IP Mobility Distributed M.Sc.

http://www.comp.lancs.ac.uk/computing/staff/joe/enext-msc/

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Joe Finney

- Lecturer within the Computing Department at Lancaster, UK
  - Working with IP mobility for many years
  - Involved in the development of Mobile IPv6
    - Collaborations with Microsoft, Orange, Cisco, BT
    - Linux, Windows NT / 2000 / XP, Cisco IOS
    - Handoff Efficiency, IPv6 transitioning and security concerns
    - Real-time collaborative mobile systems
  - Ongoing work
    - NP++: Highly flexible Internetworking Protocol and architecture.
    - NEMO: Efficient end to end telemetry networks for field workers.
    - Firefly: Networking for ad-hoc display technologies.

Agenda for Today

- Introduction to Network Layer Mobility
  - Definition and Motivations
  - Benefits, drawbacks and alternatives
  - Issues
- Mobile IPv6
  - Core protocol and its features
  - Micro Mobility
  - Analysis and limitations
- Related research work
  - Recent trends and developments in the field

Network layer mobility

- Many different types of mobility
  - Host mobility
    - Devices roaming between points of attachment
  - User mobility
    - Users roaming between devices
  - Application mobility
    - Applications roaming between devices
  - Service mobility
    - Network service roaming around networks
- Today we'll focus on **host mobility**

Network Mobility

- Host mobility can be tackled at a number of layers…

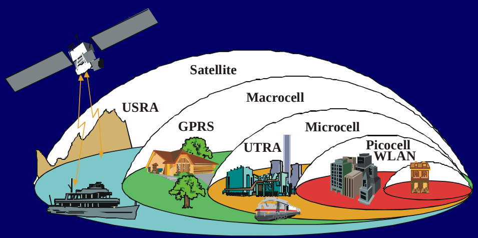
– Application Layer	Mobile Aware applications
– Session Layer	SIP, Mobile Sockets
– Transport Layer	Mobile TCP / HIP
– Network Layer	Mobile IPv4/v6, NEMO, LMM
– MAC Layer	VLANs, 802.11, GSM?
– Physical Layer	Big Transceivers!

Generalization vs. Specialization

Tradeoffs

Overlay Networks

- Large number of heterogeneous networks…
  - Satellite
  - GSM
  - CDPD/GPRS
  - DECT
  - Wireless LAN
  - Bluetooth
  - IR
  - Wired Networks



Why IP?

- Network Layer has a convenient balance of
  - Transparency
    - Common point of abstraction – hourglass model
  - Scalability
    - Designed to scale, so just don't break it.
  - Management
    - Would allow nodes to cross independently administered domains
  - Efficiency
    - Relatively simple, low state protocol
    - Close to underlying technologies
  - IP seems the natural choice…
  - Response time and privacy?
    - <ahem> well, more on that later! ☺

Limitations of IPv6 wrt Mobility...

What is IPv6

- IETF standard for the next generation Internet Protocol
  - AKA IPng
- Design goals
  - Address the failings of IPv4
  - Namely:
    - Scalability
    - Efficiency
    - Extensibility

IP and Scalability...

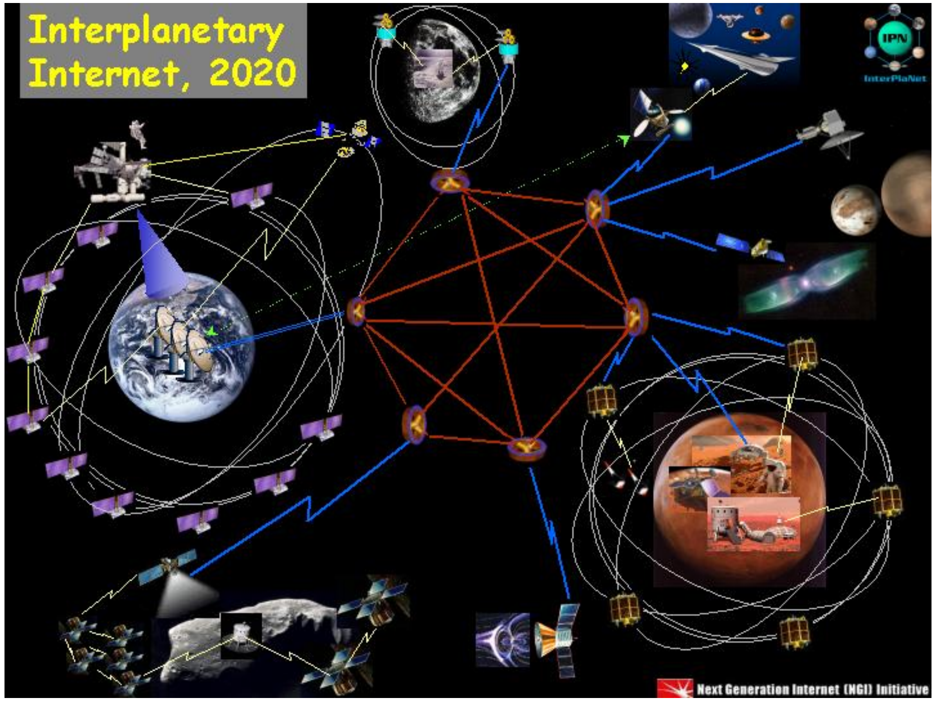
- IPv4 lacks scalability due to addressing
  - 32 bits address space (4.4 Bn addresses)
  - Most addresses allocated to US
    - MIT has more addresses than China...
    - Currently little under 1Billion IPv4 users
  - 32M addresses requested for GSM2.5
    - >1.5 Billion GSM users
    - 670 Million GSM phones shipped in 2004 alone
    - Always on IP connectivity
    - Paradigm shift - P2P, ubicomp...

IPv6 – Size Matters...

- Extended address space
  - 128 bits long
  - Unicast, Multicast or Anycast formats
  - Soft state
  - Written in hex notation as 16-bit integers
    - e.g. 2001:630:80:0:0:0:0:1

3.4 x 10^{38} Addresses...

... that's 6.7 x 10^{23} Addresses per m^2 on the earth



Aggregatable Addresses

Format prefix 3 bits (001) — Reserved 8 bits — Prefix length

(FP)	TLA	(Res)	NLA	SLA	Interface ID
	13		24	16	64

2001:0630:0080:7030:0000:0000:0000:0001/64

TLA	Top Level Aggregation identifier
NLA	Next Level Aggregation identifier
SLA	Site Level Aggregation identifier

IPv6 terminology can drop a single string of all 0s…

2001:630:80:7030::1/64
2001:630:80:7030::/64

loopback ::1   unspecified ::0   IPv4 Compatible ::148.88.8.6

Efficient Header Construction

- IPv4 contains many redundant features...
  - Variable length IP header options
  - IP header checksum
- ...some inefficient ones...
  - Packet fragmentation
- ... and some omitted
  - Packet classification
- All of which impact network performance

IP: Head to Head

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IP: Head to Head

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                         Source Address                        +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
+                                                               +
|                                                               |
+                      Destination Address                      +
|                                                               |
+                                                               +
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

What's missing?

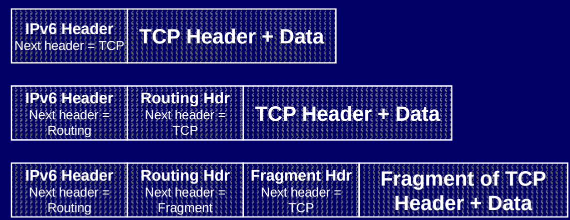
- The IPv6 protocol header is streamlined for the common-case…
  - Fixed format header (no options)
  - No **checksum** - left to transport and data link layers, no need to check/recalculate each hop
  - No fragmentation (except at source)
    - Agree path **MTU** at the source using **Path MTU discovery**

Extensible headers

- Custom headers for specialist functionality…
  - Fragmentation Headers
  - Routing Headers
  - Destination Options
  - Hop by Hop Headers
  - Authentication and ESP

IPv6 Extension Headers

- In IPv6, Options are daisy-chained in extension headers…



Autoconfiguration

- Plug 'n' Play Networking...
  - IPv6 host requires three pieces of info
    - IPv6 Address
    - IPv6 Network
    - IPv6 Gateway
  - Router Solicitation and Advertisement...

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Autoconfiguration

- Host builds IPv6 address from prefix
  - Using EUI-64 identifier of interface
  - Or padded MAC address...
  - In two frame message exchange
- Privacy Issues...

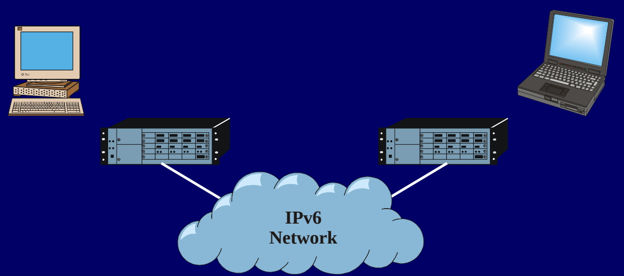
What about Roaming?

IPv6 gives you scalability and heterogeneity...

What about mobility?

Why IPv6 doesn't work...

- IPv6 routes packets based on network prefix information...



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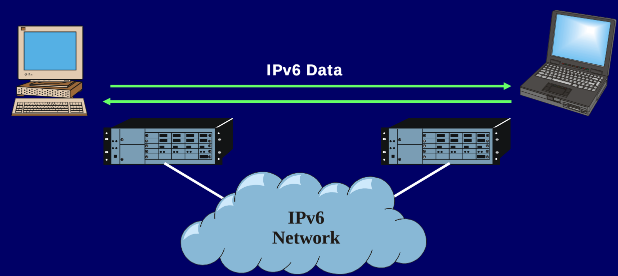

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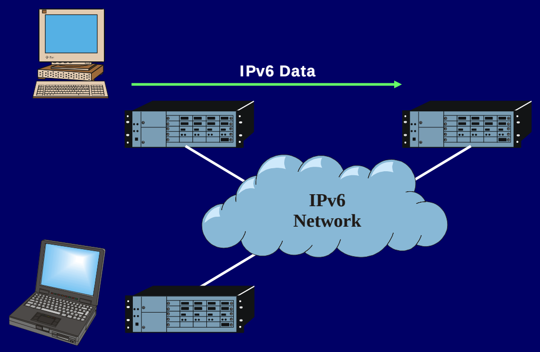

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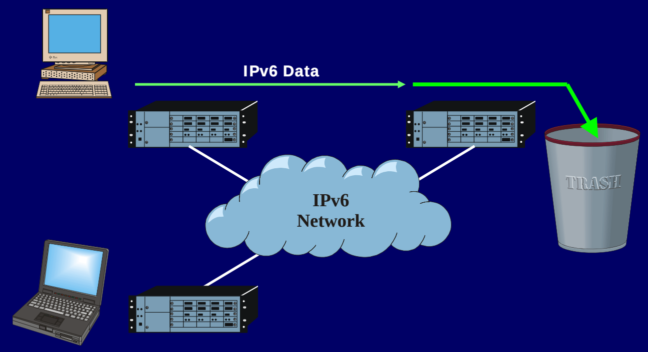


Why IPv6 doesn't work...

- An IP address has two distinct roles:
  - 1) identification
  - 2) routing information
- A mobile node needs to separate these two roles

Break...

back in 15mins!

