Performance analysis of mobility protocols and handover algorithms for IP-based networks

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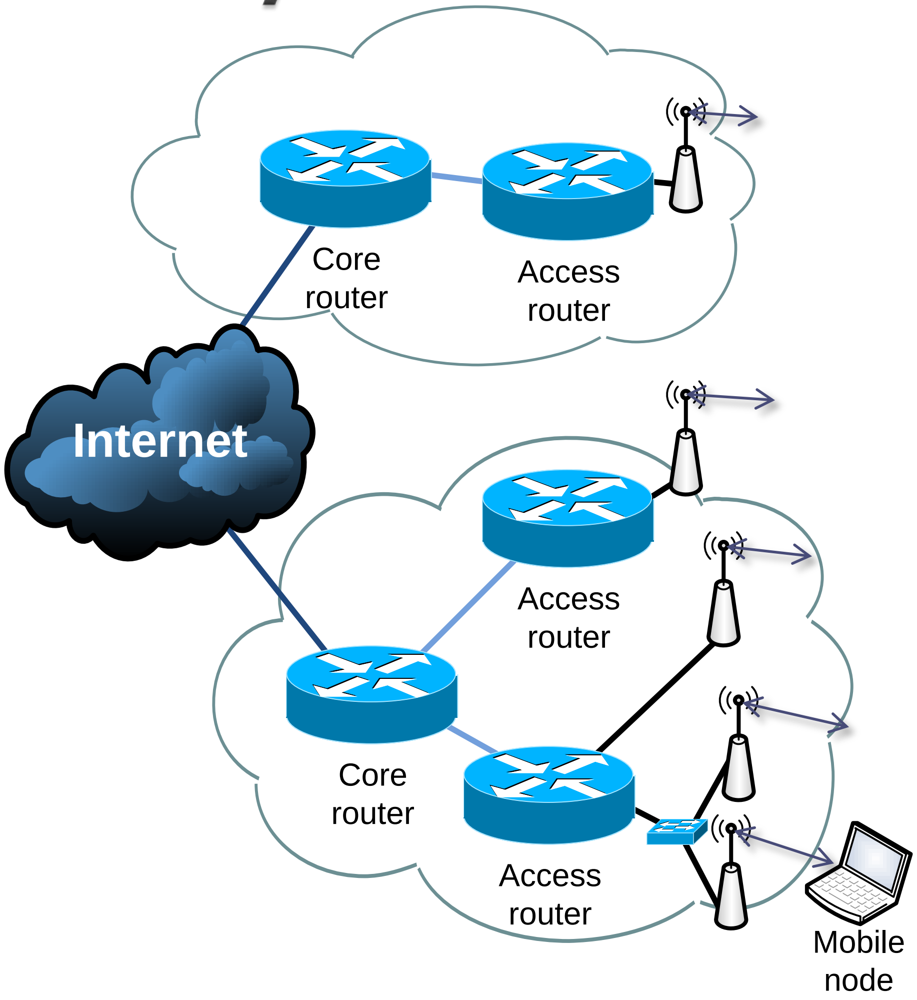
Agenda

- Introduction
- Taxonomy
- General concepts for mobility support
- Macro – and micromobility solutions
- Review of different concepts
- Main sources of handover delays
- Example handover procedures in Layer 3 – from MIPv4 to MIPv6 (optimization aspects) => *PMIPv6*
- Handover in Layer 2 => *IEEE 802.11r proposals*
- Simultaneous handover in Layers 2 and 3 => *cross-layer solutions with the use of IEEE 802.21 triggers*
- Conclusions

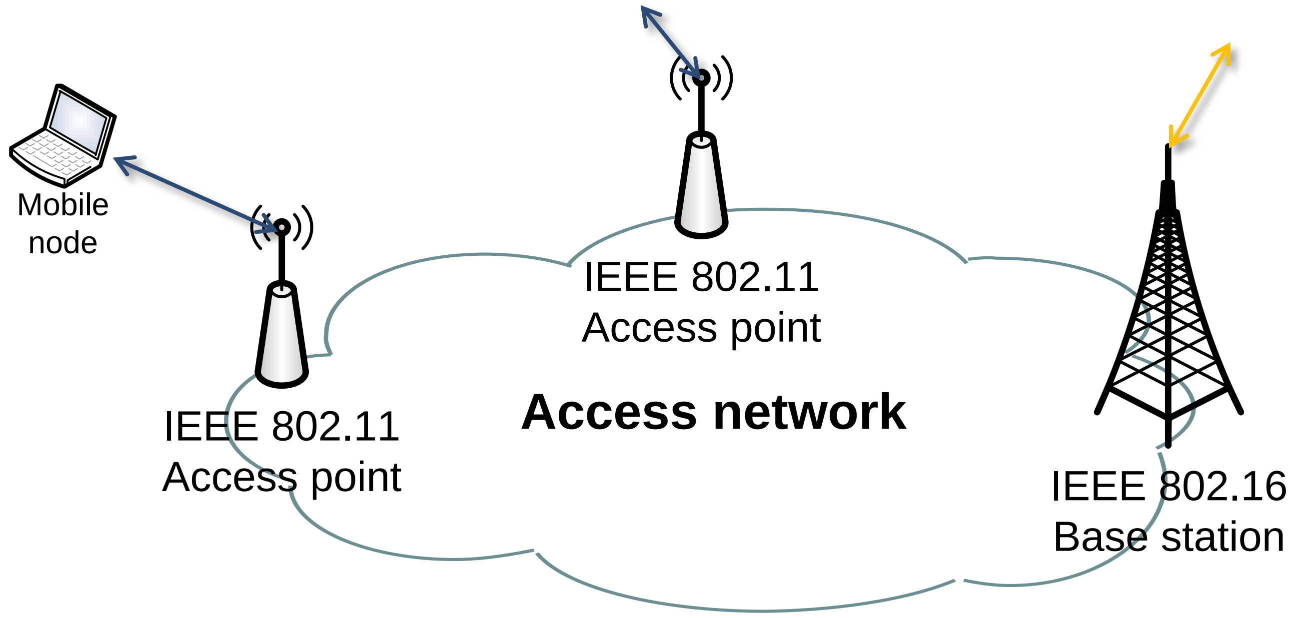
Handover taxonomy

- Layer 2 handover
- Intra-AR handover
- Intra-AN handover
- Inter-AN handover



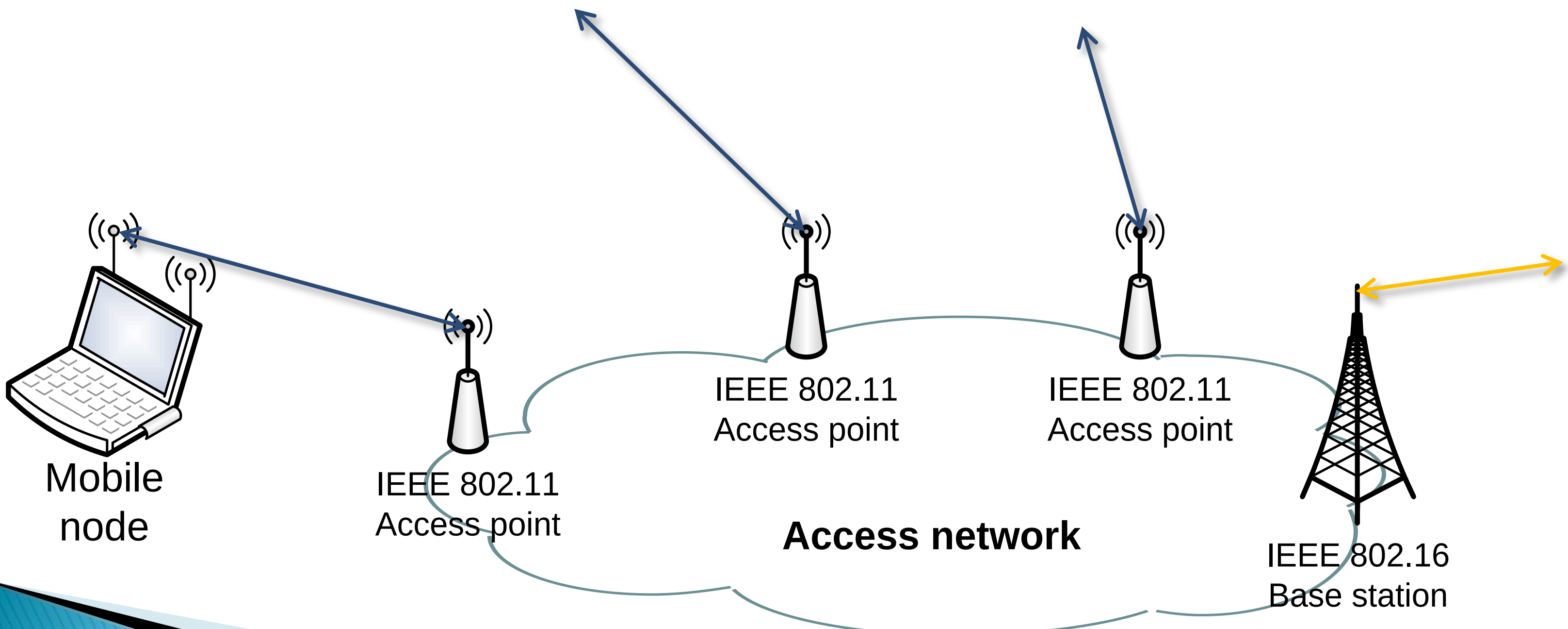
Handover taxonomy

- Intra-technology handover
- Inter-technology handover



Handover taxonomy

- Horizontal handover
- Vertical handover



Handover taxonomy

- By handover control type:
  - Mobile-initiated
  - Network-initiated handover

  - Mobile-controlled
  - Network-controlled handover

  - Mobile-assisted
  - Network-assisted
  - Unassisted handover

Handover taxonomy

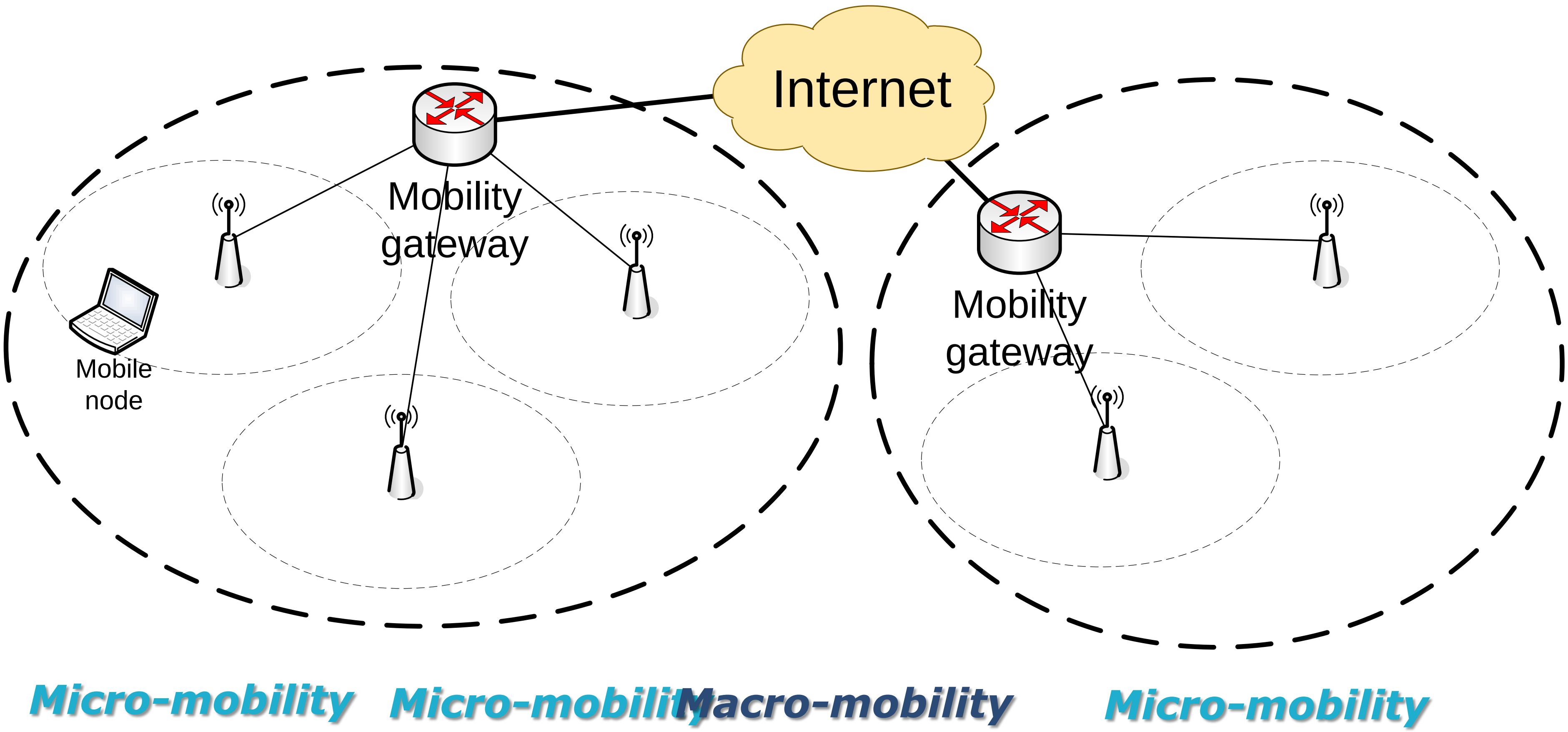
- By handover control:
  - Backward handover
  - Forward handover

