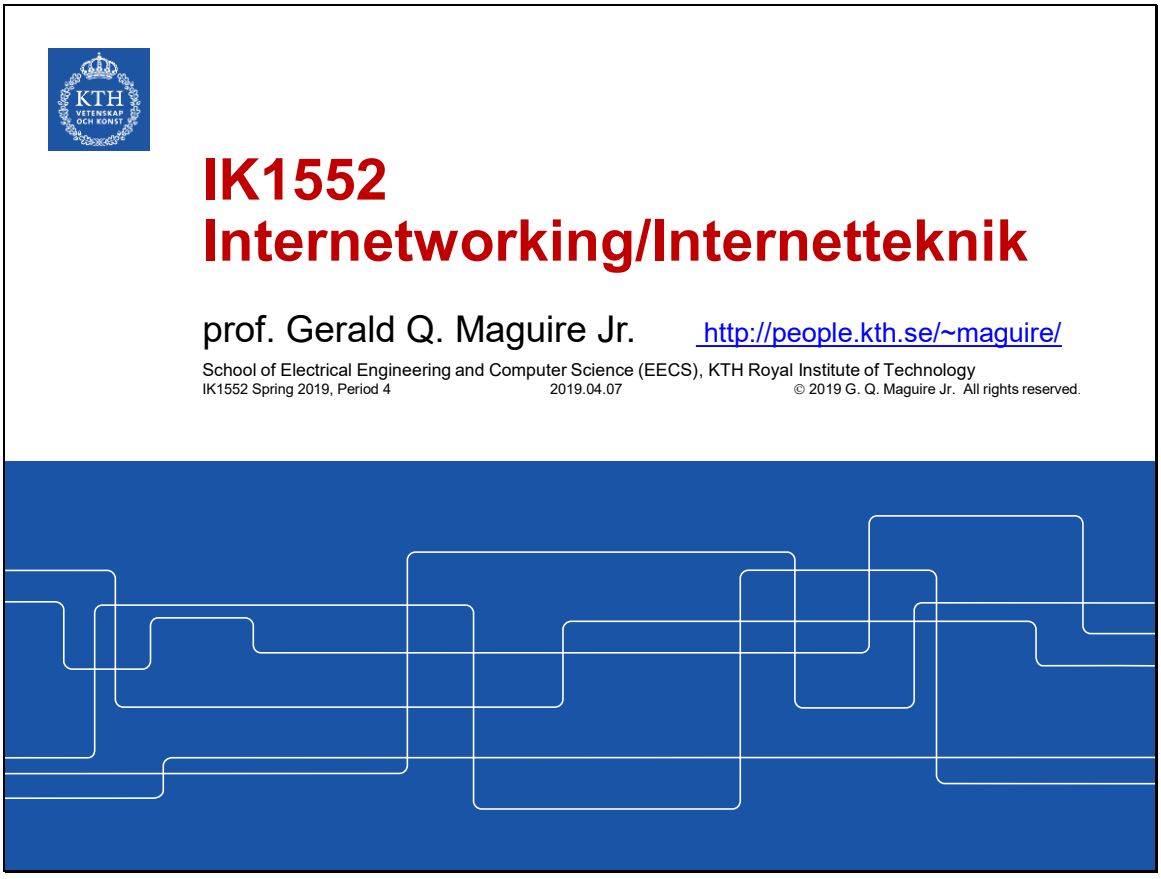
Slide 1


IK1552
Internetworking/Internetteknik
prof. Gerald Q. Maguire Jr.
http://people.kth.se/~maguire/
School of Electrical Engineering and Computer Science (EECS), KTH Royal Institute of Technology
IK1552 Spring 2019, Period 4
2019.04.07
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Slide 2

Module 11: Mobile IP

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with James F. Kurose and Keith W. Ross, *Computer Networking: A Top-Down Approach*.

Heavily influenced by:

J. Ioannidis, D. Duchamp, and G. Q. Maguire Jr., 'IP-based Protocols for Mobile Internetworking', in *Proceedings of the Conference on Communications Architecture and Protocols*, New York, NY, USA, New York, NY, USA: ACM, 1991, pp. 235–245. DOI: 10.1145/115992.116014

John Ioannidis, 'Protocols for Mobile Internetworking', Doctoral Dissertation, Columbia University, New York, NY, USA, 191 pages, 1993. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.38.284&rep=rep1&type=pdf

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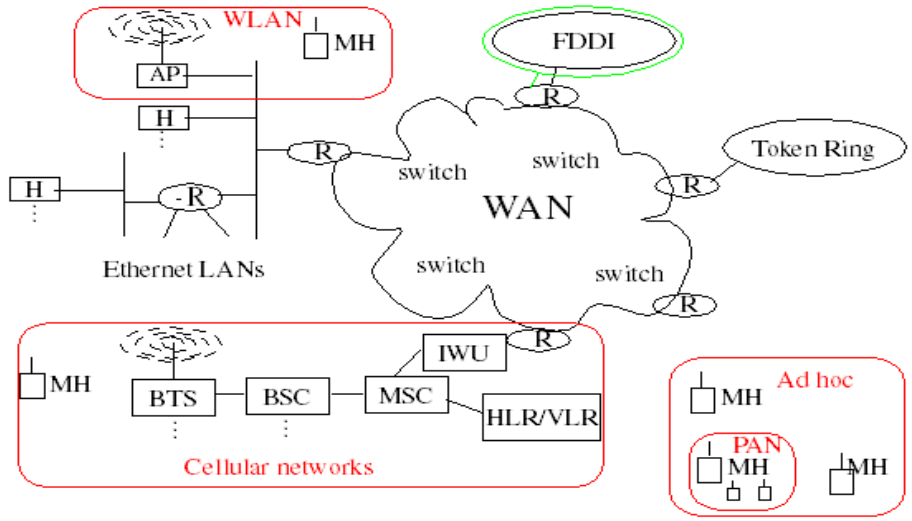
Slide 3

Internet Architecture



Multiple network technologies - *internetworked* together

Mobility (WWAN, WLAN, PAN, …) driving us towards Mobile Internet

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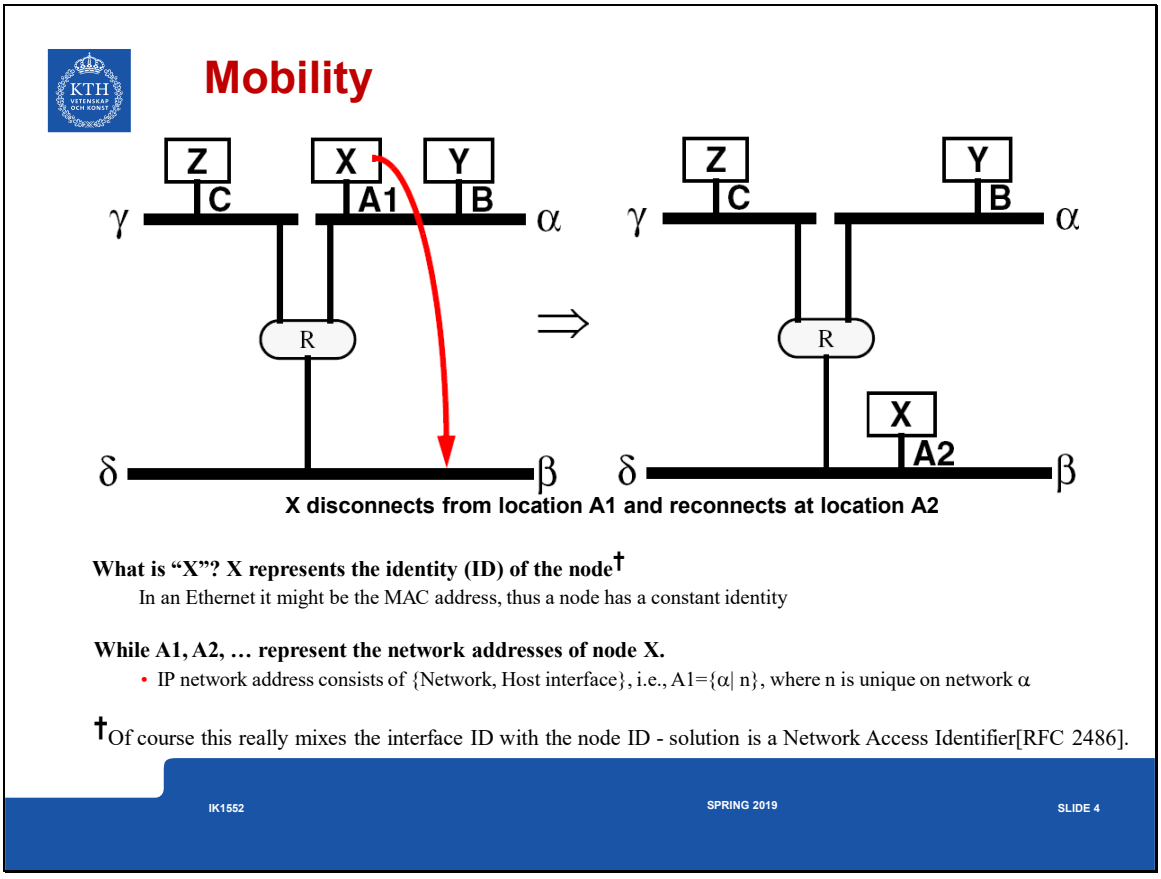
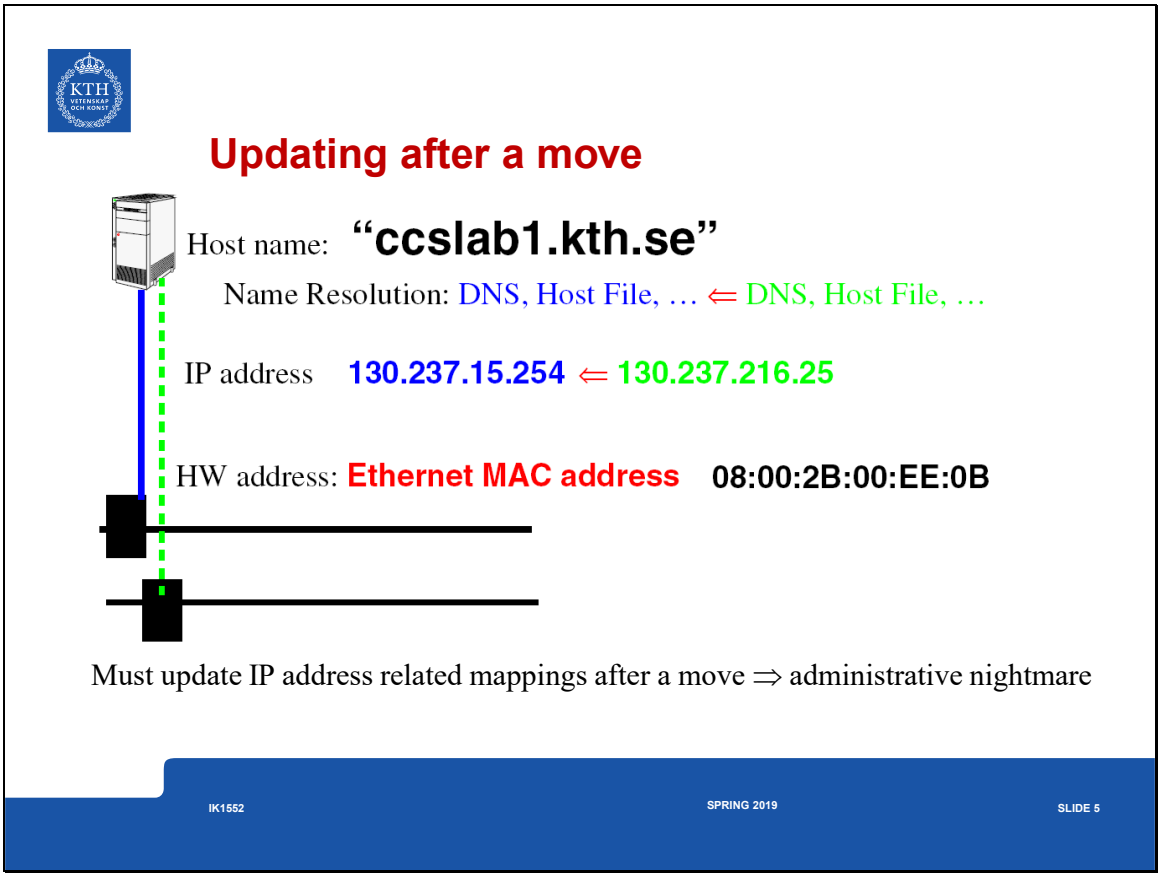
Slide 4