Mobile IPv6 Overview

- Routing protocol for mobile IPv6 hosts
  - Nothing more, nothing less
  - Transparent to upper layer protocols and applications
  - IETF standard (RFC 3775 – June 2004)
- Uncommon protocol architecture…
  - Tries to avoid actively involving routers!
  - Protocol state held in end-stations
    - Mobile nodes
    - Correspondent nodes
  - One exception… the Home Agent

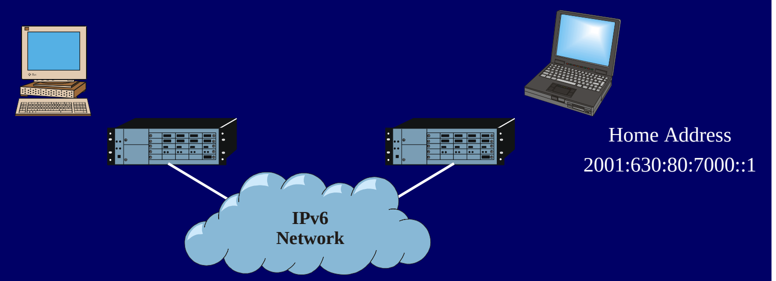
Mobile IPv6 Operation

- Mobile Nodes 'Acquire'
  - Home address
  - Home agent
- When away from home
  - Acquire care-of address
  - Register care-of address with home agent and any relevant correspondent nodes…
  - Mobile IPv6 ensures correct routing

Mobile IPv6 Operation ctd.

- Mobile IPv6 bindings cache
  - Maintains a mapping between mobile node's home and its current care-of address
  - Held by home agents and correspondents
  - Provides info to allow correct routing of IPv6 packets to mobile node via IPv6 routing header…
  - Provides a de-coupling between an IPv6 address and routing information

Mobile IPv6 Example



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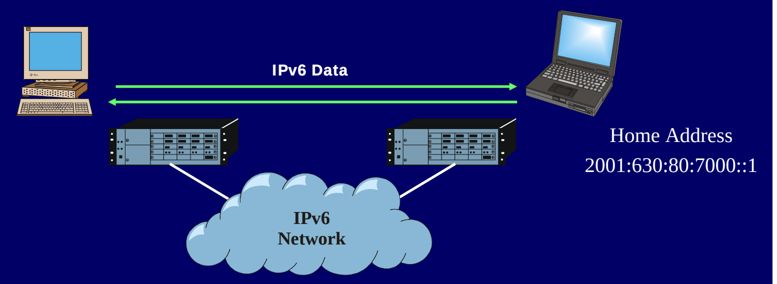

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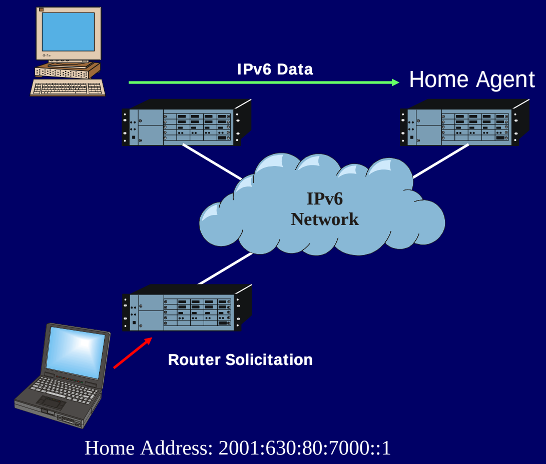

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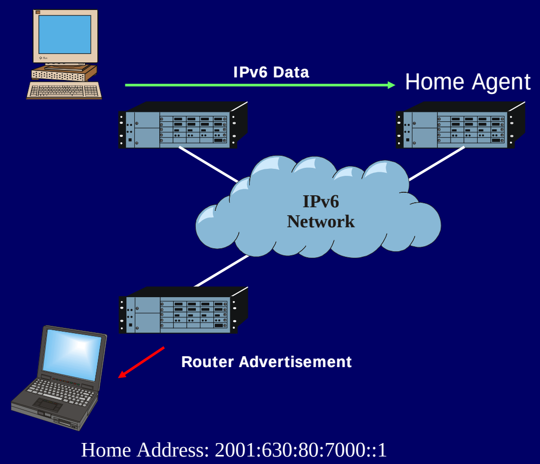

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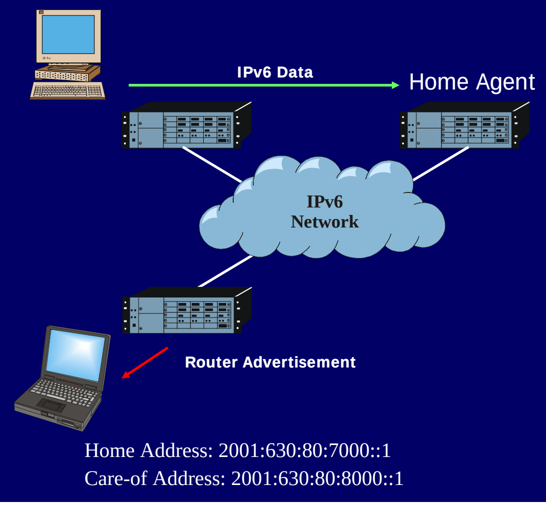

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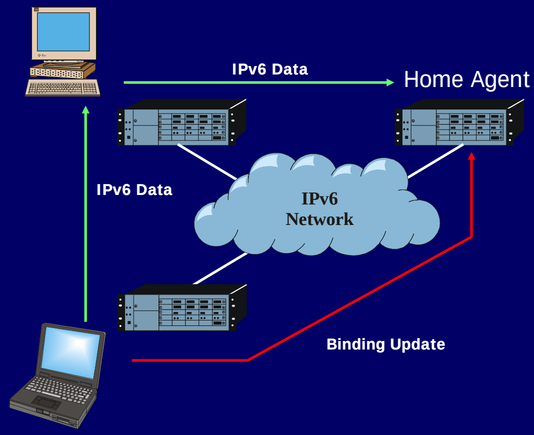

Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1

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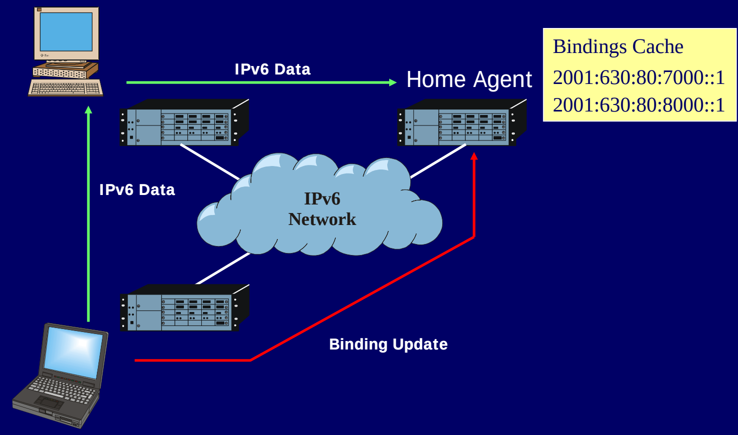

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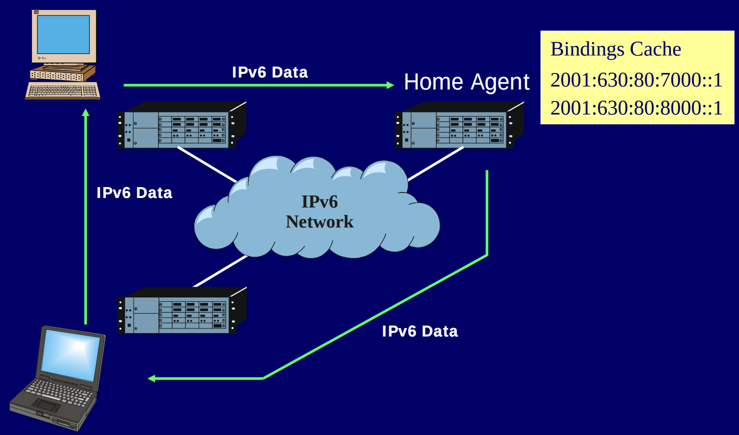


Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1

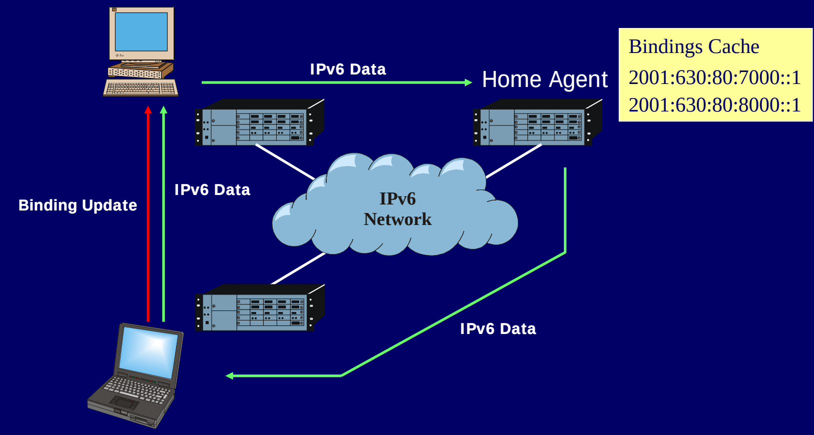
Home Agent

- MIPv6 Home Agents
  - Must reside on the network matching the mobile node's home address. i.e. be on the forwarding path.
  - Are often the subnet router. Why?
  - Use the home addresses in the bindings cache as part of routing process. Any packets destined for such an address is tunnelled to the node's care-of address.
  - also use proxy neighbour discovery (ARP)... Why?

Efficient Routing?

- The routes generated through this mechanism are rather inefficient – known as *asymmetric triangular routing.*
- This can be addressed through enabling the correspondent nodes to understand binding update messages too…
- n.b. we know which nodes to send binding update to because we receive packets from them via our home agent.

