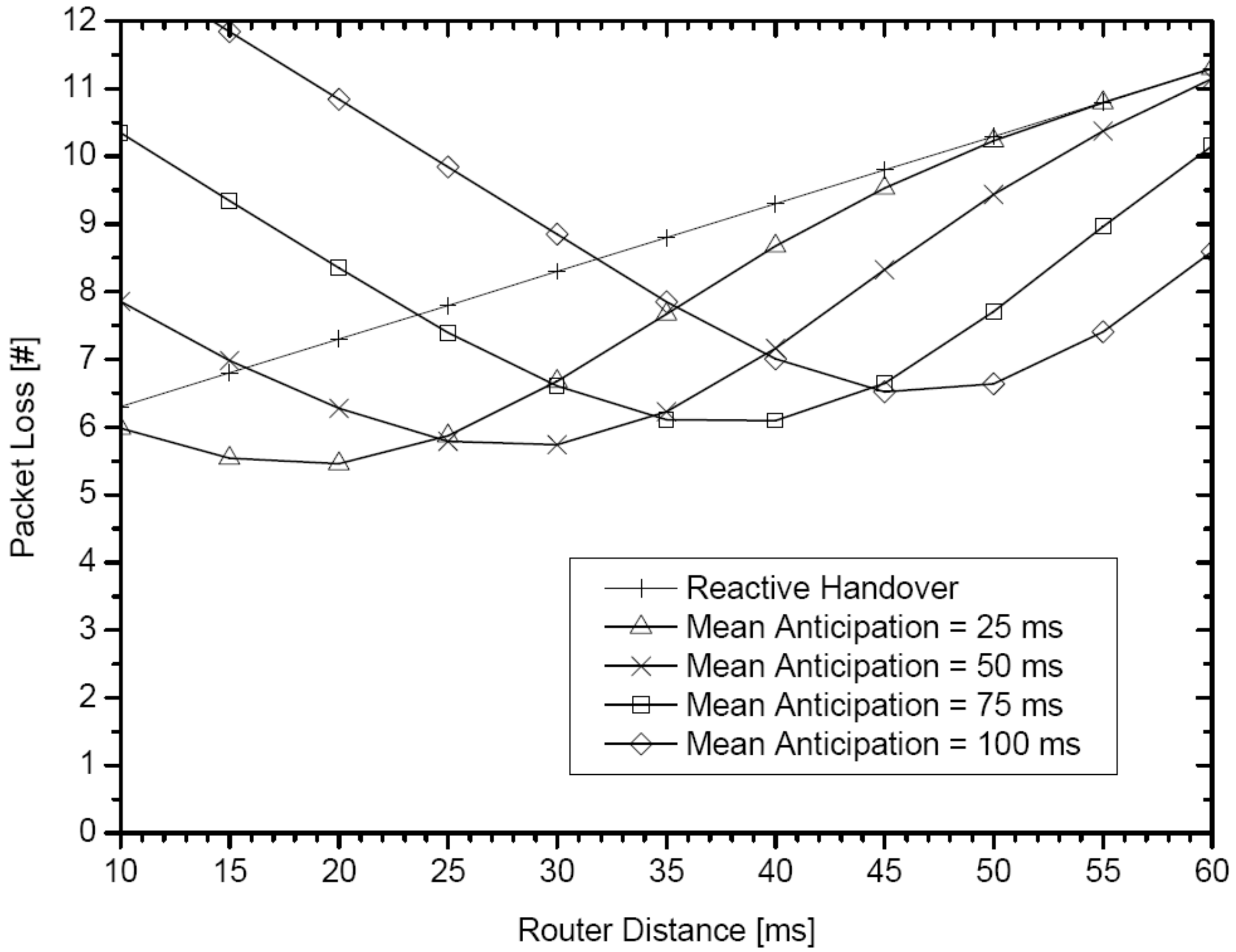
Constant bit rate traffic from CN/HA (at 10 ms)

Random perturbations (**ξ**) at each link

Parameters:

- Anticipation Time: **<x>** = * **ms, ξ = 30 ms**
- L2 Handoff: **<x>** = **50 ms, ξ = 10 ms**
- Local Links: **<x>** = **2 ms, ξ = 1 ms**

Packet Loss



Packet Loss [#]
Router Distance [ms]
0
1
2
3
4
5
6
7
8
9
10
11
12
10
15
20
25
30
35
40
45
50
55
60
Reactive Handover
Mean Anticipation = 25 ms
Mean Anticipation = 50 ms
Mean Anticipation = 75 ms
Mean Anticipation = 100 ms

Why is Reality Worse?

Analytical Model did not Account for

- Geometry
- Link Perturbation
- Limitations in Completing HO Negotiation

Number of Handovers

Relevant quantities:

- Cell residence time
- Call holding time
- AR-to-MAP ratio

Modelling assumptions:

- Cell residence & call holding time exp. distributed (homogeneous distribution)