B. Aboba and M. Beadles, 'The Network Access Identifier', *Internet Request for Comments*, vol. RFC 2486 (Proposed Standard), January 1999, Available at http://www.rfc-editor.org/rfc/rfc2486.txt

B. Aboba, M. Beadles, J. Arkko, and P. Eronen, 'The Network Access Identifier', *Internet Request for Comments*, vol. RFC 4282 (Proposed Standard), December 2005, Available at http://www.rfc-editor.org/rfc/rfc4282.txt

Slide 5


Updating after a move
Host name: "ccslab1.kth.se"
Name Resolution: DNS, Host File, … ⇐ DNS, Host File, …
IP address 130.237.15.254 ⇐ 130.237.216.25
HW address: Ethernet MAC address 08:00:2B:00:EE:0B
Must update IP address related mappings after a move ⇒ administrative nightmare
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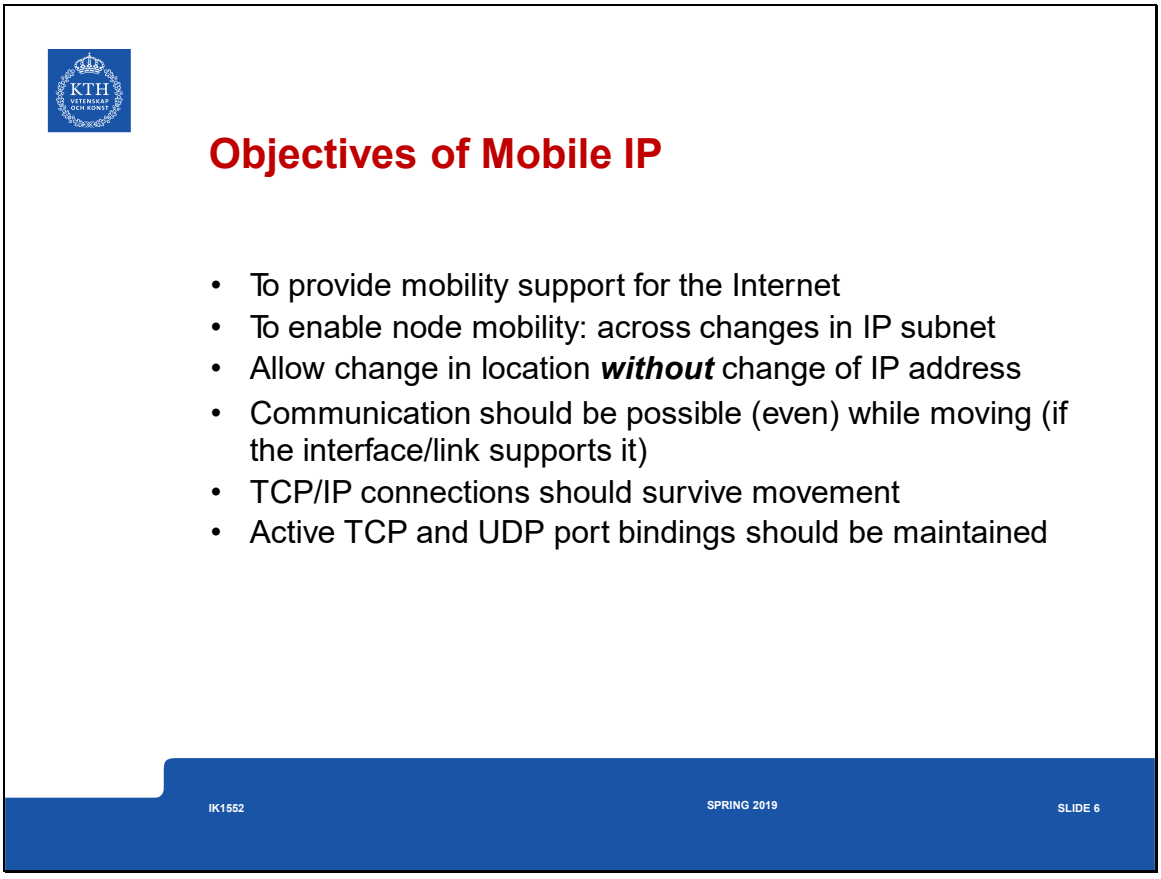
Slide 6


Objectives of Mobile IP
• To provide mobility support for the Internet
• To enable node mobility: across changes in IP subnet
• Allow change in location ***without*** change of IP address
• Communication should be possible (even) while moving (if the interface/link supports it)
• TCP/IP connections should survive movement
• Active TCP and UDP port bindings should be maintained
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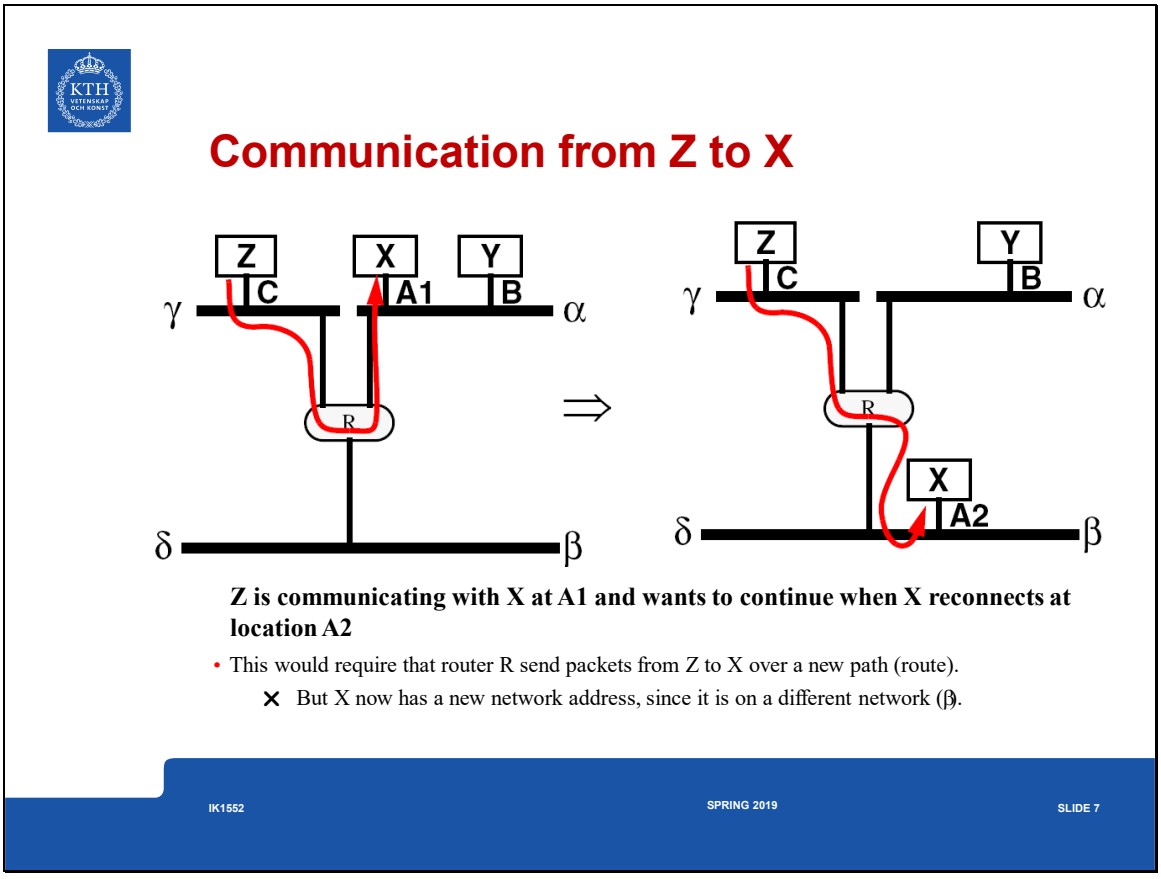
Slide 7


