



# Mobility Management in the Next Generation Internet

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# Agenda

## 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?



# What may we expect?

- o Devices using Home Address while away
- o 'Workspaces' roaming between local subnets
- o 3GPP Mobiles operating IPv6 Data Service
  - + Improvements on handover performance
  - + Improved security protocols
  - + Cheap availability of WLAN, Wimax, DVB-IPDC
  - + ...
- o VoIP/VCoIP conferencing: real-time mobility
- o 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)

# Key Mobility Approaches

## o Application: SIP Handover

- SIP-server as application specific home agent
- Requires mobility-aware applications
- Works only with SIP

## o Mobile IP

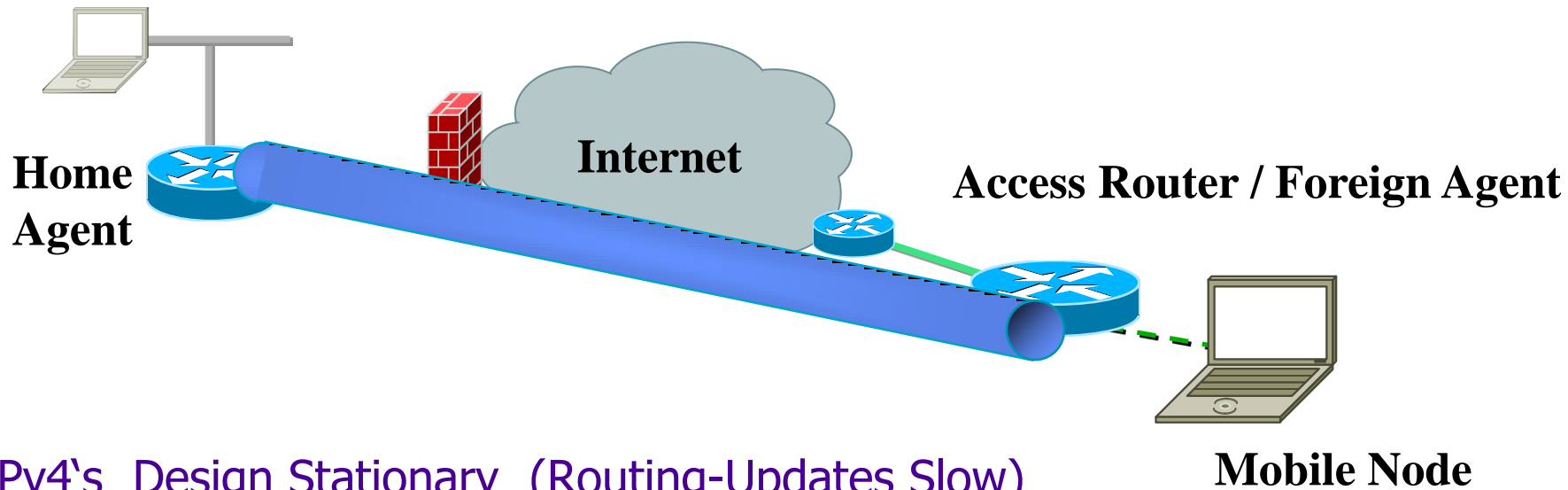
- Stateless, transport transparent handover

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

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



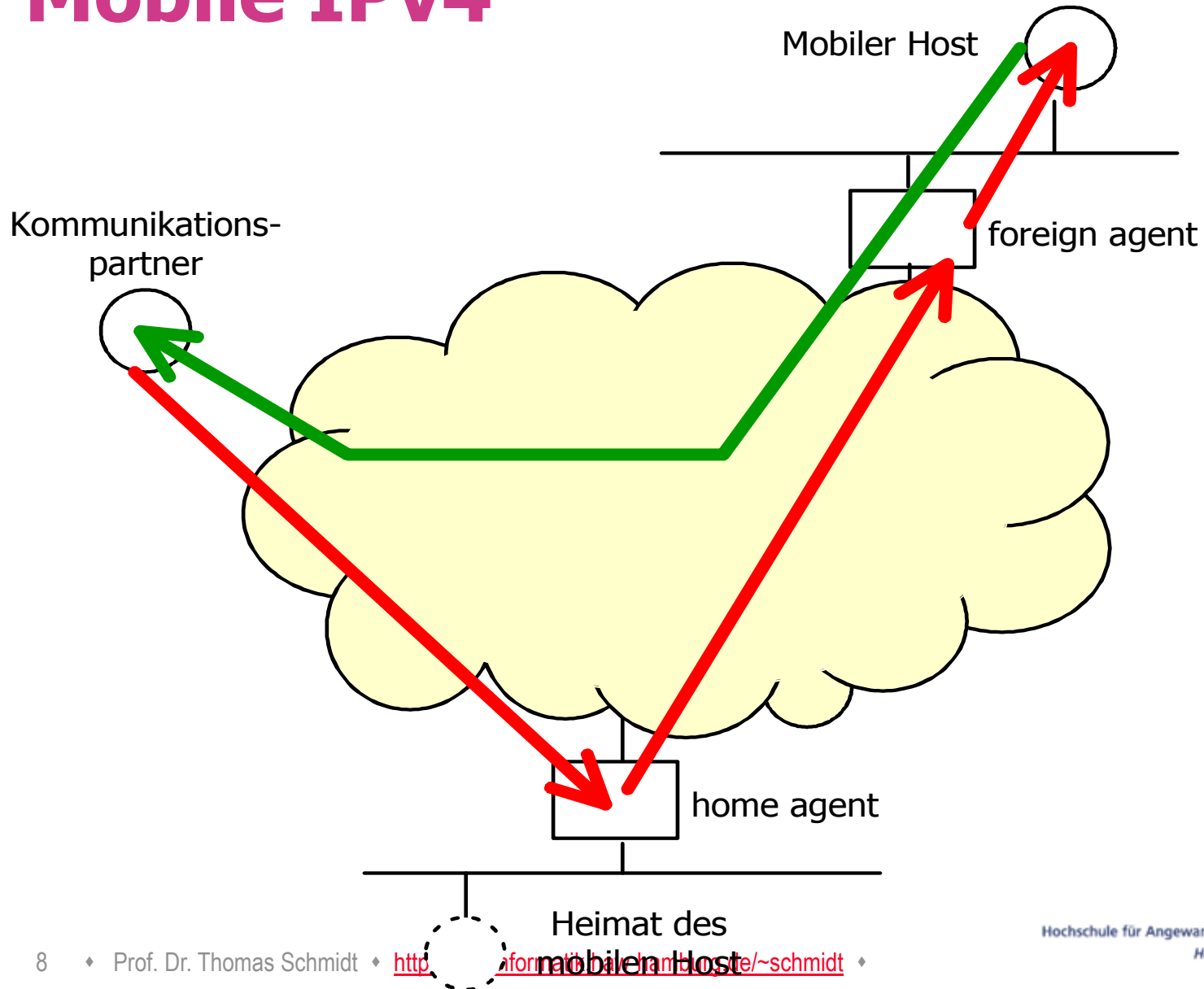
# Limits of Mobile IPv4



- o IPv4's Design Stationary (Routing-Updates Slow)
- o Implementation of Mobility Services: Tunnelling via Home Agent
- o IPv6 Potential:
  - Several Addresses (2 for Mobile Node, many for Mobile Networks)
  - Flexible, Extendable Architecture