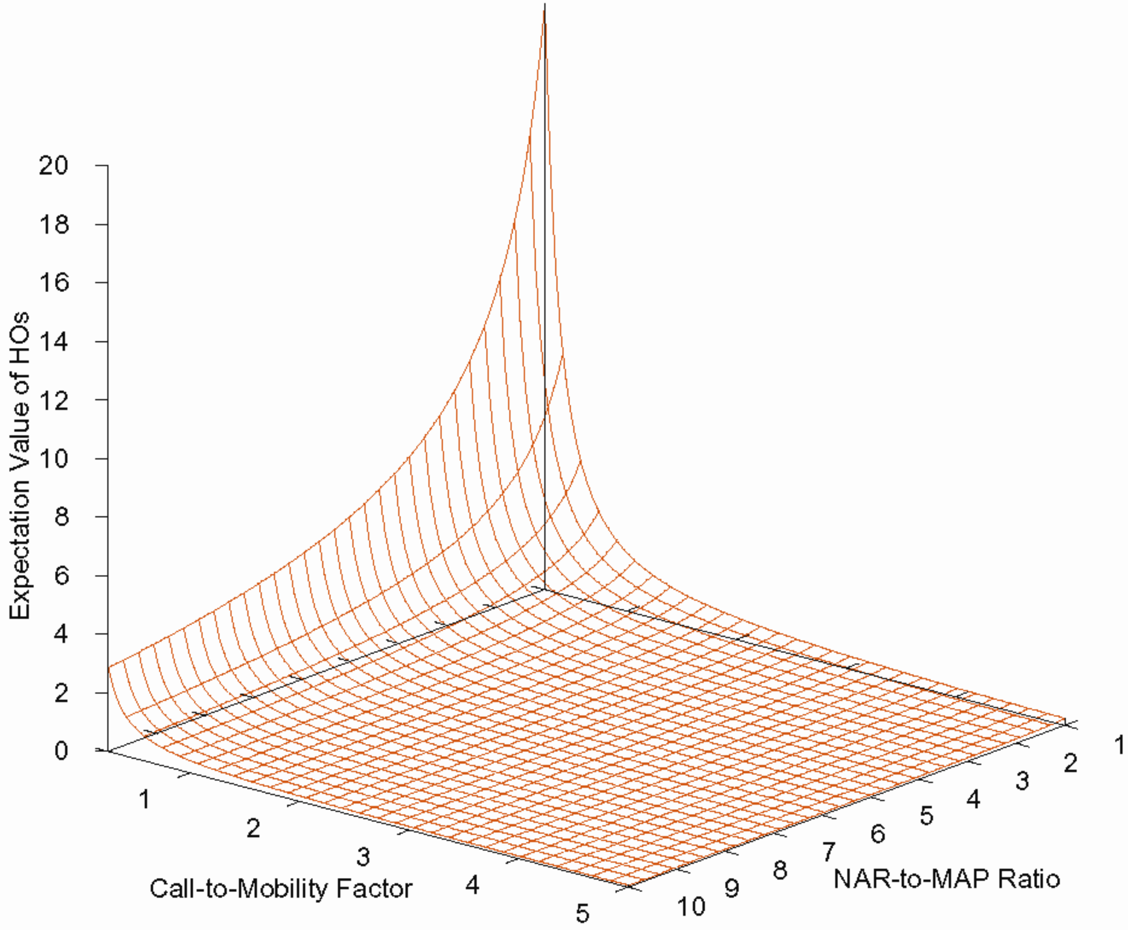
Expected # of Handovers

Analytical result:

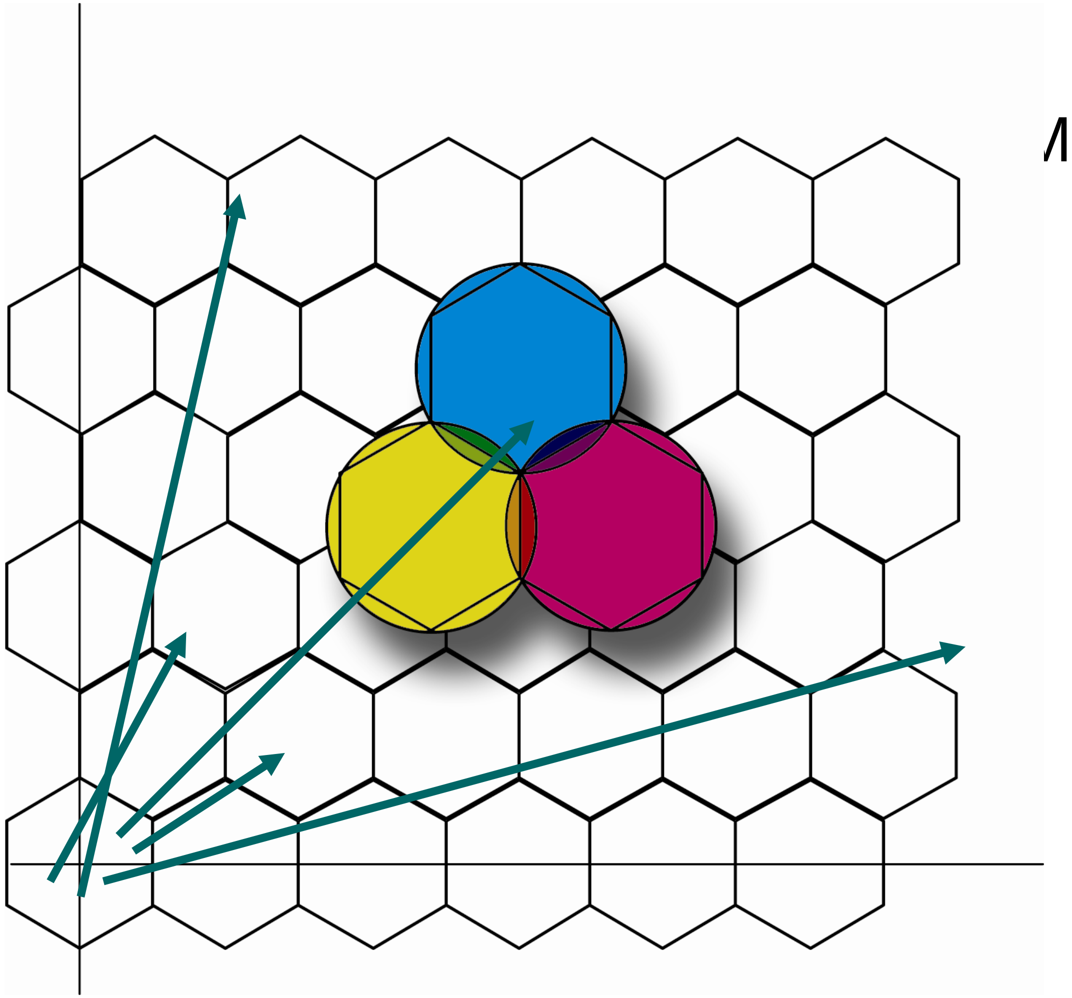
ρ = Call-to-mobility factor

k = AR-to-MAP ratio

$$E[HO] = \frac{1}{k\rho^2} + \frac{1}{\sqrt{k}\rho}$$



Handover Predictions: Stochastic Simulation

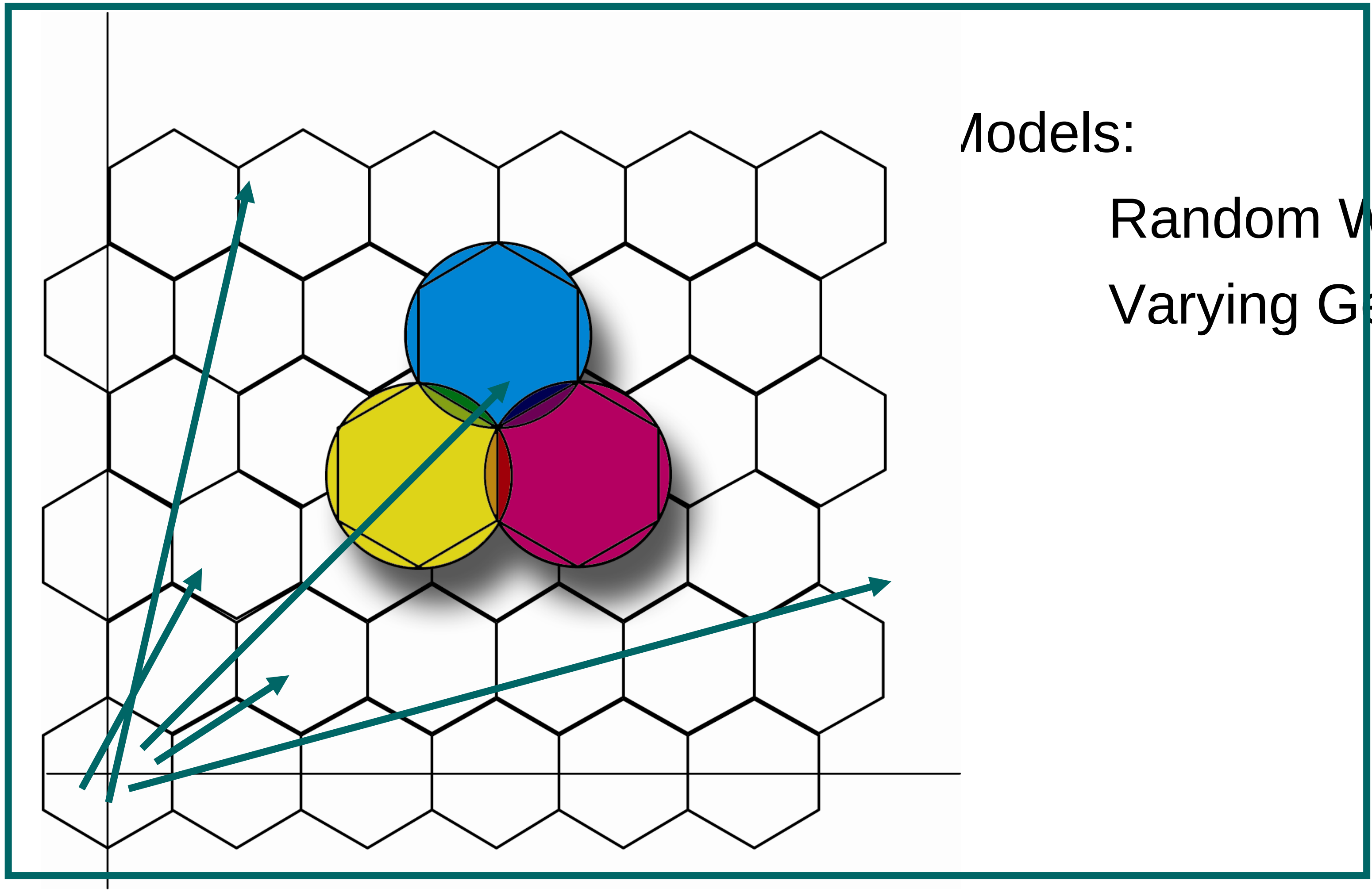