Mobile IPv6 Example



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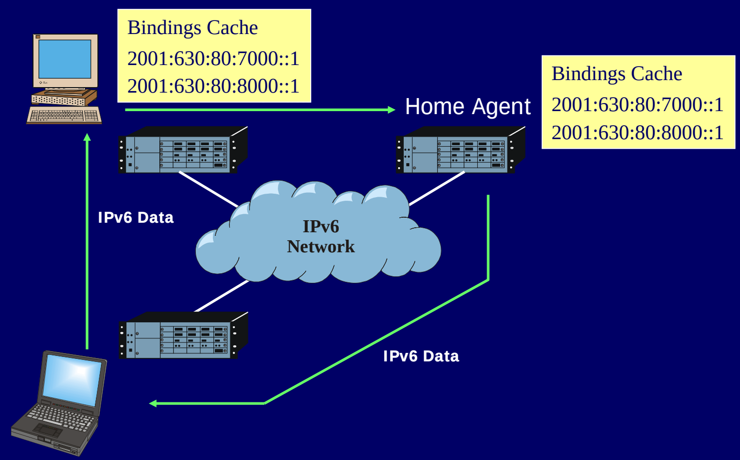

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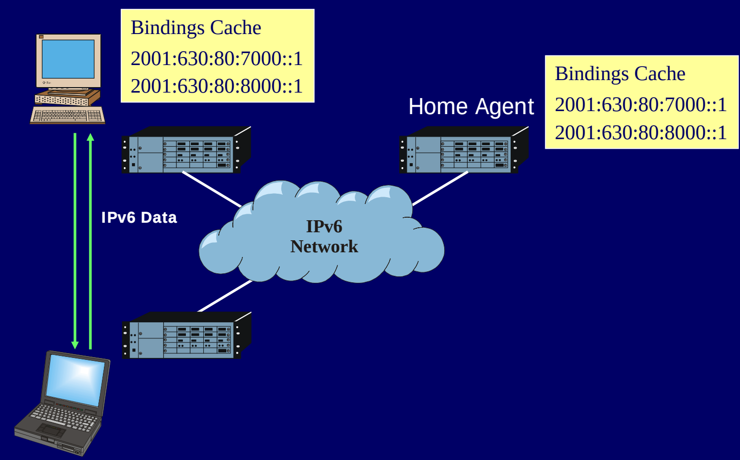
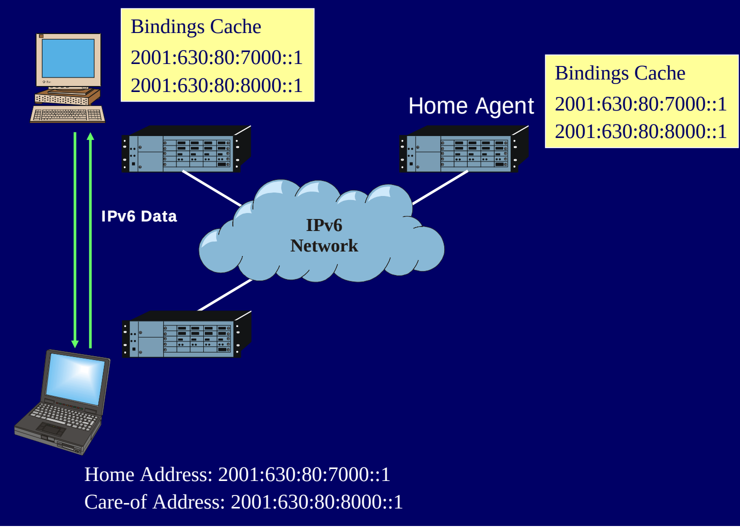


Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1

Mobile IPv6 Example

- Okay, but what if we move again?
- Two cases
  - Move from on foreign network to another
  - Return home...
- Need to send more binding updates...

Mobile IPv6 Example



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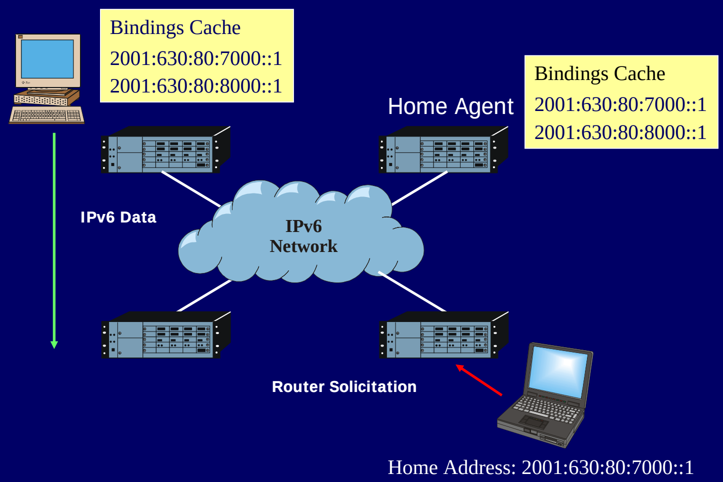

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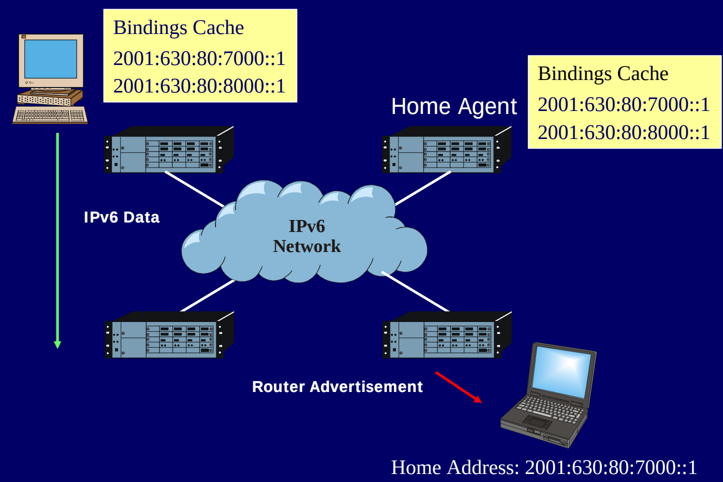

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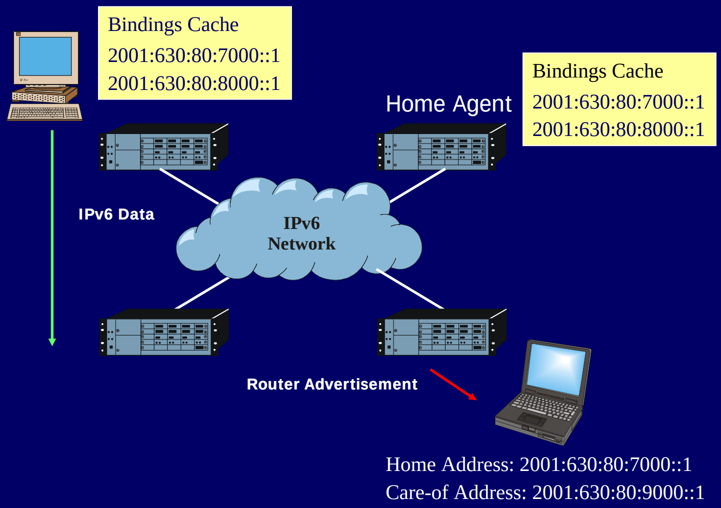

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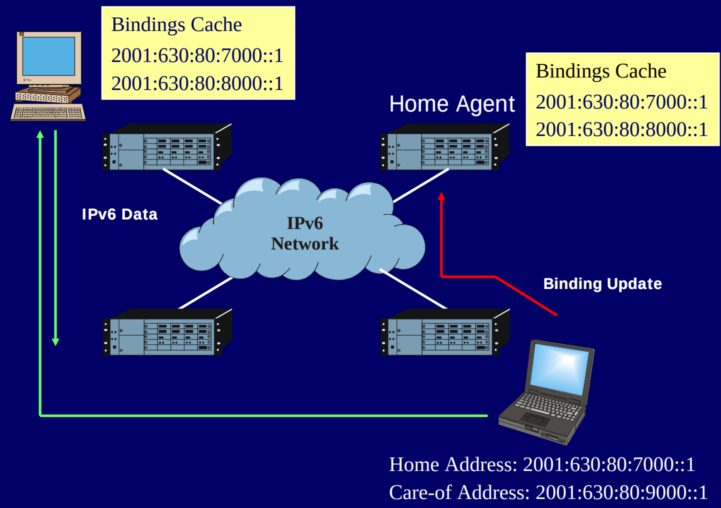

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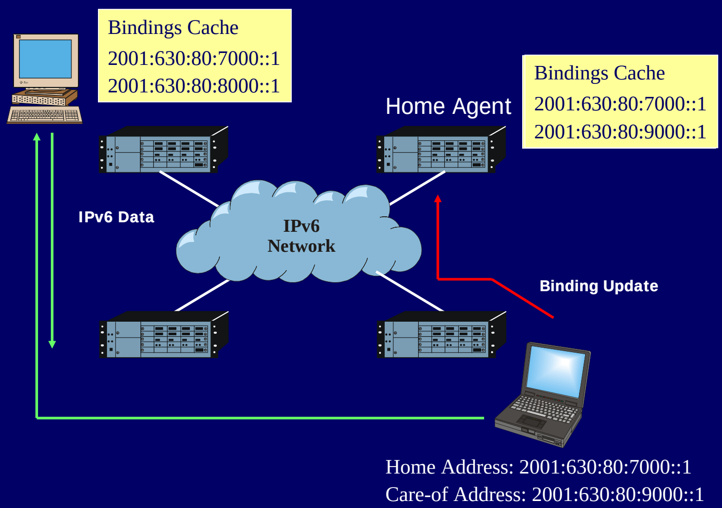
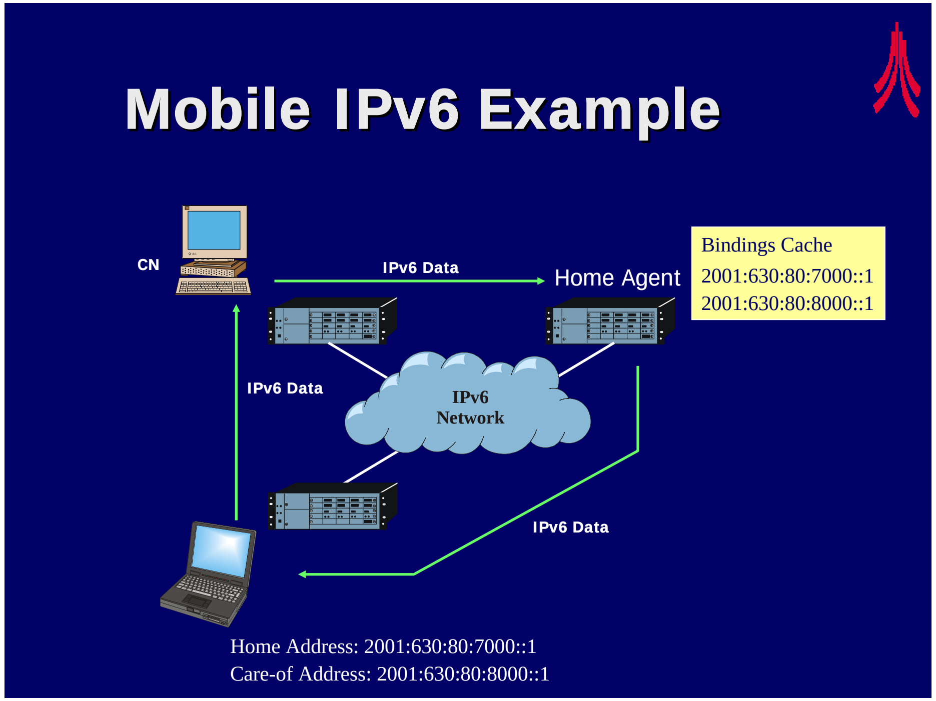
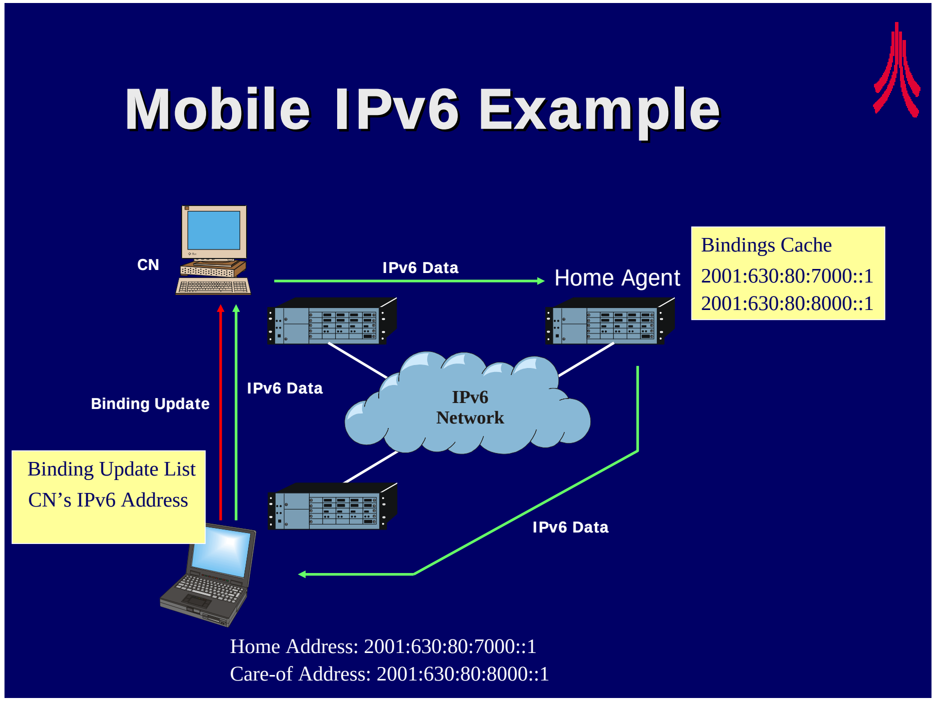


How to update correspondent?