Communication from Z to X
Z
C
X
A1
Y
B
γ
α
R
δ
β
Z
C
Y
B
γ
α
R
X
A2
δ
β
Z is communicating with X at A1 and wants to continue when X reconnects at location A2
This would require that router R send packets from Z to X over a new path (route).
But X now has a new network address, since it is on a different network (β).
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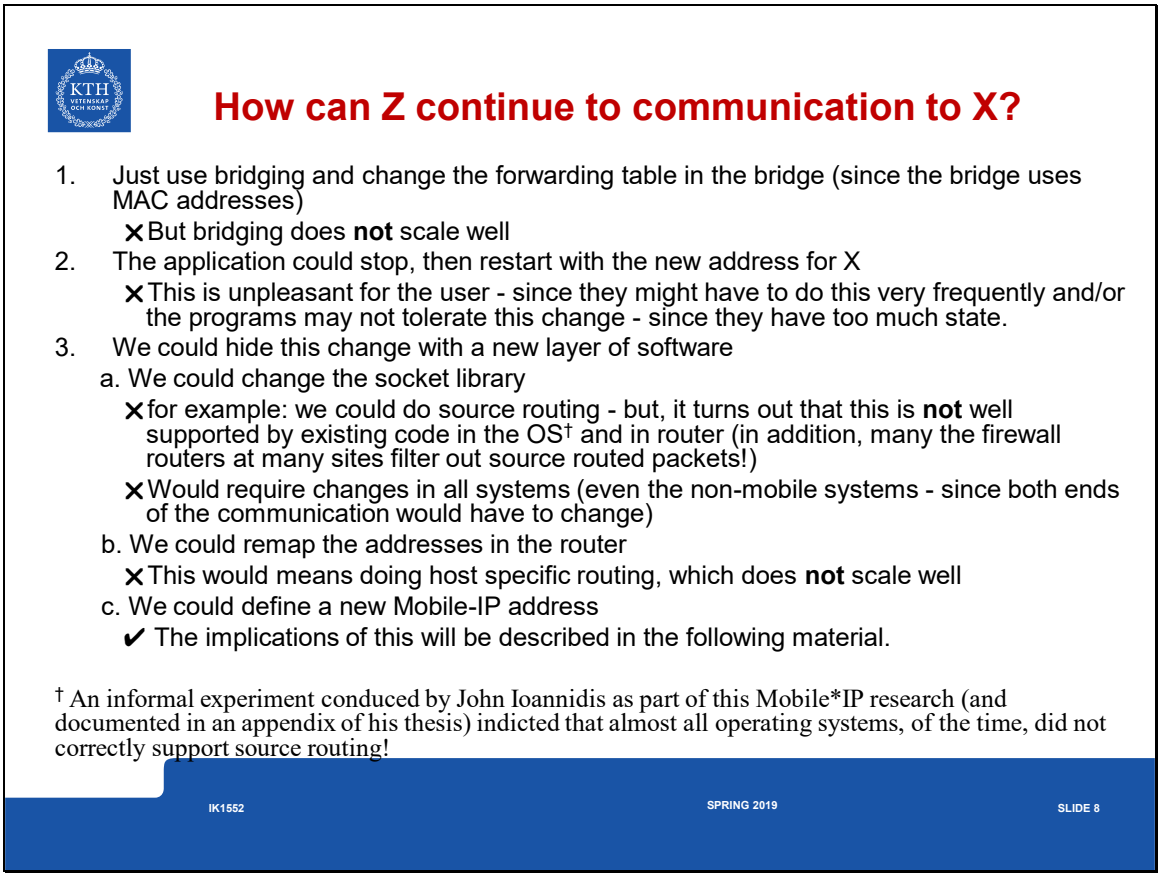
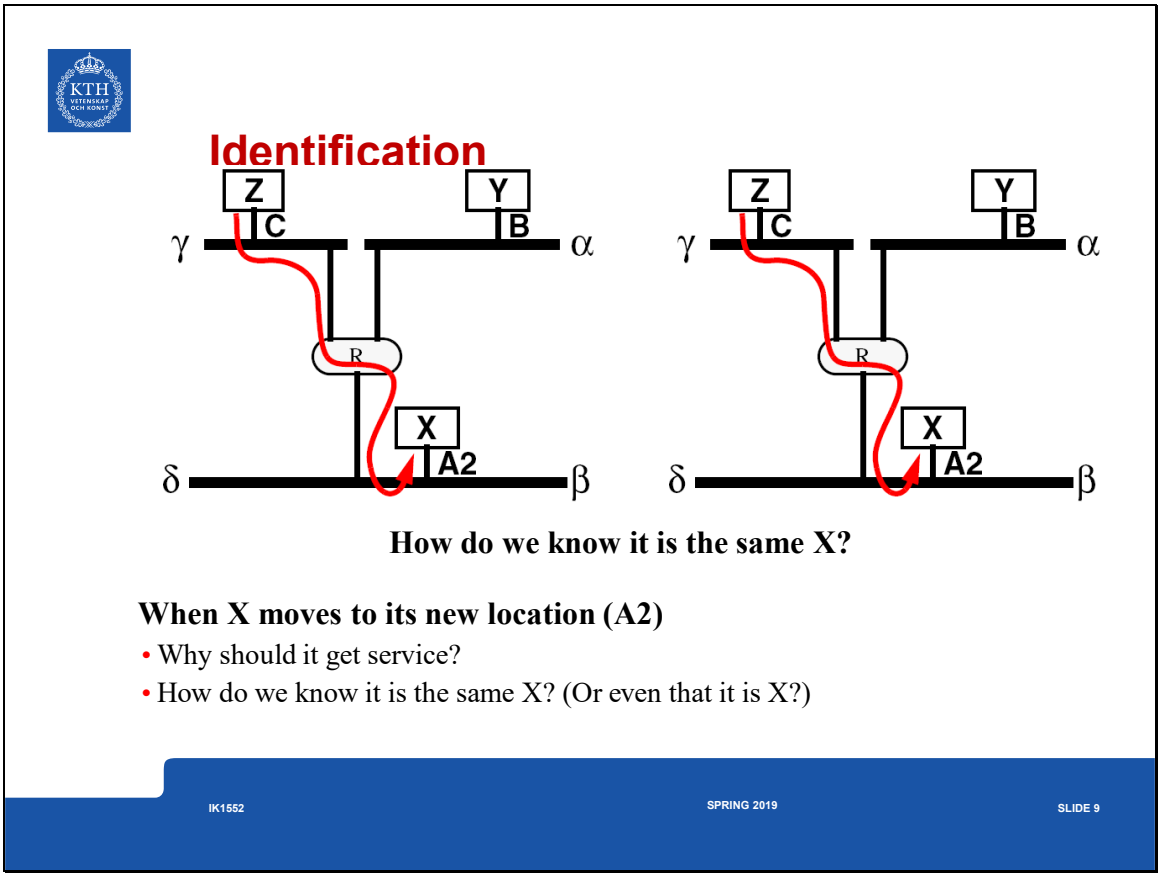
Slide 8



John Ioannidis, 'Protocols for Mobile Internetworking', Doctoral Dissertation, Columbia University, New York, NY, USA, 1993.

Slide 9


Identification
Z
C
Y
B
γ
α
R
X
A2
δ
β
Z
C
Y
B
γ
α
R
X
A2
δ
β
How do we know it is the same X?
When X moves to its new location (A2)
• Why should it get service?
• How do we know it is the same X? (Or even that it is X?)
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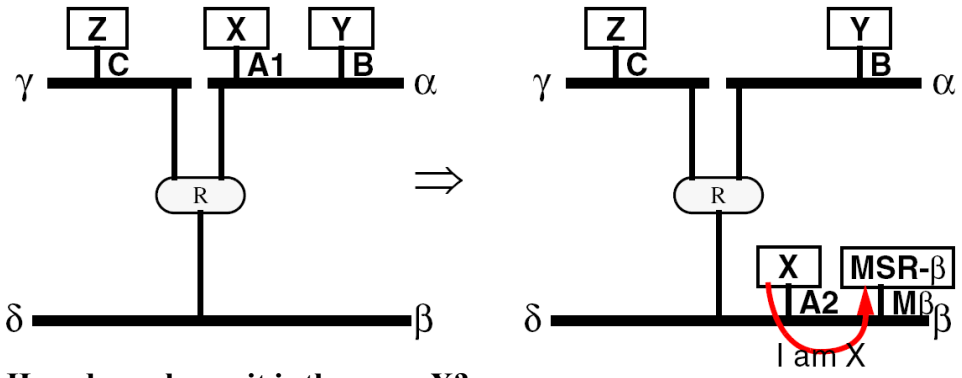
SLIDE 9

Slide 10

Establishing Identity

When a node arrives on a network it must identify itself

- mechanism: typically via a challenge response protocol
- Who should it identify itself to? **Answer**: The Mobility Support Router (MSR)



How do we know it is the same X?

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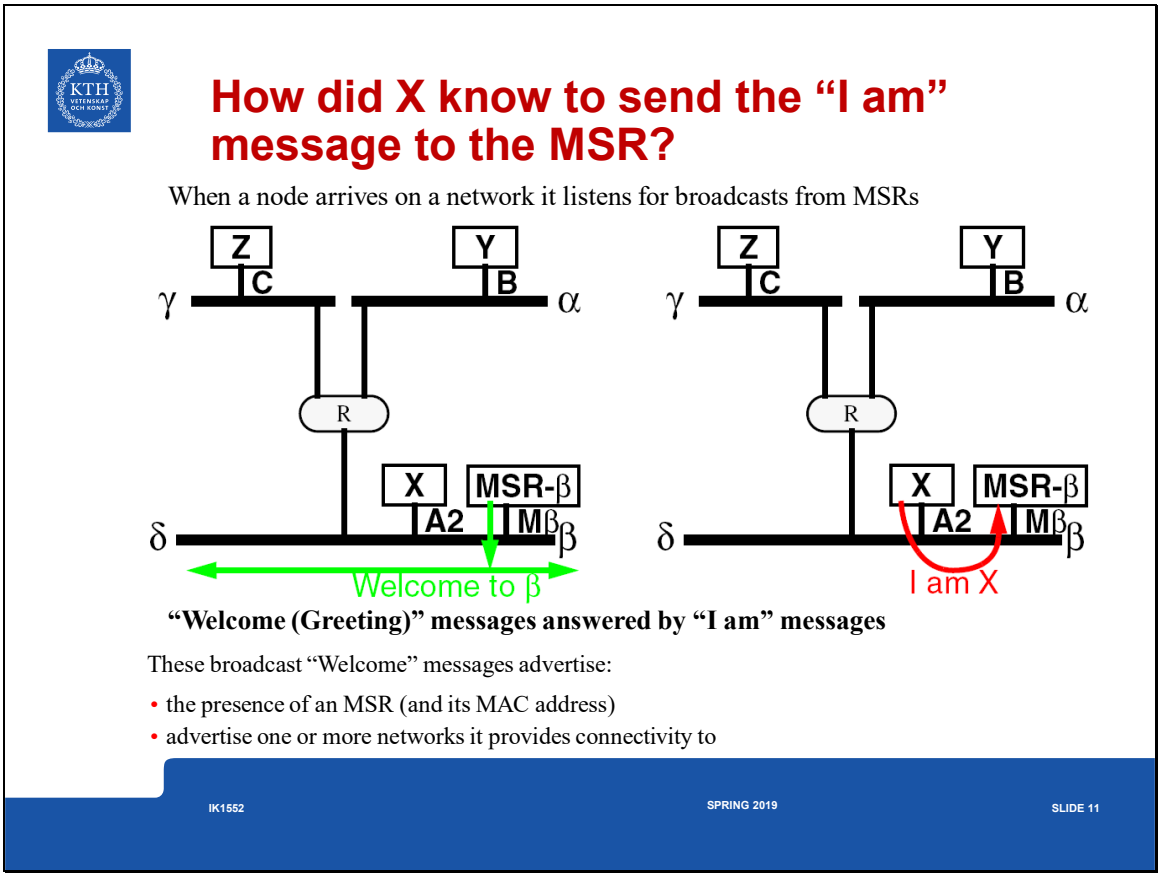
Slide 11


How did X know to send the "I am" message to the MSR?
When a node arrives on a network it listens for broadcasts from MSRs
Z
C
Y
B
γ
α
R
X
A2
MSR-β
Mβ
β
δ
Welcome to β
I am X
"Welcome (Greeting)" messages answered by "I am" messages
These broadcast "Welcome" messages advertise:
• the presence of an MSR (and its MAC address)
• advertise one or more networks it provides connectivity to
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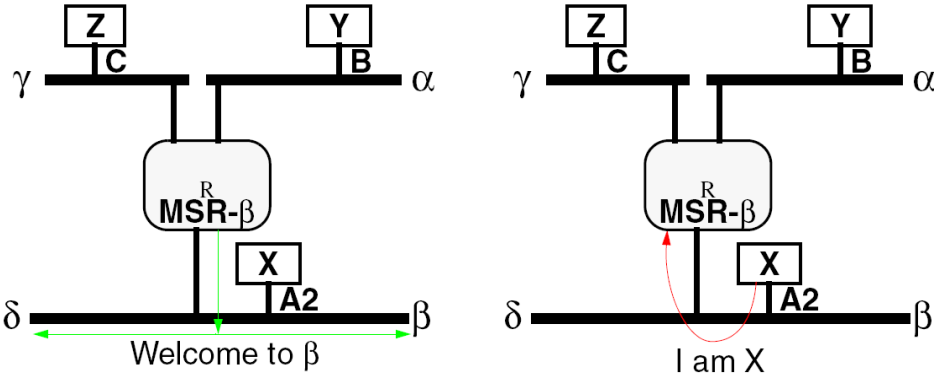
SLIDE 11

Slide 12

Could the MSR functionality be collocated with the router?