/odels:

Random Waypoint

Varying Geometry

Handover Predictions: Stochastic Simulation



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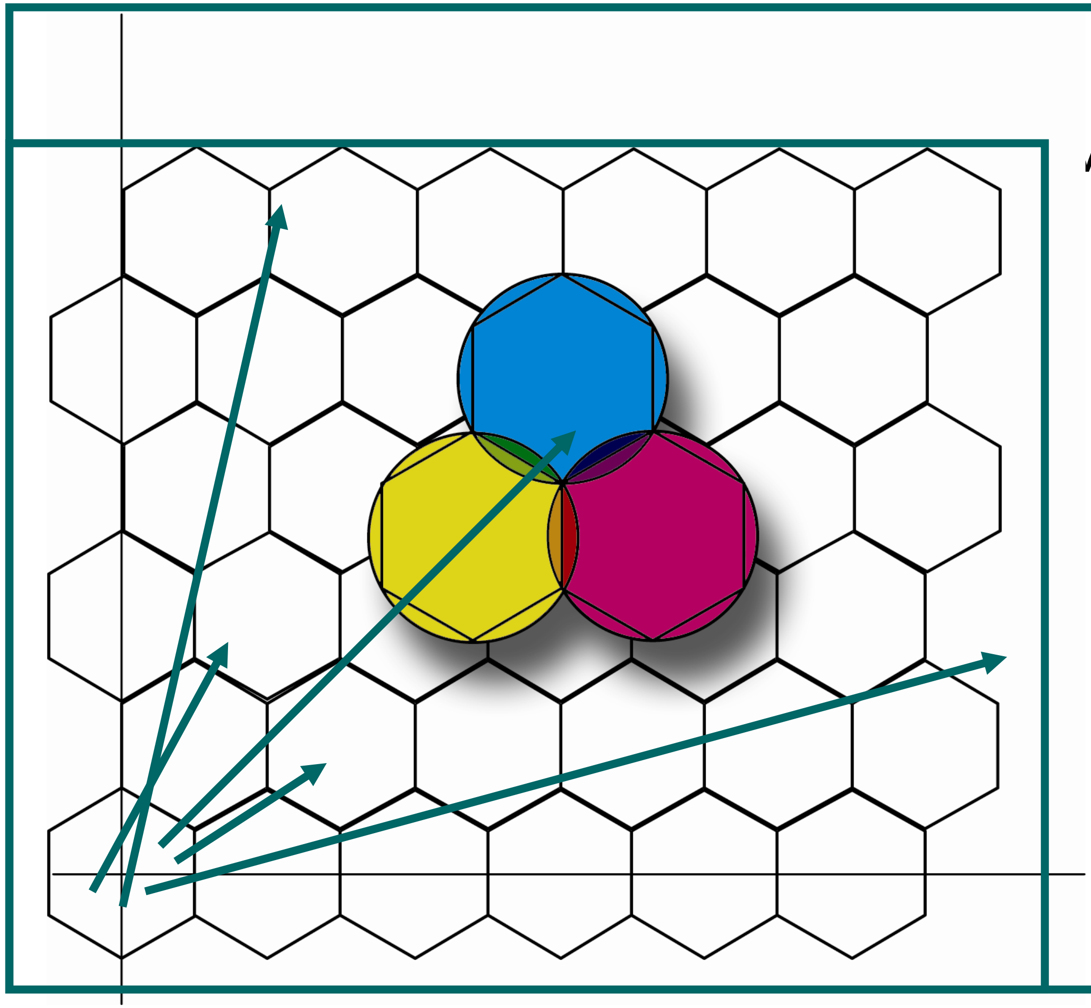
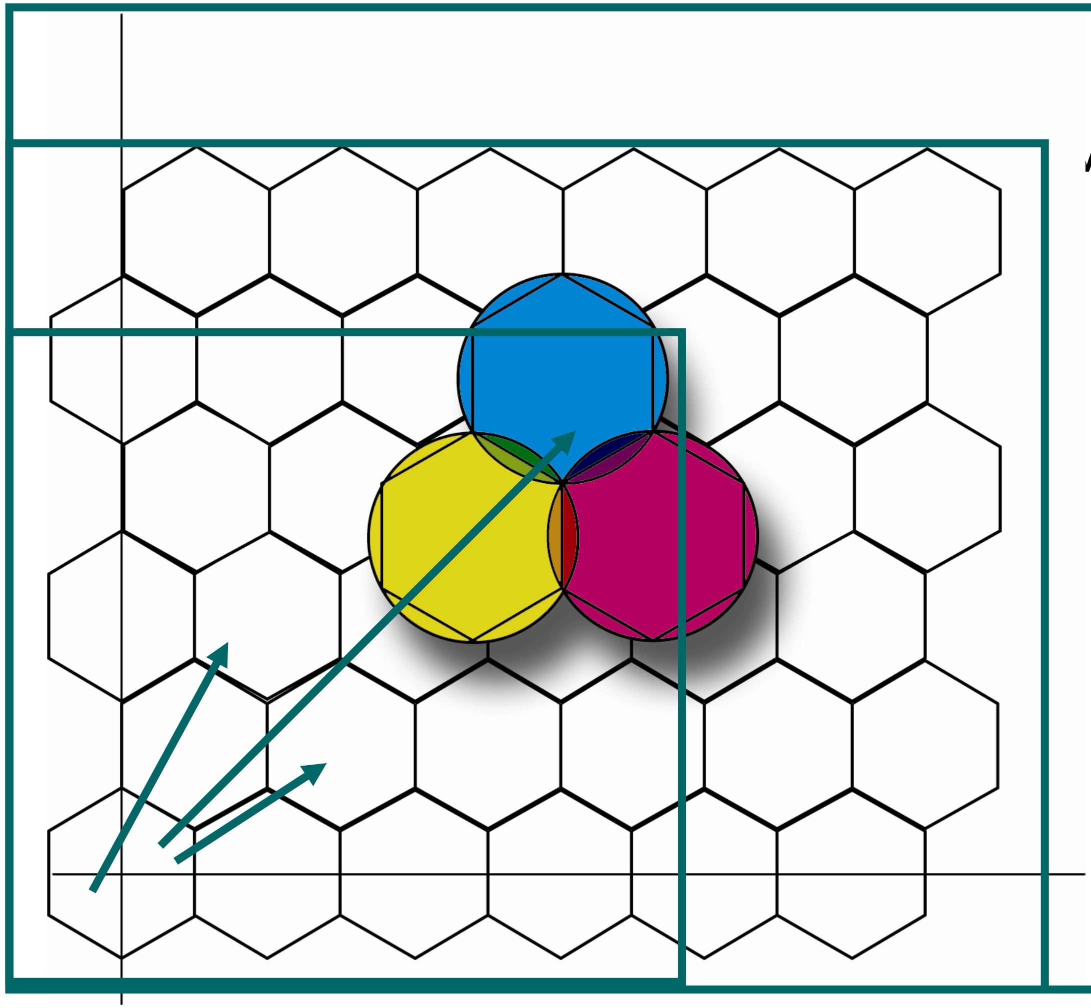