# Mobile IPv4





# Agenda

🕒 Motivation

🕒 Basic Mobile IPv6

➔ Location & Handover Management

➔ Basic Security

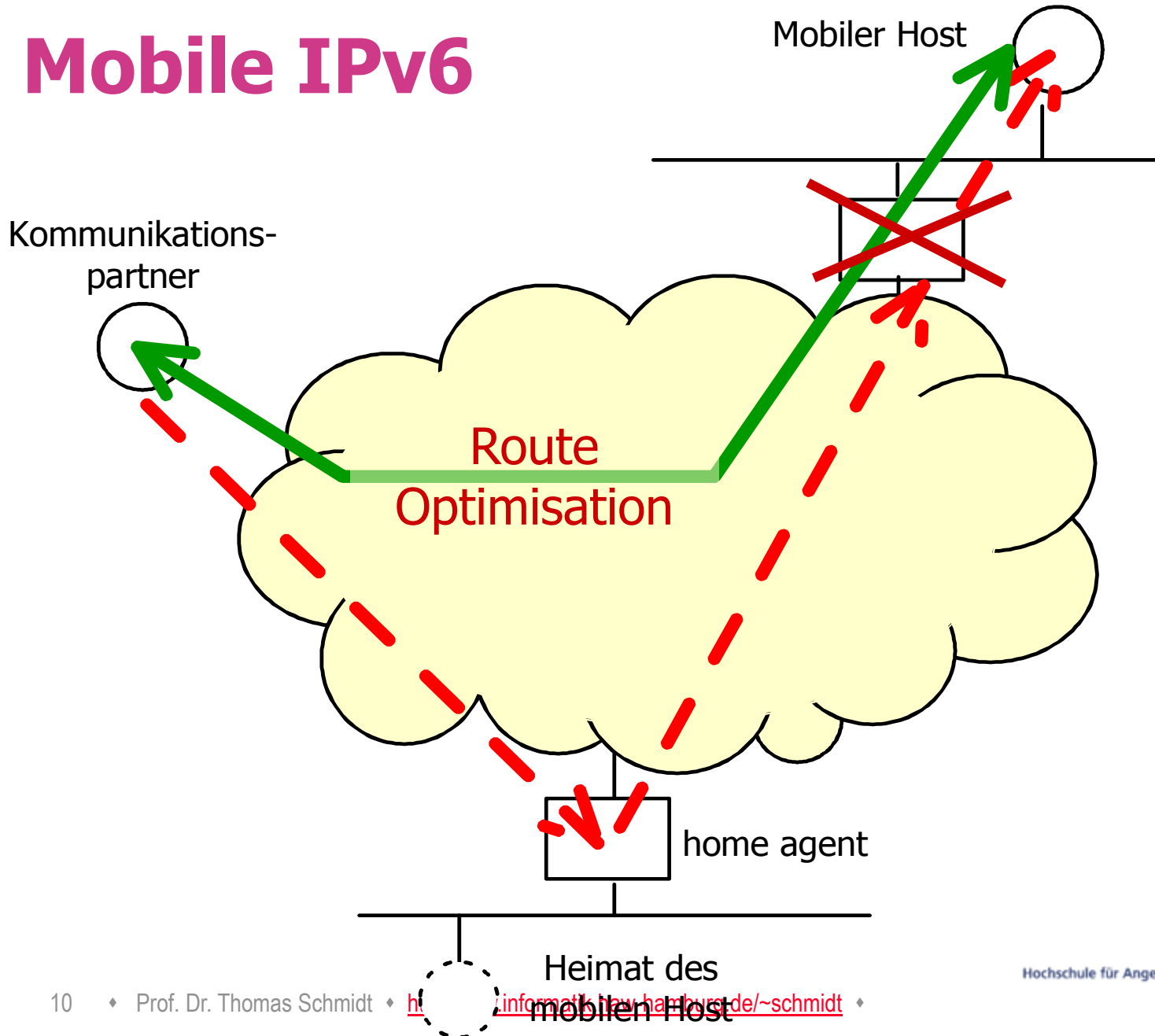
➔ Implementation & Deployment

🕒 Protocol Improvements & Development

🕒 Current Status, Conclusions & Future Trends



# Mobile IPv6



# Basic Mobile IPv6

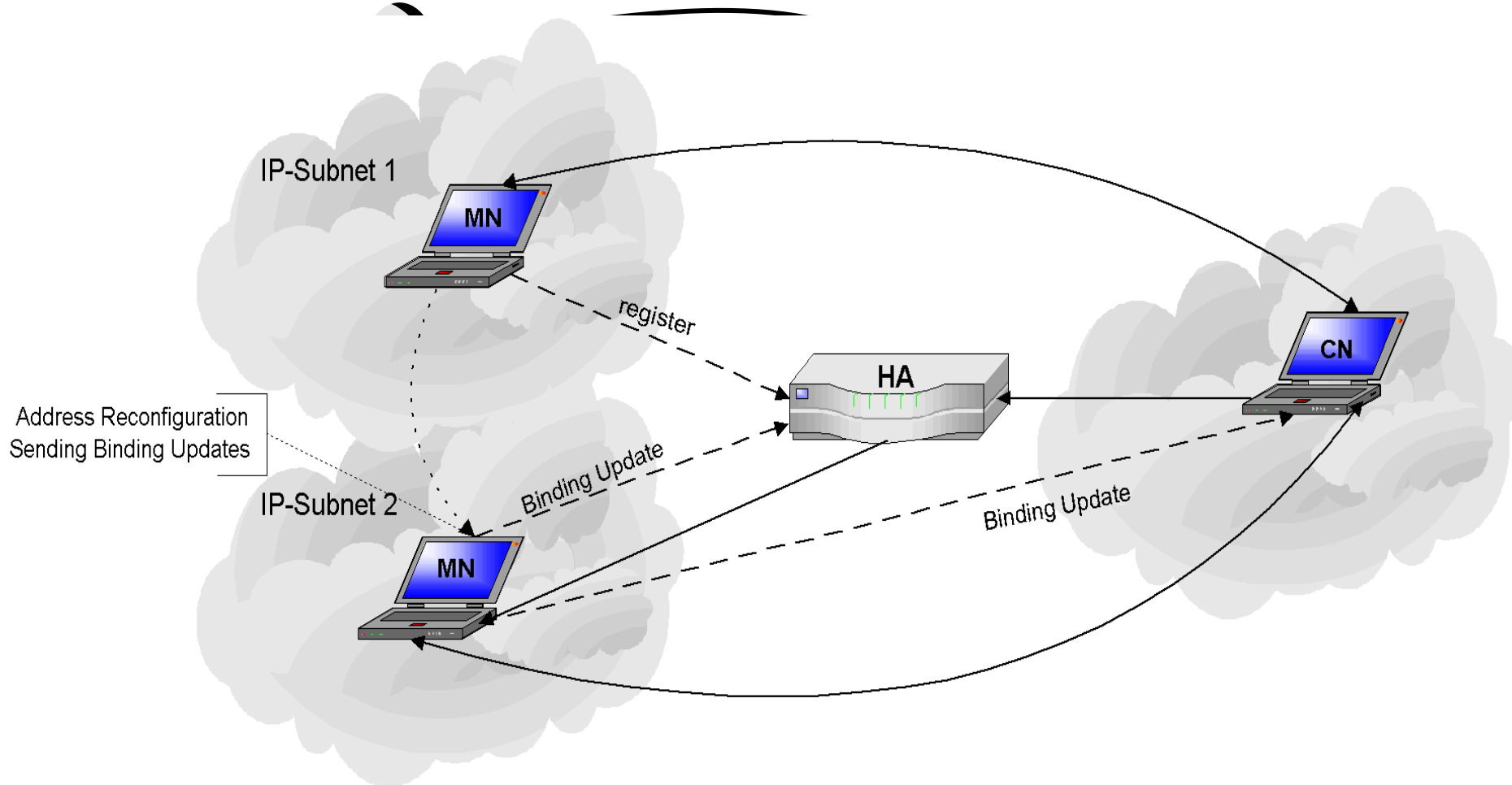
- o MN's stateless configuration of Care of Address in a foreign network and **Binding Updates** (BUs) with Home Agent (HA) and Correspondent (CNs).
- o MN, CN & HA keep **Binding Cache Tables**.
- o Home-Agent needed as Address Dispatcher.

**MIPv6** transparently operates address changes on IP layer by:

- o MN continues to use its original Home Address in a **Destination Option Header**, thereby hiding different routes to the socket layer.
- o CNs continues to use Home Address of the MN, placing it in a **Routing Header** (Type 2) as Source Route via the current CoA .

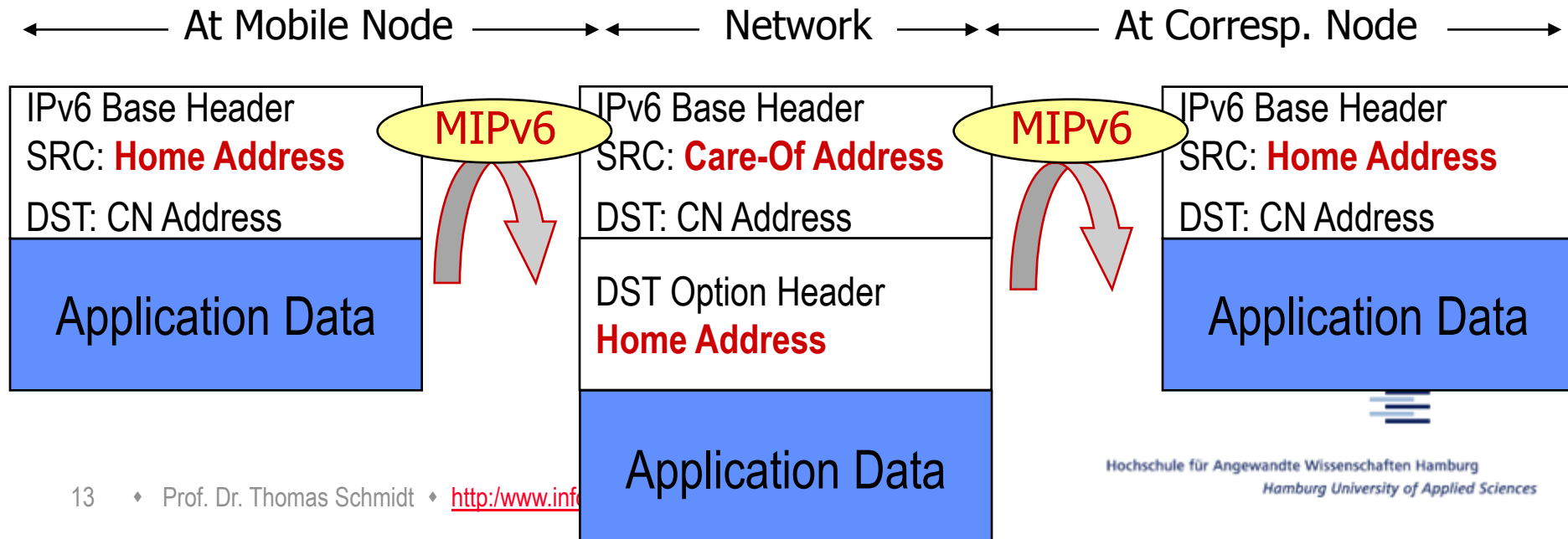


# Mobile IPv6 Signaling



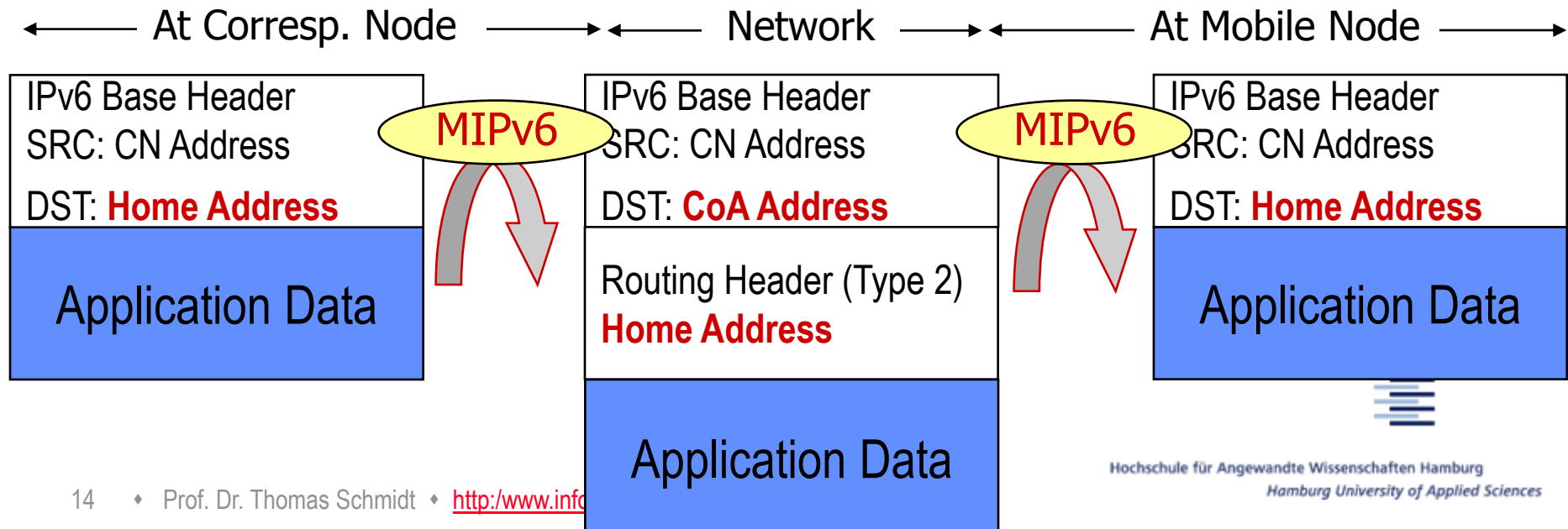
# MIPv6 Transparent Communication MN → CN

- o Application persistence requires continuous use of HoA
- o Infrastructure requires use of topologically correct source address: CoA
- o MIPv6 stack moves HoA to Destination Option Header



# MIPv6 Transparent Communication CN → MN

- o Application persistence requires continuous use of HoA
- o Route optimisation operates with CoA
- o MIPv6 extracts CoA from Binding Cache and initiates source routing to HoA via CoA



# Handover Security

Binding Updates place a severe security challenge:

**MN must provide strong authentication**

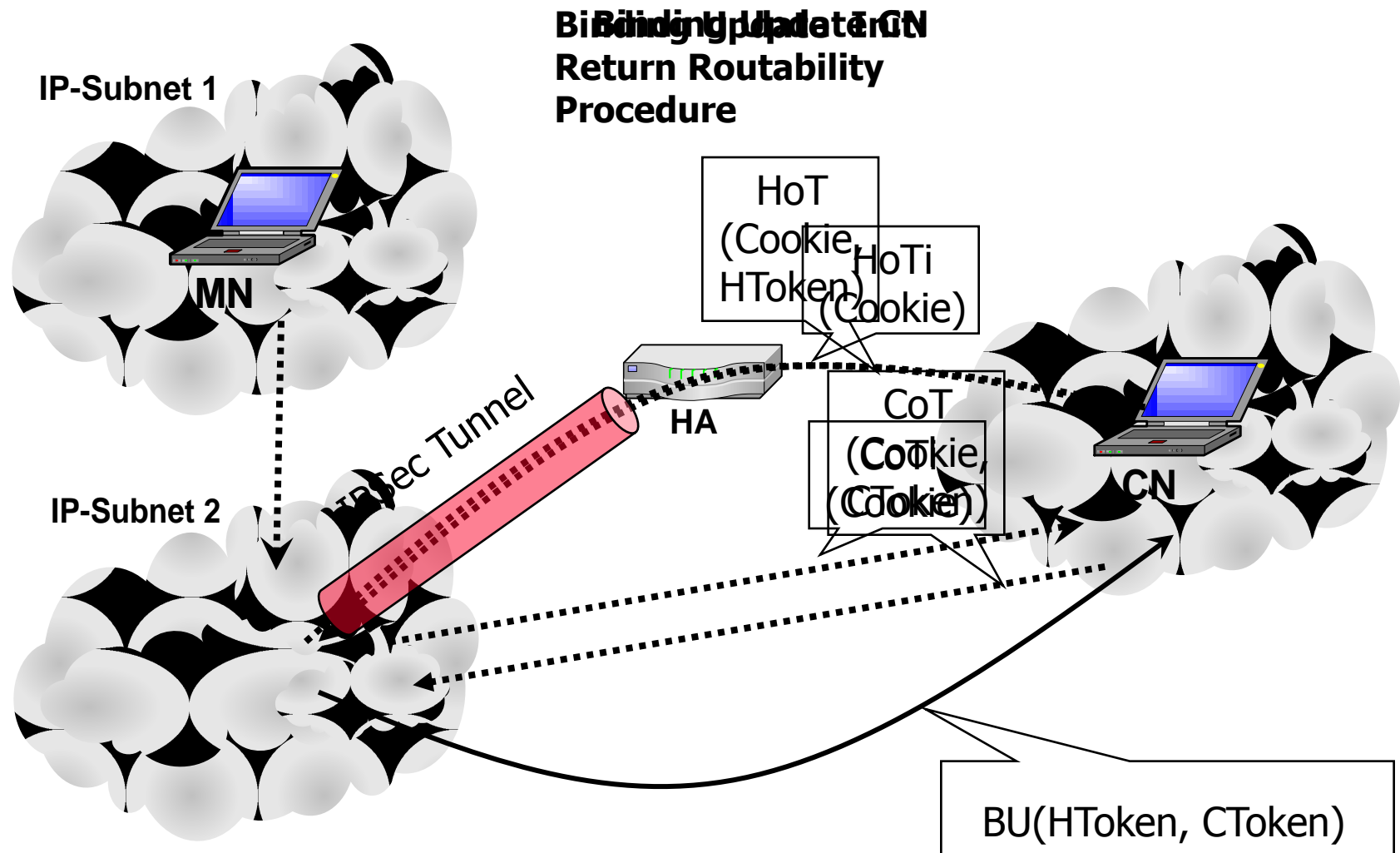
- o BU with HA: IPSec ESP Security Association (strong coupling)
- o BU with CN: Return Routability Procedure (lightweight coupling)

to test correctness of MN's HoA and CoA

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



# Securing Binding Updates: Return Routability





# Implementation Status

## o Major Releases / Bundles

OS	MN	HA	CN	Implementation
BSD	X	X	X	SHISA/KAME: <a href="http://www.mobileip.jp">www.mobileip.jp</a> , <a href="http://www.kame.net">www.kame.net</a>
HP-UX 11iv1/2		X	X	Tour 3.0: <a href="http://www.software.hp.com">www.software.hp.com</a>
HP Tru64		X	X	Mobile IPv6 4.0: <a href="http://www.hp.com">www.hp.com</a>
Linux	X	X	X	MIPL/USAGI: <a href="http://www.mobile-ipv6.org">www.mobile-ipv6.org</a> , <a href="http://www.linux-ipv6.org">www.linux-ipv6.org</a>
Windows XP			X	Included
Windows	X		X	Treck Mobile IPv6: <a href="http://www.treck.com">www.treck.com</a>

- o Full RFC3775 conformal implementation from Microsoft Research for Windows/Windows Mobile
- o MN/CN implementation in Nokia/Symbian
- o ...