When a node arrives on a network it listens for broadcasts from MSRs



"Welcome (Greeting)" messages from router answered by "I am" messages

- ✕ Requires updating **all** of the routers on network segments which are going to support mobility to be updated.

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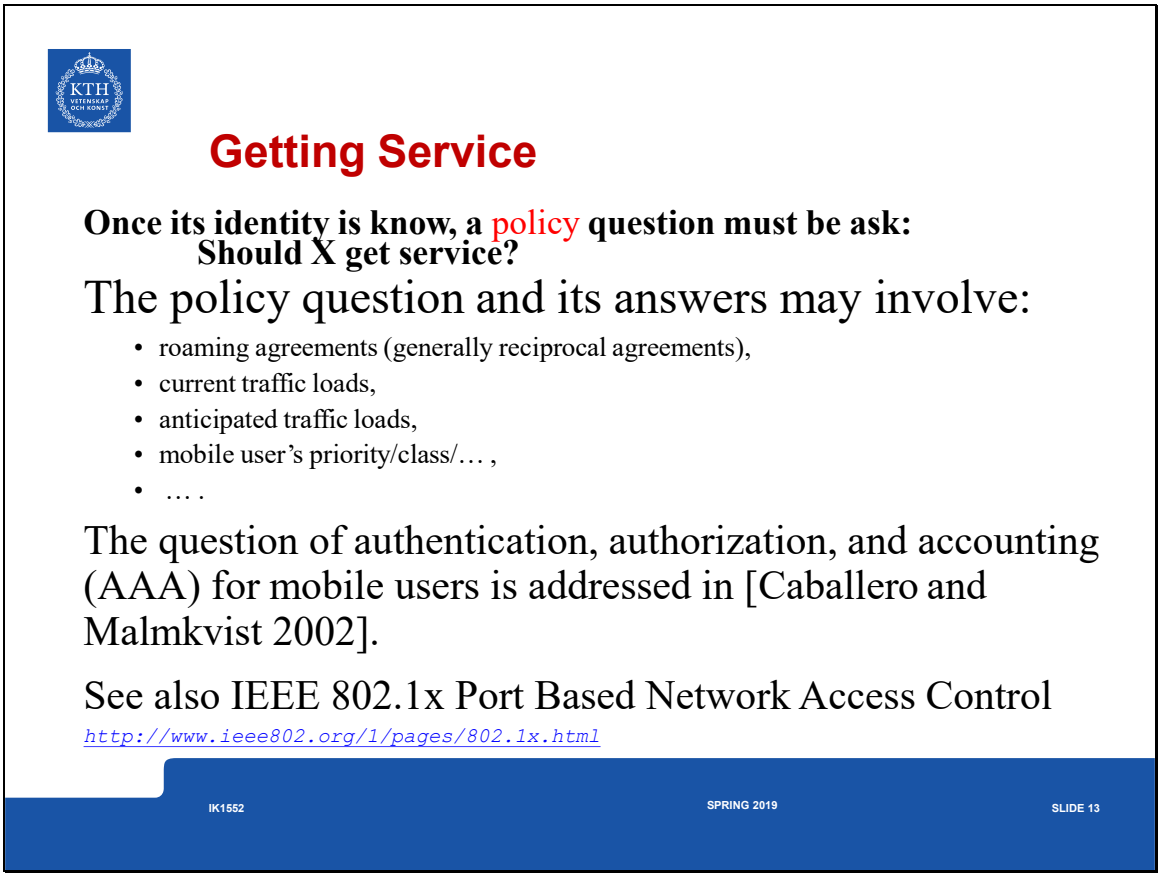
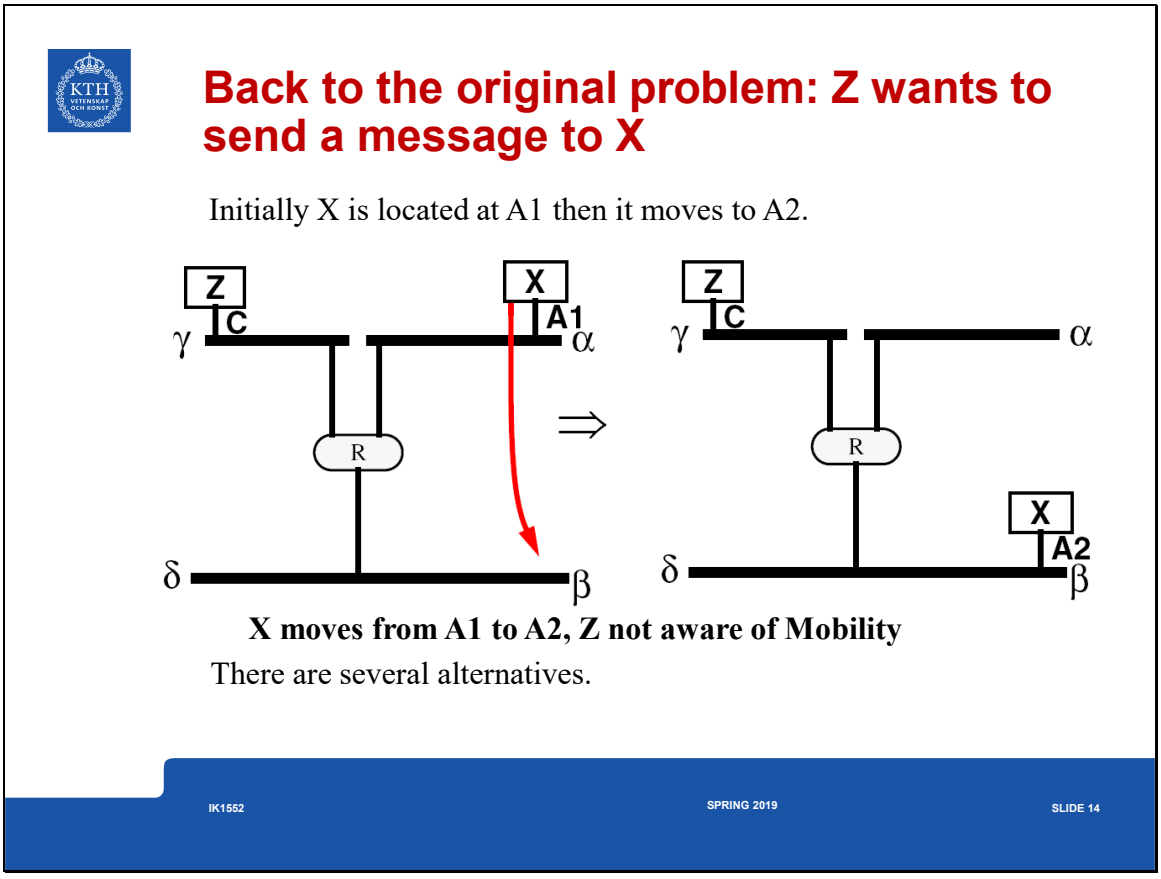
Slide 13



Juan Caballero Bayerri and Daniel Malmkvist, Experimental Study of a Network Access Server for a public WLAN access network, M.S. Thesis, KTH/IMIT, Jan. 2002

Slide 14


Back to the original problem: Z wants to send a message to X
Initially X is located at A1 then it moves to A2.
Z
C
X
A1
γ
α
R
δ
β
⇒
Z
C
γ
α
R
X
A2
δ
β
X moves from A1 to A2, Z not aware of Mobility
There are several alternatives.
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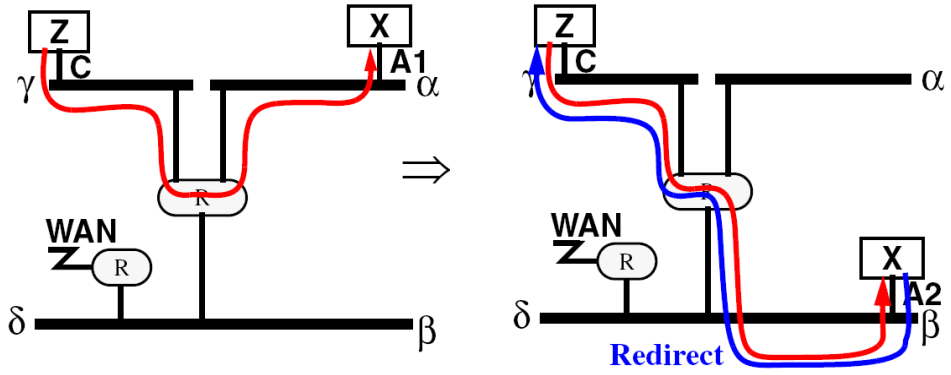
SLIDE 14

Slide 15

Alternative 1

Initially X is located at A1 then it moves to A2.



X must send a redirect message to Z, to tell it it's new address A2.

- ✗ Z must be aware of where X currently is.
- ✗ X must get a new local address A2 (How? perhaps DHCP)

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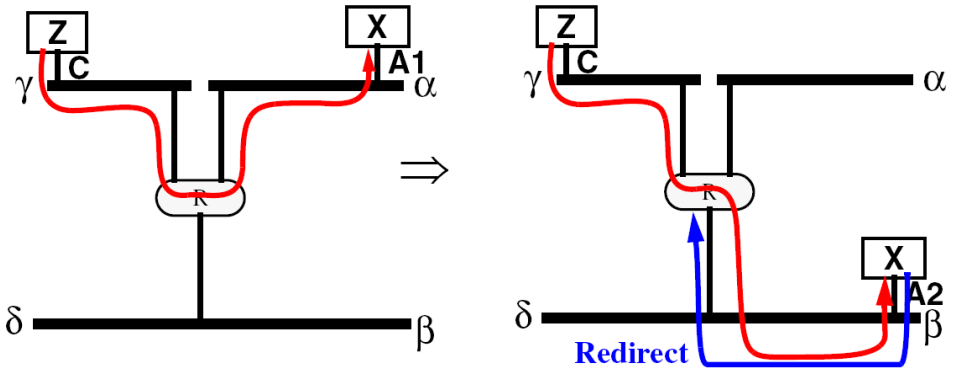
Slide 16

Alternative 2

Initially X is located at A1 then it moves to A2.



X must send a redirect message to the **Router**, to tell it it's new address A2 (rather than A1).