- Bindings cache entry out of date...
- Solution
  - Maintain a list of active correspondent nodes in mobile node.
  - Generated when a tunnelled packet received from home agent
  - Known as the ***binding update list***


Mobile IPv6 Example
CN
IPv6 Data
Home Agent
Bindings Cache
2001:630:80:7000::1
2001:630:80:8000::1
IPv6 Data
IPv6
Network
IPv6 Data
Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1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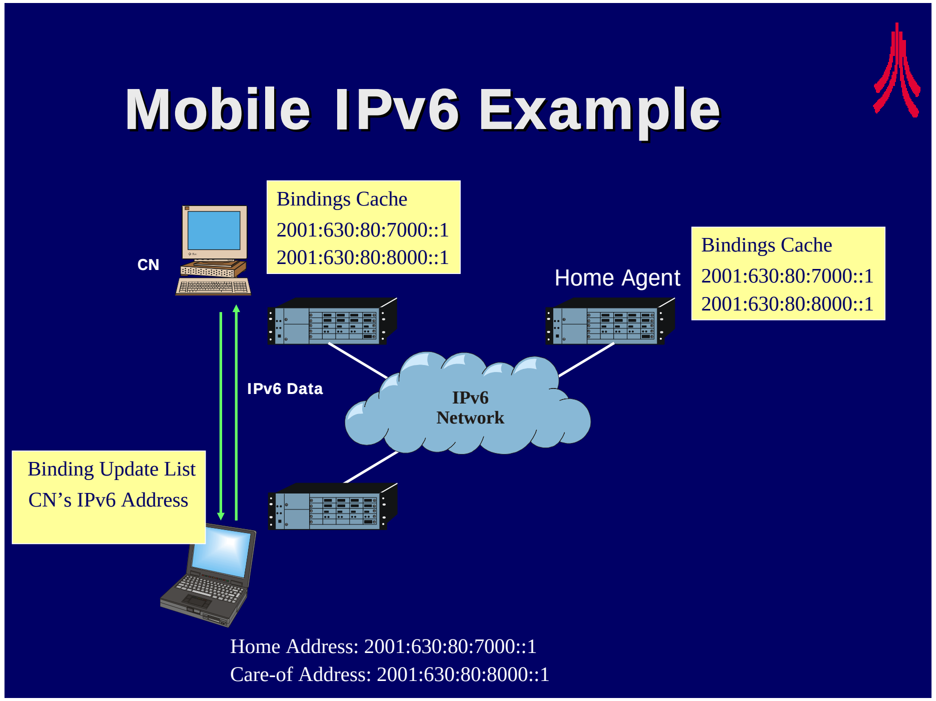
Home Agent
Bindings Cache
2001:630:80:7000::1
2001:630:80:8000::1
Binding Update
IPv6 Data
IPv6
Network
Binding Update List
CN's IPv6 Address
IPv6 Data
Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1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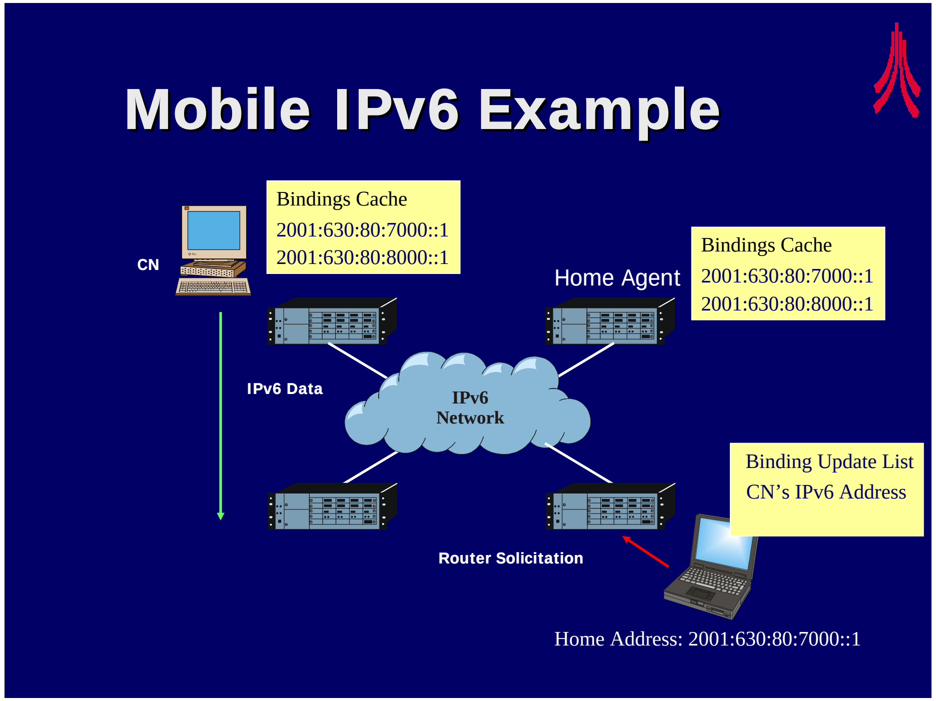
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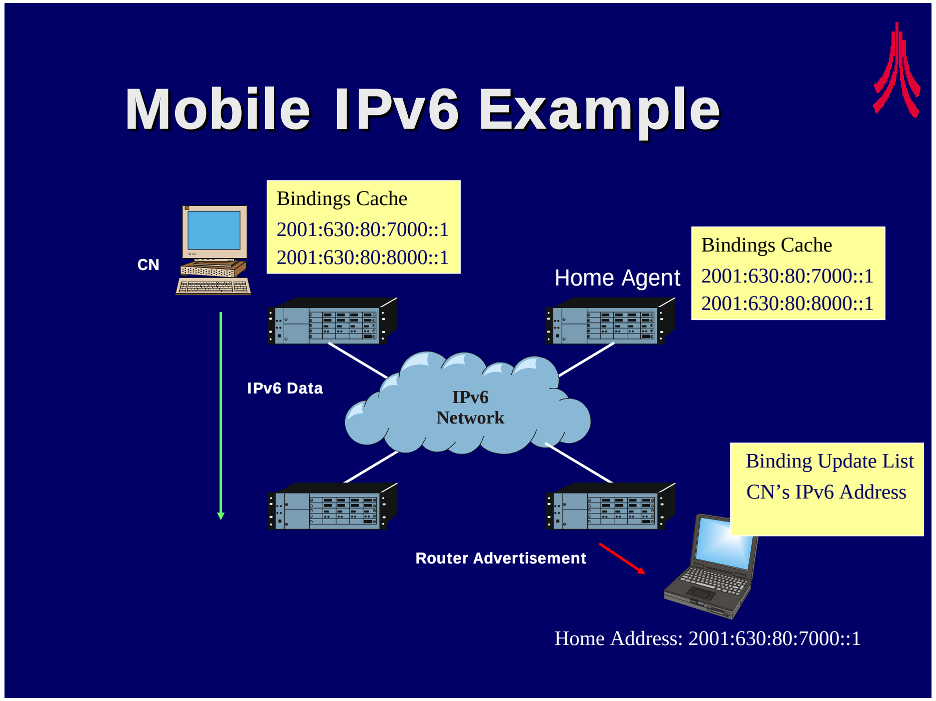
Home Agent
Bindings Cache
2001:630:80:7000::1
2001:630:80:8000::1
IPv6 Data
IPv6
Network
Binding Update List
CN's IPv6 Address
Router Solicitation
Home Address: 2001:630:80:7000::1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IPv6 Data
IPv6
Network
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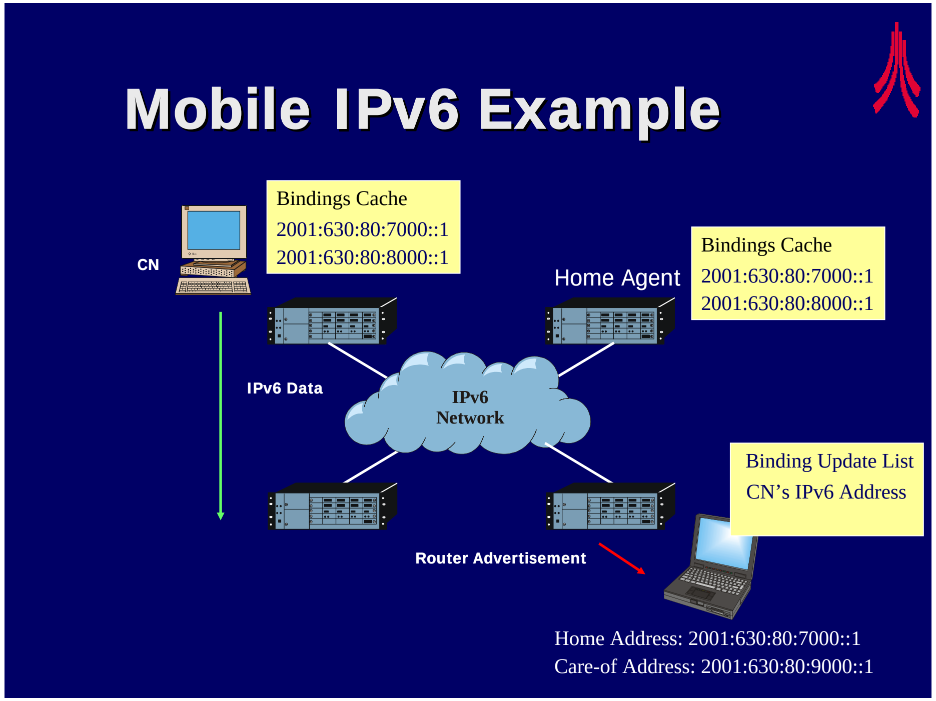
CN's IPv6 Address
Router Advertisement
Home Address: 2001:630:80:7000::1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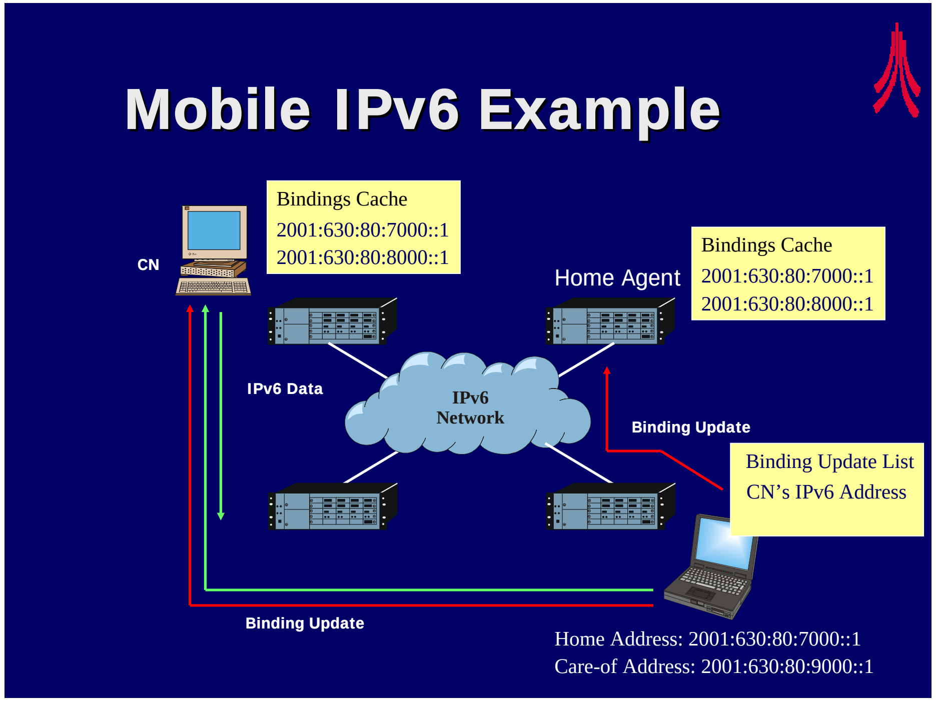
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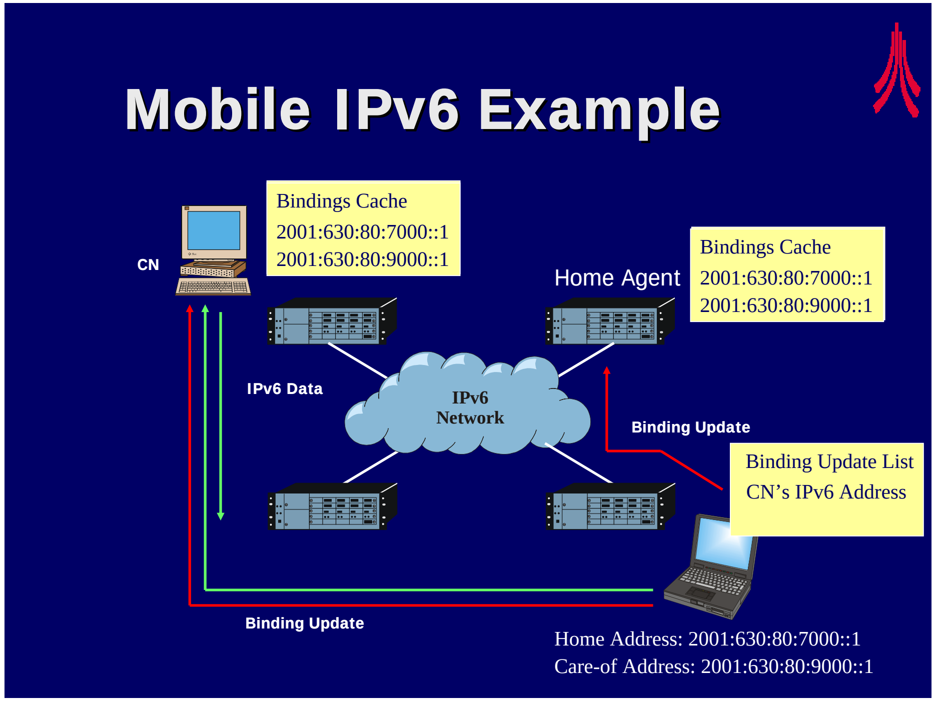
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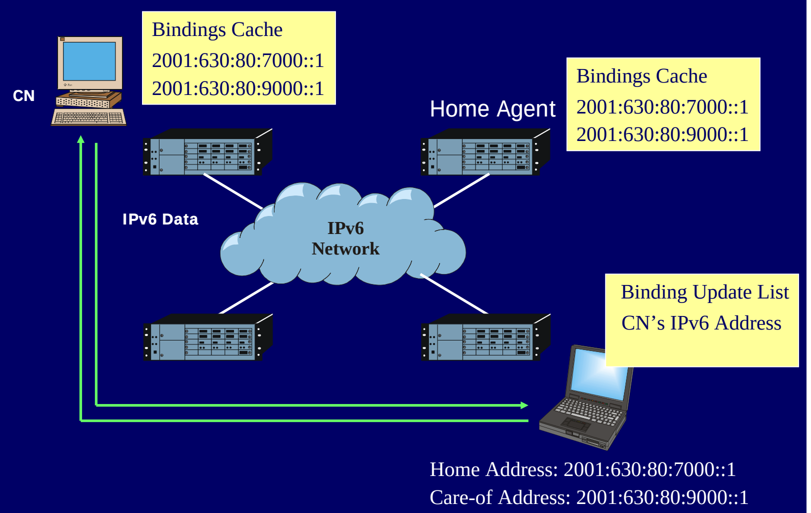