# Deployment Status

- o Many tests in labs and experiments
- o Experimental Open Access Networks
- o US: Cellular Networks
- o Public experimental HA-service from Nautilus (Wide) project: [www.nautilus6.org](http://www.nautilus6.org)
- o Operators favour: SIP + NAT ... IMS
- o Firewall issues:
  - ESP filters
  - Port filter states: BU (partly) independent of forwarding
  - Debate on source routing / routing headers



# 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



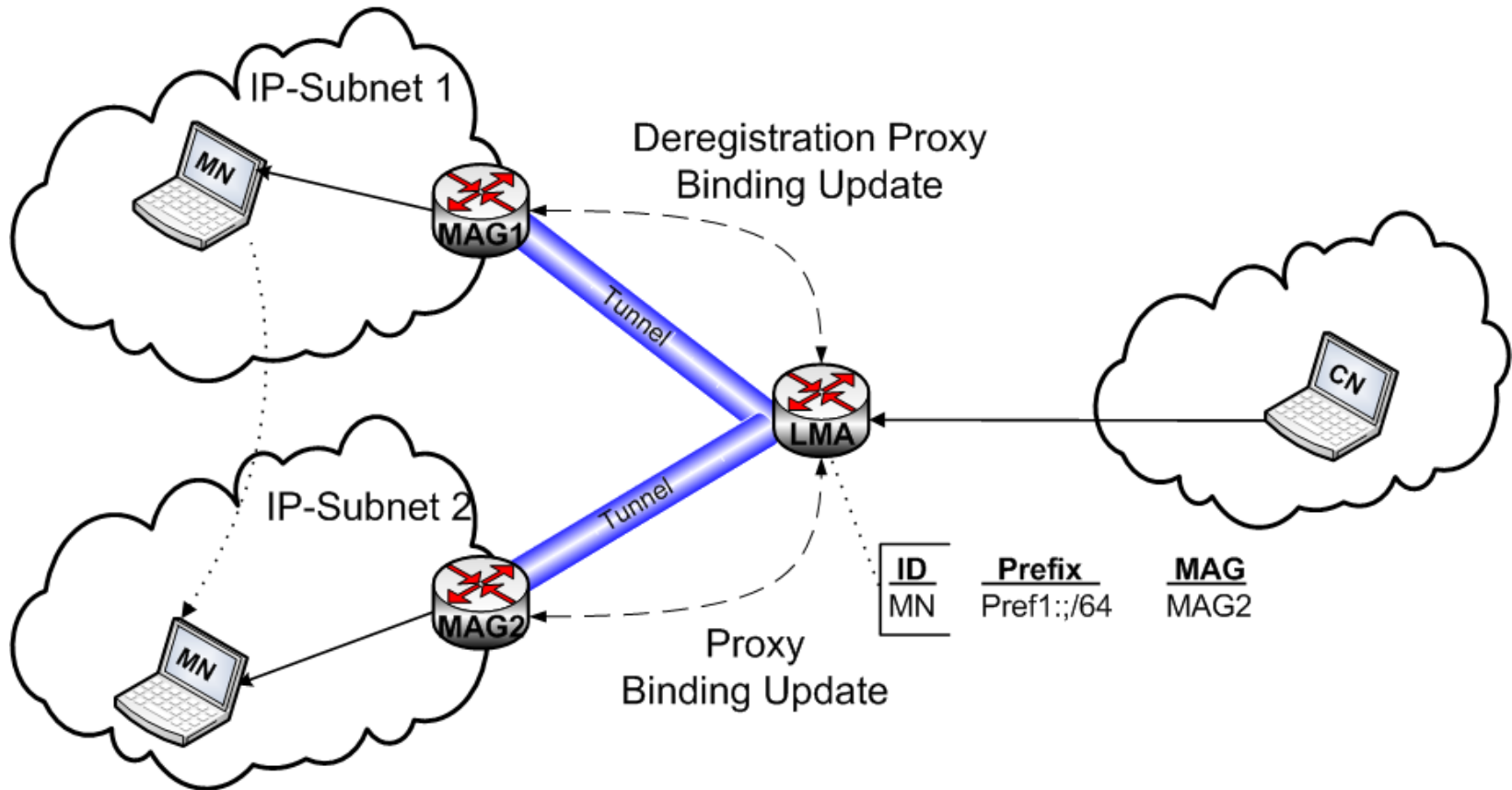
# Transparent Mobility: Proxy Mobile IPv6 (RFC 5213)

**Objective:** Support IPv6 Mobility without Client Support/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  $\approx < 100$  ms

! Jitter  $\approx < 50$  ms

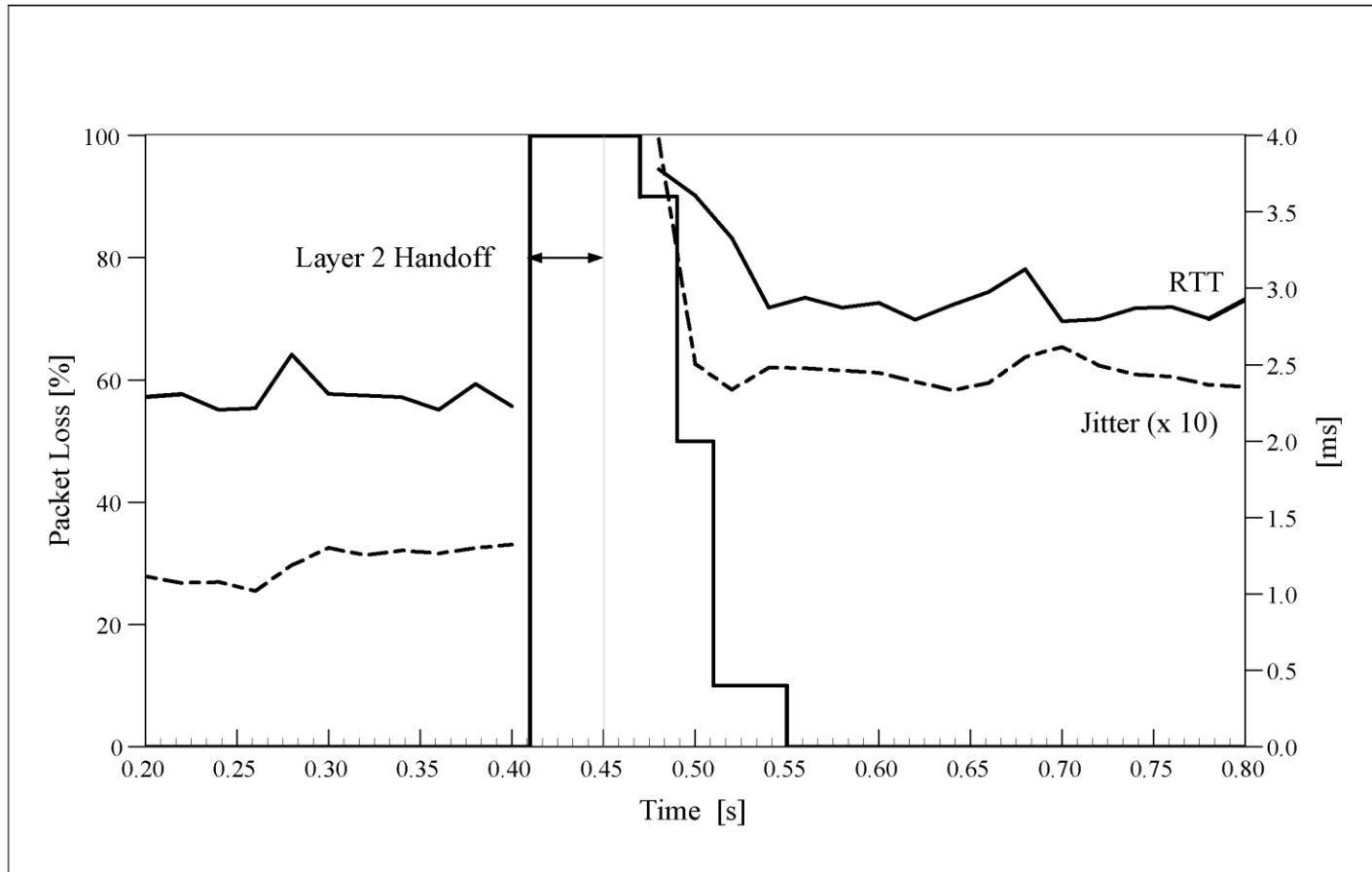
! Packet loss  $\approx < 1$  %

! Interruption: 100 ms  $\approx 1$  spoken syllable

→ 100 ms are critical bound

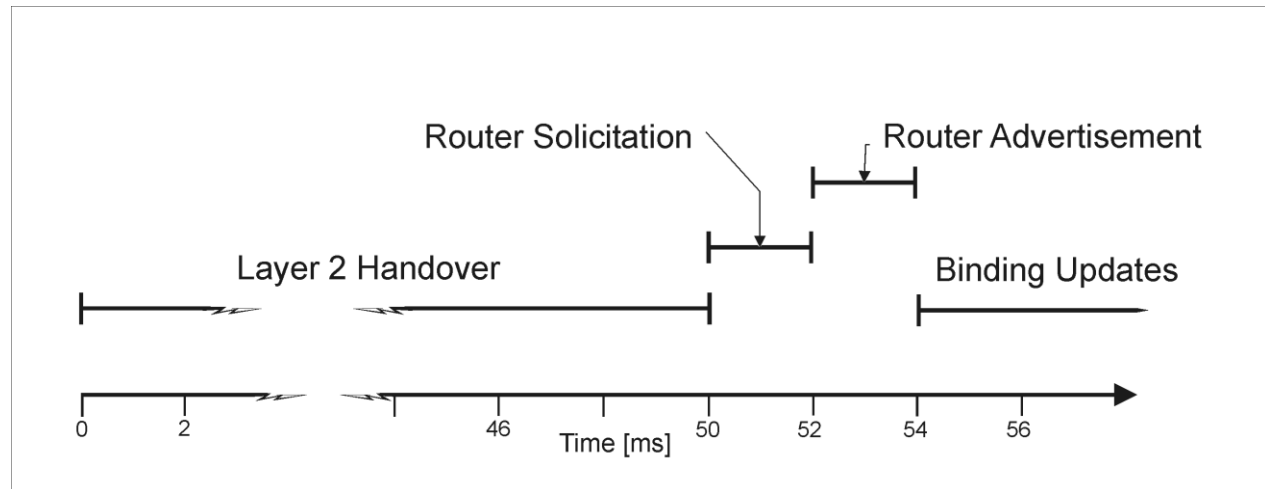


# Local Handover Measurements: Empirical Results





# Local Handover Acceleration: L2-Trigger & DAD Suppression



## IP-Config: Reduce

- MAX\_RA\_DELAY\_TIME  $\approx 1 - 5$  ms
- MAX\_RTR\_SOLICITATION\_DELAY  $\approx 1 - 5$  ms

## Problem:

**Binding Updates are strongly topology dependent**



# MIPv6 Handover: Topology Problem

o Generally HA and CN are at Significant Distance

o Handover Time: ( $t_x$  is RTT MN  $\leftrightarrow$  X)

$$t_{handoff} = t_{local} + t_{BU-of-HA} + t_{BU-of-CN}$$
$$\approx t_{local} + \frac{3}{2} t_{CN} + 2t_{HA}$$