  - Proactive handover
  - Reactive handover

  - Make-before-break (MBB) handover
  - Break-before-make (BBM) handover

  - Hard handover
  - Soft handover

Micro and macro-mobility



General concepts for mobility support

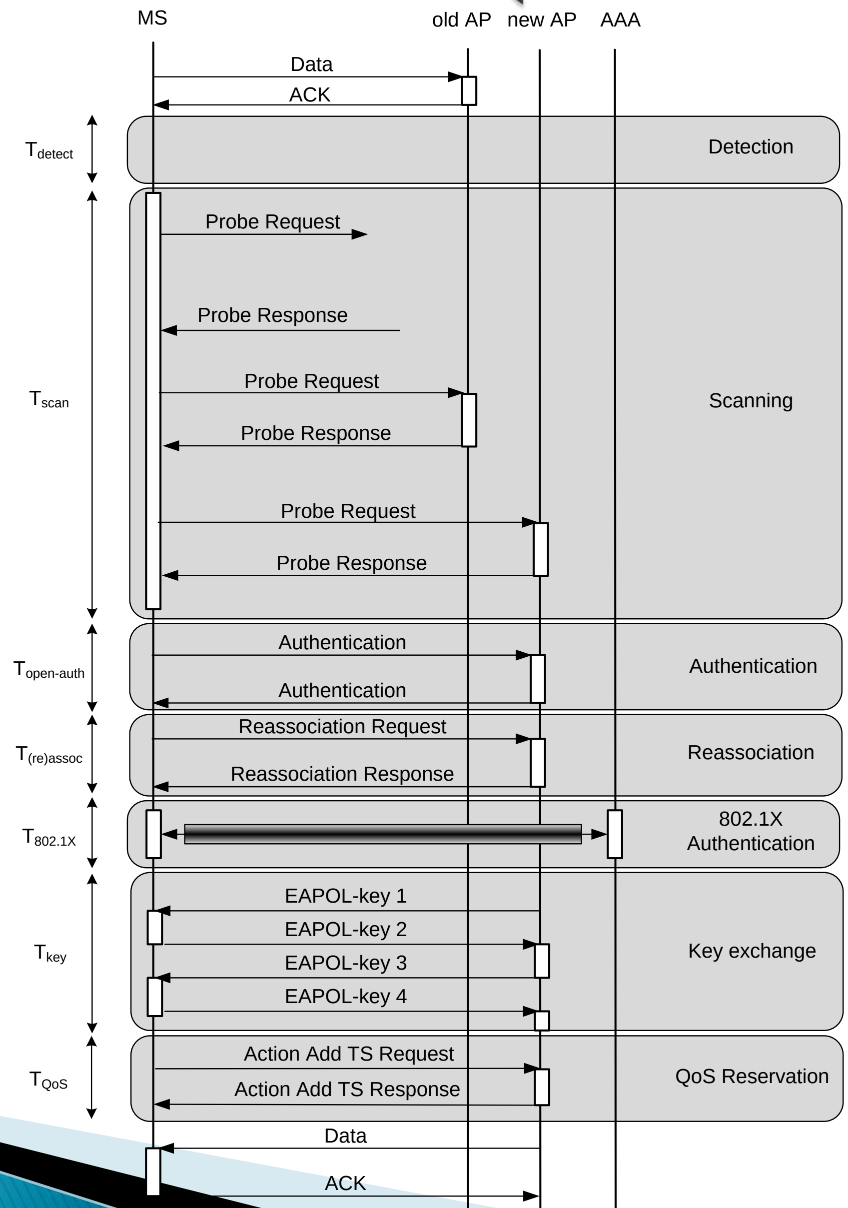
- Mobile IPv4 nodes:
  - MN (Mobile Node),
  - CN (Corresponding Node),
  - HA (Home Agent),
  - FA (Foreign Agent).

- Mobile IPv4 addresses:
  - HoA (Home Address),
  - CoA (Care-of-Address).

General concepts for mobility support

- Agent discovery
  - Mobile Node arrives at new network, obtains Care-of-Address (CoA) and discovers local Mobile IP (MIP) infrastructure elements (if necessary).
- Registration
  - Mobile node informs local or home MIP infrastructure elements about its current location.
- Data transfer
  - MIP infrastructure forwards traffic addressed to Mobile Node's Home Address to its current location (CoA).

Layer 2 handovers (IEEE 802.11)



L2 Handover delay

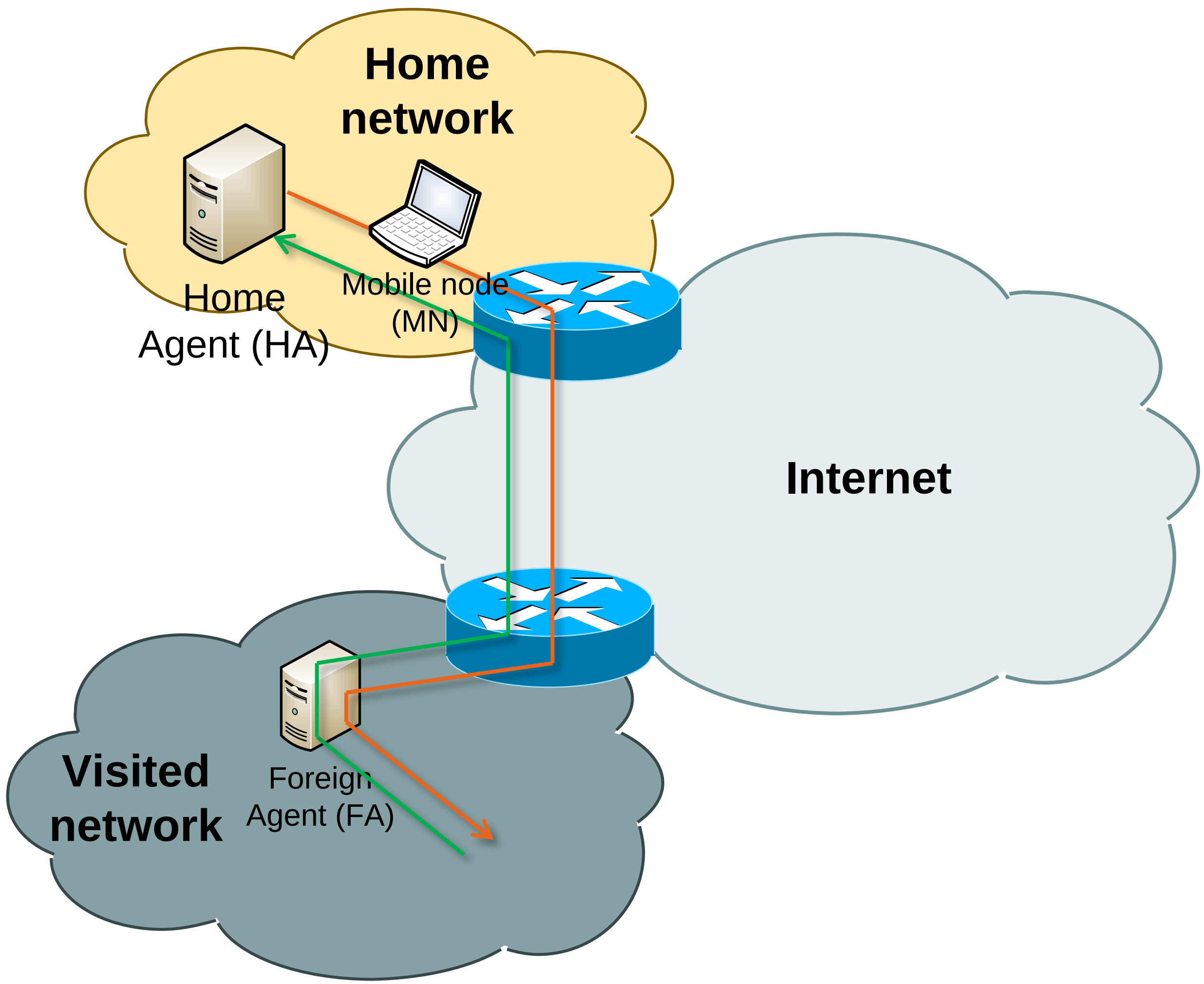
$$T_{802.11} = T_{detect} + T_{scan} + T_{open-auth} + T_{(re)assoc} + T_{802.1X} + T_{key} + T_{QoS}$$

Parameter	Empirical values
T_{detect}	0 –1600 ms
T_{scan}	58 –400 ms
$T_{open-auth}$	1 –10 ms
$T_{(re)assoc}$	1 –10 ms
$T_{802.1X}$	200 –700 ms
T_{key}	5 –50 ms
T_{QoS}	1 –10 ms
$\mathbf{T_{802.11}}$	**267 –2790 ms**

From: VATN J.O., ”An experimental study of IEEE 802.11b handover performance and its effect on voice traffic”

Mobile IPv4 – Registration

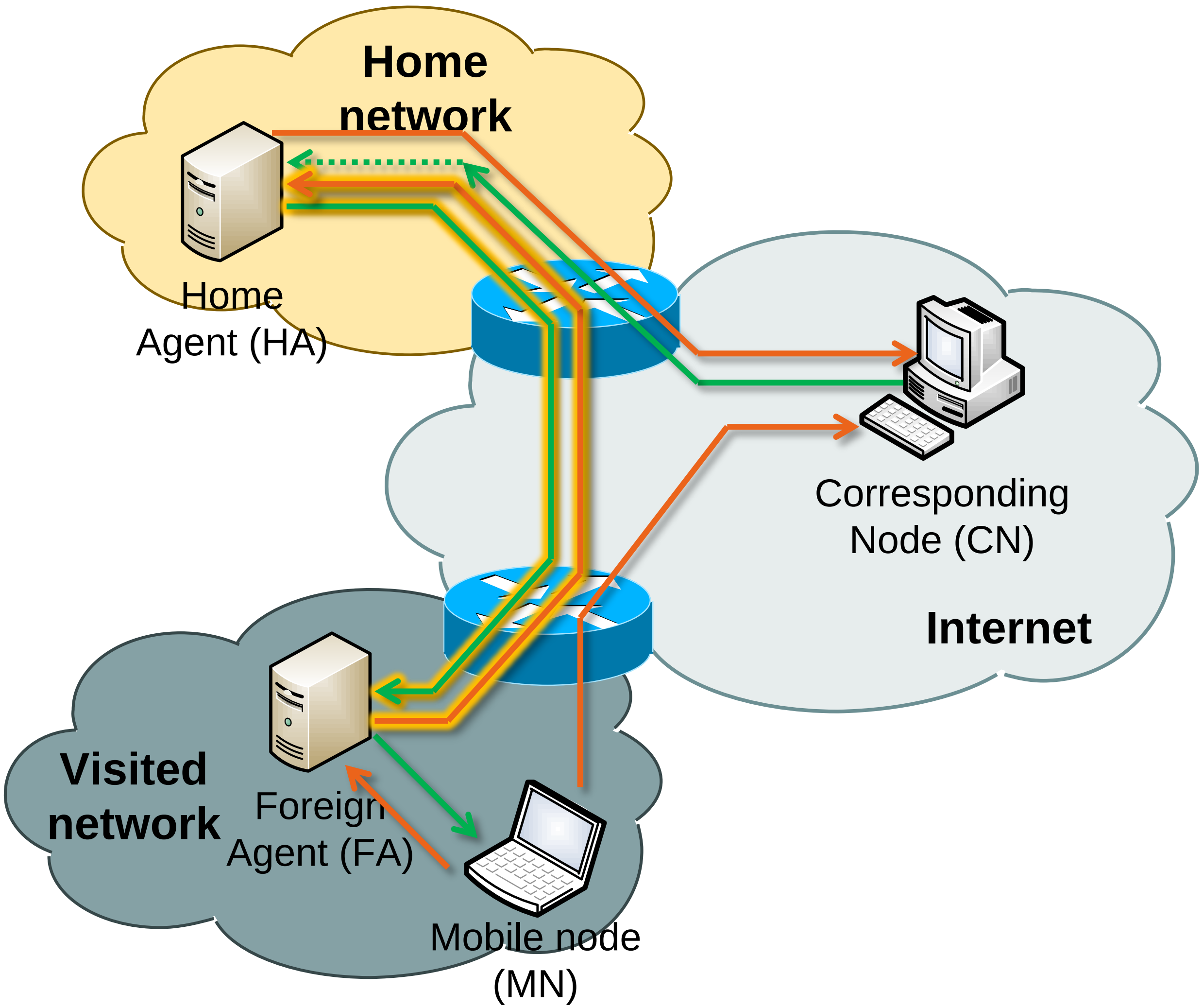
- MN arrives at Visited network and obtains local Care-of-Address (CoA).
- MN discovers appropriate local FA.
- MN sends Registration Request to HA through FA.
- HA responds to MN through FA with Registration Response.



Mobile IPv4 – Data forwarding

- CN sends data to MN's Home Address.
- Data is delivered to Home Network and intercepted by HA.
- HA tunnels data to FA.
- FA delivers data to MN's CoA.