Models:

- Random Waypoint
- Varying Geometry

Handover Predictions: Stochastic Simulation



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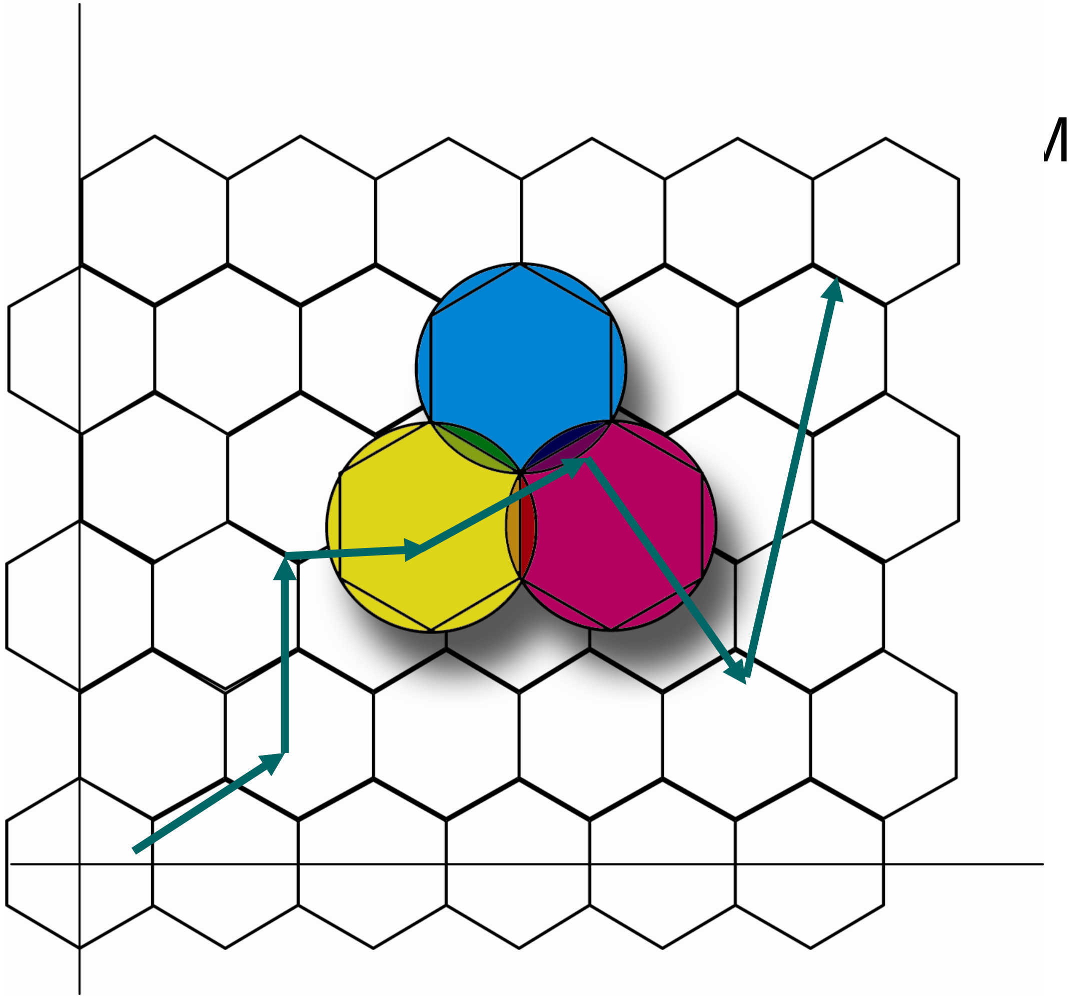
Handover Predictions: Stochastic Simulation



/lodels:

Random Waypoint

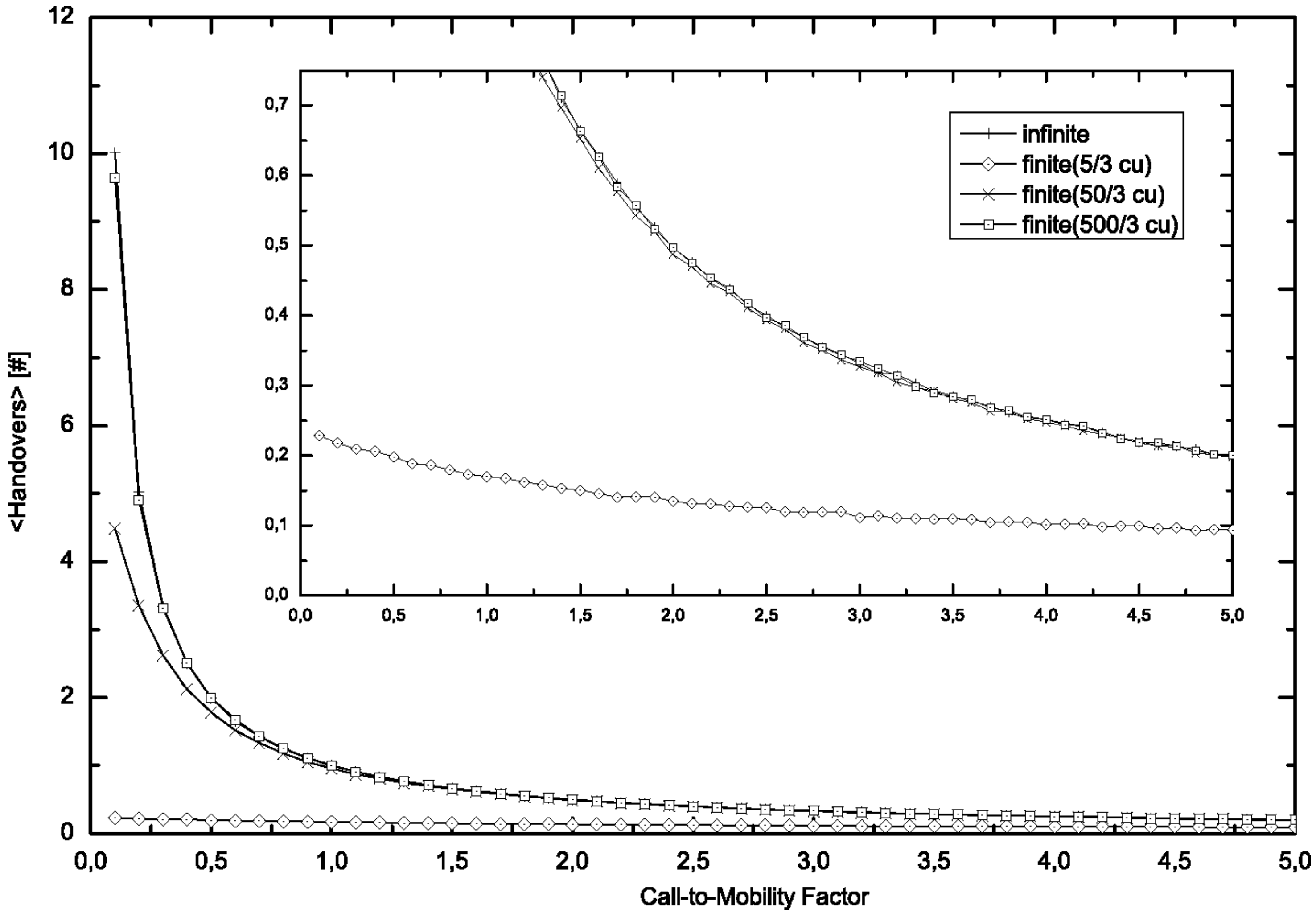
Varying Geometry

Random Direction

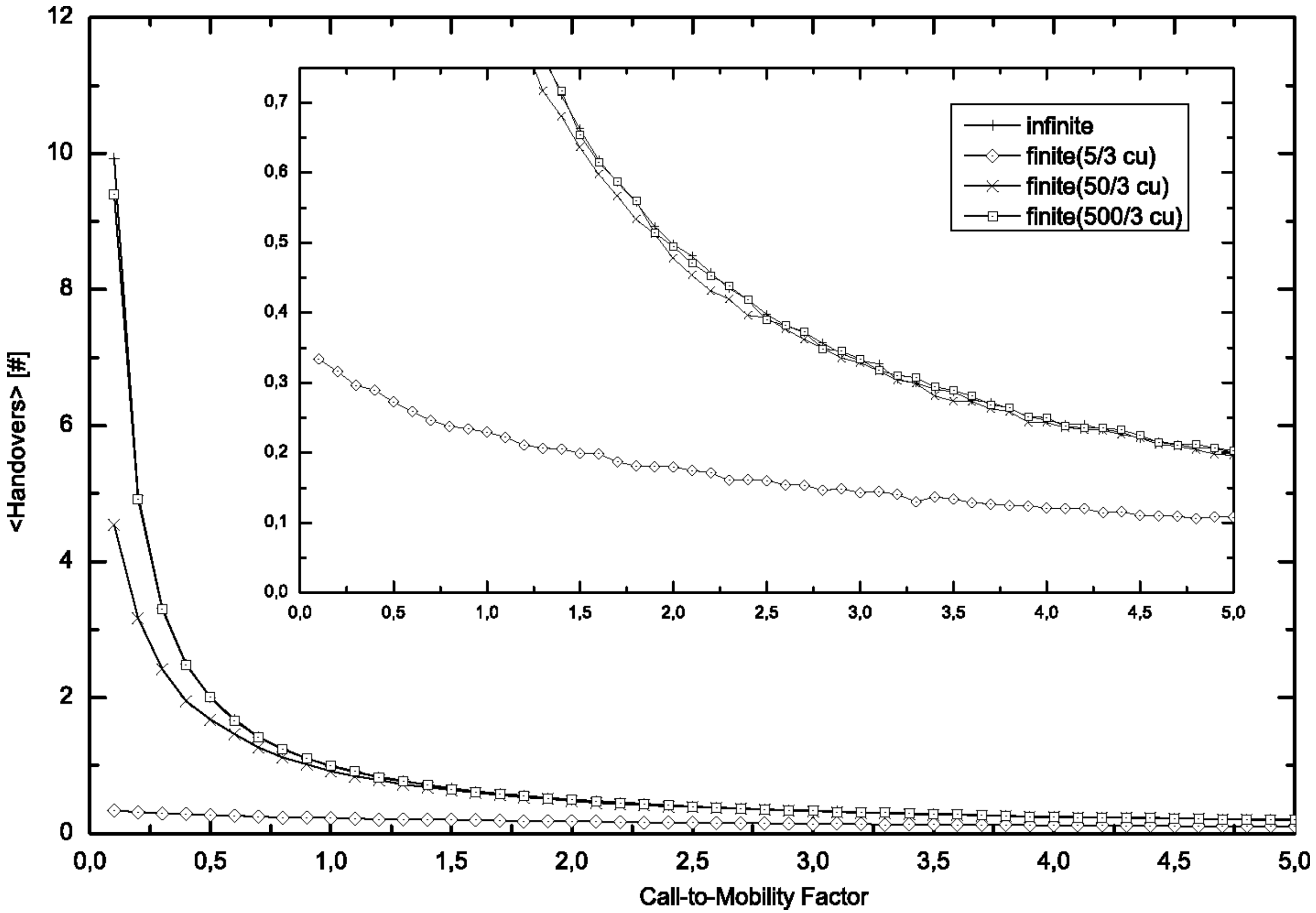
Varying Geometry

Varying Speeds

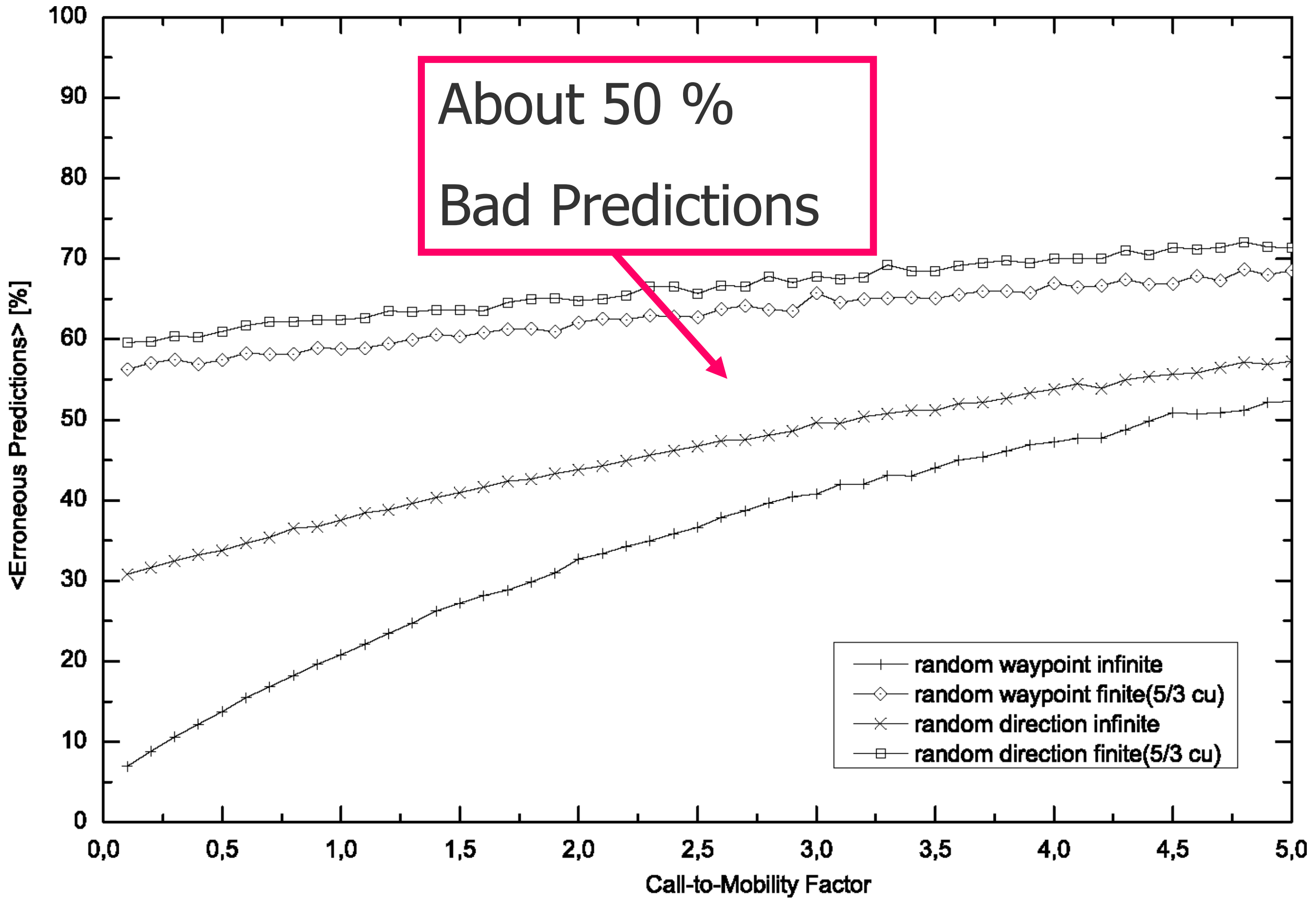
Mean Handover Frequencies: Random Waypoint Model