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

o Essential: Eliminate HA/CN



## RTT Dependence

# Handover Acceleration: HMIPv6 & FMIPv6

## Hierarchical Mobile IPv6

- o 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
- o Inter-domain HO requires regular BUs via MAPs

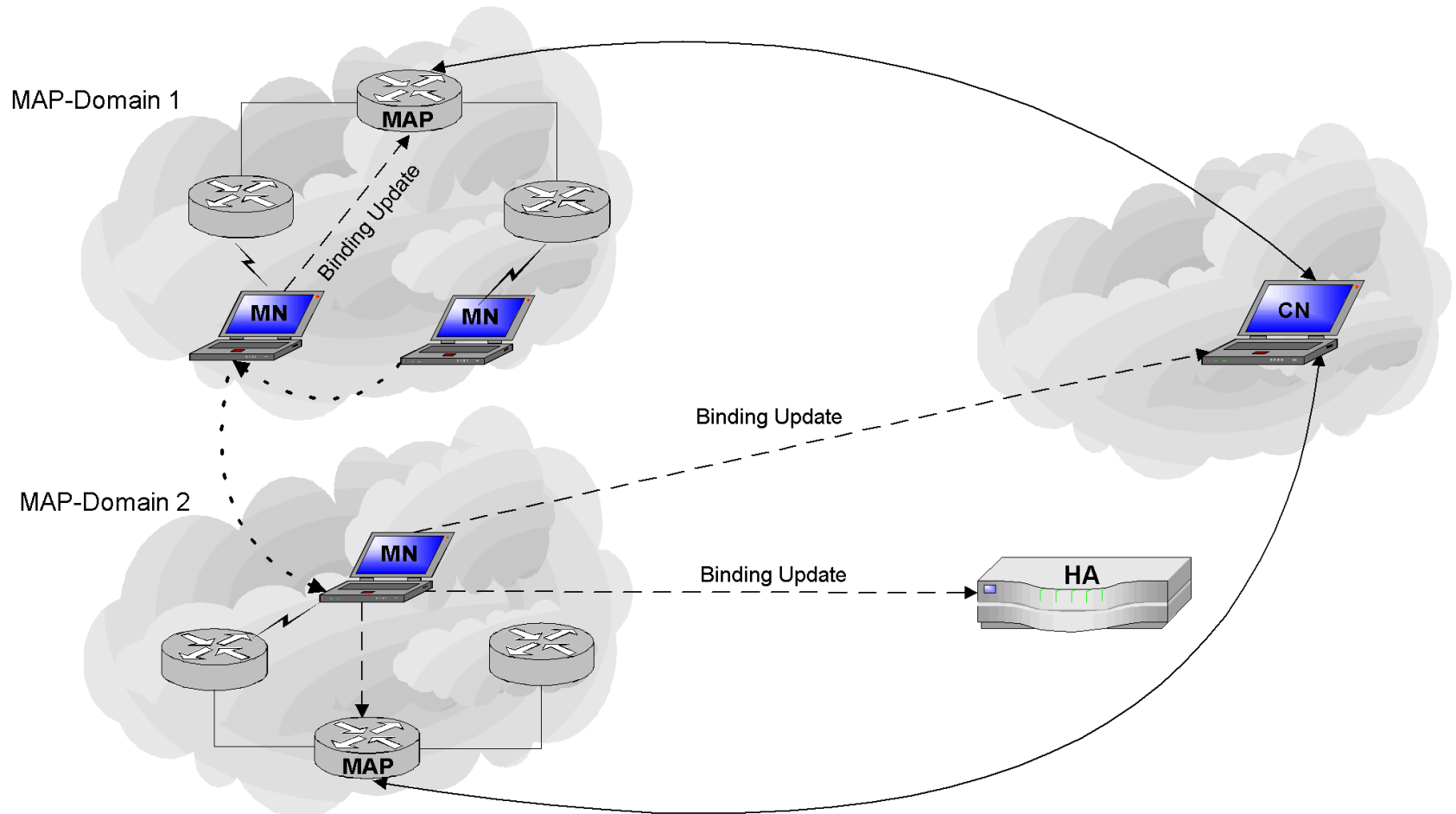
## Fast Mobile IPv6

- o Handover Management at Access Routers
  - Predictive HO based on L2:L3 topology map, pre-configures New CoA
  - Reactive HO as fallback
- o BUs operated asynchronously

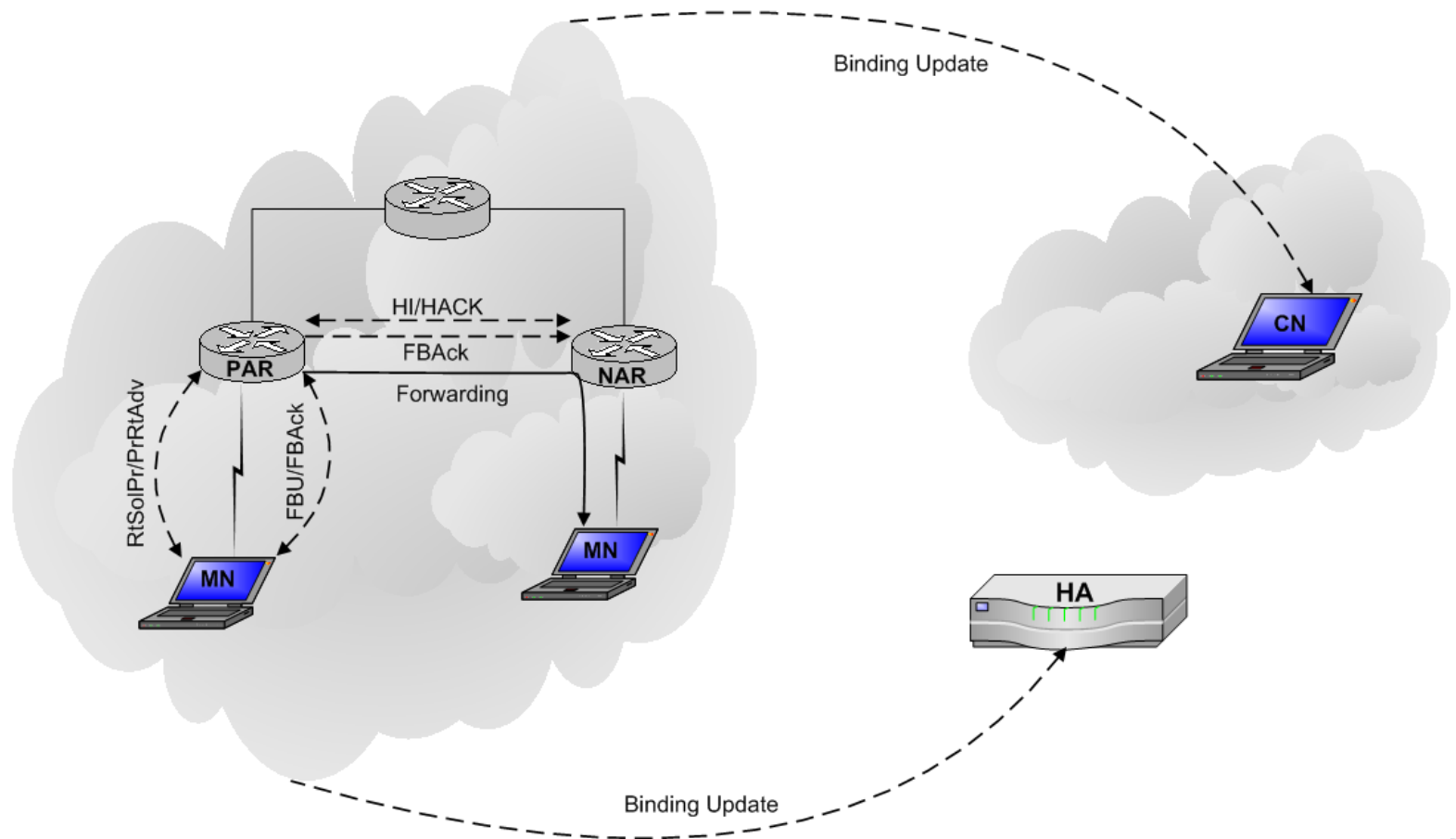
Both approaches resolve topological dependences



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



# Edge Handover Management: Fast MIPv6 (RFC 5568)



# Handover Analysis: Predictive versus Reactive

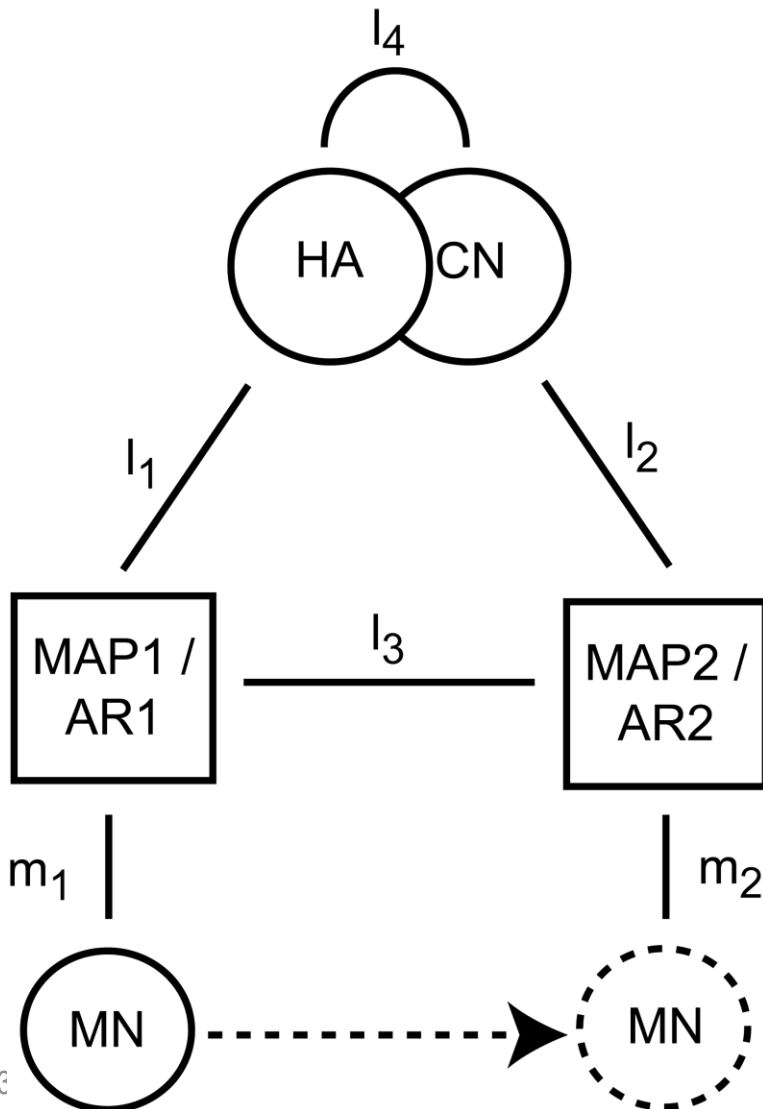
## Relevant criteria

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



# Handover Performance

## Simple analytical model:



- o Compare reactive vers. predictive handover
- o Characteristic to problem: Router distance  $t_{l_3}$
- o Charac. to predictive HO:
 
$$(t_{Ant} - 2t_{l_3}) + (t_{L2} - t_{l_3})$$
- o Charac. to reactive HO:

$$t_{l_3} + t_{L2}$$



# More detailed ...

## o Reactive Handover:

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

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

## o 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

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

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



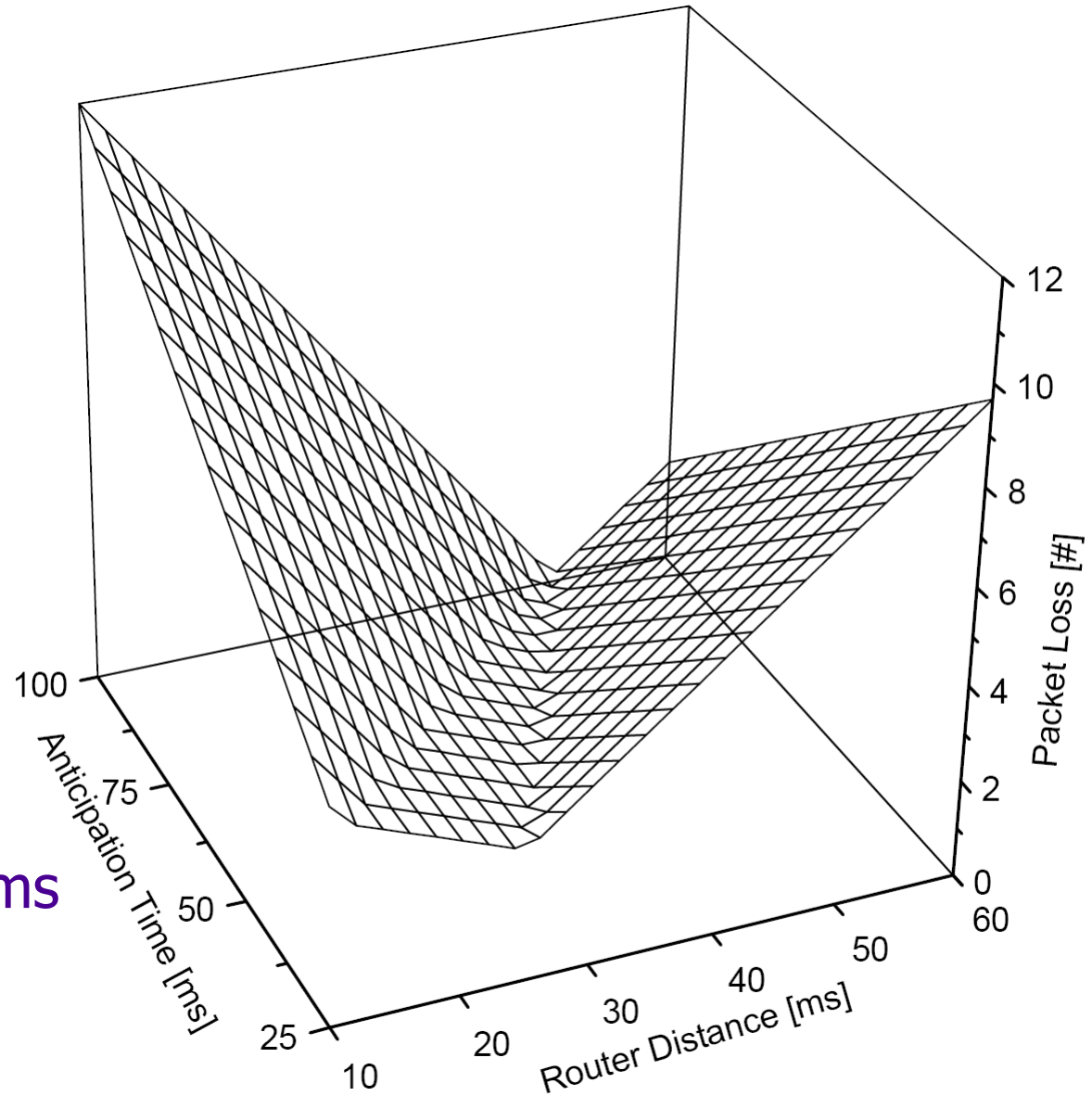


# Packet Loss Function

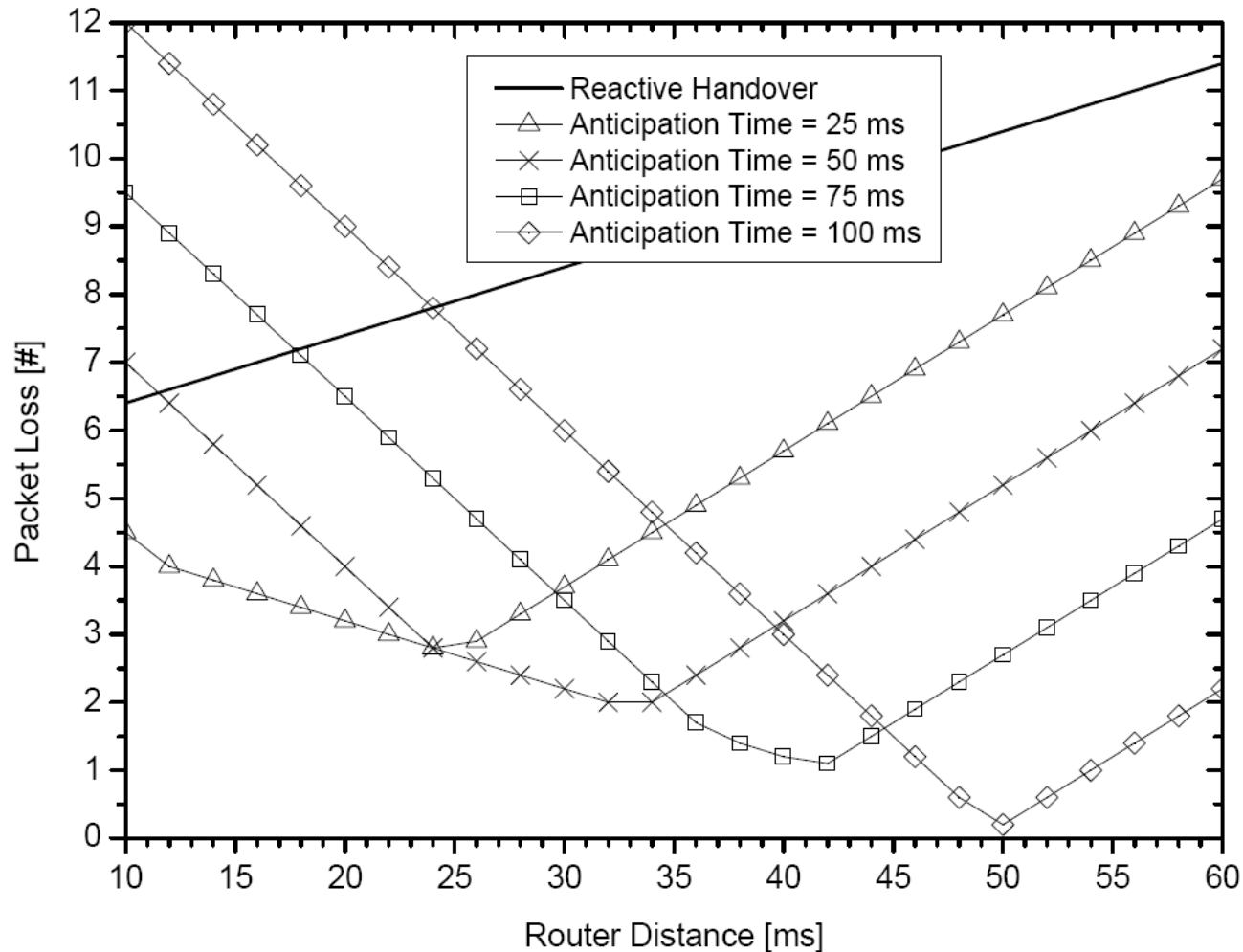
L2 Delay: 50 ms

Traffic:

CBR at 1 Pkt/10 ms



# Comparative Samples

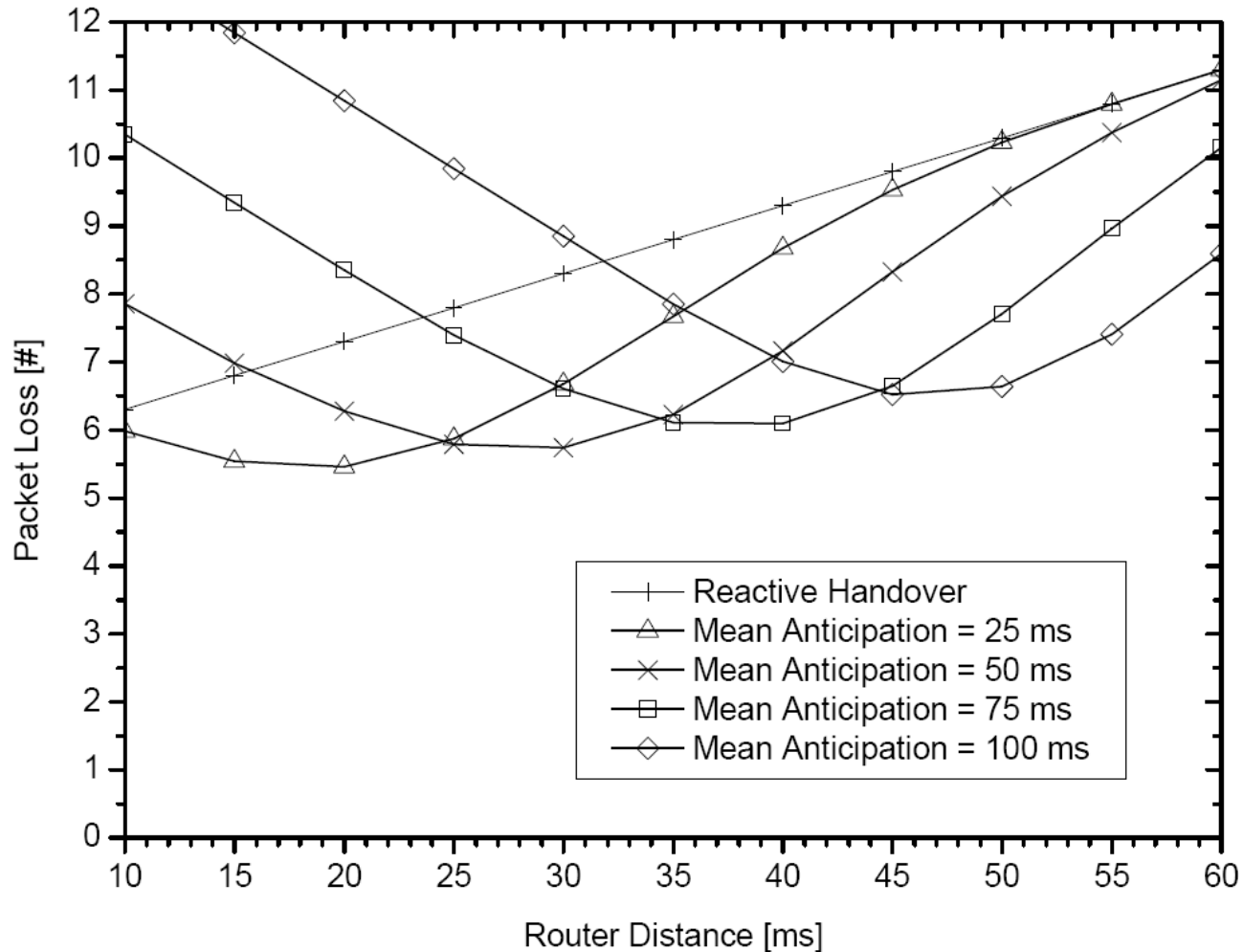


# Packet Loss: Stochastic Simulation

- o Constant bit rate traffic from CN/HA (at 10 ms)
- o Random perturbations ( $\xi$ ) at each link
- o Parameters:
  - Anticipation Time:  $\langle x \rangle = * \text{ ms}, \xi = 30 \text{ ms}$
  - L2 Handoff:  $\langle x \rangle = 50 \text{ ms}, \xi = 10 \text{ ms}$
  - Local Links:  $\langle x \rangle = 2 \text{ ms}, \xi = 1 \text{ ms}$



# Packet Loss



# Why is Reality Worse?

Analytical Model did not Account for

- o Geometry

- o Link Perturbation

- o 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)