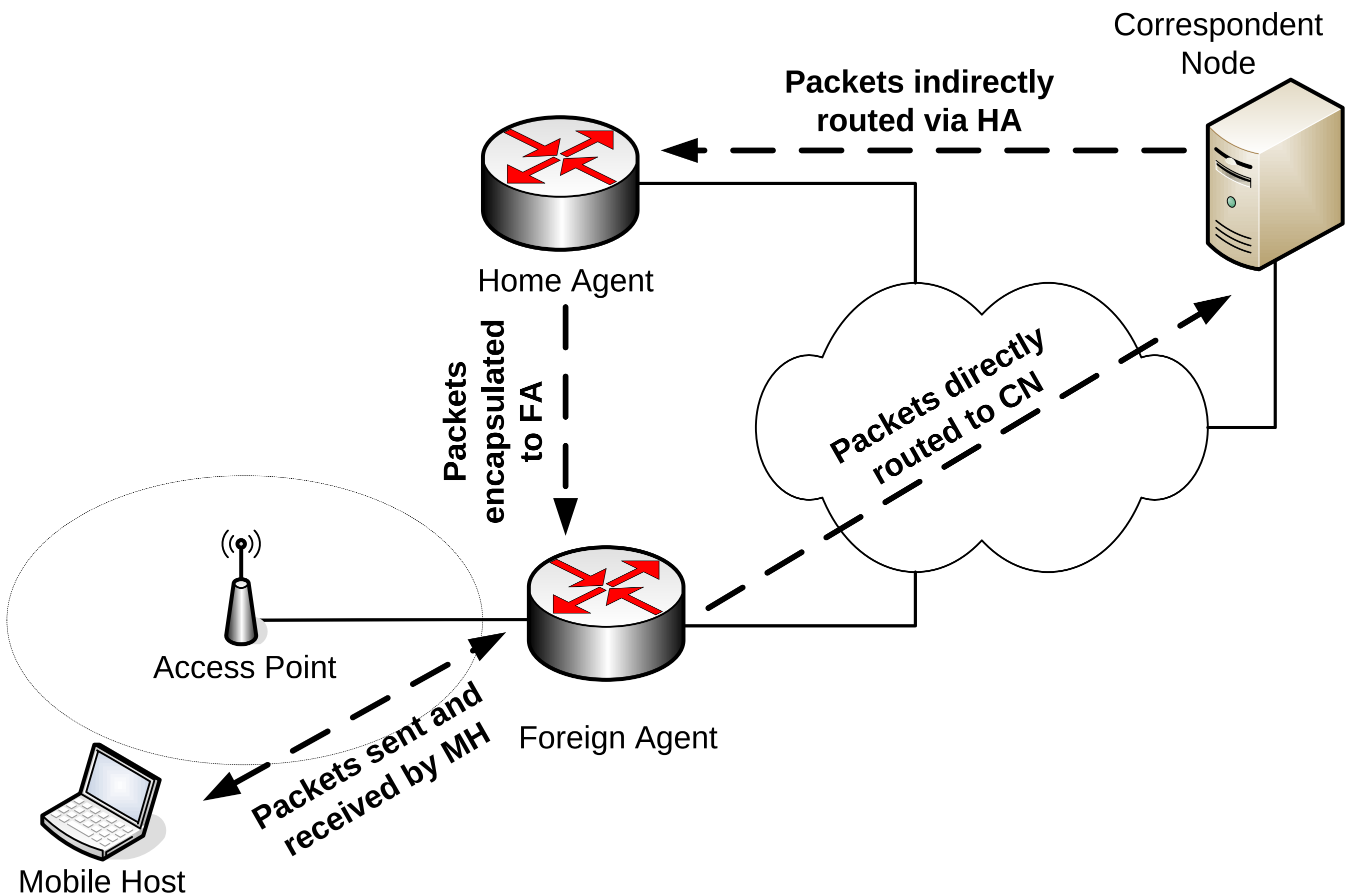
- MN sends data to CN.
- Data is delivered to CN by standard IP mechanisms – triangle routing.
- Alternatively Reverse Tunnel feature can prevent triangle routing.



Mobile IPv4 issues

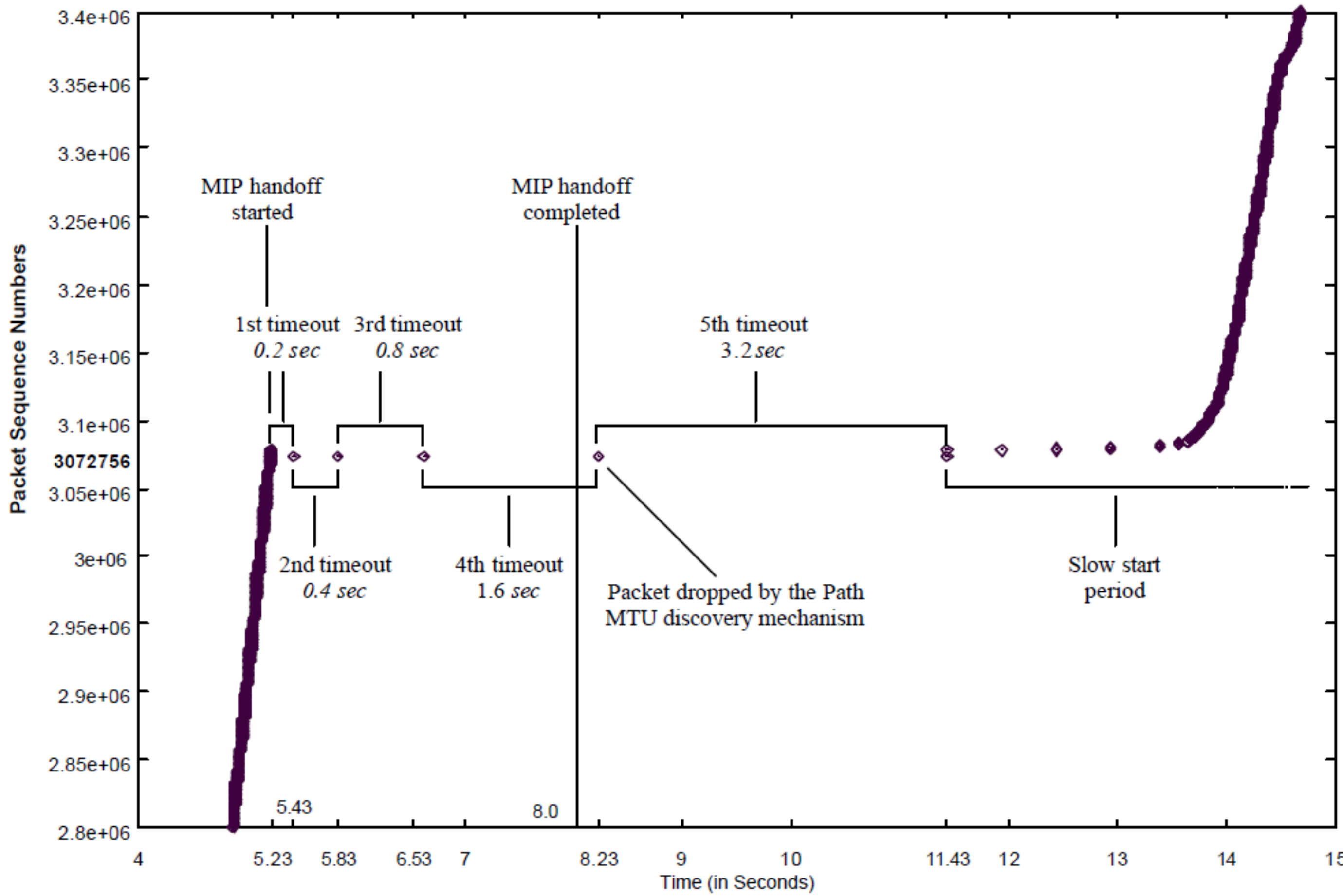
- Triangle routing
  - Link overhead
  - Additional delay
  - Node processing overhead
- Large amount of signaling
  - No separation for local and global handovers
  - No support for idle/sleeping nodes
- Each mobile system requires global IP home address – tight IPv4 address space

Triagle routing in MIPv4



Mobile IP Handover Performance

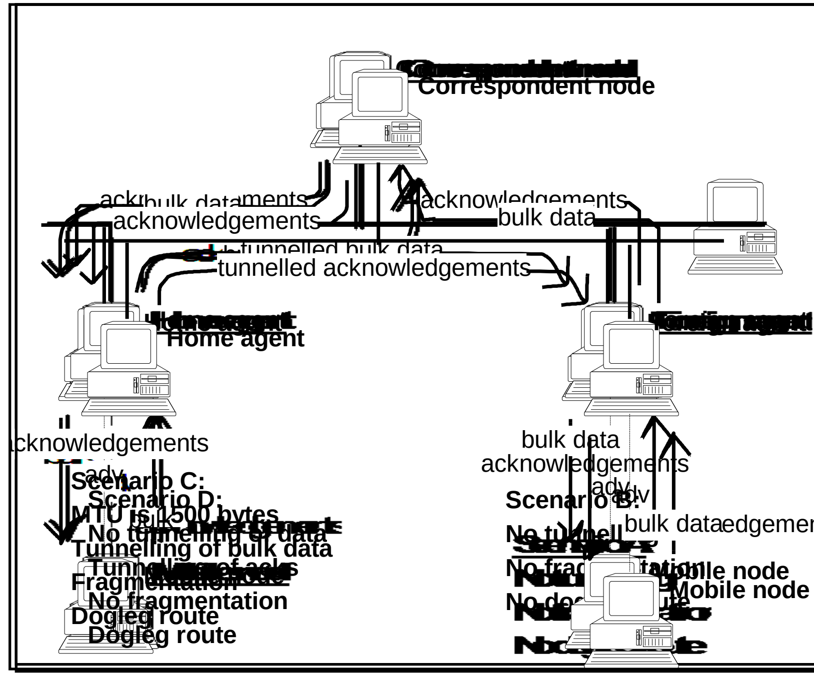
- Real-time services are sensitive to MIP delays.
- Non-real-time services can also be affected.



From " Performance Evaluation of TCP over Mobile IP, PIMRC 1999, Fikouras, El Malki et al.

Impact of Mobile IP on bulk data transmission

- Scenario A:
  - MN at home network receiving bulk data from CN.
- Scenario B:
  - MN at home network sending bulk data to CN.
- Scenario C:
  - MN at visited network receiving bulk data from CN.
- Scenario D:
  - MN at visited network sending bulk data to CN.



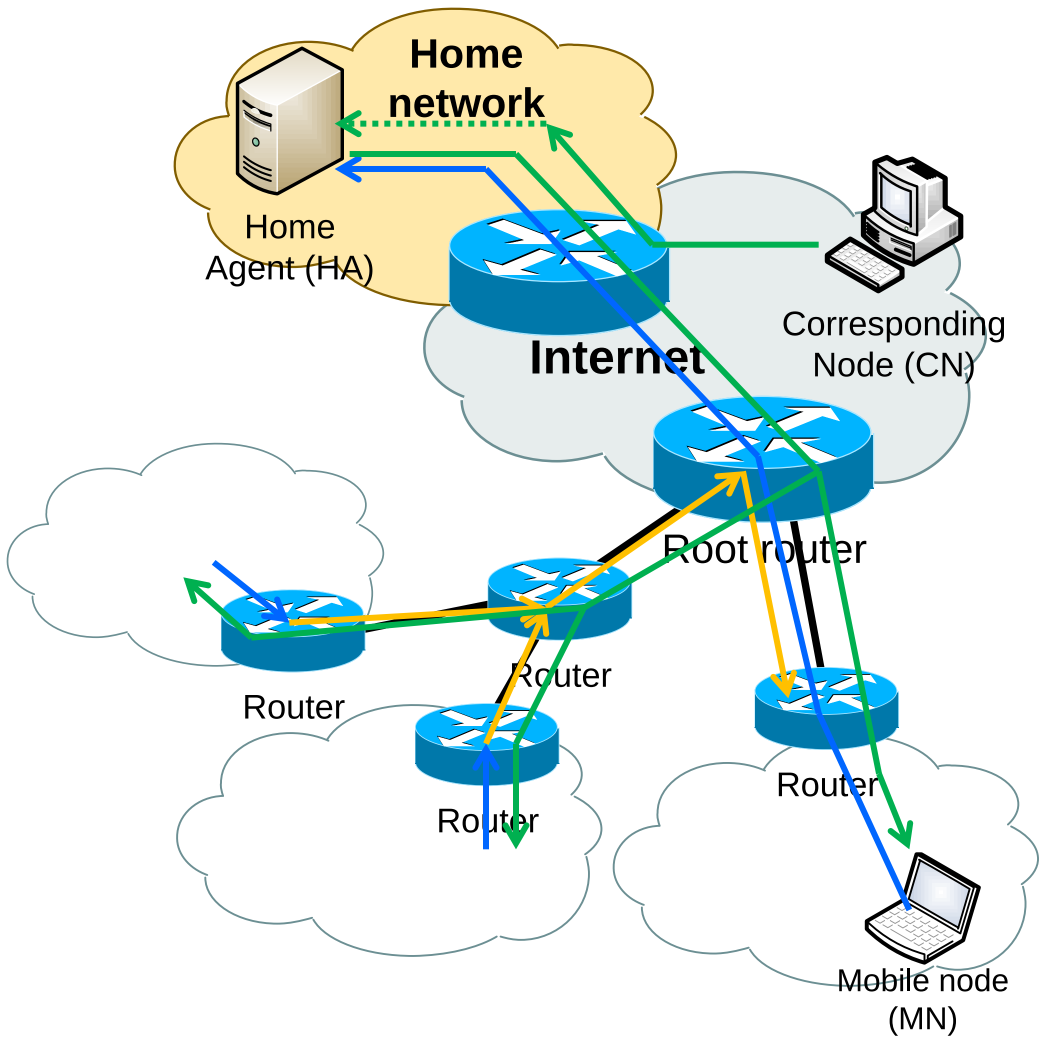
Scenario	Troughput
A	5.86 Mb/s
B	5.58 Mb/s
C	3.09 Mb/s
D	5.23 Mb/s

- <u>Important Mobile IP-induced factors:</u>
  - Tunneling overhead
  - Dogleg route (MN-**FA**-**HA**-CN) overhead,
  - Fragmentation overhead,
  - Handover overhead.