- ✗ Router must now perform host specific routing.
- ✗ X must get a new local address A2 (How? perhaps DHCP)

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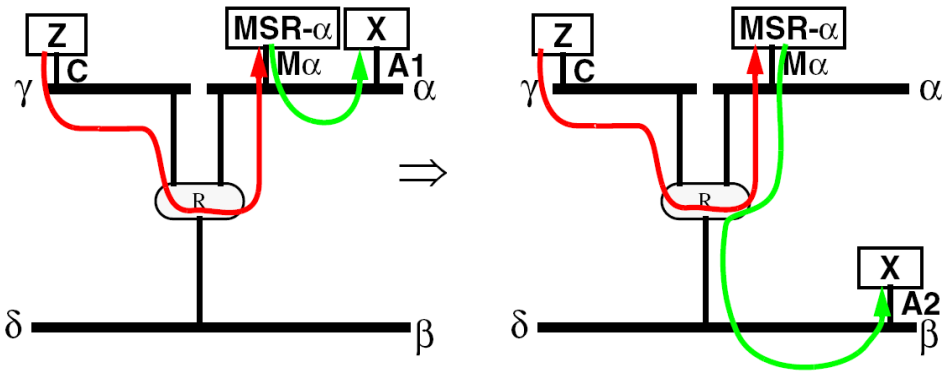
Slide 17

Alternative 3

Initially X is located at A1 then it moves to A2.



X must send a redirect message to a Mobility Support Router (**MSR-α**), to tell it it's new address A2 (rather than A1).

- ✕ **MSR-α** must now perform host specific routing.
- ✕ X must get a new local address A2 (How? perhaps DHCP)
- ✔ Z is now completely unaware of the move.
- ✔ Router R is now completely unaware of the move (except for twice the traffic over the link to/from α).

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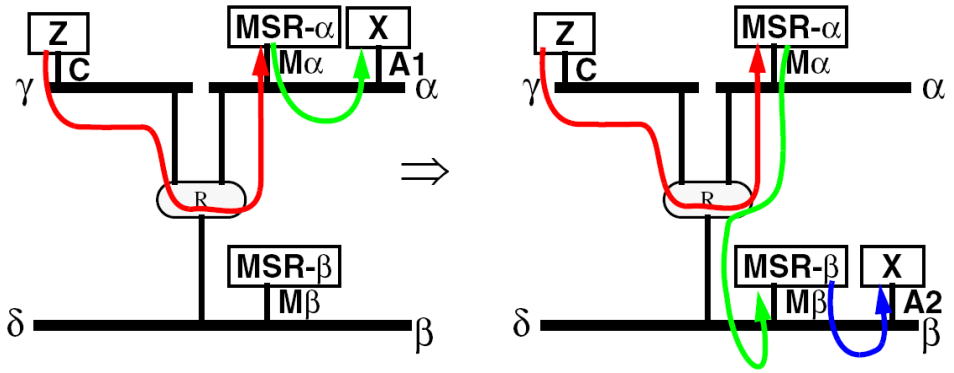
Slide 18

Alternative 4

Initially X is located at A1 then it moves to A2.



X sends a message to **MSR-β** to get it's new address A2 and says it's old MSR was **MSR-α**

- ✗ **MSR-α** must now perform host specific routing to **MSR-β** (which can provide the local address A2)
- ✔ Z is now completely unaware of the move - it always sends traffic to **MSR-α**
- ✔ If X moves again, Z does not change where it sends traffic to & traffic need not go via **MSR-β** - it will go directly from **MSR-α** to the MSR responsible for the new segment.

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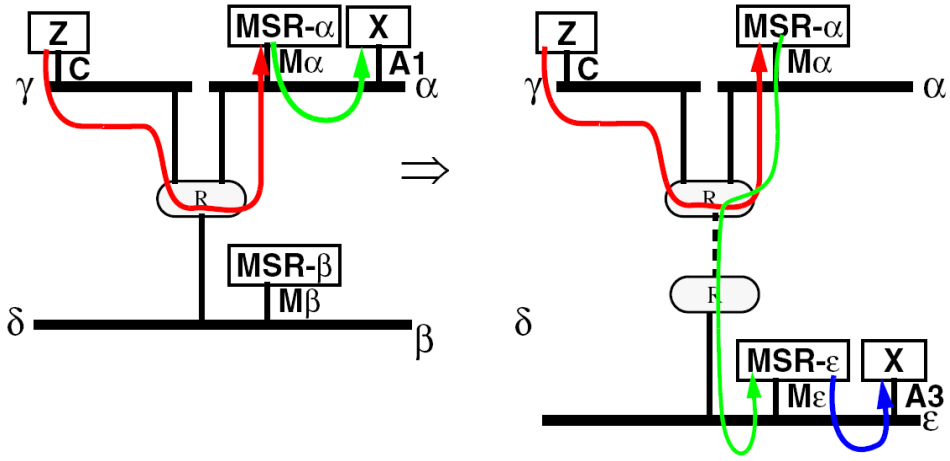
Slide 19

Alternative 4 continued

Initially X is located at A1 then it moves to A2 and then moves to A3.



X sends a message to **MSR-ε** to get it's new address A3 and says it's old MSR was **MSR-α**

✔ The traffic from **MSR-α**to **MSR-β**or **MSR-α**to **MSR-ε**can be encapsulated, using for example IP in IP (written IP-IP) encapsulation. Thus none of the intervening routers needs know about mobility.

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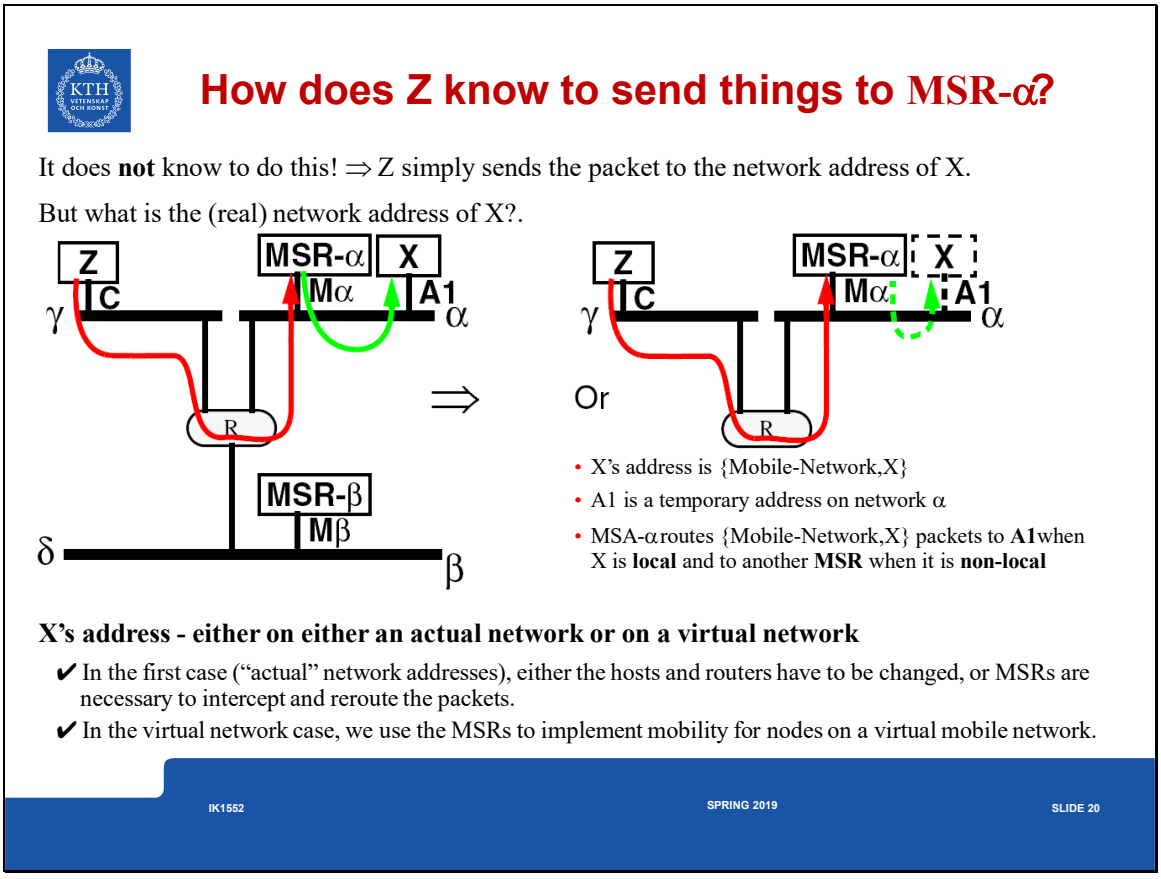
Slide 20


How does Z know to send things to MSR-α?
It does **not** know to do this! ⇒ Z simply sends the packet to the network address of X.
But what is the (real) network address of X?.
Z
C
γ
MSR-α
X
Mα
A1
α
R
MSR-β
Mβ
δ
β
⇒
Or
• X's address is {Mobile-Network,X}
• A1 is a temporary address on network α
• MSA-α routes {Mobile-Network,X} packets to **A1** when X is **local** and to another **MSR** when it is **non-local**
X's address - either on either an actual network or on a virtual network
✔ In the first case ("actual" network addresses), either the hosts and routers have to be changed, or MSRs are necessary to intercept and reroute the packets.
✔ In the virtual network case, we use the MSRs to implement mobility for nodes on a virtual mobile network.
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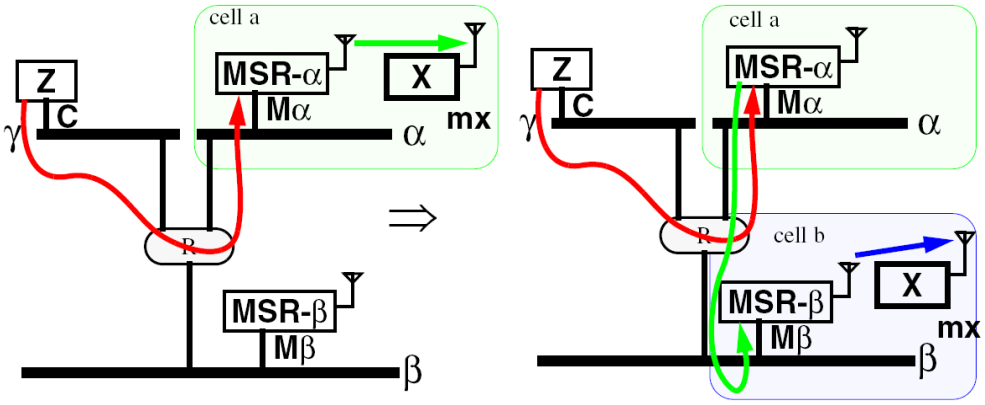
SLIDE 20

What happens in the case of wireless networks?



X moves from the cell a to the cell b

- The wireless cells are implemented by a basestation co-located with the MSR.
- Note that X retains its mobile network address "mx".