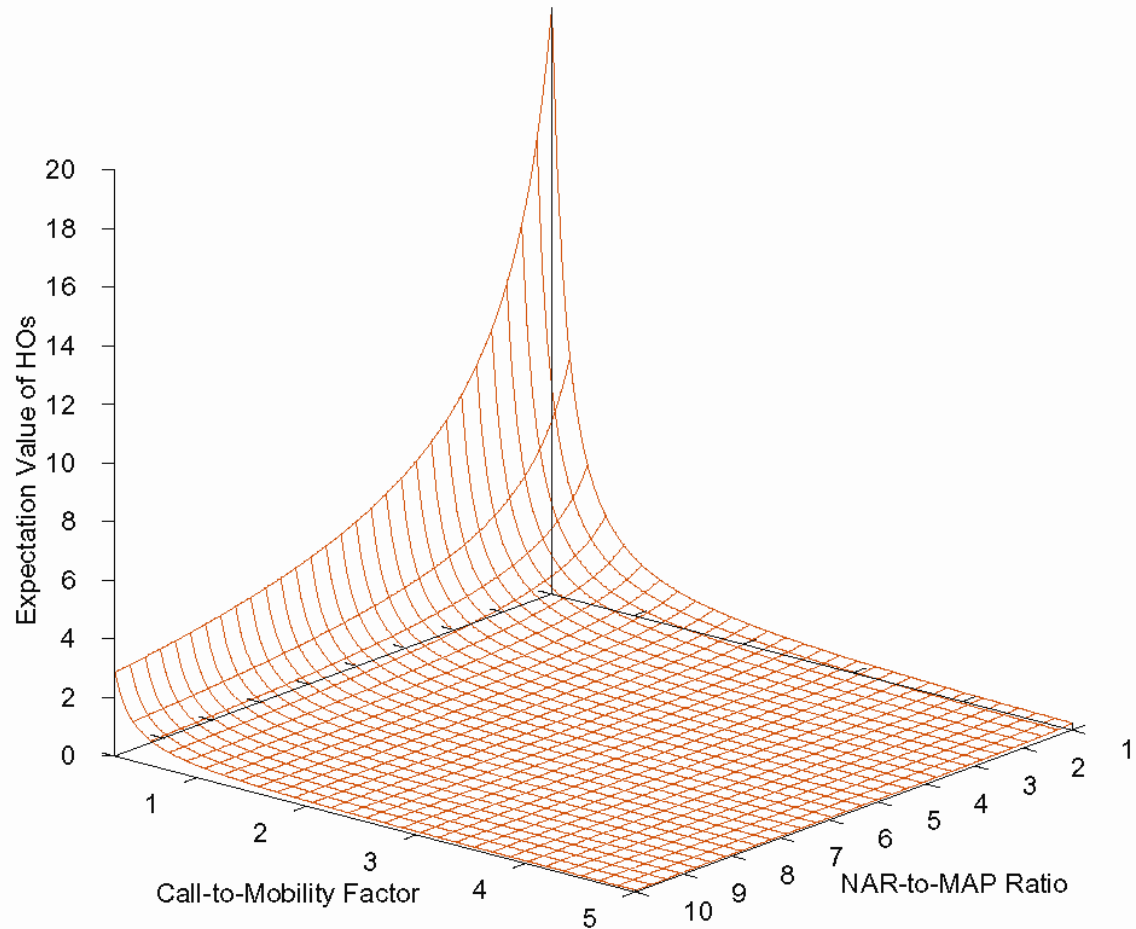
# Expected # of Handovers

Analytical result:

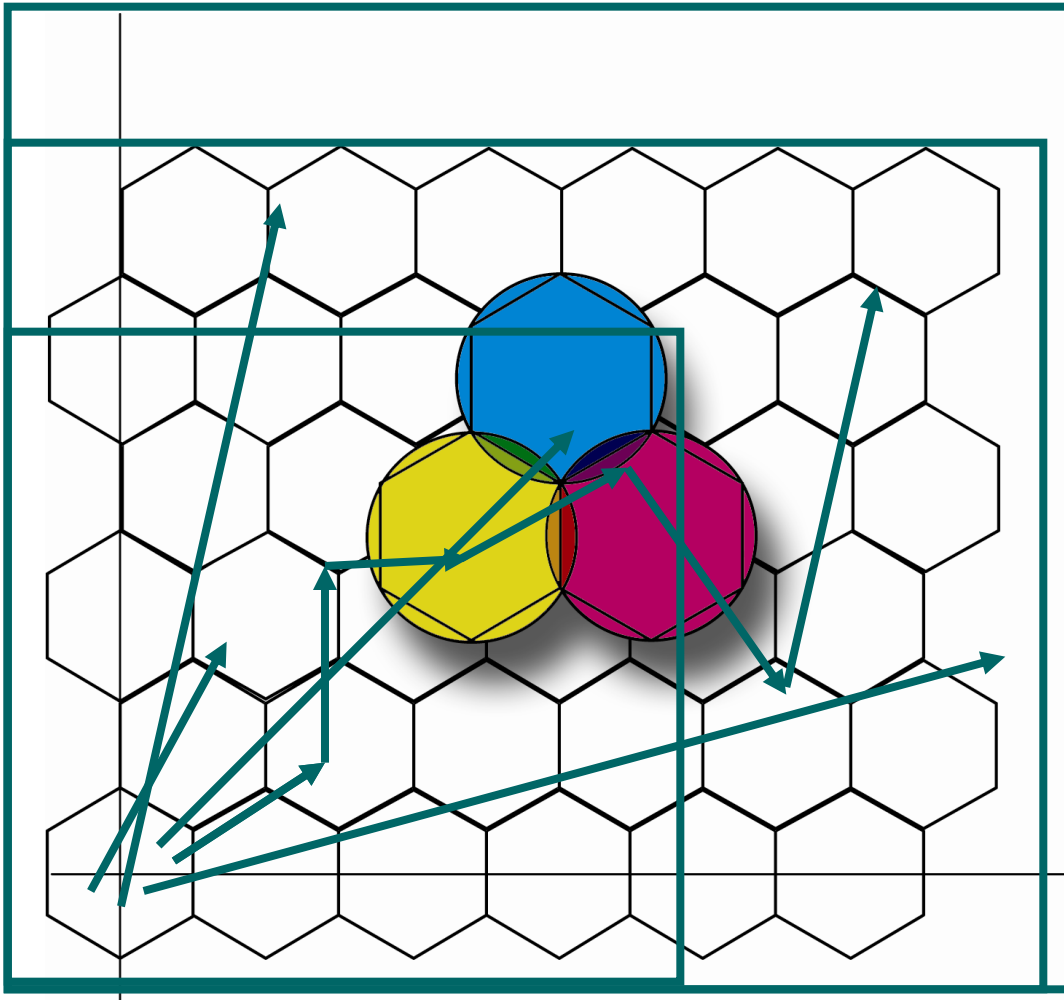
$\rho$  = Call-to-mobility  
factor

$k$  = AR-to-MAP ratio

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



# Handover Predictions: Stochastic Simulation



Models:

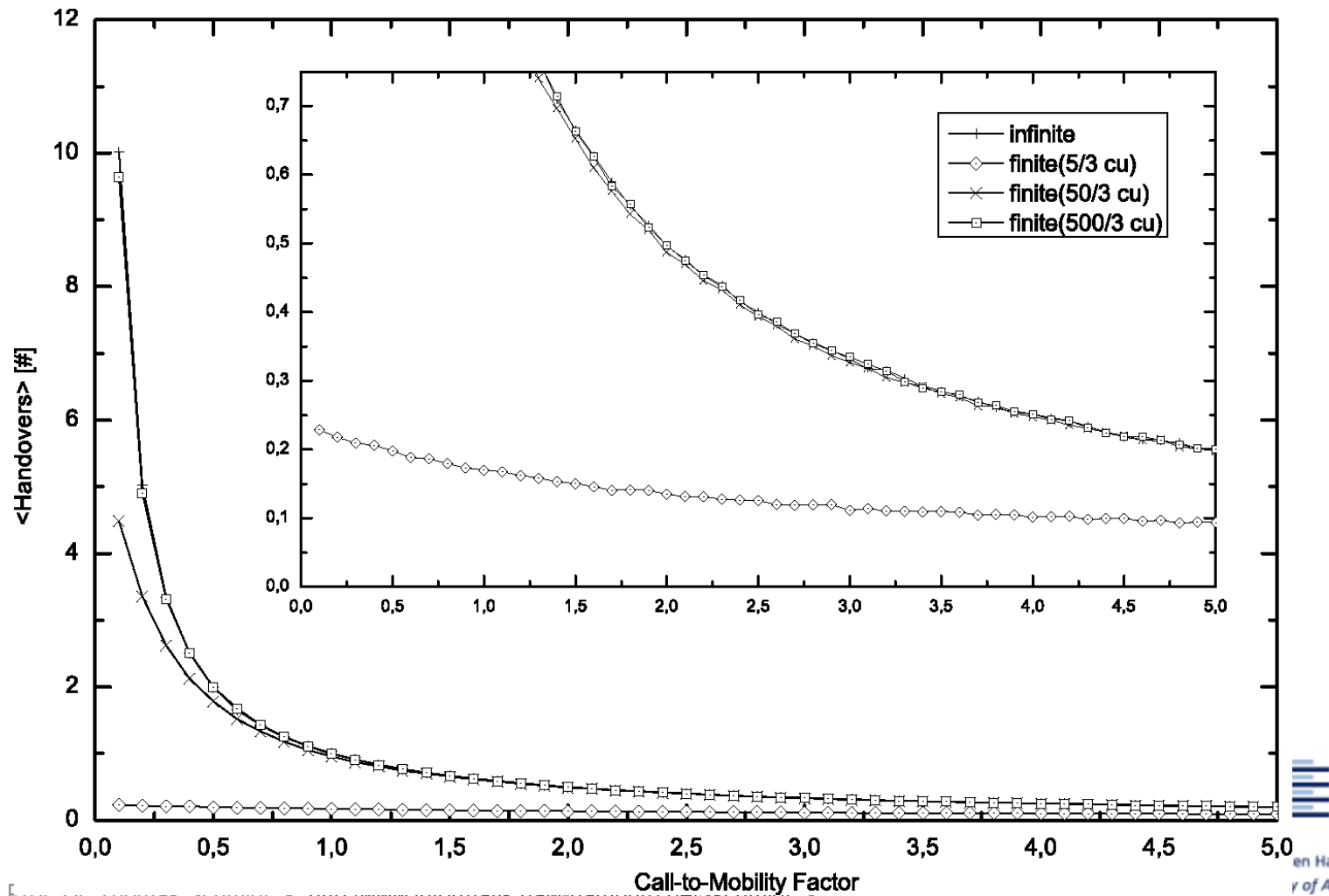
Random Waypoint  
Varying Geometry

Random Direction  
Varying Geometry  
Varying Speeds

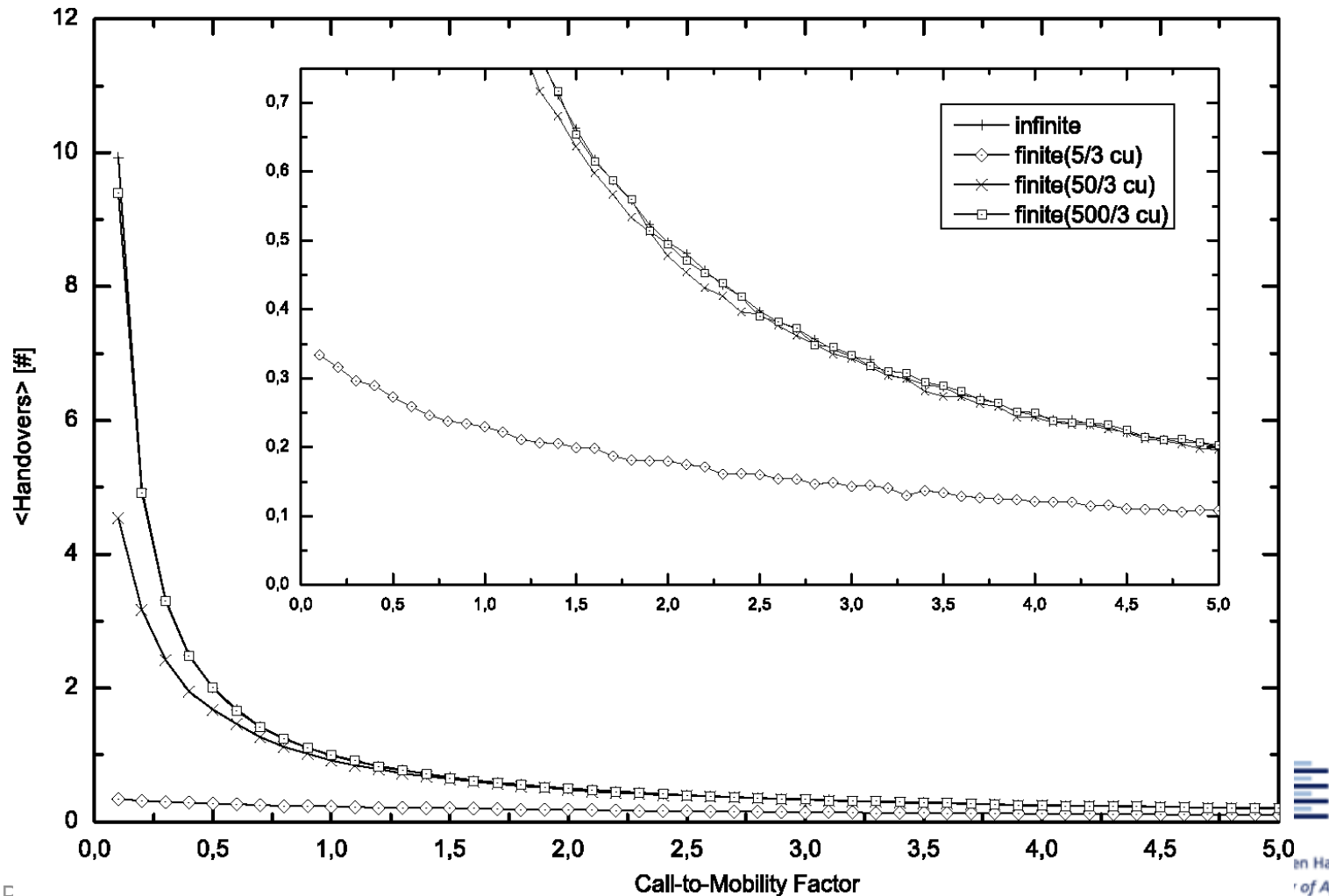




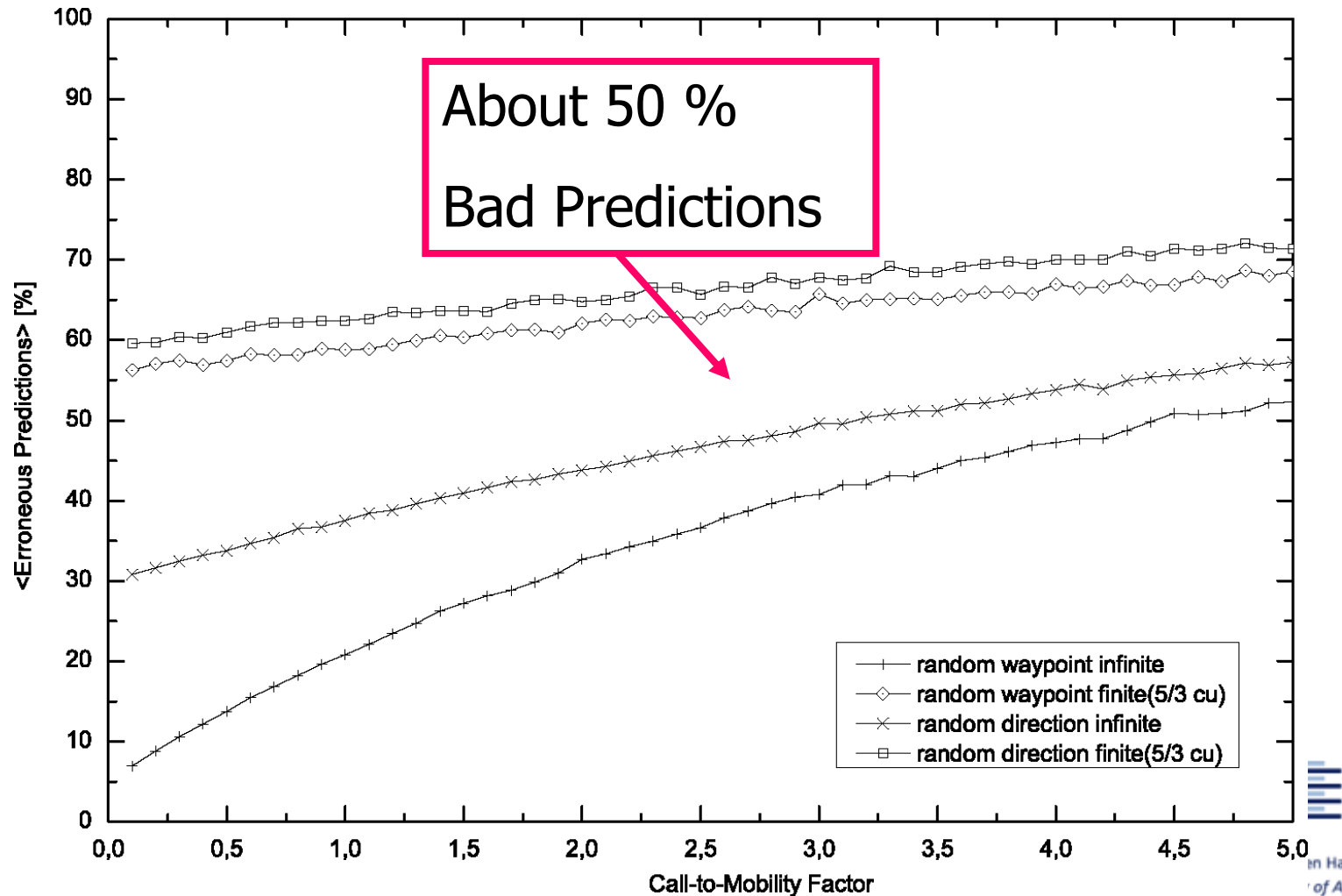
# Mean Handover Frequencies: Random Waypoint Model



# Mean Handover Frequencies: Random Direction Model



# Erroneous Prediction Yields

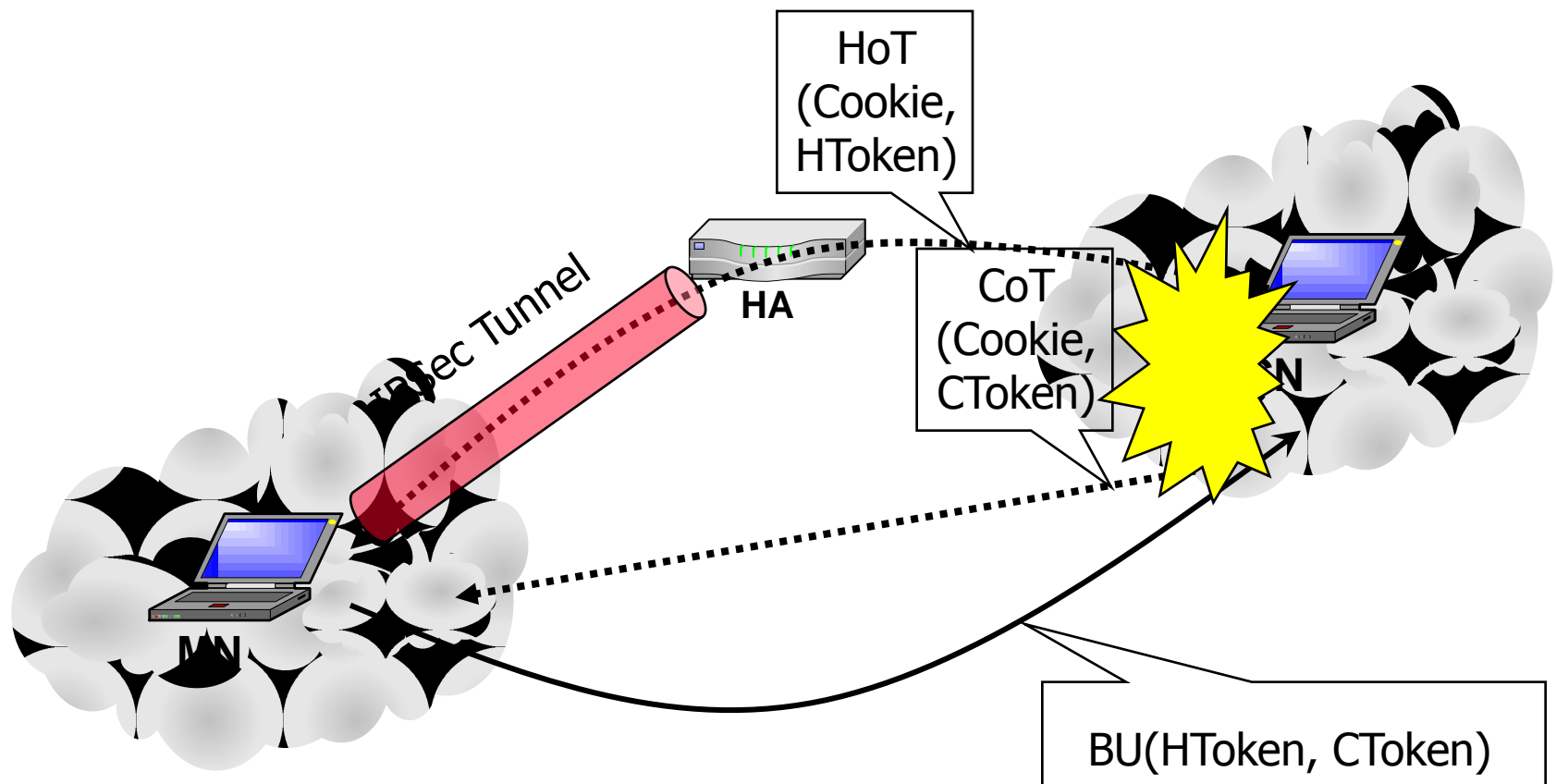


# Handover Security Problems

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



# Problem: Man in the Middle



# The Core of the Problem?

For Authentication

A Mobile Node must proof ownership of HoA

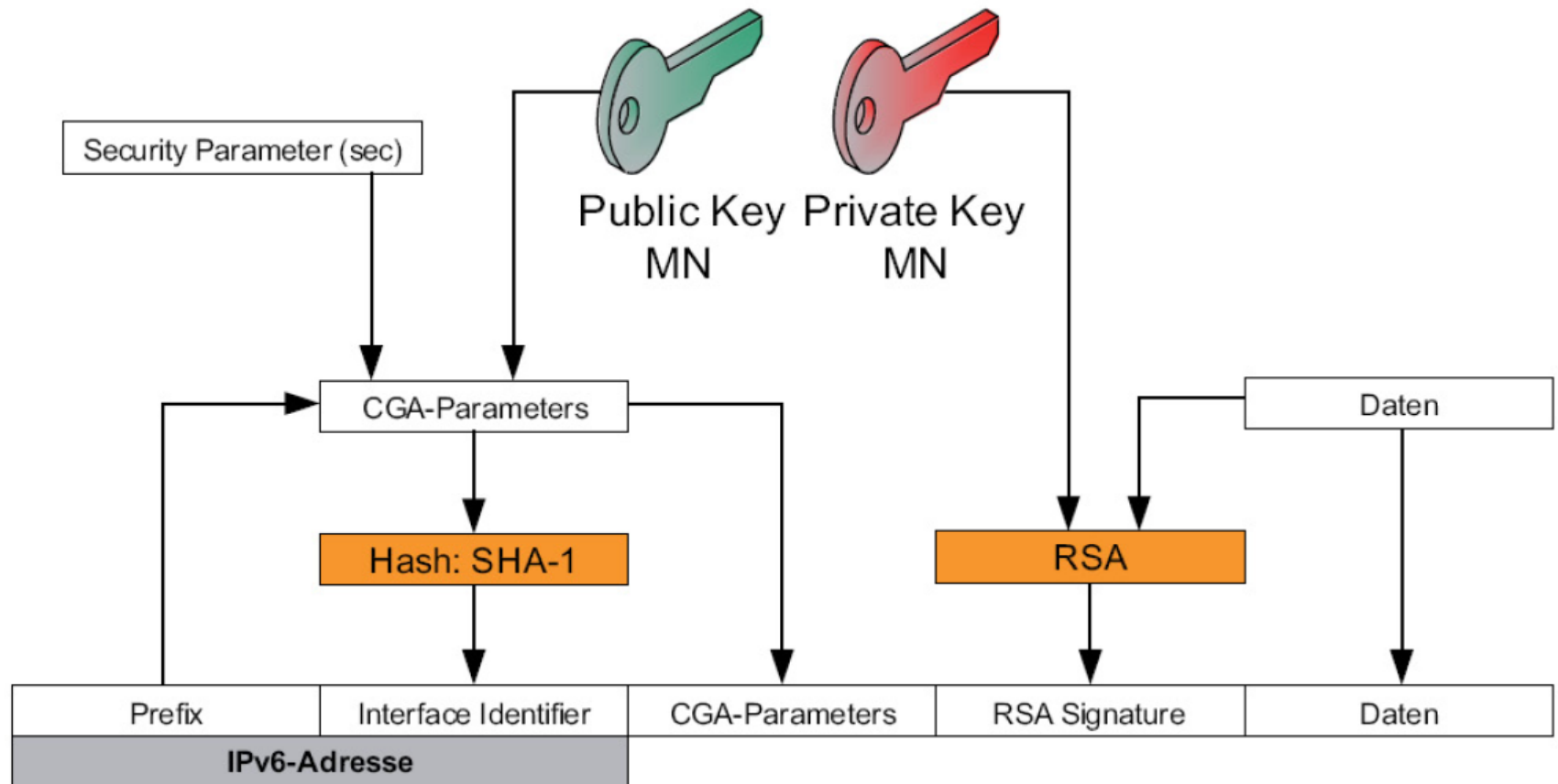
But: Certification Infrastructure (PKI) is out of scope

Idea in IPv6:

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

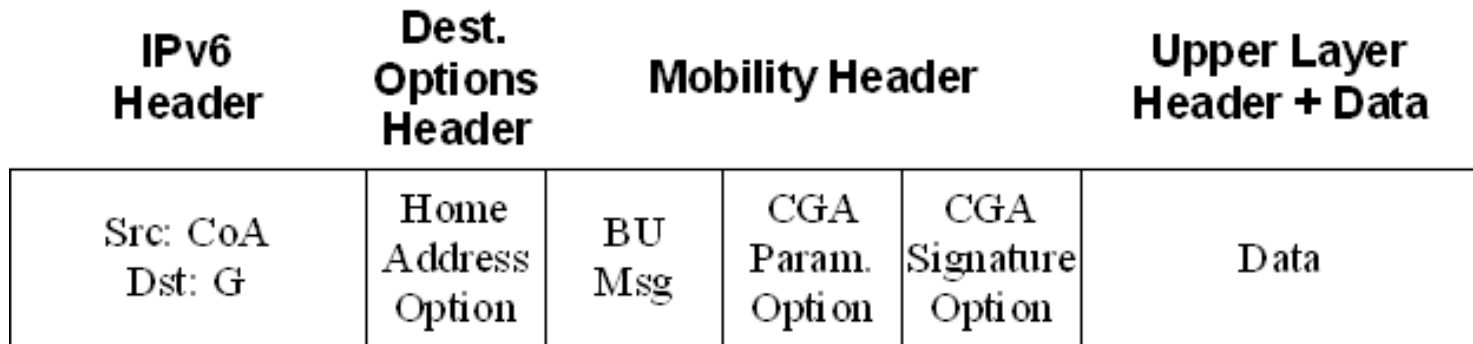
- o Generate public/private key pair: e, d
  - o Generate host-ID from public key: 64 sha1(e)
- ➔ Packets now can authenticate their address (and content) self-consistently!