Mean Handover Frequencies: Random Direction Model



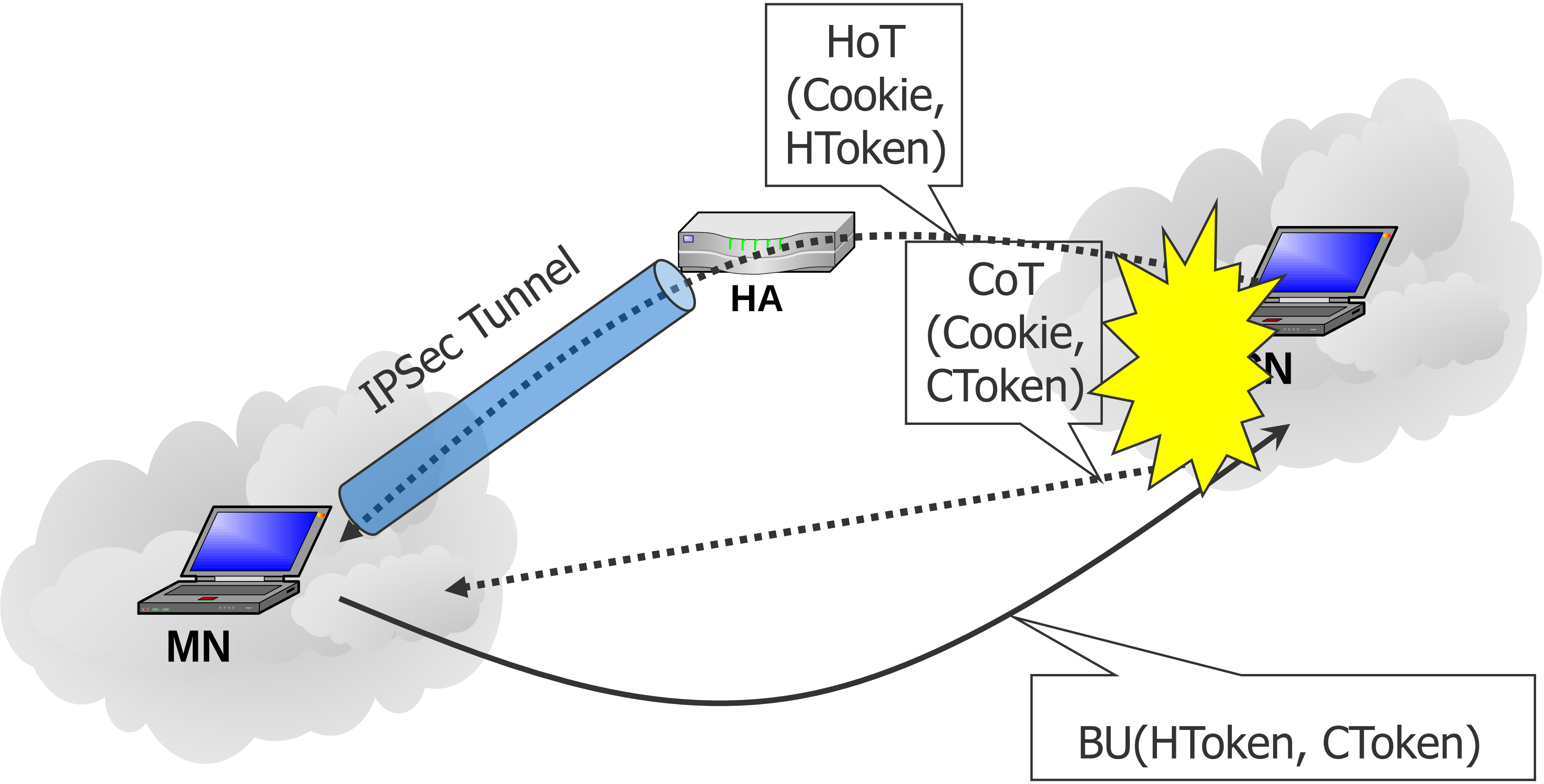
Erroneous Prediction Yields



Handover Security Problems

- RRP vulnerable to Man-in-the-Middle attacks
- Degrades handover performance
  - RRP tightens topological dependence
- Agnostic of FMIPv6
- Incompatible with Multicast

Problem: Man in the Middle



The Core of the Problem?

For Authentification

A Mobile Node must proof ownership of HoA

But: Certification Infrastructure (PKI) is out of scope

Idea in IPv6:

Cryptographically Generated Addresses (Aura, Castellucia, Montenegro & Petander – RFC 3972):

Generate public/private key pair: e, d

Generate host-ID from public key: 64 sha1(e)

➔ Packets now can authenticate their address (and content) self-consistently!

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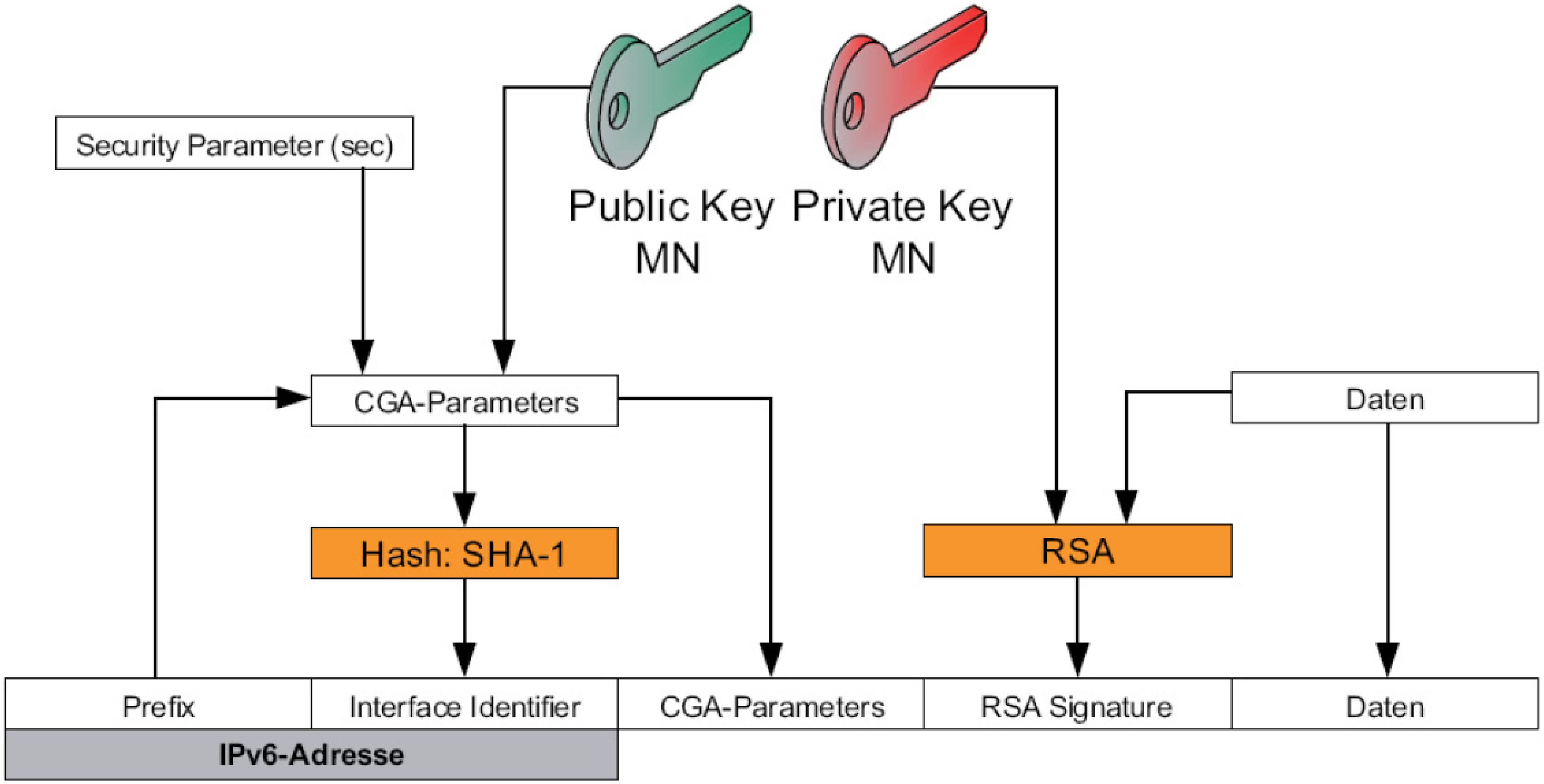
CGA Packet Authentification



Binding Update

Enhanced Route Optimization for Mobile IPv6 (RFC 4866)

IPv6 Header	Dest. Options Header	Mobility Header			Upper Layer Header + Data
Src: CoA Dst: G	Home Address Option	BU Msg	CGA Param. Option	CGA Signature Option	Data

Base header is Home Address unaware.

Binding Update

Enhanced Route Optimization for Mobile IPv6 (RFC 4866)

IPv6 Header	Dest. Options Header	Mobility Header			Upper Layer Header + Data
Src: CoA Dst: G	Home Address Option	BU Msg	CGA Param. Option	CGA Signature Option	Data

The destination receives the Home Address in the Destination Options Header.