What address do we use?

- When away from home what address does a mobile node source from?

Its Home Address?

- But what about ingress filtering?
  - Ingress filtering is a security measure taken by many border routers.
  - Any packets received by a router on an interface which ***do not match*** the source address of that packet are discarded.
  - Avoids many 'spoofing' attacks…
- Can't source from home address, as its prefix doesn't match current location…

Its Care-Of Address?

- But what about TCP?
  - TCP uses the IP(v6) source address as an index
  - Without a consistent IPv6 address, any ongoing TCP connections would break…
- Can't source from care-of address, for reasons of protocol stability…

Source from BOTH…

- New IPv6 destination option
- The ***Home Address*** Option
  - Included in **EVERY** outgoing packet
  - Understood by all correspondent nodes
  - Home address replaces source address on reception by destination (correspondent node)
- IPv6 packets
  - sourced from care-of address
  - Contain home address as an option

What about network errors?

- Mobile IPv6 bindings are ***soft state***
  - Refreshed periodically
  - Contain sequence numbers
  - Can be ack'd-
    - ***binding acknowledgements***
  - ***Binding Updates and Acks are retransmitted (rate limited) until the protocol converges***

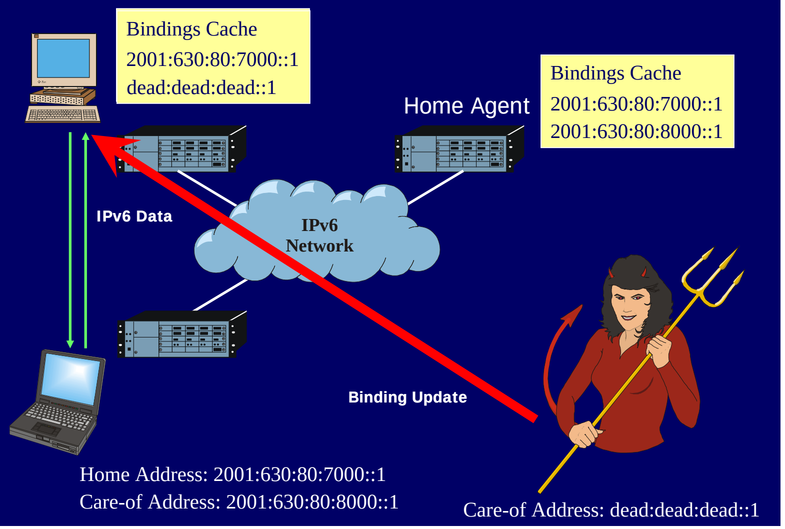
What Format are the Control Messages?

- MIPv6 control messages are carried using IPv6 destination options
  - Not reliant on higher level protocols
  - Multiple messages per IP packet
  - Messages can append existing packets
  - E.g. TCP connection requests…

One problem remains…

- Authentication
  - Massive security / denial of service attack in MIPv6 as described so far.
  - What's to stop an attacker sending bogus Binding Update messages?

Mobile IPv6 Example



IPv6 and Security

- IPv6 specifies the ESP and AH headers for security + existing mechanisms (e.g. SSL and IPSEC)
  - Also, semantic misunderstanding here.
  - Authentication vs. authorization
- Intended to employ IPSec to provide algorithms, policies and key exchange.
- Mobile IPv6 was the first foray into the field, and fell foul of IPsec's lack of progress in standardization and deployment… (IKE + AAA)
- Developed its own mechanism…

Return Reachability…

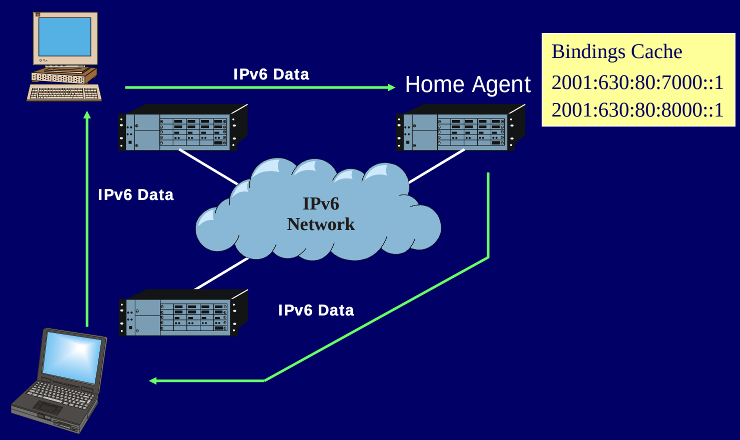
- …or ***Route Equivalence***.
- Argument:

  "All that really matters is that the optimized route is functionally equivalent to a non-optimized route"

Return Reachability

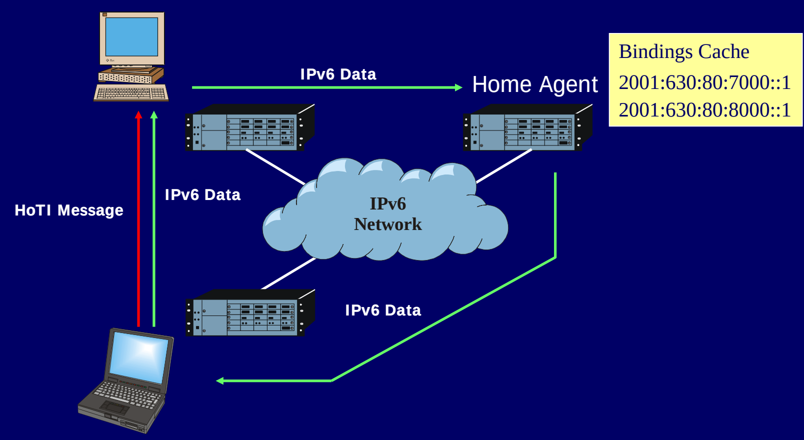
- Home Agent implicitly trusted
  - Assumed it is hosted on secure site
  - Specified that IPsec is used between mobile host and its home agent.
- Dynamic key distribution for use with correspondent nodes.
- Uses cookies to build session keys
- Remember: We're not looking to build a secure IP, just ensure MIPv6 is no less secure than IPv6.