From: Mobile IP, Prashant Bhargava, CS 599 : Wireless Communications and Mobile Computing

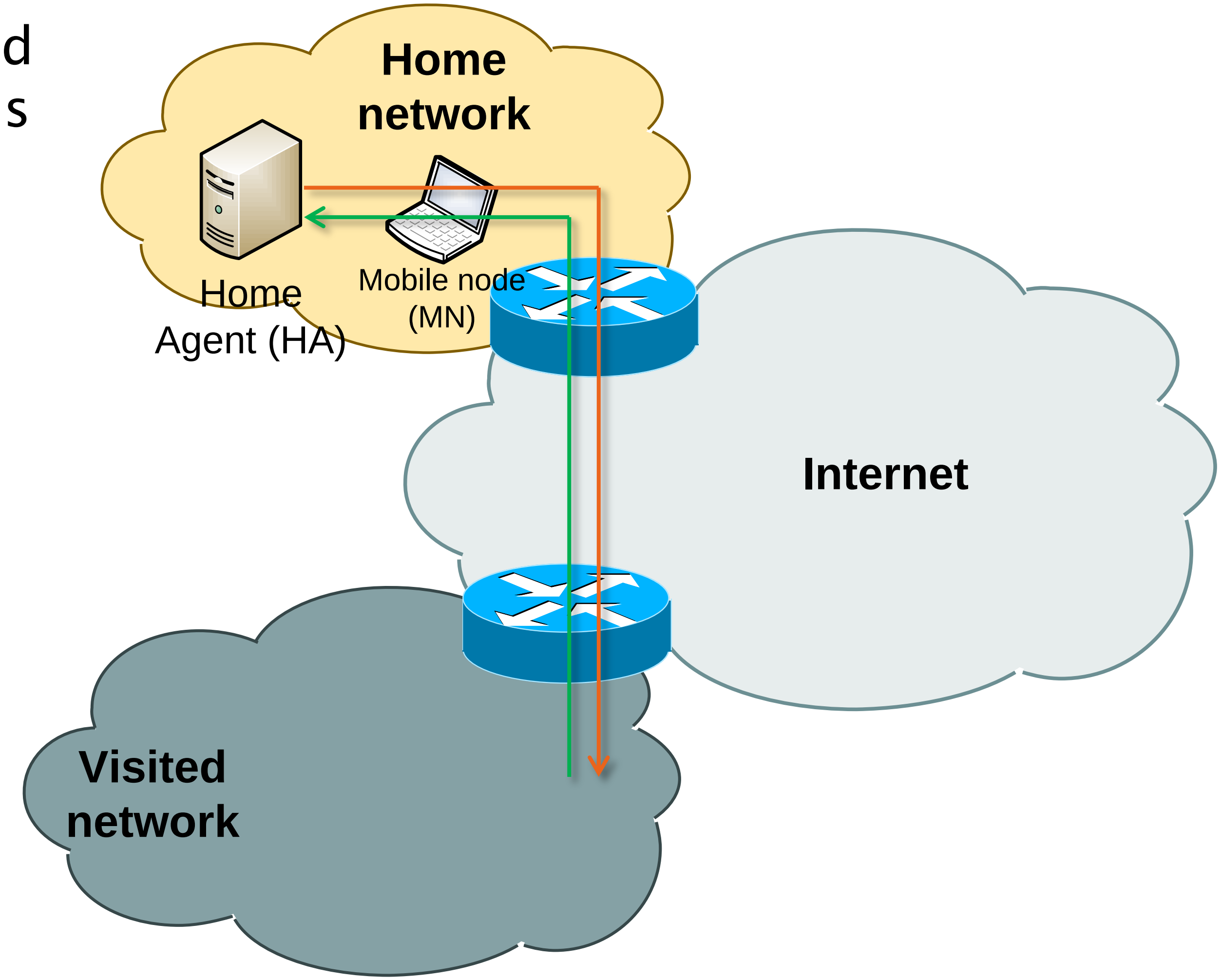
Handoff-Aware Wireless Access Internet Infrastructure (HAWAII)

- MN arrives at visited network, obtains local CoA and informs HA.
- MN changes access network, **keeps CoA** and informs its access router (base station).
- Access router updates routers within a domain.
- Traffic for unchanged CoA is routed to a new location.



Mobile IPv6 – Registration

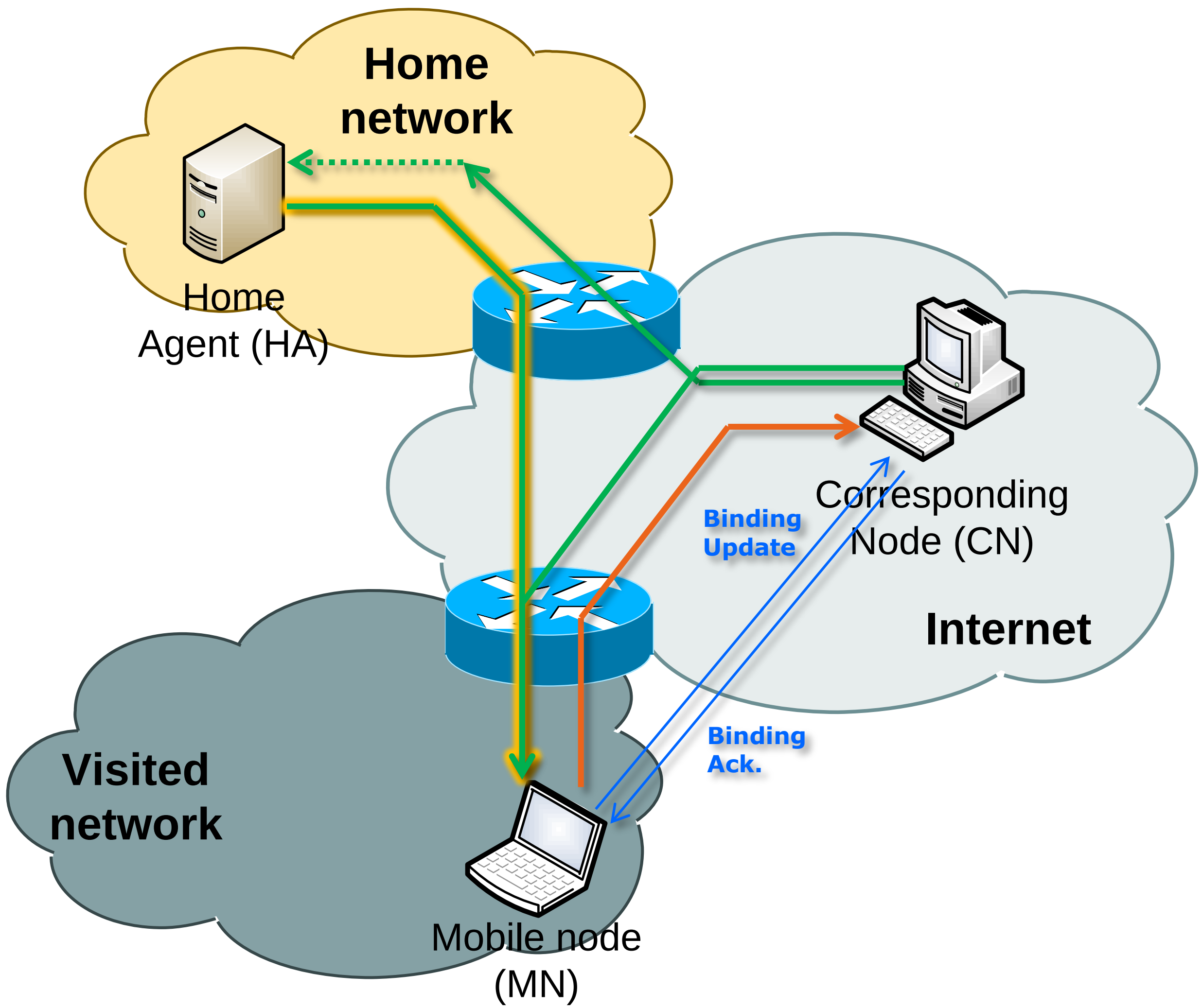
- MN arrives at Visited network and obtains local Care-of-Address (CoA).
- MN sends Binding Update to HA.
- HA responds to MN with Binding Acknowledgement.

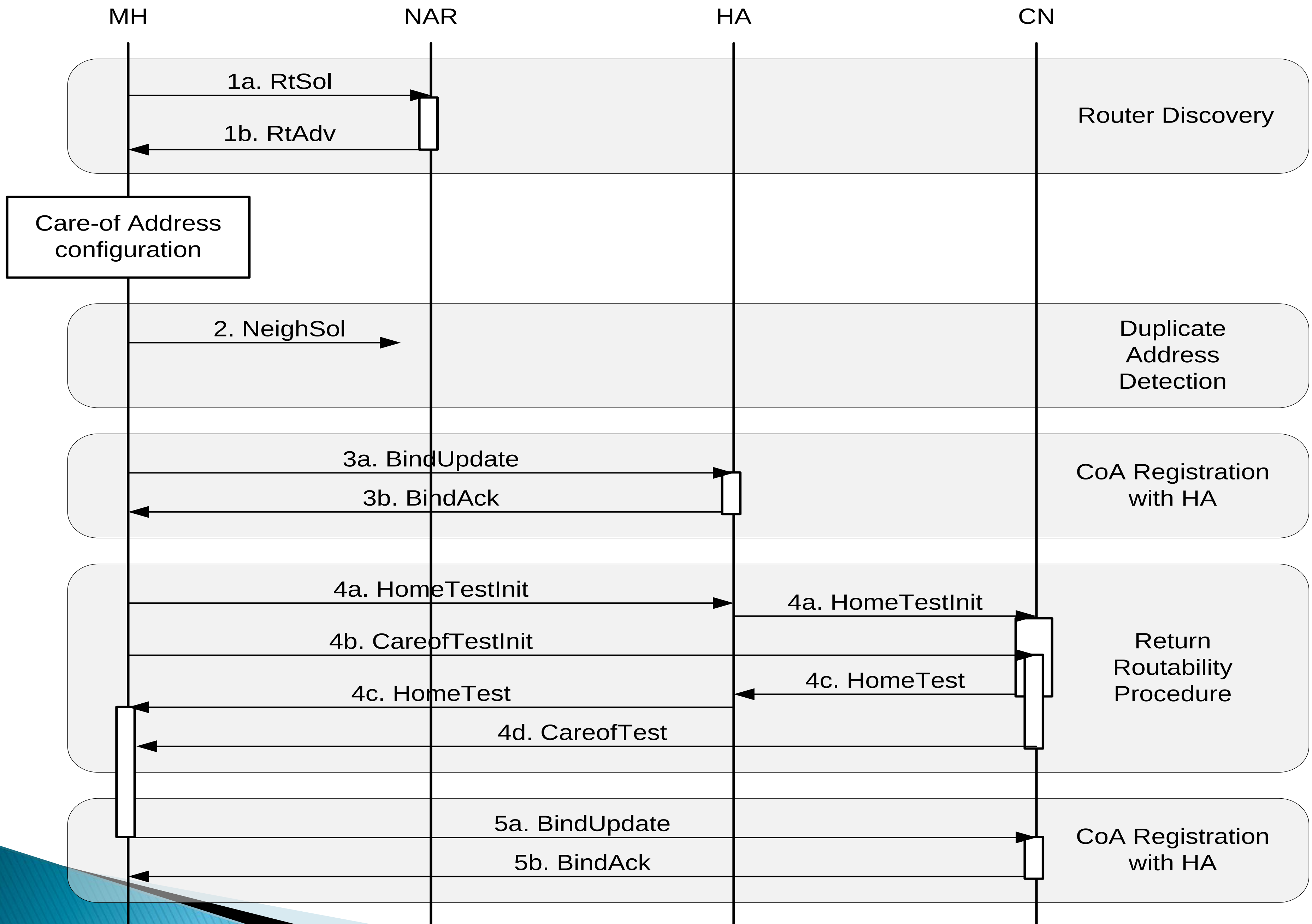


Mobile IPv6 – Data forwarding

- CN sends data to MN's Home Address.
- Data is delivered to Home Network and intercepted by HA.
- HA tunnels data to to MN's CoA.

- MN sends data to CN.
- Data is delivered to CN by standard IPv6 mechanisms – triangle routing.
- If CN supports MIPv6 mechanisms route optimization might be used.