# CGA Packet Authentication



# Binding Update

*Enhanced Route Optimization for Mobile IPv6 (RFC 4866)*



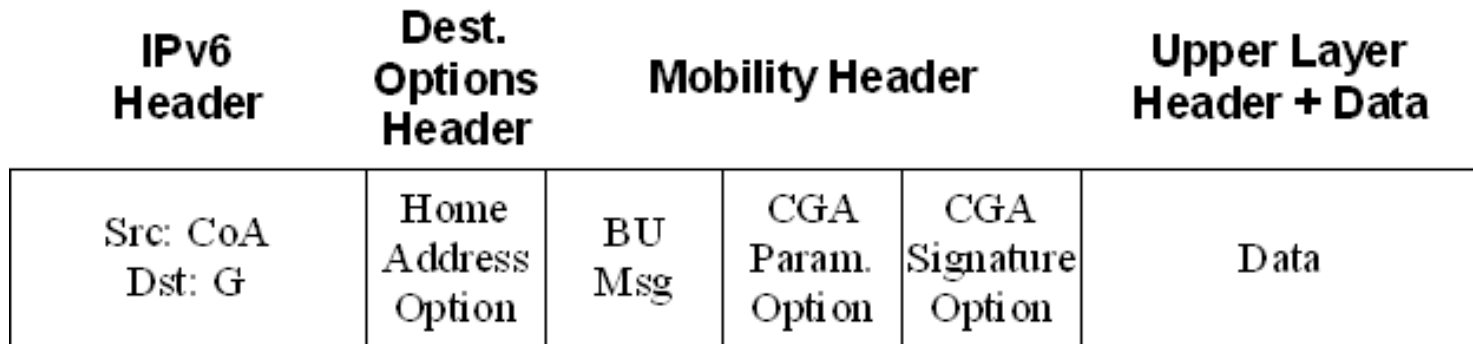
Base header is Home Address unaware.





# Binding Update

*Enhanced Route Optimization for Mobile IPv6 (RFC 4866)*

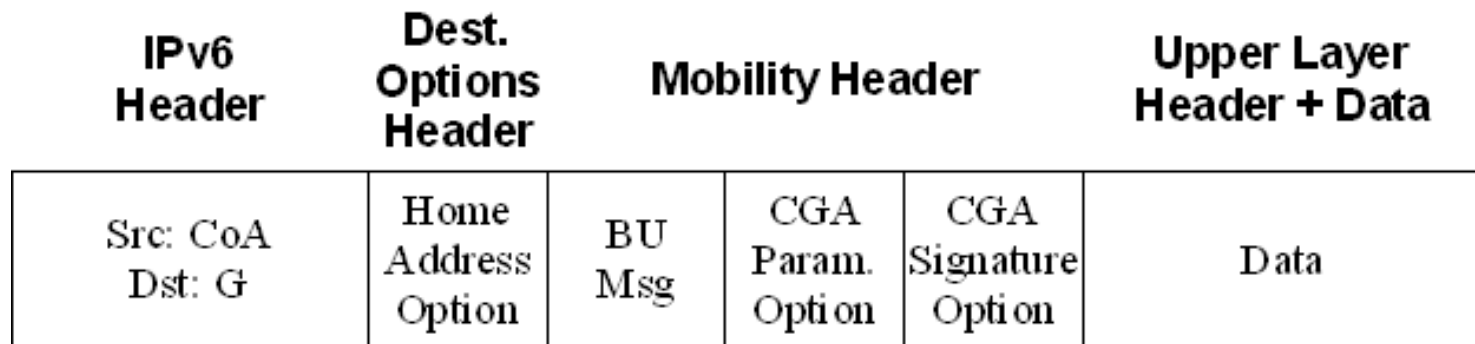


The destination receives the Home Address in the Destination Options Header.



# Binding Update

*Enhanced Route Optimization for Mobile IPv6 (RFC 4866)*

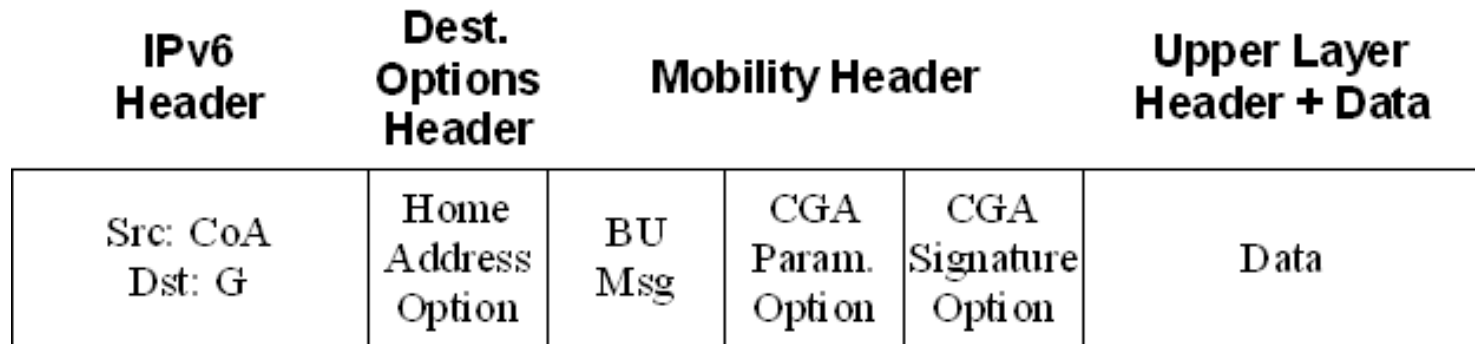


The update itself is stored in the Mobility Header.



# Binding Update

*Enhanced Route Optimization for Mobile IPv6 (RFC 4866)*

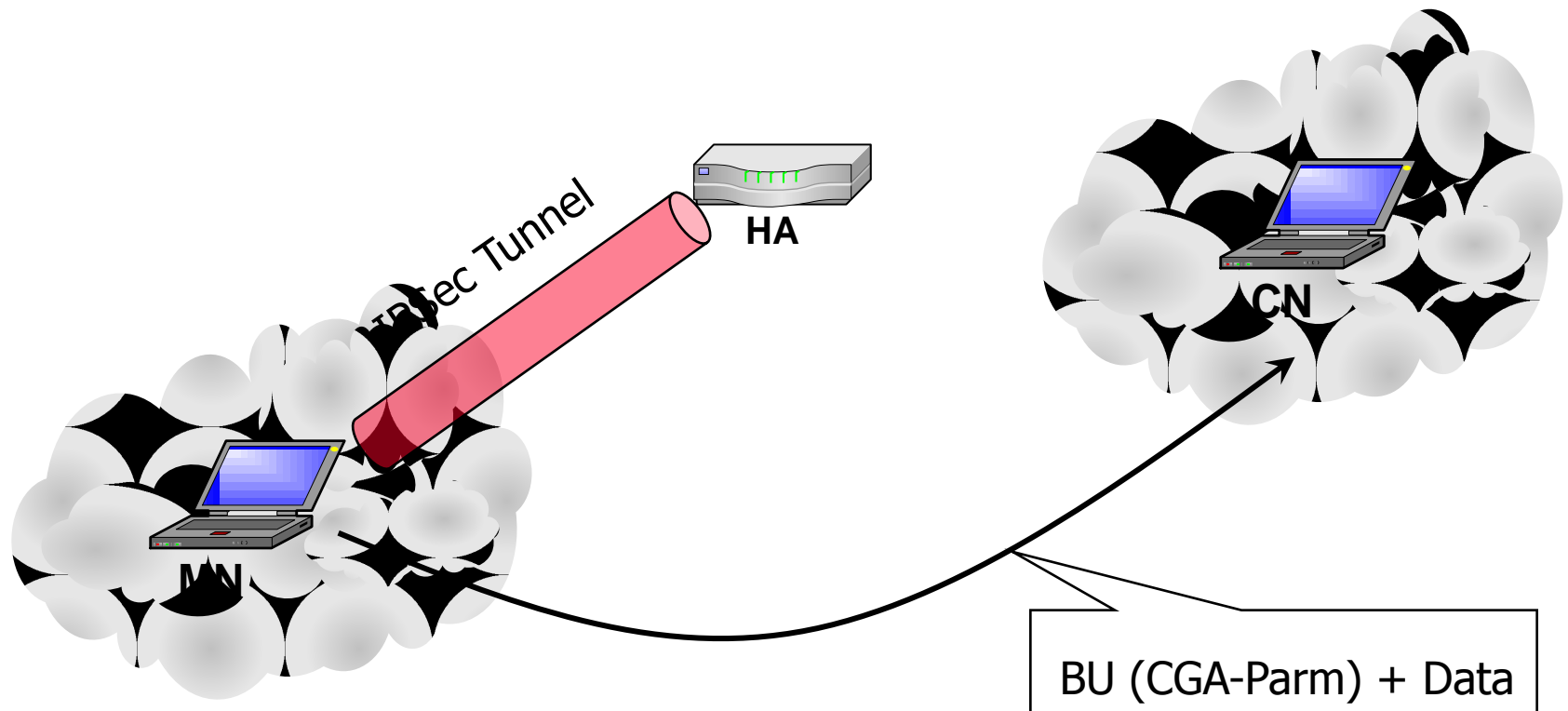


CGA options verify the HA and sign the packet



# CGA-Authenticated BU (RFC 4866)

Initial HoA-Reachability Test  
Further on per Handover:



# Multicast Mobility: Problems & Objectives

## Multicast Mobility in MIPv6: Problem Statement

Provide Seamless Multicast Services to and from MNs

- o Approach native multicast forwarding in an infrastructure-compliant manner
- o At Listeners:
  - Ensure multicast reception in visited networks
  - Organize context transfer between mcast-enabled access networks
- o At Sources:
  - Sustain address transparency at end nodes (address duality problem)
  - Ensure persistence of receiver contact (decoupling problem)
  - Bridge tardy tree reconstruction/transformation procedures
- o Focus on deployable solutions, minimize protocol extensions

# Multicast Mobility Approaches

## o Remote Subscription

- Show all movement by local multicast subscription

## o Bi-directional Tunnelling

- Hide all movement by tunnelling via Home Agent

## o Agent Based

- Compromise: Intermediate agents shield Mobile
- Approaches: Extend unicast expediting schemes  
M-FMIPv6, M-HMIPv6, ...



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- 🕒 Current Status, Conclusions & Future Trends



# Status: Where are we today?

- o Internet Mobility
  - Mobile IPv6 - RFC 3775 (June 2004, widely implemented)
- o 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)
- o Carrier-Operated Mobility for MIPv6-unaware Nodes
  - PMIPv6 – RFC 5213 (PtP Links only, August 2008)
- o Multicast Mobility
  - WG in IETF (Multimob), first RFC for PMIPv6
- o Multihoming & MIPv6 – on debate





# Conclusions & Future Trends

- o MIPv6 is about ready for deployment ...  
... and a beautiful illustration of IPv6's potentials
- o MIPv6 operates in end-to-end paradigm, a conflict with operator concepts
- o PMIPv6 could serve as a “mediating protocol”, deployment in preparation
- o Key issue of developing the mobile regime:  
Gain control on end-devices





# References

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- Schmidt, Wählisch: *Predictive versus Reactive – Analysis of Handover Performance and Its Implications on IPv6 and Multicast Mobility*, Telecomm. Systems, 30, 1-3, Nov., 2005.