Return Reachability



Home Address: 2001:630:80:7000::1
Care-of Address: 2001:630:80:8000::1

Return Reachability



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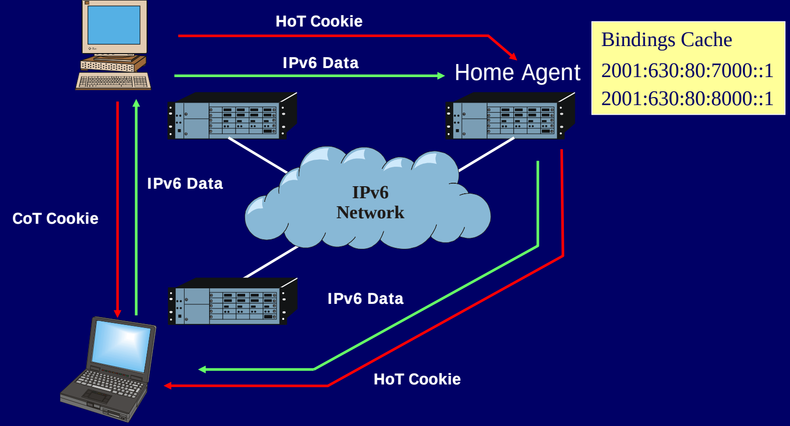
Return Reachability



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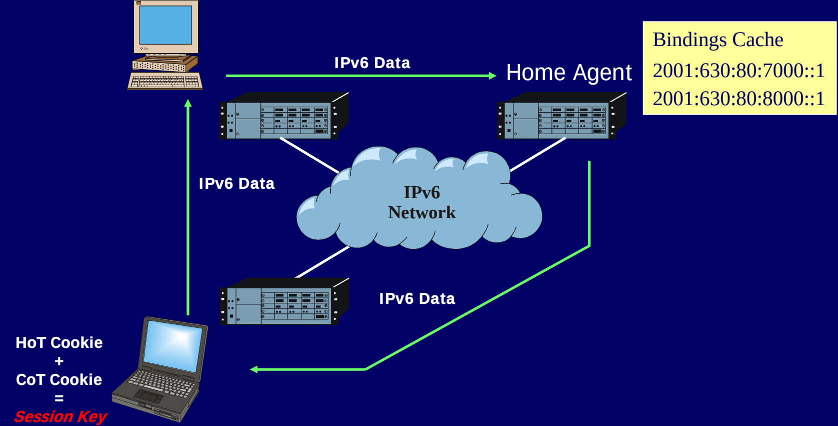
Return Reachability



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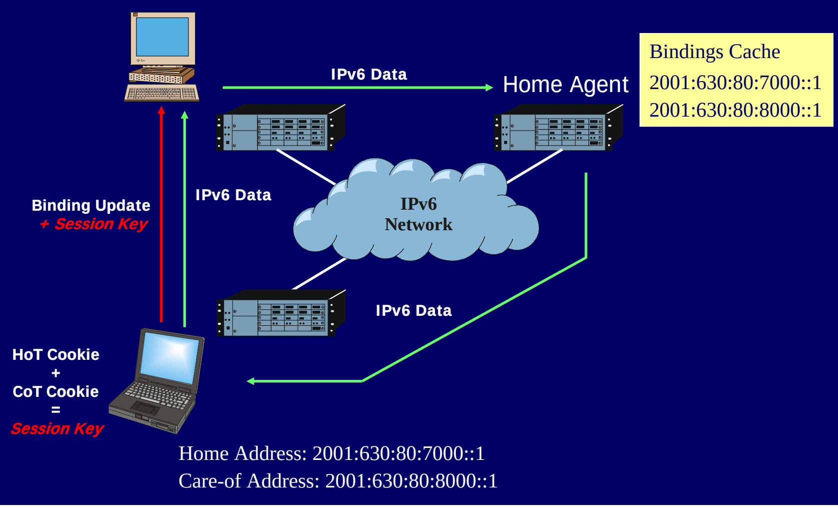
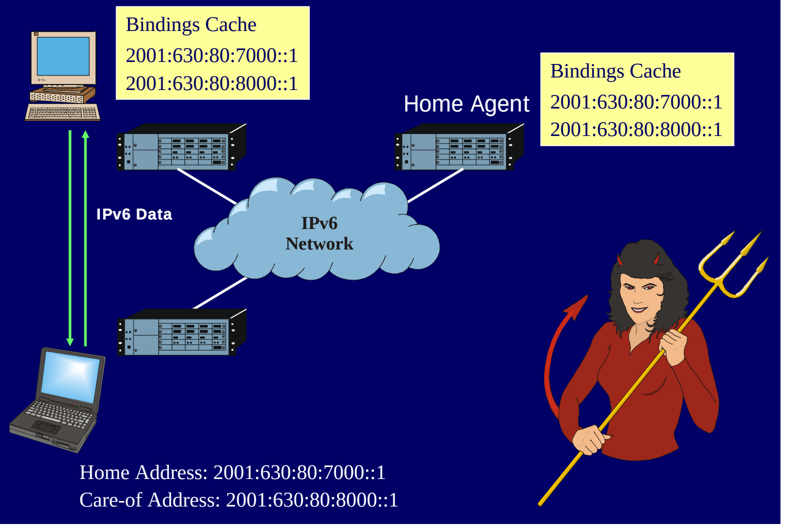
Return Reachability



Mobile IPv6 Example



Mobile IPv6

A Short Evaluation

Transparency

- We have gained transparency
  - Layers above IP do not see change in address…
- BUT
  - Mobility aware applications may be adversely affected
    - Often rely upon address change events to react
  - Side effects of mobility can never be abstracted away…
    - Changes in QoS
    - Bandwidth, delay and jitter
    - including TCP throughout
    - Impact on MAC too… (Proxy Neighbour Discovery)

Scalability

- End to End nature of the protocol guarantees a degree of scalability
- BUT
  - Home agent still a single point of failure
    - Some support in new specs for failover
  - Effect of highly mobile nodes
    - Relatively large amount of control traffic. Particularly if active with many CNs.
  - Effect on large servers
    - Explosion of state in Bindings cache. E.g. imagine google...
    - Could proactively topple Bus onto TCP SYN handshake

Efficiency

- Significant packet overhead
  - Additional 20 bytes / **data** packet
  - Much more overhead in control packets
    - ~200 bytes per CN per handoff.
  - Plus security overheads
    - IPSEC
    - Route Equivalence overhead
  - Quite heavyweight for ultra lightweight devices
    - MS implementation increased IPv6 stack codesize by around 25%...

Response Time

- Mobile IPv6 detects handoff predominantly by router advertisements
  - Typically set to around 5 seconds by IPv6 specification
  - MIPv6 spec defines this can be reduced to millisecond range, but...
    - This is responsibility of visited network. Cannot be controlled by device or its native network operator...
  - Hardware hints can significantly improve handoff time.

Privacy

- When away from home, a mobile node freely gives away its location to any correspondent node that contacts it...
  - Potential for abuse
  - Tracking of people through network locations
    - Remember the granularity of IPv6 networks...
    - Audit tracking of visited hosts (www sites, etc...)

Break...

back in 15mins!

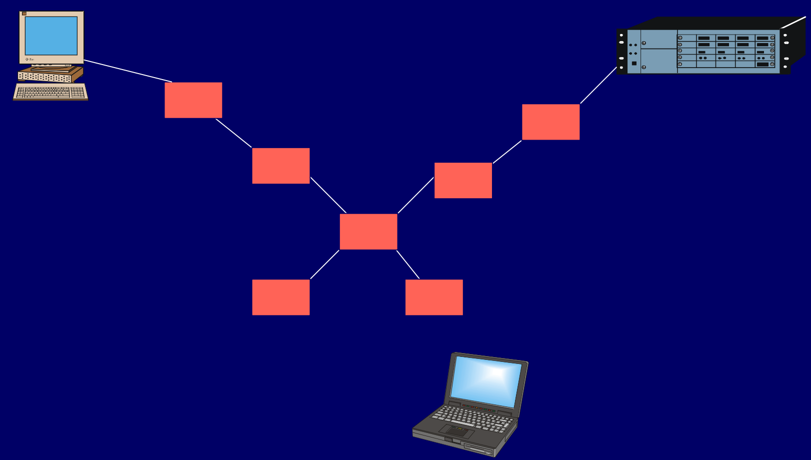
Mobile IPv6: Advanced Topics

Improving scalability, handoff time and privacy.

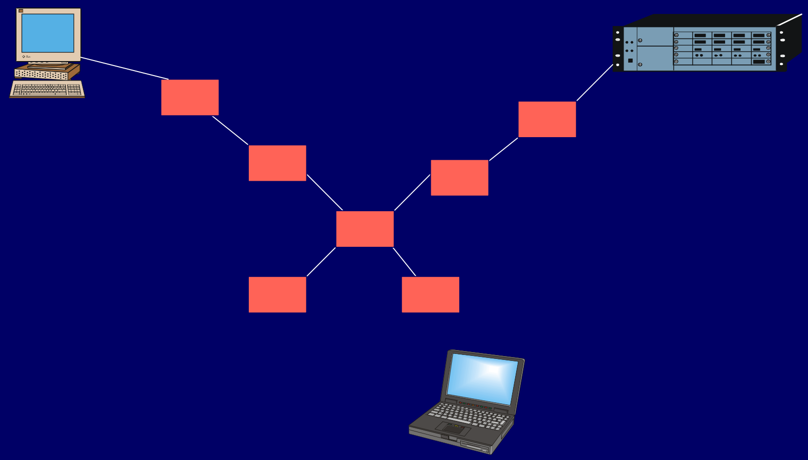
Improving Handoff Time

- Handoff time limited by
  - Movement detection
    - Hardware hints and beacons
  - Hardware disconnect/reconnect time
    - Cannot improve on this at layer 3
    - But can support it, if it's available
  - Protocol convergence time
    - Can make some assumptions of common case of host mobility...
    - Optimize the protocol to take this into account

MIPv6 and Latency



Improving Latency (1)



Hierarchical MIPv6

- Hierarchy of 'home agents', known as Mobility Anchor Points (MAPs)
  - Addition to the IETF standard
  - Each act as a local point of indirection for mobile traffic
  - Domains wishing to participate install at least one MAP node in their domain, typically on a border router.
  - MAPs indirect packets for the mobile node while the device roams inside its administrative domain
  - Transparent to CNs, and even the HA.

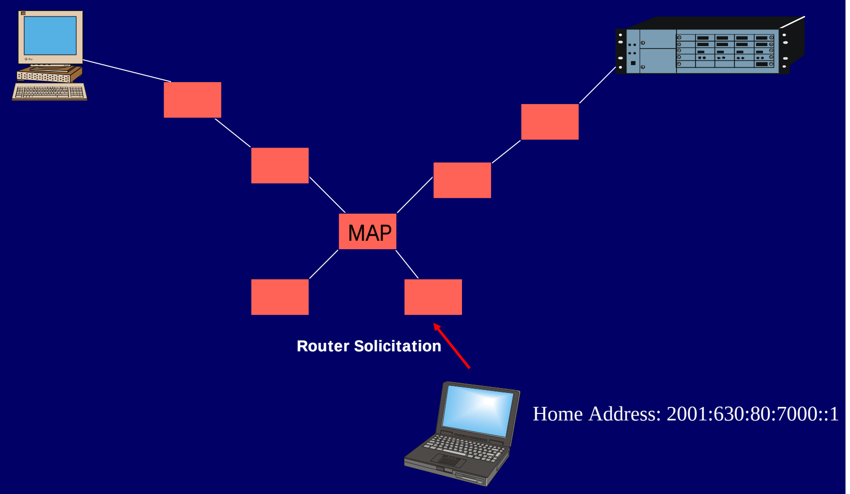
Hierarchical MIPv6 (2)

- Detecting MAP
  - Mobile nodes detect the presence of HMIPv6 through an extension to Router Advertisements.
    - ID for domain
    - Service discovery for MNs
  - MNs create yet another IPv6 address
    - Regional care-of address (RCoA)
      - (more like a regional Home Address, really)
      - Formed by stateless configuration on MAPs prefix...
    - Also a Local care-of address (LCoA)
      - Renamed purely for clarity (?!)
  - MNs register a binding between RCoA and LCoA with MAP.
  - MAP tunnels packets to MN, just like a HA.