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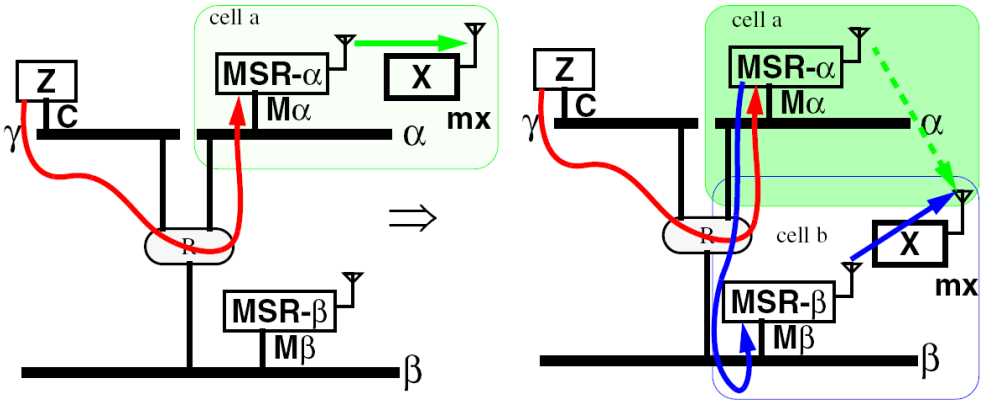
Slide 22

Wireless Local Area Networks



X moves from the cell a to the cell b, but is still reachable by cell a!

- Mobile network address "mx" is reachable from both MSR-α and MSR-β
- This could not occur in the wired case (unless there were multiple interfaces), since X would have to disconnect from network α to connect to network β
- If the cell size is small the movement between cells could be frequent (and caused by other events, such as a new user, a door moving, …).

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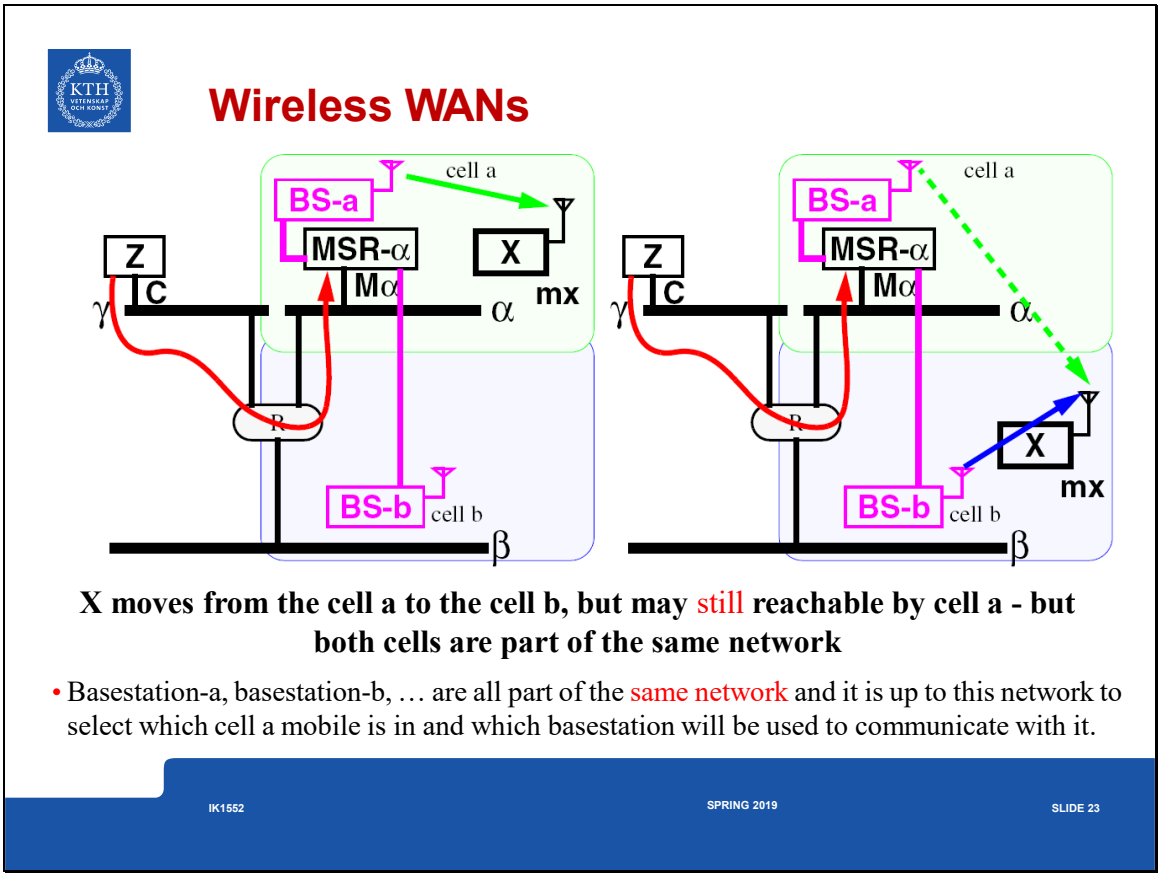
Slide 23


Wireless WANs
cell a
BS-a
MSR-α
Mα
X
mx
Z
C
γ
α
R
BS-b
cell b
β
cell a
BS-a
MSR-α
Mα
Z
C
γ
α
R
X
mx
BS-b
cell b
β
X moves from the cell a to the cell b, but may still reachable by cell a - but both cells are part of the same network
• Basestation-a, basestation-b, … are all part of the same network and it is up to this network to select which cell a mobile is in and which basestation will be used to communicate with it.
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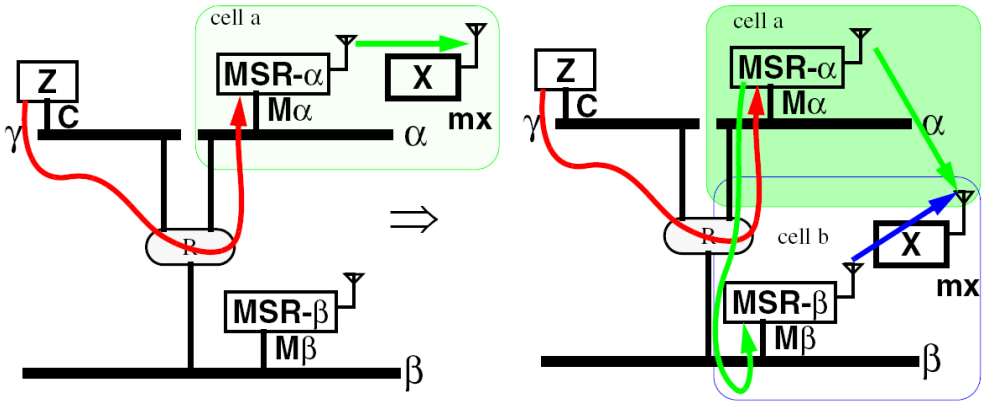
SLIDE 23

Slide 24

Simulcasting in Wireless Local Area Networks (WLANs)



X is moving from the cell a to the cell b

- Mobile network address "mx" is partially reachable from both MSR-αand MSR-β- thus we will send packets via both MSR-αand MSR-β This insures:
  - ✔ Lower probability of packet loss (important if we must provide low latency and high reliability - such as is needed for voice and some other services)
  - ✕ increases traffic in both cells

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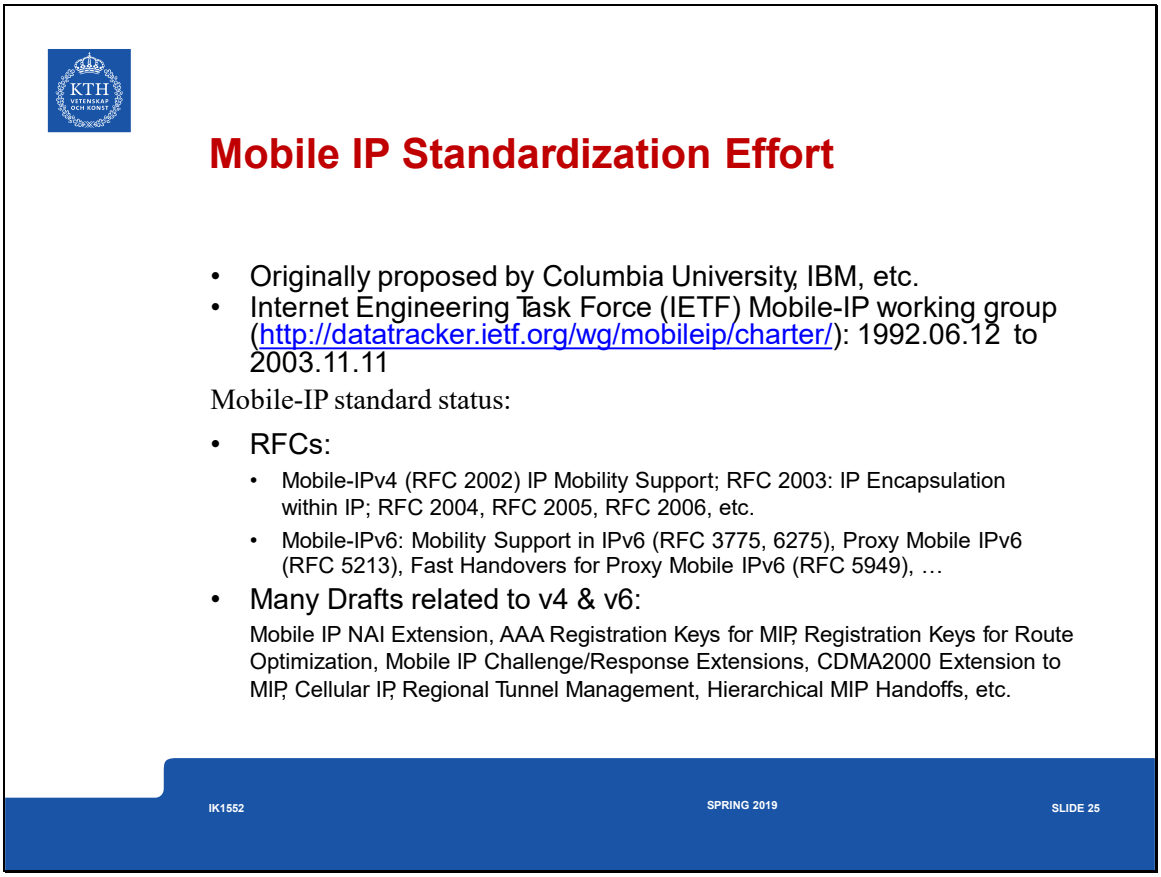
Slide 25



D. Johnson, C. Perkins, and J. Arkko, 'Mobility Support in IPv6', *Internet Request for Comments*, vol. RFC 3775 (Proposed Standard), June 2004, Available at http://www.rfc-editor.org/rfc/rfc3775.txt