The MIPv6 handover algorithm

L2/L3/L4 Latency Budget

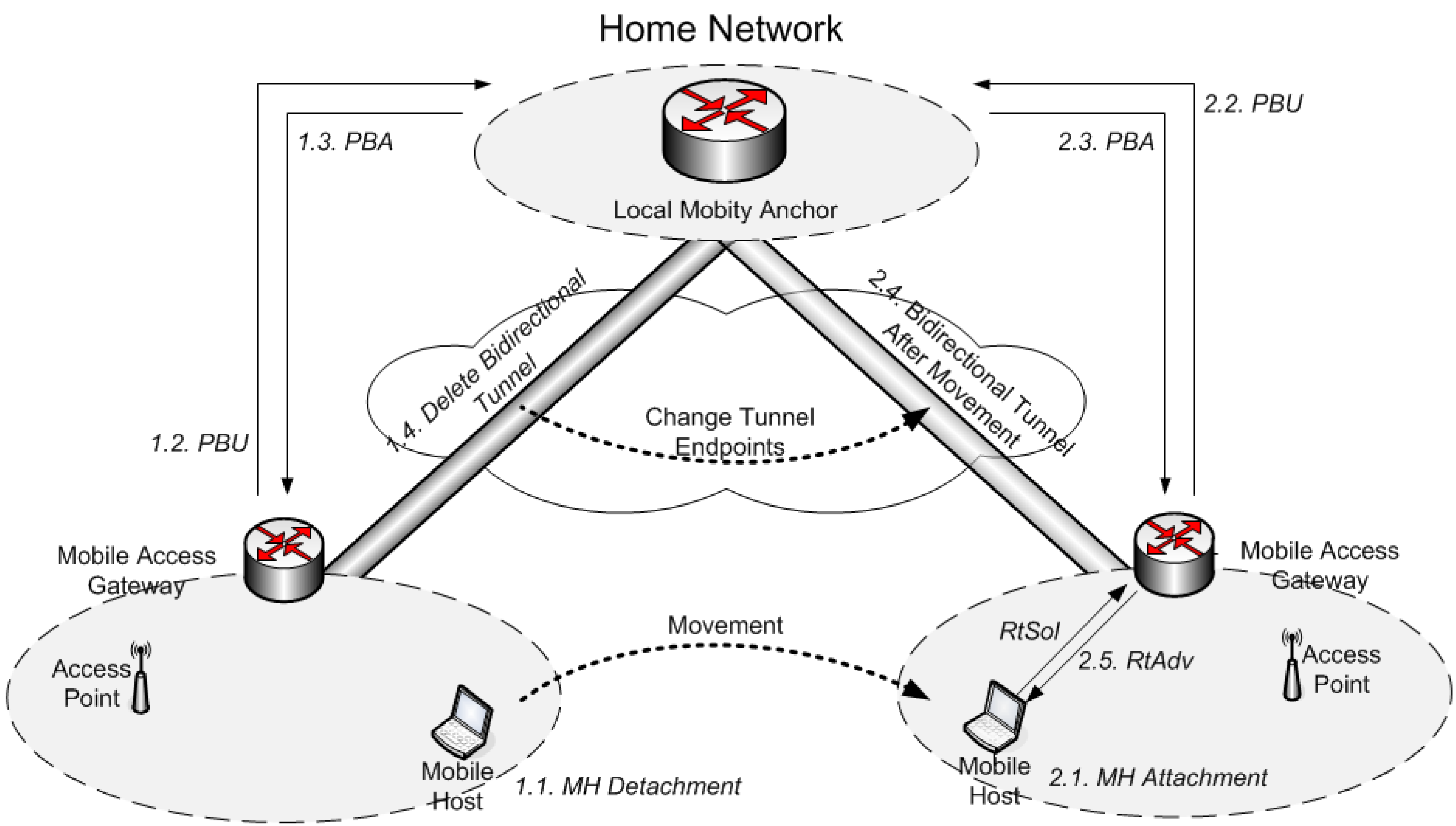
Layer	Item	IPv4 Best Case (ms)	IPv4 Worst Case (ms)	IPv6 Best Case (ms)	IPv6 Worst Case (ms)
L2	802.11 scan (passive)	0 (cached)	1 sec (wait for Beacon)	0 (cached)	1 sec (wait for Beacon)
L2	802.11 scan (active)	20	300	20	300
L2	802.11 assoc/reassoc (no IAPP)	4	20	4	20
L2	802.11 assoc/reassoc (w/ IAPP)	20	80	20	80
L2	802.1X authentication (full)	750	1200	750	1200
L2	802.1X Fast resume	150	300	150	300
L2	Fast handoff (4-way handshake only)	10	80	10	80
L3	DHCPv4 (6to4 scenario only)	200	500	0	0
L3	IPv4 DAD	0 (DNA)	3000	0	0
L3	Initial RS/RA	0	0	5	10
L3	Wait for more RAs	0	0	0	1500
L3	IPv6 DAD	0	0	0 (Optimistic DAD)	1000
L3	MN-HA BU	0	200	0	200
L3	MN-CN BU	100	200	100	200
L4	TCP adjustment	0	Varies	0	Varies

From: Areg Alimian, Bernard Aboba, “Analysis of Roaming Techniques”

Network Based Mobility => PMIPv6

- Core network devices perform the signaling and management on behalf of the mobile node
- The signaling and tunnels occur only in core network – more bandwidth in wireless links
- It does not require any modification of standard implementation of MH's IPv6 stack

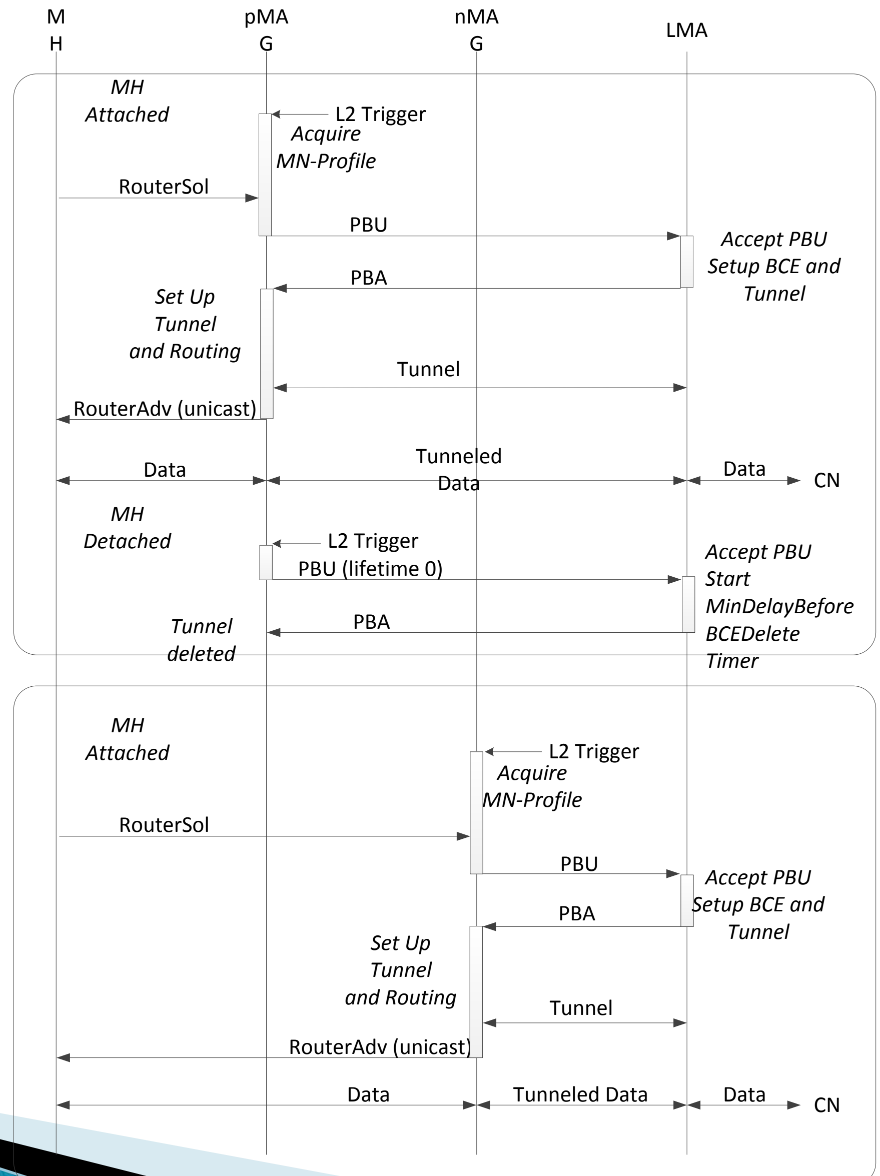
Architecture 1/2



Architecture 2/2

- Local Mobility Anchor
  - similar to Home Agent in Mobile IPv6
  - responsible for maintaining routes and forwarding information for all MHs in domain
- Mobile Access Gateway
  - responsible for tracking the MH's movements
  - Sets up of bidirectional tunnel to LMA
  - Manages connectivity between MH and LMA
  - all MAGs act as a default router for MH

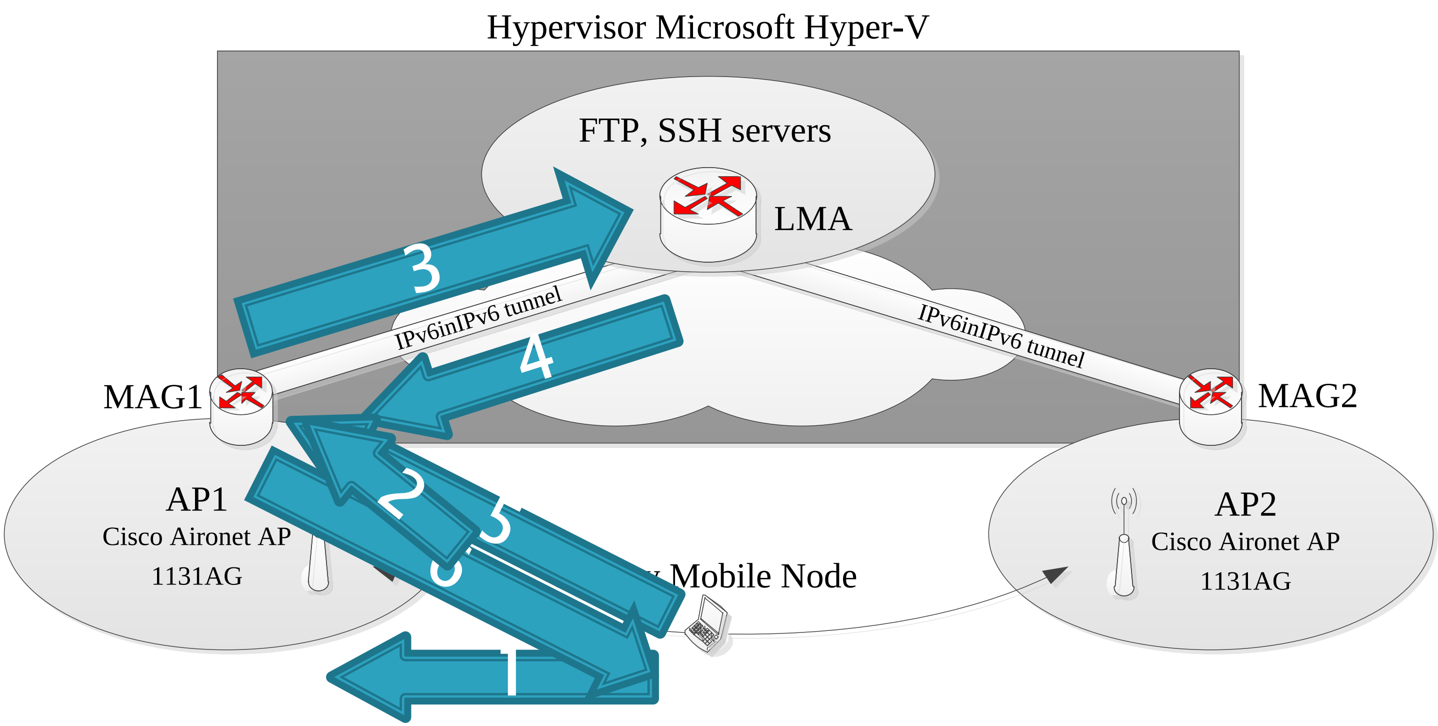
Massages flow



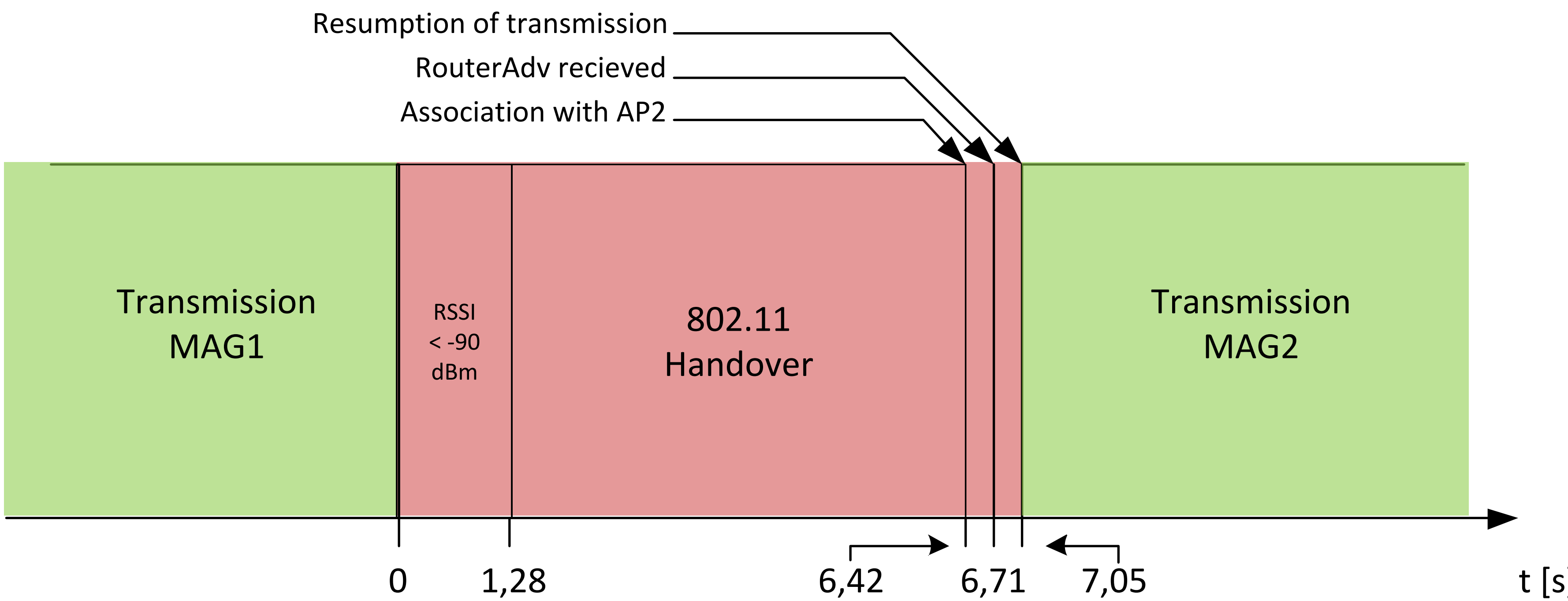
PMIPv6 implementation

- Written in Python with Scapy modules
- Base on standard MIPv6 implementation
- Routing and tunnels managment with unix system tools – *ip*
- Easy to develop and improve for future feature
- Work still in progress

System under test



Example results



A total 7.05 s handover time consists of:

- 6.42 s – Layer 2 IEEE 802.11 handover
    - 1.28 s – poor connectivity due to low signal quality before the handover decision,
    - 5.14 s – network disovery, authentication and association.
- 0.63 – Layer 3 PMIPv6 handover.