Binding Update

Enhanced Route Optimization for Mobile IPv6 (RFC 4866)

IPv6 Header	Dest. Options Header	Mobility Header			Upper Layer Header + Data
Src: CoA Dst: G	Home Address Option	BU Msg	CGA Param. Option	CGA Signature Option	Data

The update itself is stored in the Mobility Header.

Binding Update

Enhanced Route Optimization for Mobile IPv6 (RFC 4866)

IPv6 Header	Dest. Options Header	Mobility Header			Upper Layer Header + Data
Src: CoA Dst: G	Home Address Option	BU Msg	CGA Param. Option	CGA Signature Option	Data

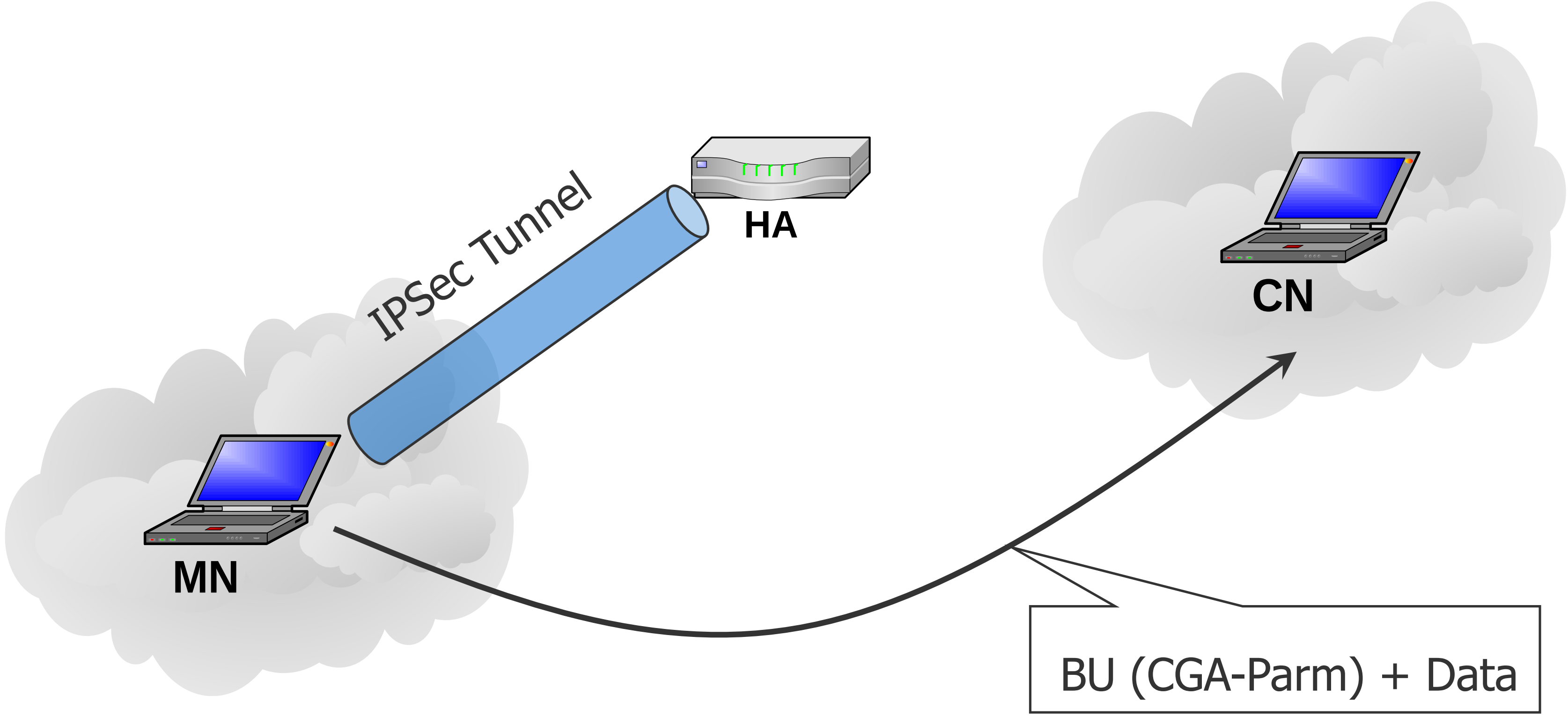
CGA options verify the HA and sign the packet

CGA-Authenticated BU (RFC 4866)

Initial HoA-Reachability Test
Further on per Handover:

CGA-Authenticated BU (RFC 4866)

Initial HoA-Reachability Test
Further on per Handover:



Multicast Mobility: Problems & Objectives

Multicast Mobility in MIPv6: Problem Statement – RFC 5757

Provide Seamless Multicast Services to and from MNs

Approach native multicast forwarding in an infrastructure-compliant manner

At Listeners:

- Ensure multicast reception in visited networks
- Organize context transfer between mcast-enabled access networks

At Sources:

- Sustain address transparency at end nodes (address duality problem)
- Ensure persistence of receiver contact (decoupling problem)
- Bridge tardy tree reconstruction/transformation procedures

Focus on deployable solutions, minimize protocol extensions

Multicast Mobility Approaches

Remote Subscription

- Show all movement by local multicast subscription

Bi-directional Tunnelling

- Hide all movement by tunnelling via Home Agent

Agent Based

- Compromise: Intermediate agents shield Mobile
- Approaches: Extend unicast schemes
  M-PMIPv6, M-FMIPv6, M-HMIPv6, …

Agenda

- 🕐 Motivation
- 🕑 Basic Mobile IPv6
- 🕒 Protocol Improvements & Development
- 🕓 Current Status, Conclusions & Future Trends

Status: Where are we today?

Internet Mobility

- Mobile IPv6 – Since June 2004 widely implemented, but little deployment

Real-Time Mobility

- FMIPv6 – RFCs 5268 (June 2008, updated to standard track)
- HMIPv6 – RFC 5380 (Oct. 2008, updated to standard track)
- Enhanced Route Optimisation – RFC 4866 (May 2007)

Carrier-Operated Mobility for MIPv6-unaware Nodes

- PMIPv6 – RFC 5213 (PtP Links only, distributed PMIPv6)
- Work on Distributed Mobiltiy (DMM) continues in IETF

Multicast Mobility

- Base RFC 6224 for PMIPv6, several extensions

Conclusions & Future Trends

MIPv6 is a beautiful illustration of IPv6's potentials ... but suffers deployment deficits

MIPv6 operates in end-to-end paradigm, a conflict with operator concepts

PMIPv6 serves as a "mediating protocol", deployment ongoing

Key issue of developing the mobile regime: Gain control on end-devices

Thank

You !

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