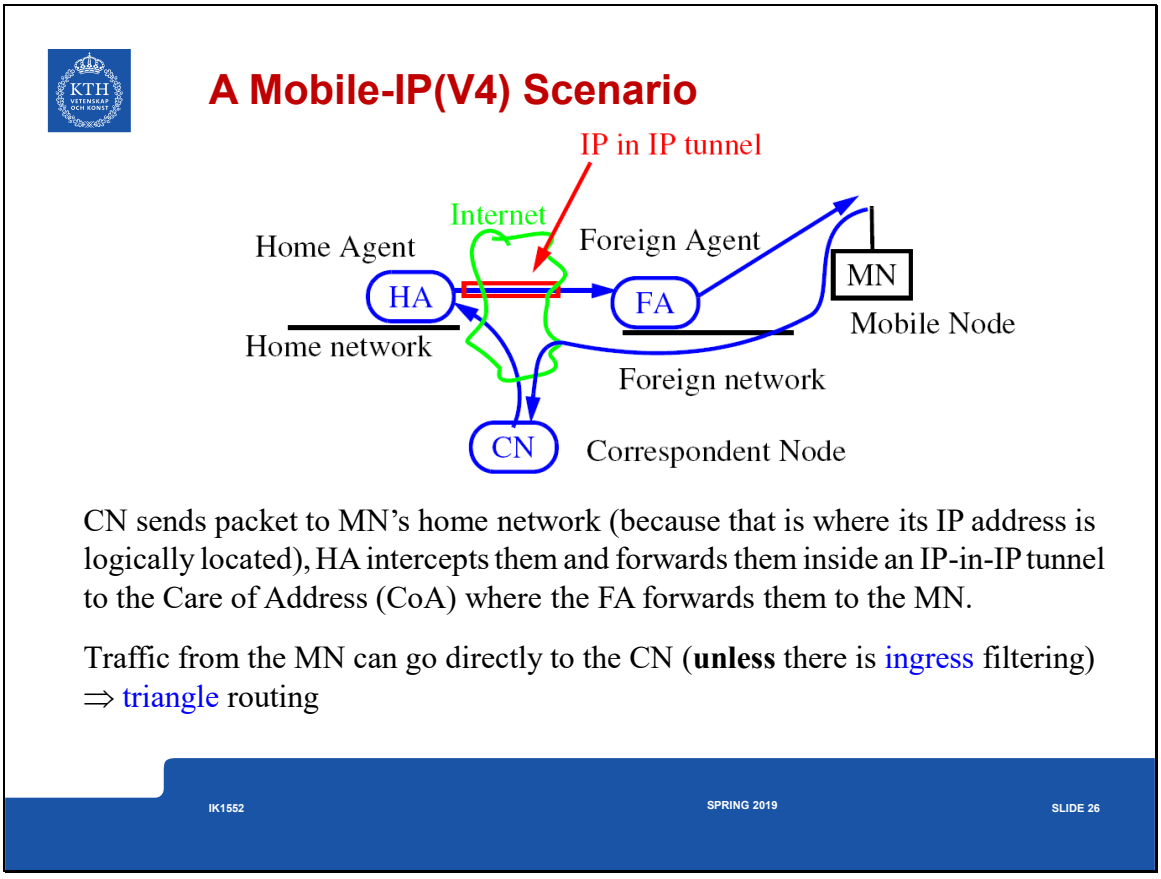
C. Perkins, D. Johnson, and J. Arkko, 'Mobility Support in IPv6', *Internet Request for Comments*, vol. RFC 6275 (Proposed Standard), July 2011, Available at http://www.rfc-editor.org/rfc/rfc6275.txt

S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury, and B. Patil, 'Proxy Mobile IPv6', *Internet Request for Comments*, vol. RFC 5213 (Proposed Standard), August 2008, Available at http://www.rfc-editor.org/rfc/rfc5213.txt

H. Yokota, K. Chowdhury, R. Koodli, B. Patil, and F. Xia, 'Fast Handovers for Proxy Mobile IPv6', *Internet Request for Comments*, vol. RFC 5949 (Proposed Standard), September 2010, Available at http://www.rfc-editor.org/rfc/rfc5949.txt

S. Gundavelli, 'Reserved IPv6 Interface Identifier for Proxy Mobile IPv6', *Internet Request for Comments*, vol. RFC 6543 (Proposed Standard), May 2012, Available at http://www.rfc-editor.org/rfc/rfc6543.txt

Slide 26


A Mobile-IP(V4) Scenario
IP in IP tunnel
Internet
Home Agent
Foreign Agent
HA
FA
MN
Mobile Node
Home network
Foreign network
CN
Correspondent Node
CN sends packet to MN's home network (because that is where its IP address is logically located), HA intercepts them and forwards them inside an IP-in-IP tunnel to the Care of Address (CoA) where the FA forwards them to the MN.
Traffic from the MN can go directly to the CN (**unless** there is ingress filtering) ⇒ triangle routing
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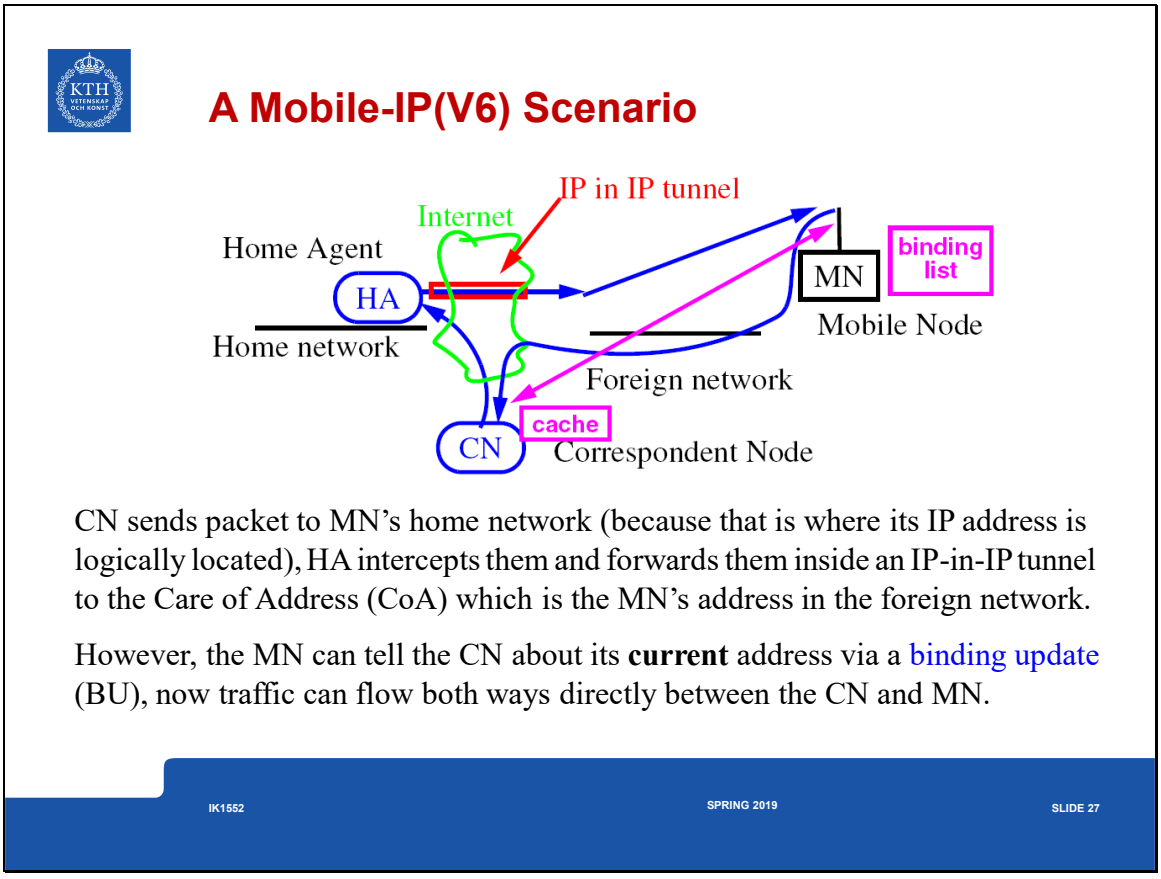
SLIDE 26


A Mobile-IP(V6) Scenario
IP in IP tunnel
Internet
Home Agent
HA
Home network
MN
binding list
Mobile Node
Foreign network
cache
CN
Correspondent Node
CN sends packet to MN's home network (because that is where its IP address is logically located), HA intercepts them and forwards them inside an IP-in-IP tunnel to the Care of Address (CoA) which is the MN's address in the foreign network.
However, the MN can tell the CN about its current address via a binding update (BU), now traffic can flow both ways directly between the CN and MN.
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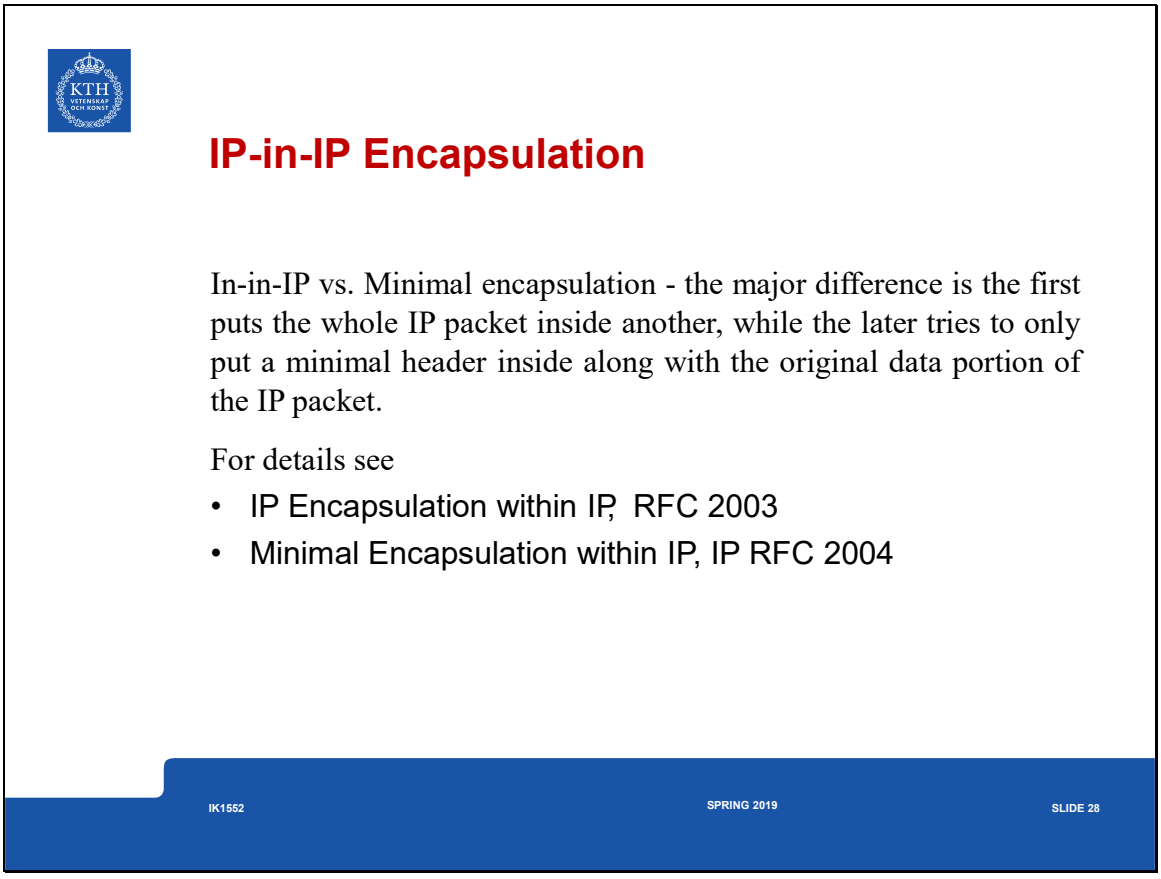
SLIDE 27