Comparison of IP mobility protocols

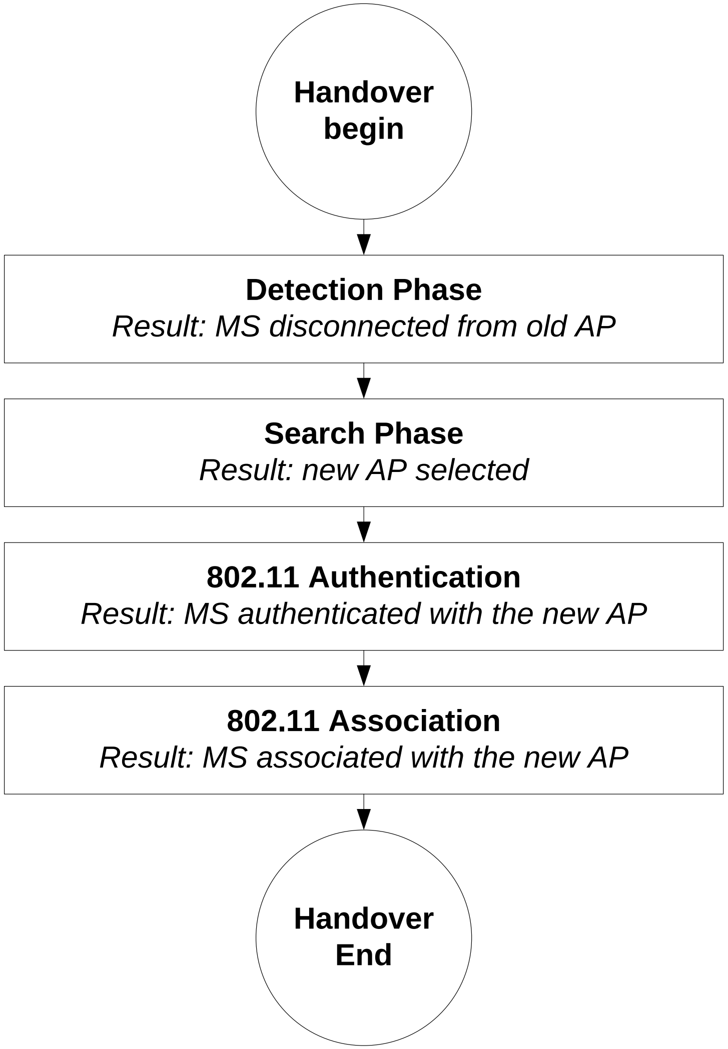
Protocol	Mobility Type	Handover Type	Link Detection	Registration	Address Translation
Mobile IPv6 (basic)	Macro	Hard	Router advertisement	At Home Agent	Encapsulation
Hierarchical Mobile IPv6	Universal	Hard	Router advertisement	At Mobility Anchor Point	Encapsulation
Proxy Mobile IPv6	Universal (network-based)	Hard	Events or DNAv6	At Mobile Access Gateway	Encapsulation
Fast Handovers	Universal	Hard	Proxy Router Adv.	At Home Agent	Encapsulation
Cellular IP	Micro	Semi-soft or hard	Network specific	Route Updates	No
HAWAII	Micro	Forwarding and non-forwarding schemes	Network specific	Path Updates	No
RAT	Macro	Hard (no TCP sup.)	Network specific	At registration server	NAT
MobileNAT	Universal	Hard	Using DHCP ext.	At Home NAT	NA(P)T
Extended SIP	Macro	Hard (no TCP support)	Network specific	At SIP router	via SIP server

IEEE 802.11 Standard (Wi-Fi)

- The most popular solution for wireless LANs.
- Relatively high bandwidth of WLANs (up to 300/450 Mbps in case of IEEE 802.11n).
- The coverage of WiFi networks is quite limited.
- The station-initiated handover is performed in the MAC sublayer.
- The station can be associated only with one AP at a time.

IEEE 802.11 handover

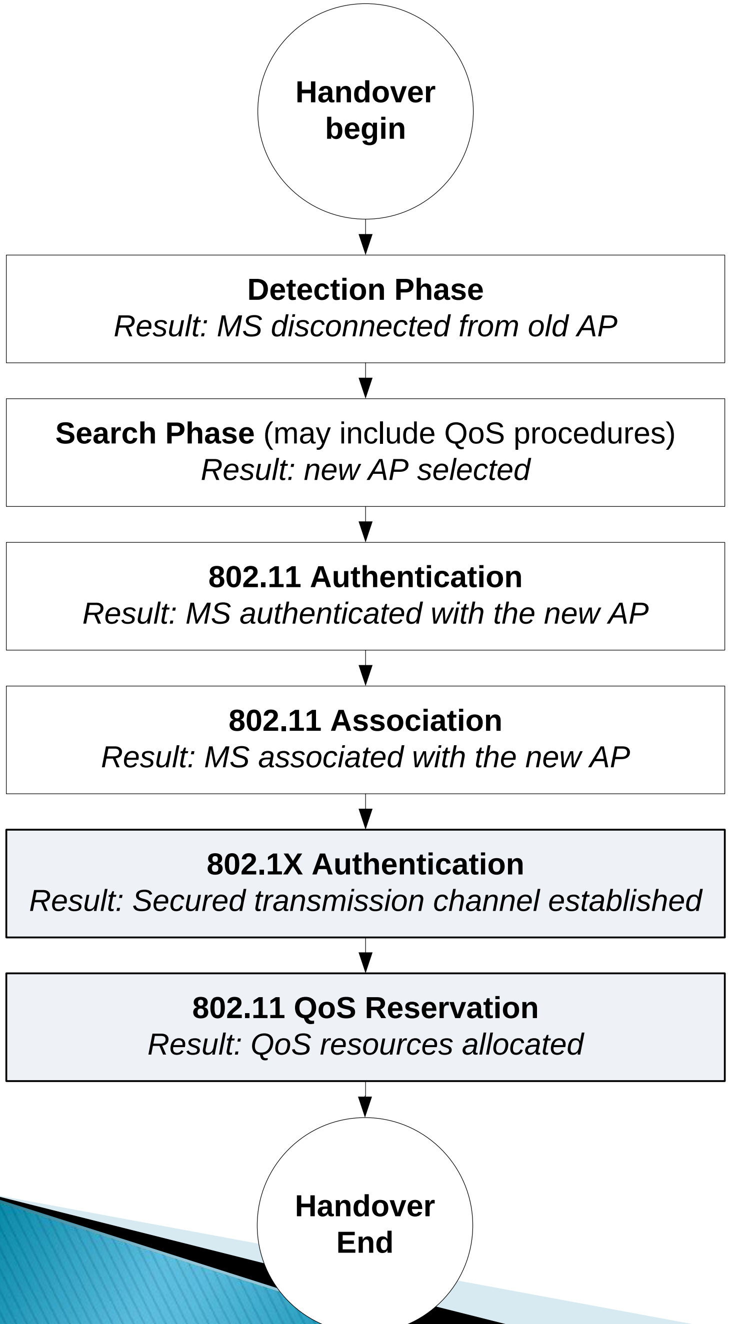
- Handover performance is one of crucial factors for multimedia services support.
- Multimedia applications are very sensitive to channel disruption, handover delays or packet losses.
- The handover delay went up dramatically with the number of management frames introduced in a new extensions of the IEEE 802.11 standard.



802.11-1999 handover

Phase	Time [ms]
Detection	5-50
Search	20-600
802.11 Authentication	0.25-5
802.11 Association	0.25-5
Total	**25.5-660**

802.11-2007 handover



Phase	**Time [ms]**
Detection	5-50
Search	20-600
802.11 Authentication	0.25-5
802.11 Association	0.25-5
802.1X Authentication	200-600
802.11 QoS	0.5-5
Total	**226-1265**

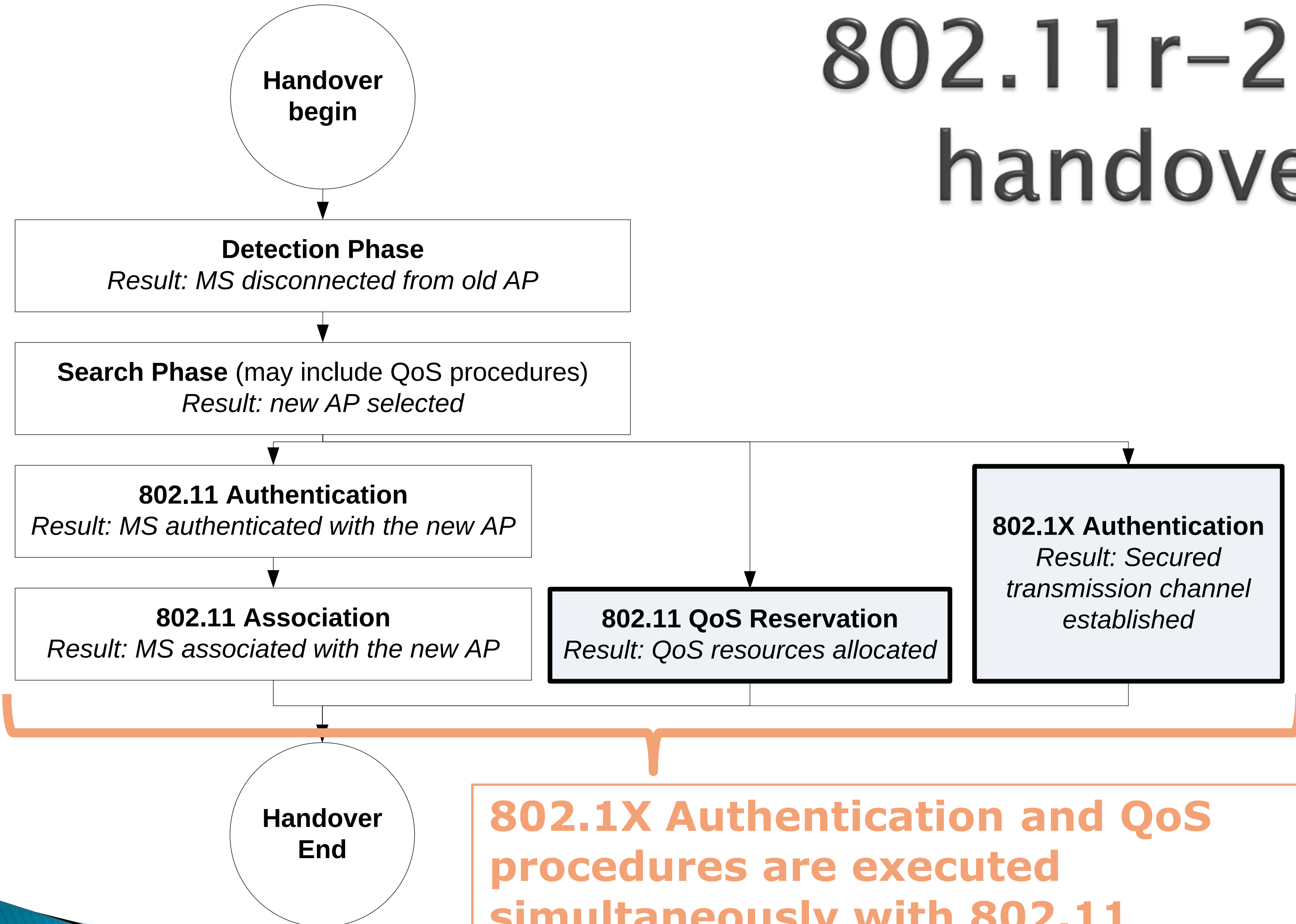
L2 Handover delay

$$T_{802.11} = T_{detect} + T_{scan} + T_{open-auth} + T_{(re)assoc} + T_{802.1X} + T_{key} + T_{QoS}$$

Parameter	Empirical values
T_{detect}	0 –1600 ms
T_{scan}	58 –400 ms
$T_{open-auth}$	1 –10 ms
$T_{(re)assoc}$	1 –10 ms
$T_{802.1X}$	200 –700 ms
T_{key}	5 –50 ms
T_{QoS}	1 –10 ms
$T_{802.11}$	**267 –2790 ms**

From: VATN J.O., ”An experimental study of IEEE 802.11b handover performance and its effect on voice traffic”