Which Address to Use? (Again!)

- Mobile nodes register their RCoA as a CoA for their global Home Address.
  - HA and correspondent nodes see only one address
  - Changes in LCoA are transparent
- MNs detect changes in domain via MAP advertisements
  - Different MAP address, different domain
  - Update HA and CNs, else, just the MAP

H-MIPv6 Example



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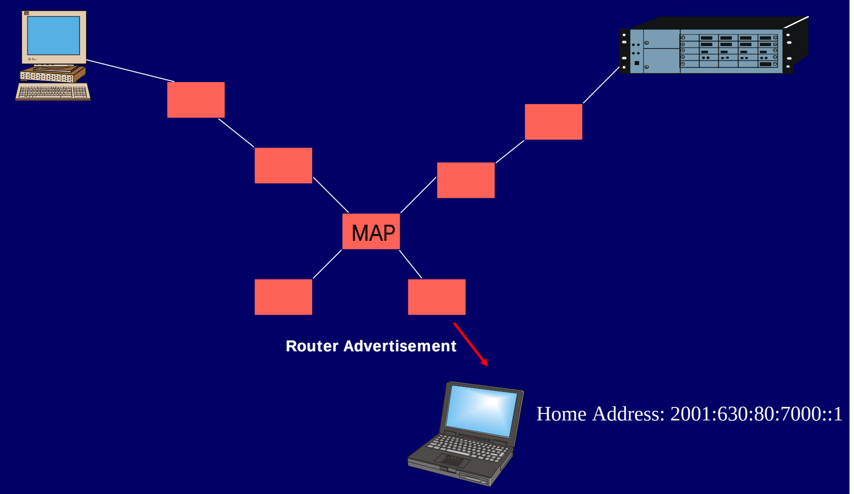
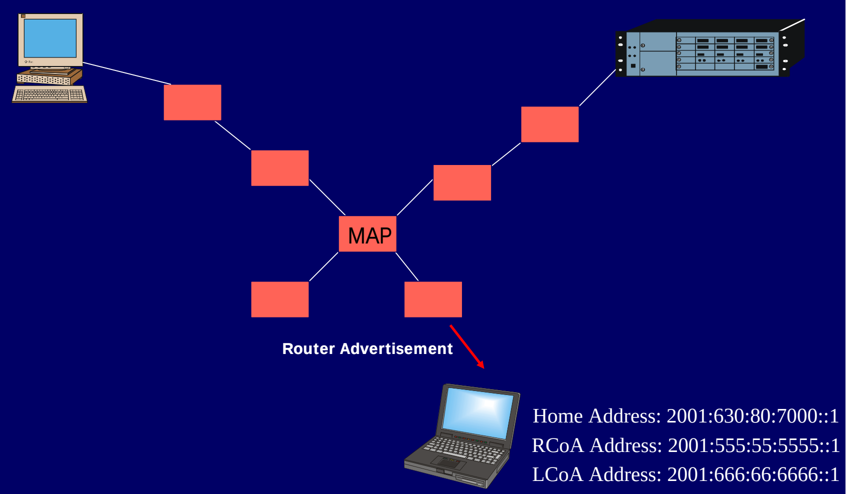


H-MIPv6 Example



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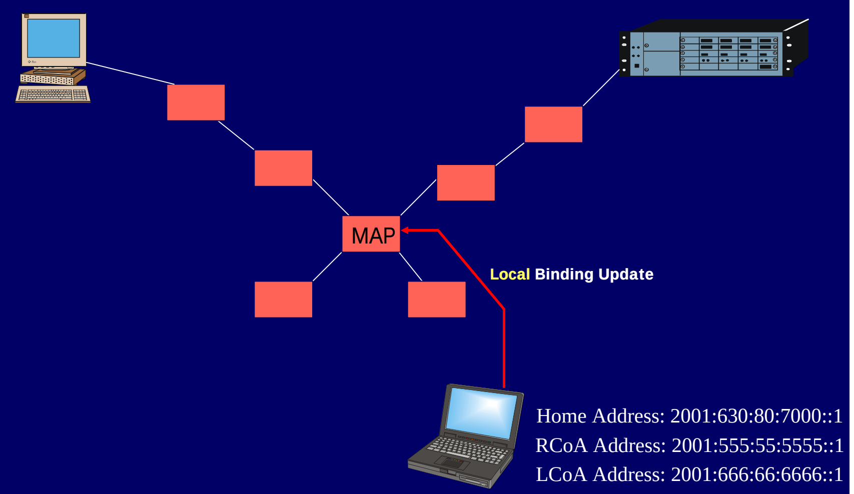

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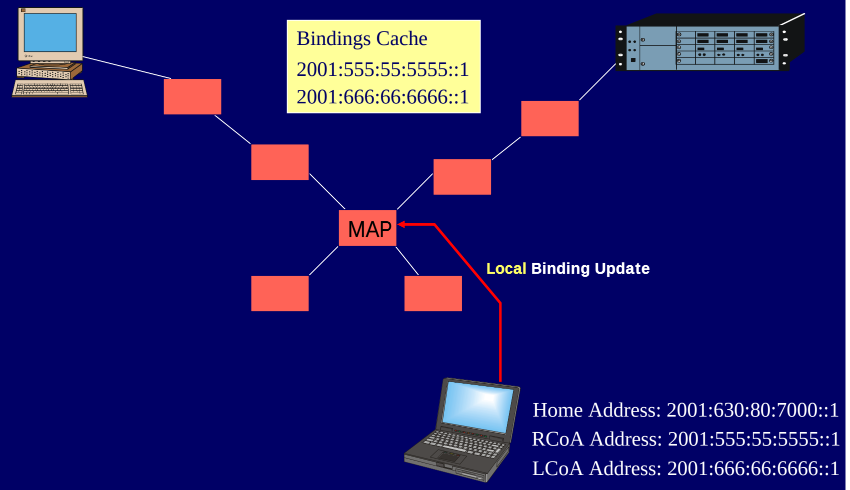

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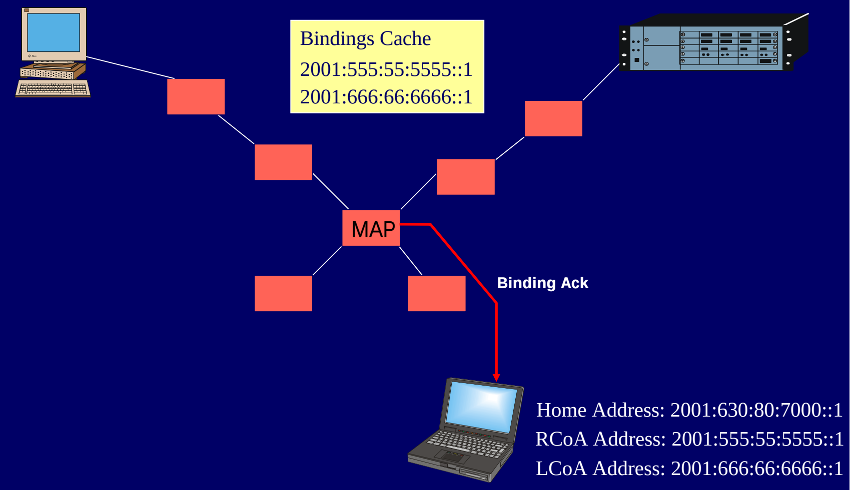
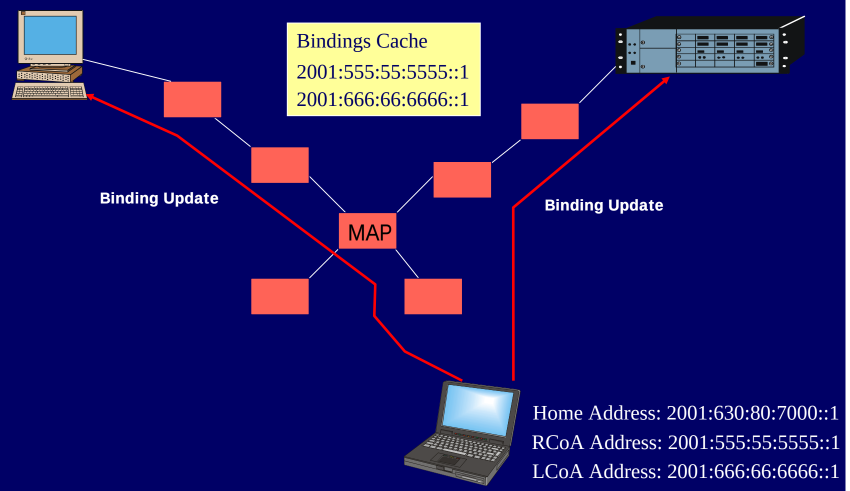


H-MIPv6 Example



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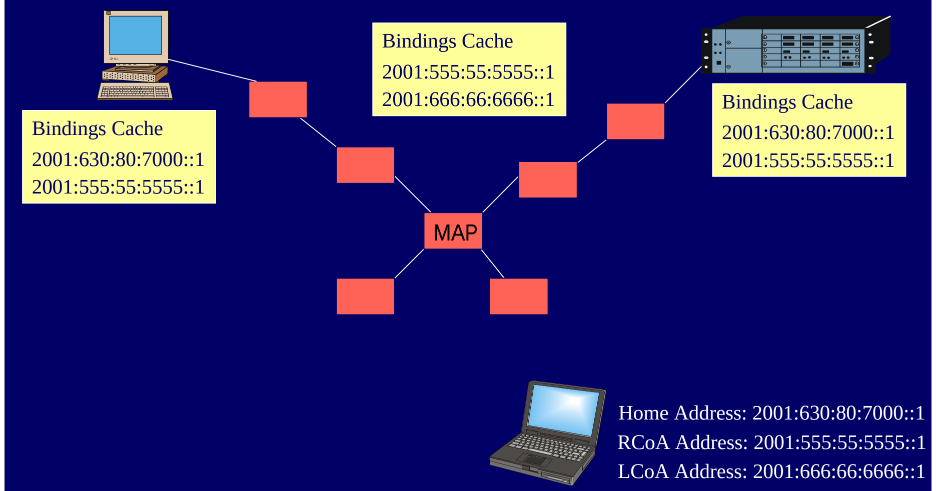
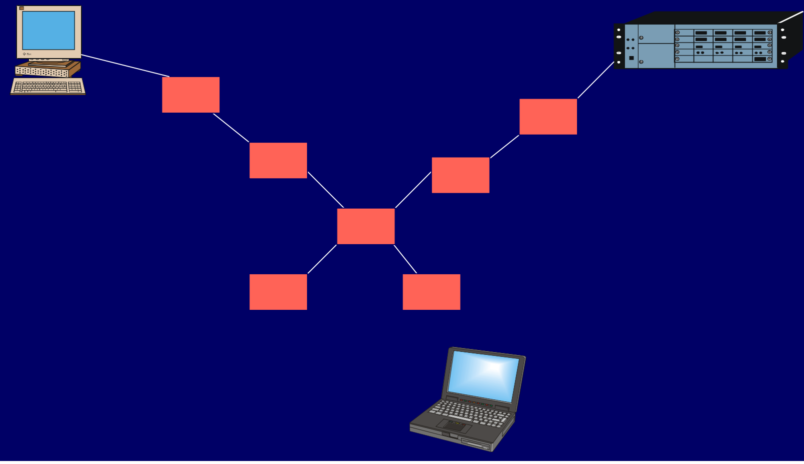