802.11r-2008 handover

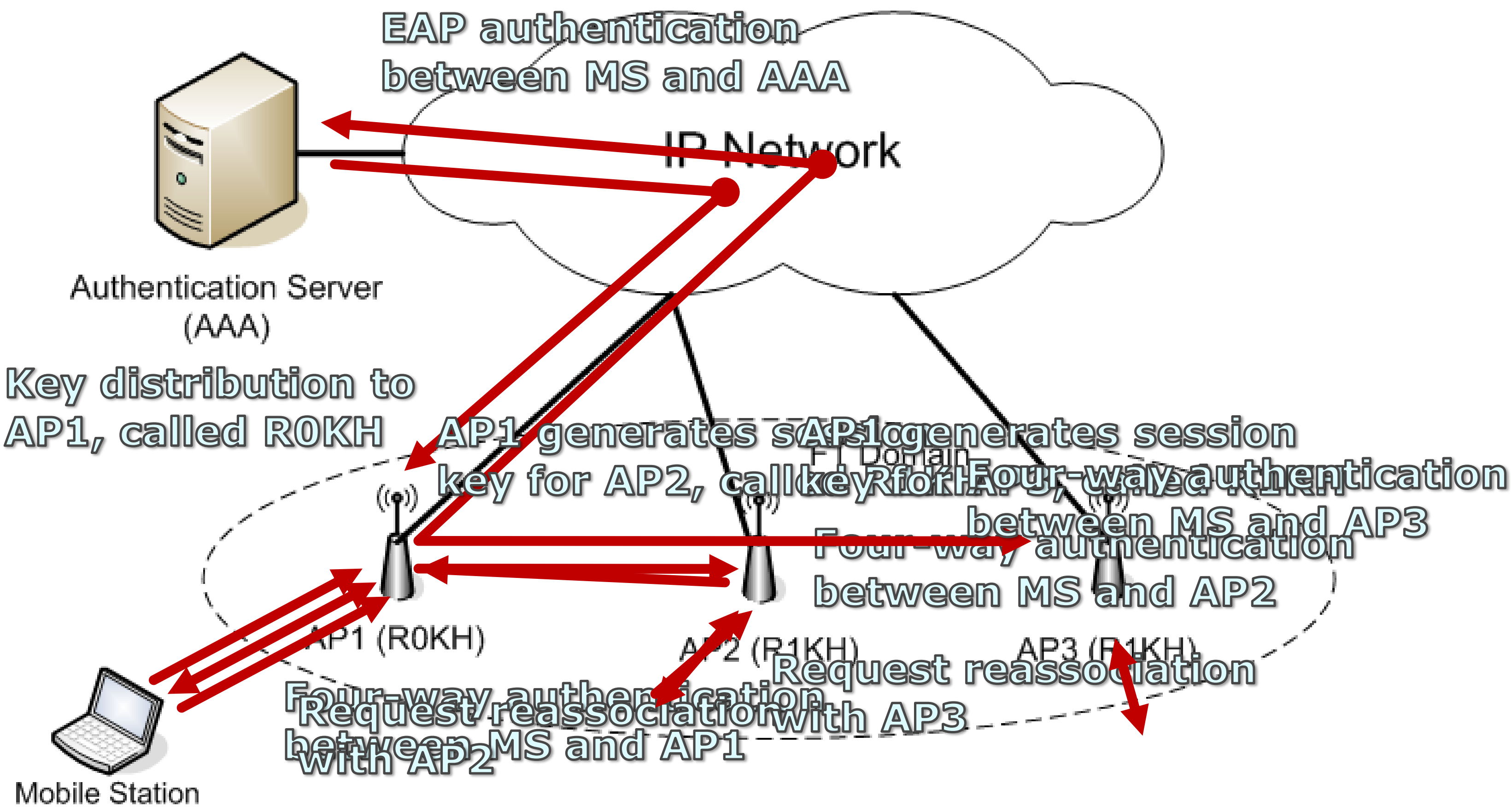


802.1X Authentication and QoS procedures are executed simultaneously with 802.11 Authentication and Association.

802.11r-2008

- IEEE 802.11r-2008 amendment proposes algorithms to bring the number of frames required for handover down to the level of 802.11-1999.
- **Can multimedia applications be properly supported in IEEE 802.11r networks?**

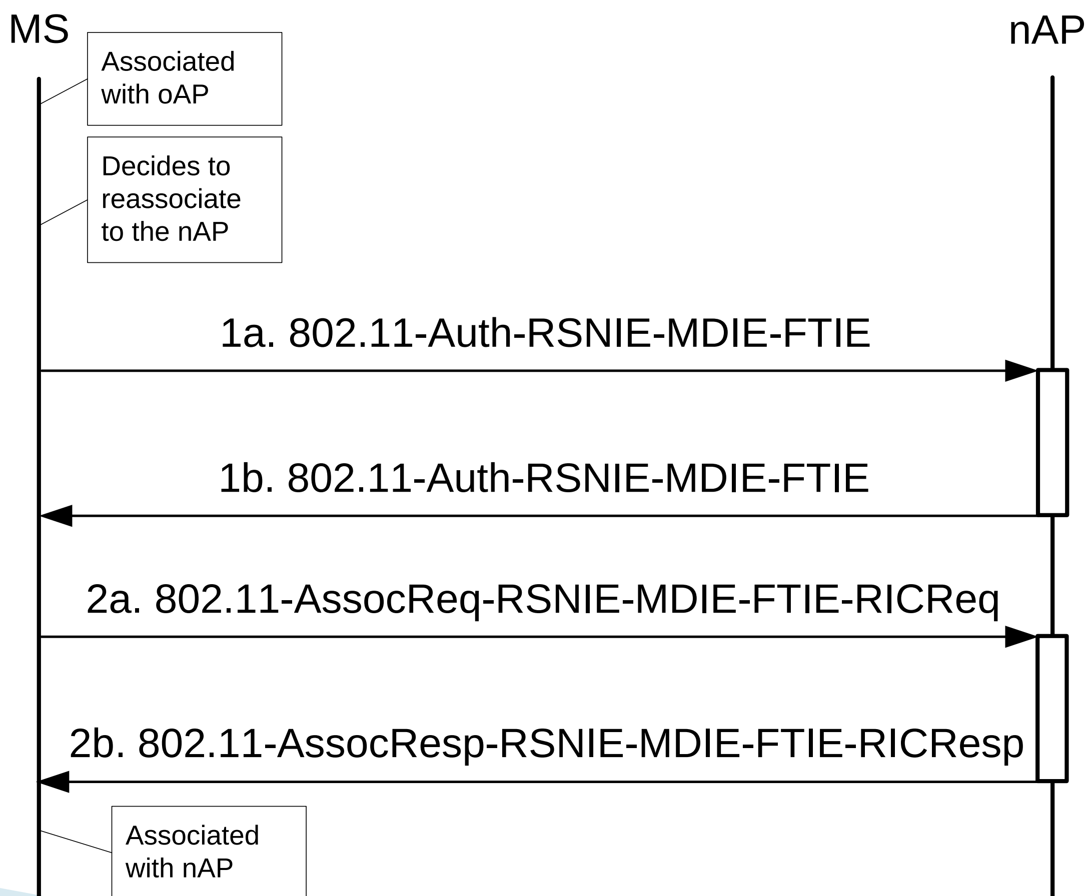
Fast BSS Transition (FT)



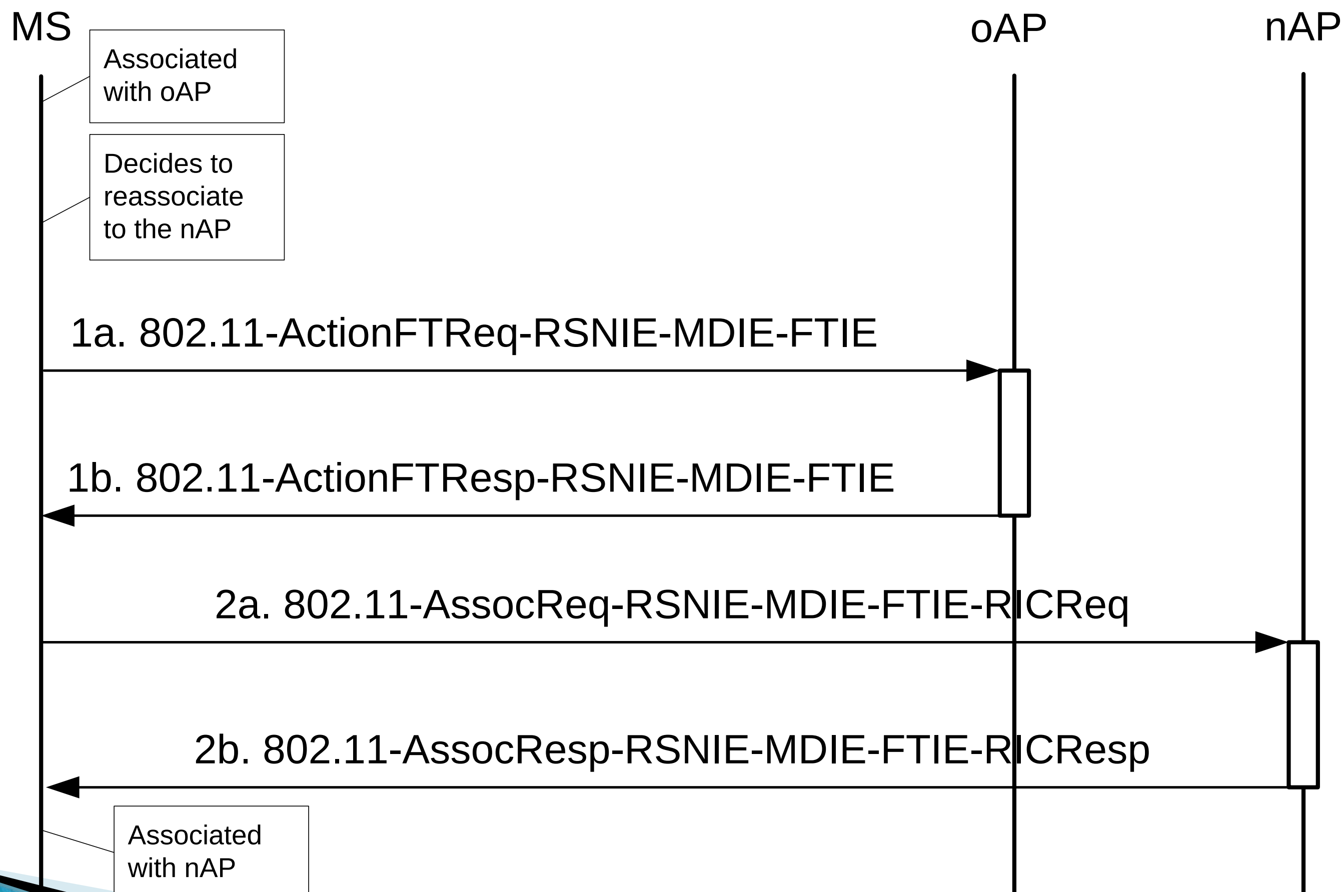
FT protocols

- Over-the-air FT protocol
  - Mobile Station communicates over a direct 802.11 link to the new AP
- Over-the-DS FT protocol
  - Mobile Station communicates with the new AP via the old AP

Over-the-air FT protocol



Over-the-DS FT protocol



802.11r-2008 performance

- The handover delay is smaller for both Over-the-Air and Over-the-DS scenarios comparing to the 802.11-2007.
- Over-the-DS algorithm can reduce handover delay below 50 ms which is accepted for the multimedia services.

IEEE 802.11r: Performance

Authentication method	Average Roaming time (ms)	Average Packet loss %	Maximum consecutive lost datagrams (Average)
Baseline – Full 802.1X EAP authentication	525	1.8	53
Fast Transition using 802.11r	42	0.2	6

From: Sangeetha Bangolae, Carol Bell and Emily Qi, “Performance Study of Fast BS Transition using IEEE 802.11r”

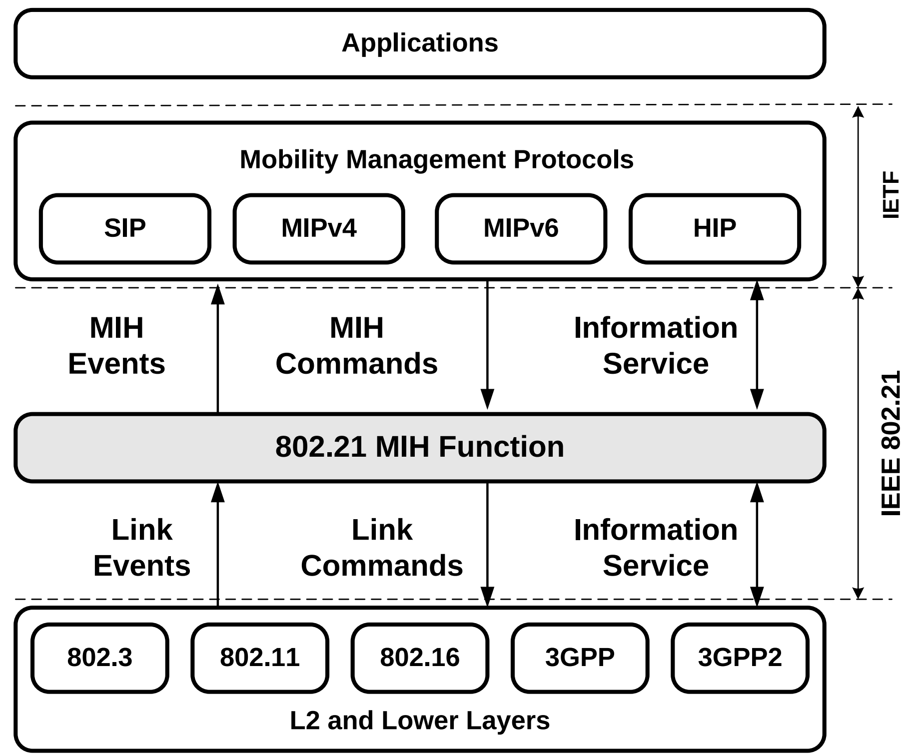
Handover delay for FT protocols

Phase / Algorithm	Regular 802.11	Over-the-Air FT	Over-the-DS FT
Scanning	315.14 ± 3.24	314.90 ± 3.62	0
Authentication	0.37 ± 0.14	0.82 ± 0.24	0
Association	0.79 ± 0.28	1.25 ± 0.58	3.30 ± 2.77
1X Authentication	542.19 ± 0.85	0	0
4Way Authentication	0.97 ± 0.47	0	0
QoS	1.23 ± 0.98	0	0
Channel switching	10.00 ± 0.00	10.00 ± 0.00	10.00 ± 0.00
Layer 2 delay	**866.93 ± 5.38**	**324.65 ± 5.12**	**13.22 ± 2.87**

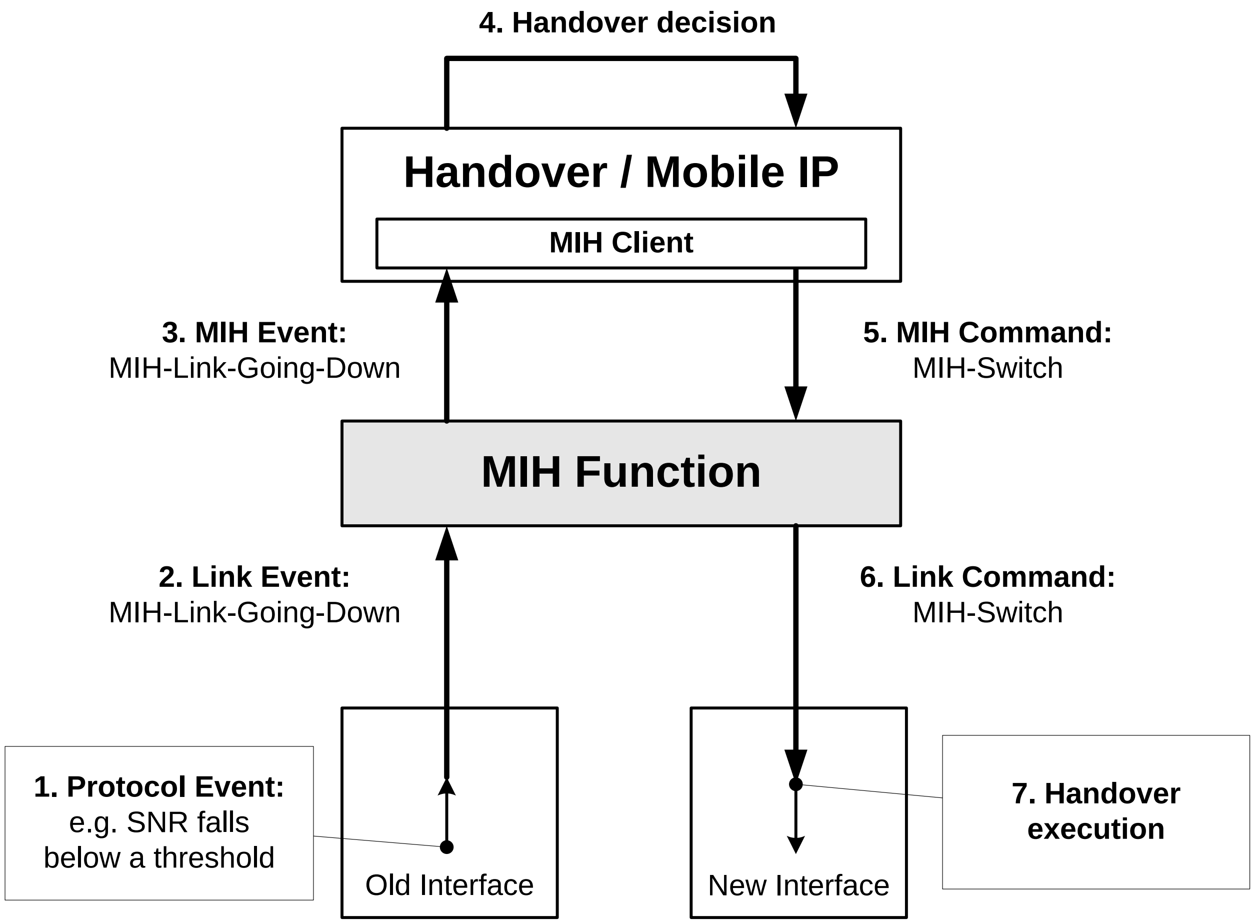
From: Machań, P., Wozniak, J., ”Performance evaluation of IEEE 802.11 fast BSS transition algorithms”

IEEE 802.21 Standard

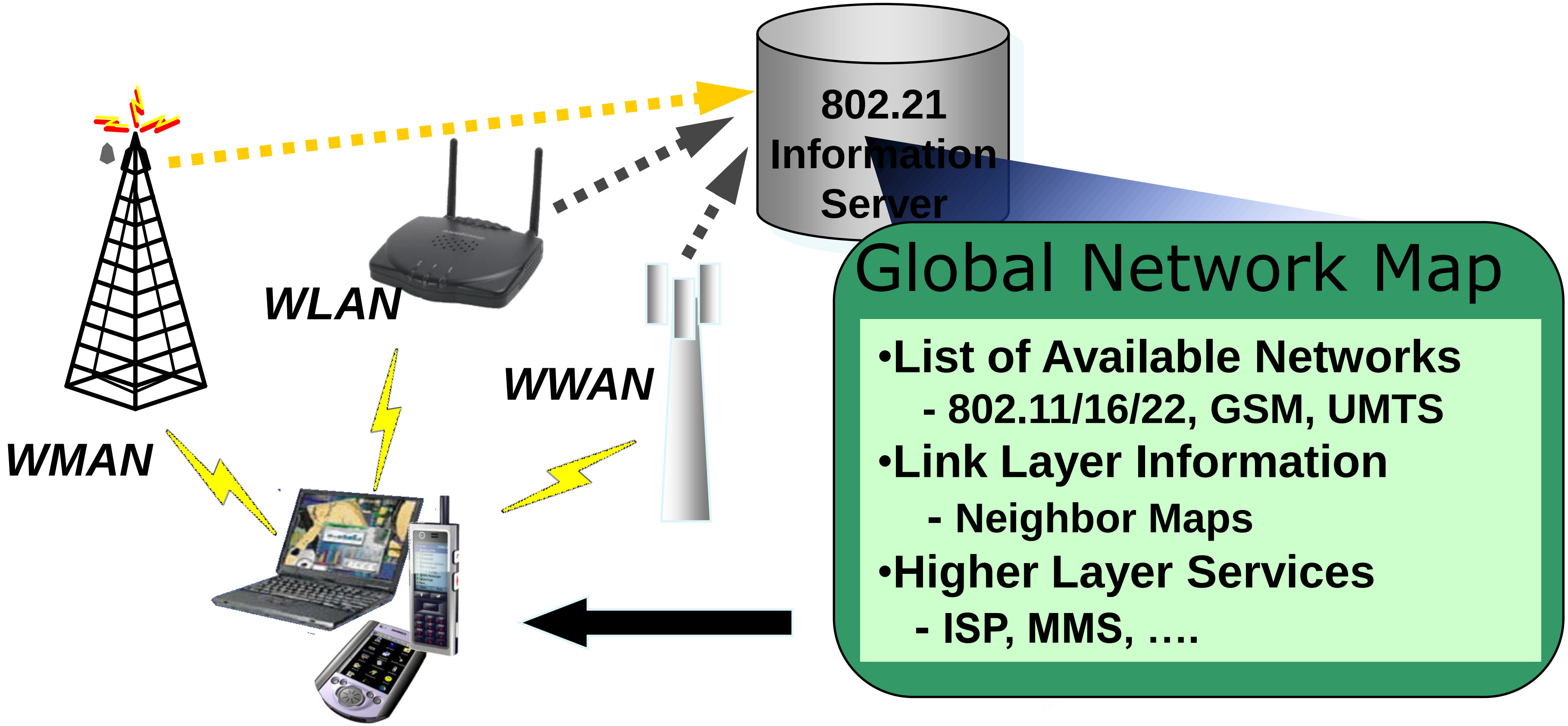
- Introduces Media Independent Handover (**MIH**) Function
- Defines handover framework
- Handover decision algorithms are out of scope
- Existing standards need extensions



MIH-Supported Handover



Media Independent Information Service



Network Type	SSID/ Cell ID	BSSID	Operator	Security	EAP Type	Channel	QoS	Physical Layer	Data Rate
GSM	13989	N/A	Oper-1	NA	NA	1900	N/A	N/A	9.6 Kbps
802.11n	Enterprise	00:00:…	Oper-2	.11i	EAP-PEAP	6	.11e	OFDM	100 Mbps
802.16e	NA	NA	Oper-3	PKM	EAP-PEAP	11	Yes	OFDM	40 Mbps

Source: http://www.ieee802.org/802_tutorials/july06/802 21-IEEE-Tutorial.ppt

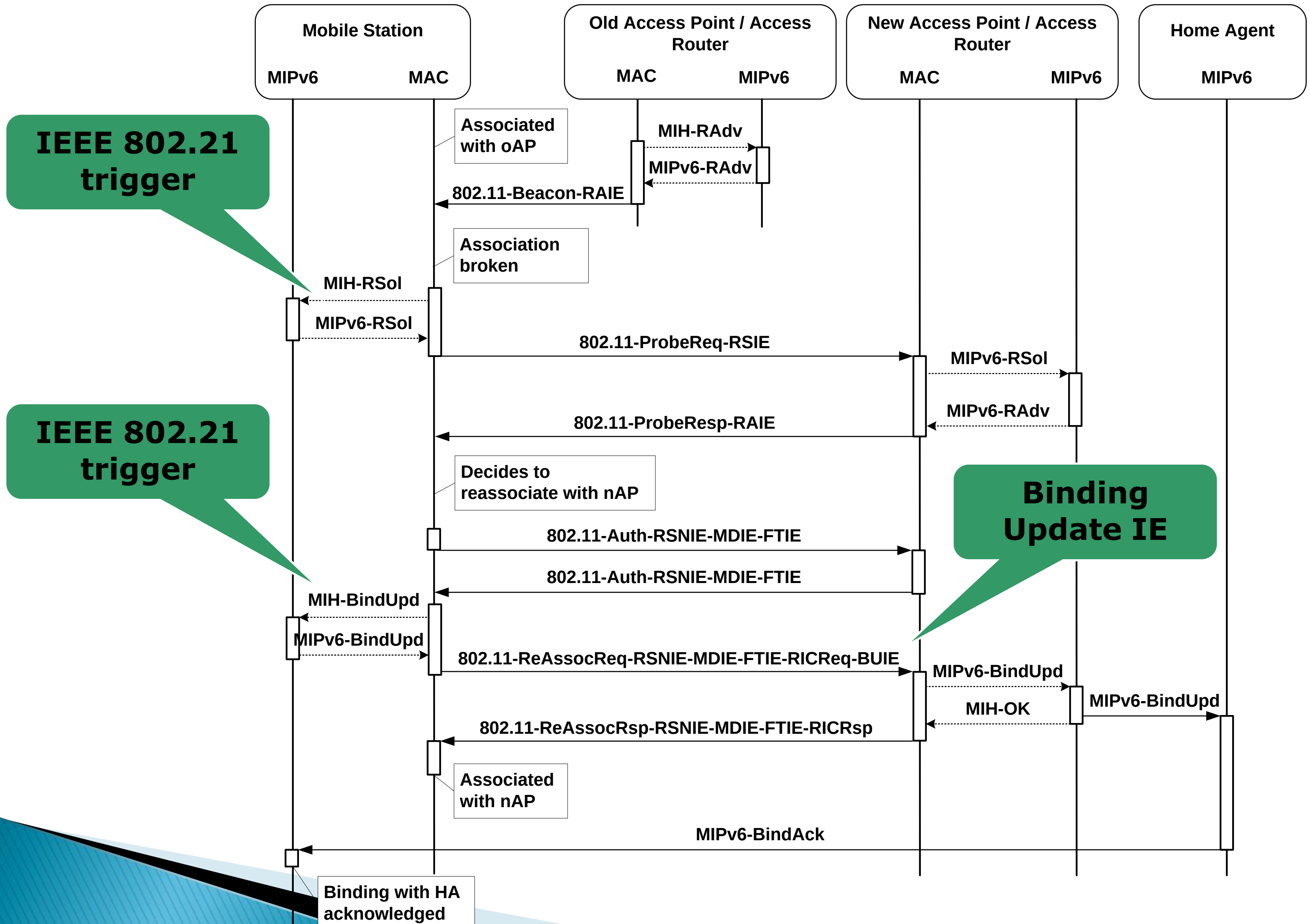
Simultaneous handover IEEE 802.11r for Mobile IPv6

- The strict separation between IP Layer and Link Layer results in built-in sources of delay, e.g. MIP detection delay.
- **Execute Mobile IP and IEEE 802.11r handovers simultaneously.**

A novel approach – Our proposal

- Extend simultaneous handover algorithm with IEEE 802.21 triggers.
- Use ”handover end” trigger instead of ”handover begin” as in LLH.
- Generate MIH_Link_Up event when association is completed.
- First simulation model and results for simultaneous handover

Simultaneous handover



Handover delay for simultaneous handover

Phase / Algorithm	Over-the-Air FT / MIPv6	Over-the-DS FT / Simultaneous MIPv6
Scanning	*314,90*	*315,41*
Authentication	*0,82*	*0,84*
Association	*1,25*	*1,47*
Channel switching	*10,00*	*10,00*
Layer 2 delay	324,65	324,43
Layer 3 overhead	500,40	0,84
Total delay (ms)	**825,05**	**325,27**

Conclusions

- 1. Mobility support is one of hot topics;
- 2. A few standardized handover solutions for Layers 2 and 3 exist;
- 3. Optimized solutions are still in progress;
- 4. New handover proposals are elaborated => speeding up (optimizing) handover procedures and improving both quality and security;
- 5. Promissing solutions refer to cross-layer approaches.

Dziękuję!

- Thank you!

Classification of unicast-based IP mobility approaches