H-MIPv6 Evaluation

- Reduce amount of packet loss during handoff
- Can also save bandwidth, fewer binding updates transmitted across the network
- Degree of privacy can be achieved…

- Even more packet overhead (tunnelled route optimised packets)
- Security issues, c.f. IPSEC with MAP
- Requires changes to mobile node operation

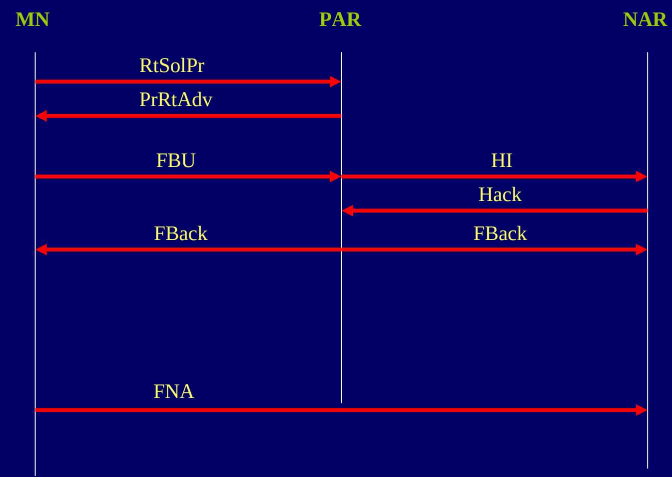
Improving Latency (2)



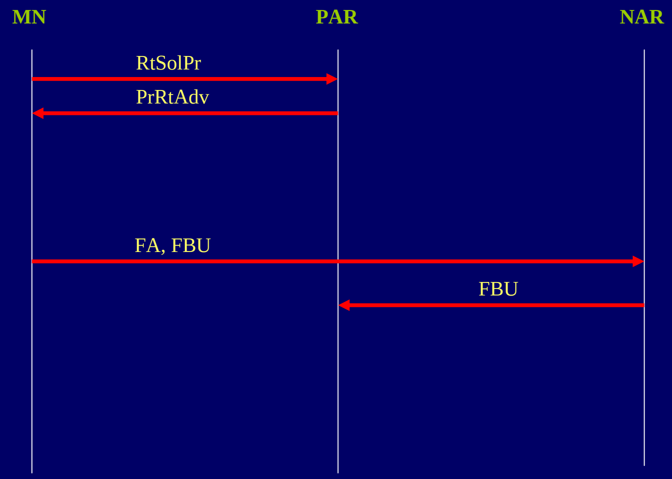
Fast Handoff

- Local repair of routing between two access routers
- Designed primarily for cellular environments based purely on IP
- Additional mechanism that operates in parallel to normal MIPv6 procedures.
- Temporary, buffered tunnel set up between previous access router (PAR) and new access router (NAR)
- Proxy Router Solicitations and Advertisements
  - Address acquired before node moves (where possible)
  - Support a level of proactivity from MAC layer

Fast Handoff: Proactive



Fast Handoff: Reactive



Fast Handoff: Evaluation

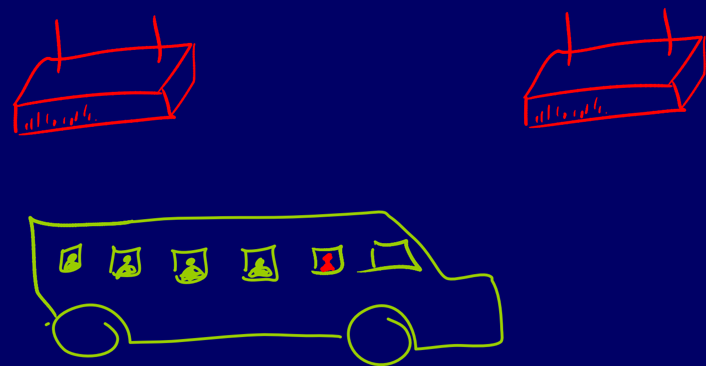
- Generic support for proactive MAC
  - In particular future wireless LAN, and 4G.
- Simple support for reactive
  - Rapid handoffs less scalable
  - Sub-optimal routing vs. H-MIPv6
  - Can result in out of order packets
  - No impact on MIPv6 (including privacy!)
  - Only across single administrative domain

Other IP Mobility Techniques

- Although effective and rather elegant, MIPv6 has limitation
  - Scalability. Built end to end, it scales well with the network size, however only considers the movement of individual nodes. There are other migration patterns…
  - Privacy. By sending care-of addresses to anyone on the network who communicates with a user, it is difficult to provided anonymity, and prevent users from being tracked.

Network Mobility

- Single user model is only one of many…



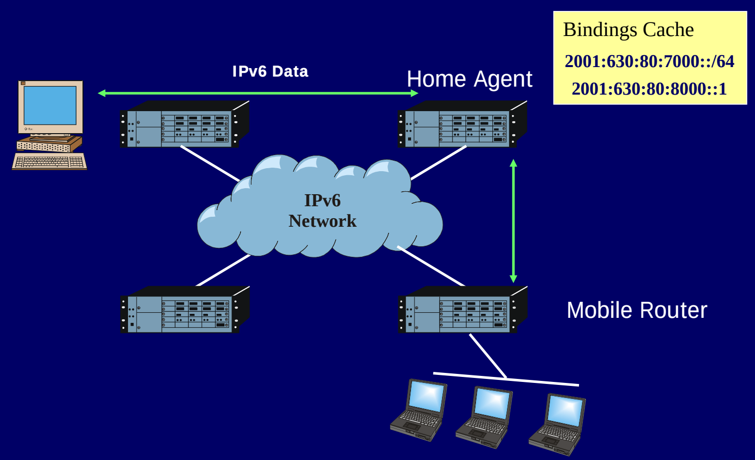
IETF NEMO protocol suite

- Designed to provide support not for mobile hosts, but for mobile networks
  - **NE**tworked **Mo**bility… Ongoing work inside IETF.
  - Many scenarios exist where many nodes migrate together
  - Cars, buses, trains, planes…
  - If MIPv6 were used, this would result in large overhead in control messages.
  - NEMO protocol is designed for these scenarios.

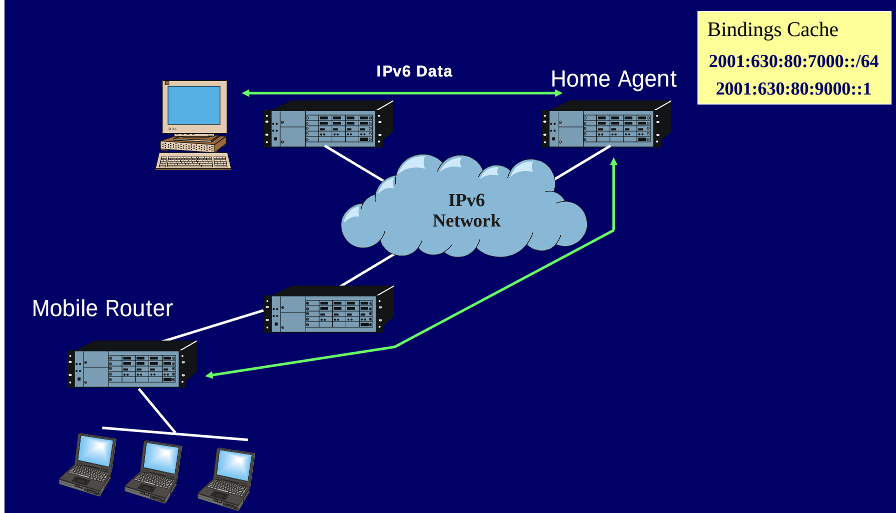
NEMO: Basic Operation

- New conceptual device – the **mobile router** (MR).
  - MRs act much like mobile nodes…
  - …but have >1 interface (at least one local and global)
  - They register a network prefix with a home agent, rather than an individual IPv6 address
  - Home agent then routes all traffic destined to that network to the MR via bidirectional tunnel
  - MR forwards all traffic from tunnel to its local interface and vice versa
  - Will only forward packet to local interface for packets destined to that network and from HA. Why?

NEMO operation



NEMO operation



NEMO: Analysis

- Advantages
  - Can support mass migration of devices more efficiently
  - No need for MIPv6 in all nodes. NEMO MRs can maintain transparency for IPv6 devices.
- Disadvantages
  - Not yet clear how to define policy for network creation
    - Is it static or ad-hoc?
  - What if a mobile network attaches to another mobile network?
    - Pinball routing! (multi-angular routing)
    - No standardized support for route optimisation yet
      - Work in progress

NET-LMM

- Local Mobility Management
  - Adopts a split level approach
  - Widespread use of host routes in network
    - Exactly what MIPv6 was trying to avoid!
  - However, on an intranet level, can be very effective.
  - Can link with MAC layer handoff schemes in bridges
  - Nodes are still MIPv6 capable, but intra-domain routers make local movements transparent to internetwork.
  - No issues with ingress filtering as access routers are aware
  - Work in Progress!
  - c.f. Cross point architecture...

Summary

- Mobile IPv6 and affiliated protocols are a good solution for network layer mobility
  - ...but mobility affects all layers in the stack
  - Ongoing trend toward network intelligence
  - Small shift from extreme end to end model
  - At the end of the day, just another routing protocol. ☺

Ongoing Research

- Primarily evaluation and analysis
- But still some significant issues in
  - Transitioning
  - Home less MIPv6
  - Applying the protocol to real networks
    - E.g. implication for dynamic service selection
    - Multiple interfaces (c.f. overlay networks)
    - Many more applications of a new level of indirection…
- A prediction…
  - Need to handle mobility at all level of the stack
  - Dynamically choose the best level based on network and application conditions and semantics

References

Two (fairly) recent papers in Mobile Computing and Communications Review:

- "A performance comparison of Mobile IPv6, Hierarchical Mobile IPv6, fast handovers for Mobile IPv6 and their combination", Xavier Perez-Costa, Marc Torrent-Moreno and Hannes Hartenstein, ACM MC2R Volume 8, Issue 2, April 2004
- "Survey on network mobility support", Eranga Perera, Vijay Sivaraman and Aruna Seneviratne, ACM MC2R Volume 8, Issue 2, April 2004

And some pioneering works in the field that developed the area:

- "Mobility support in IPv6", Charles E. Perkins and David B. Johnson, Proceedings of 2nd ACM MOBICOM, 1996.
- "Fast and Scalable handoffs for wireless internetworks", Ramon Caceres, Venkata Padmanabhan, Proceedings of 2nd ACM MOBICOM, 1996.
- "Vertical handoffs in Wireless Overlay Networks", Mark Stemm and Randy Katz, ACM Journal on Mobile Networks and Applications (MNA) Volume 3, Issue 4, 1999.