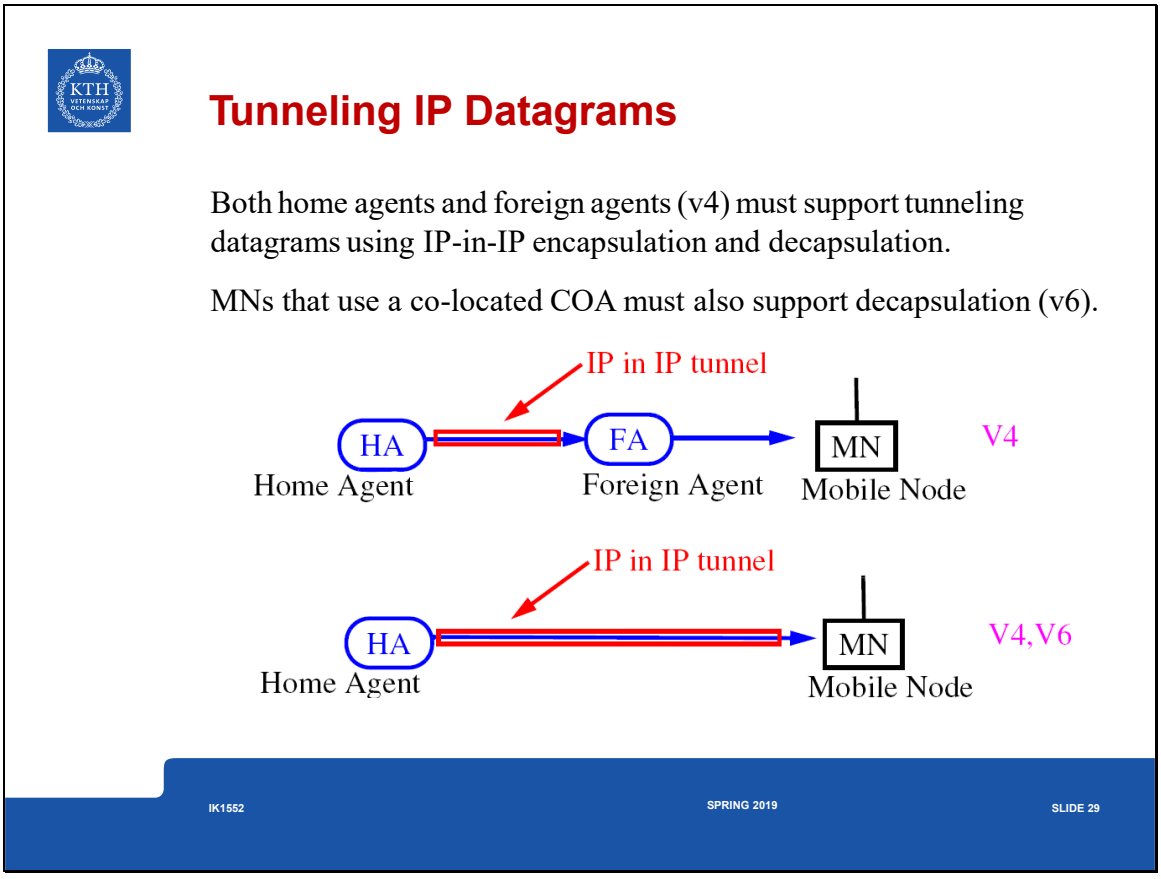
Slide 28



C. Perkins, 'IP Encapsulation within IP', *Internet Request for Comments*, vol. RFC 2003 (Proposed Standard), October 1996, Available at http://www.rfc-editor.org/rfc/rfc2003.txt

C. Perkins, 'Minimal Encapsulation within IP', *Internet Request for Comments*, vol. RFC 2004 (Proposed Standard), October 1996, Available at http://www.rfc-editor.org/rfc/rfc2004.txt

Slide 29


Tunneling IP Datagrams
Both home agents and foreign agents (v4) must support tunneling datagrams using IP-in-IP encapsulation and decapsulation.
MNs that use a co-located COA must also support decapsulation (v6).
IP in IP tunnel
HA
Home Agent
FA
Foreign Agent
MN
Mobile Node
V4
IP in IP tunnel
HA
Home Agent
MN
Mobile Node
V4,V6
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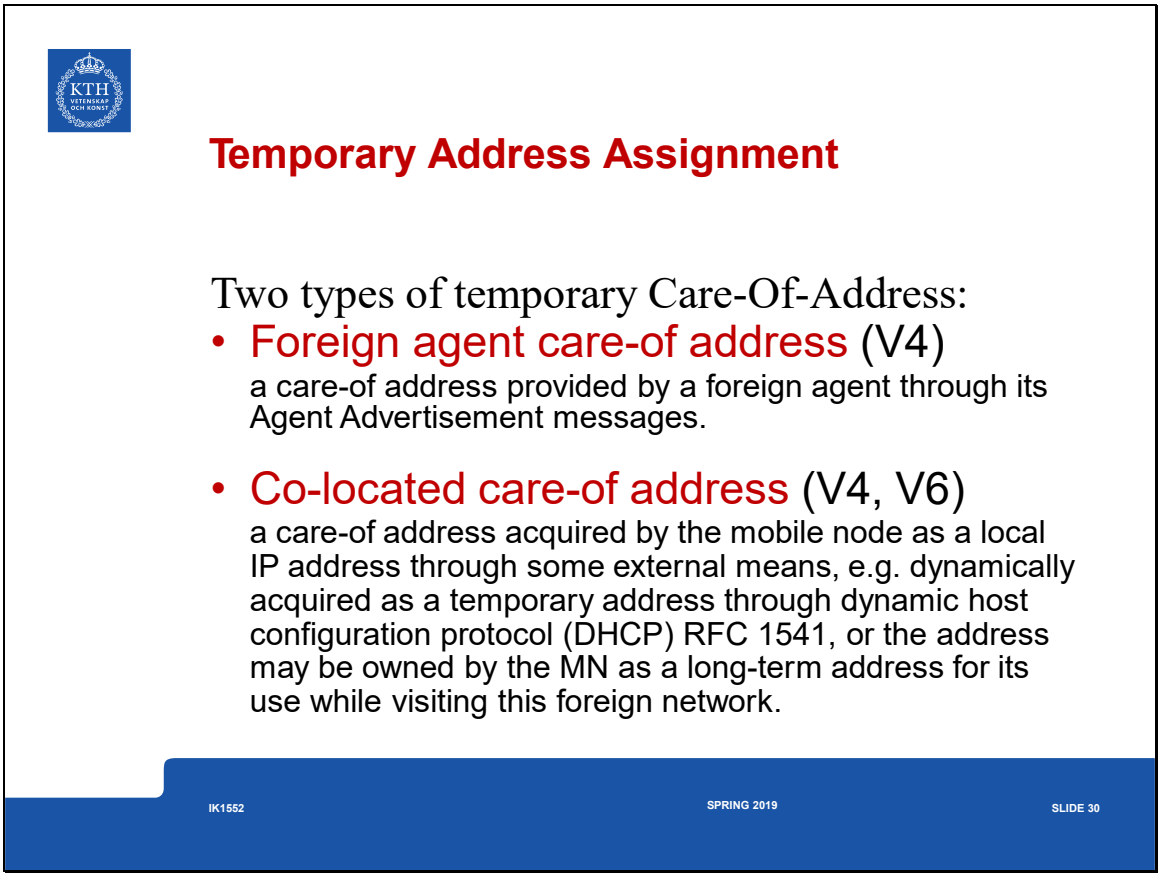
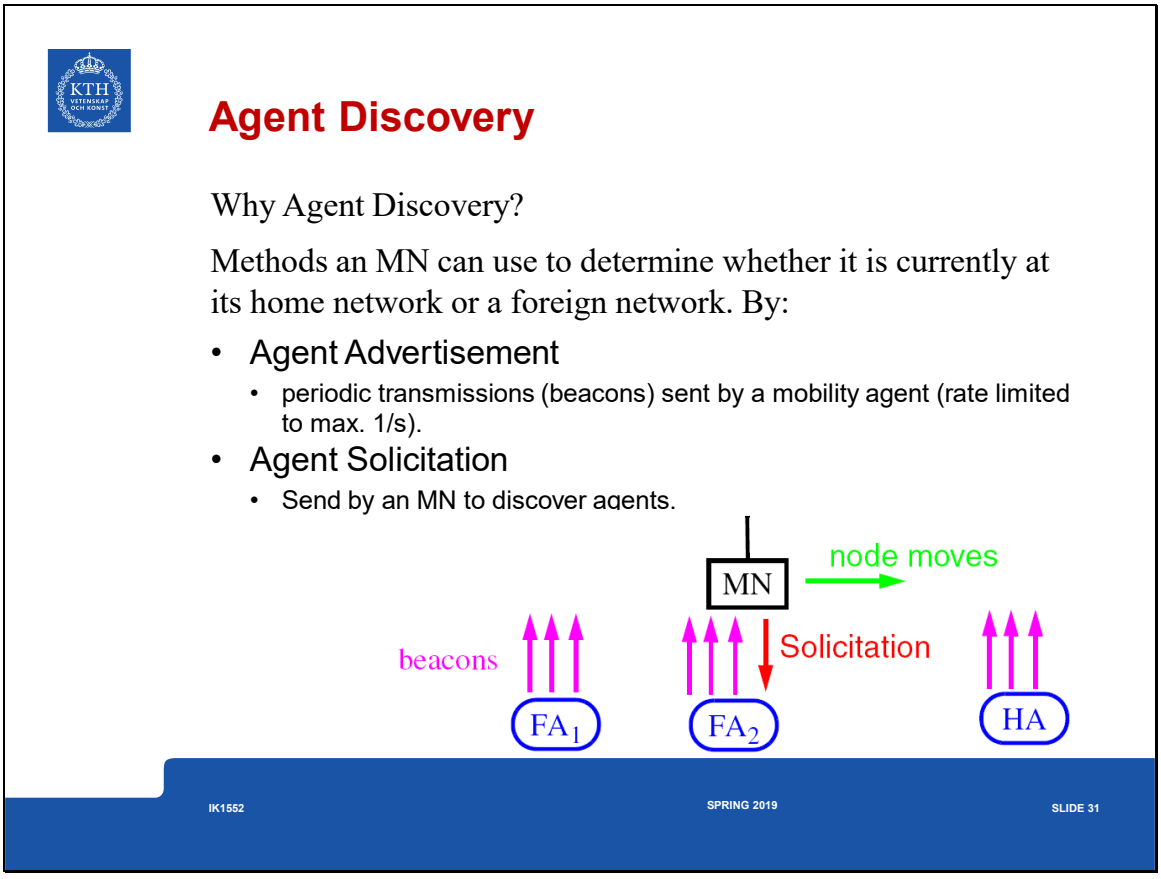
SLIDE 29

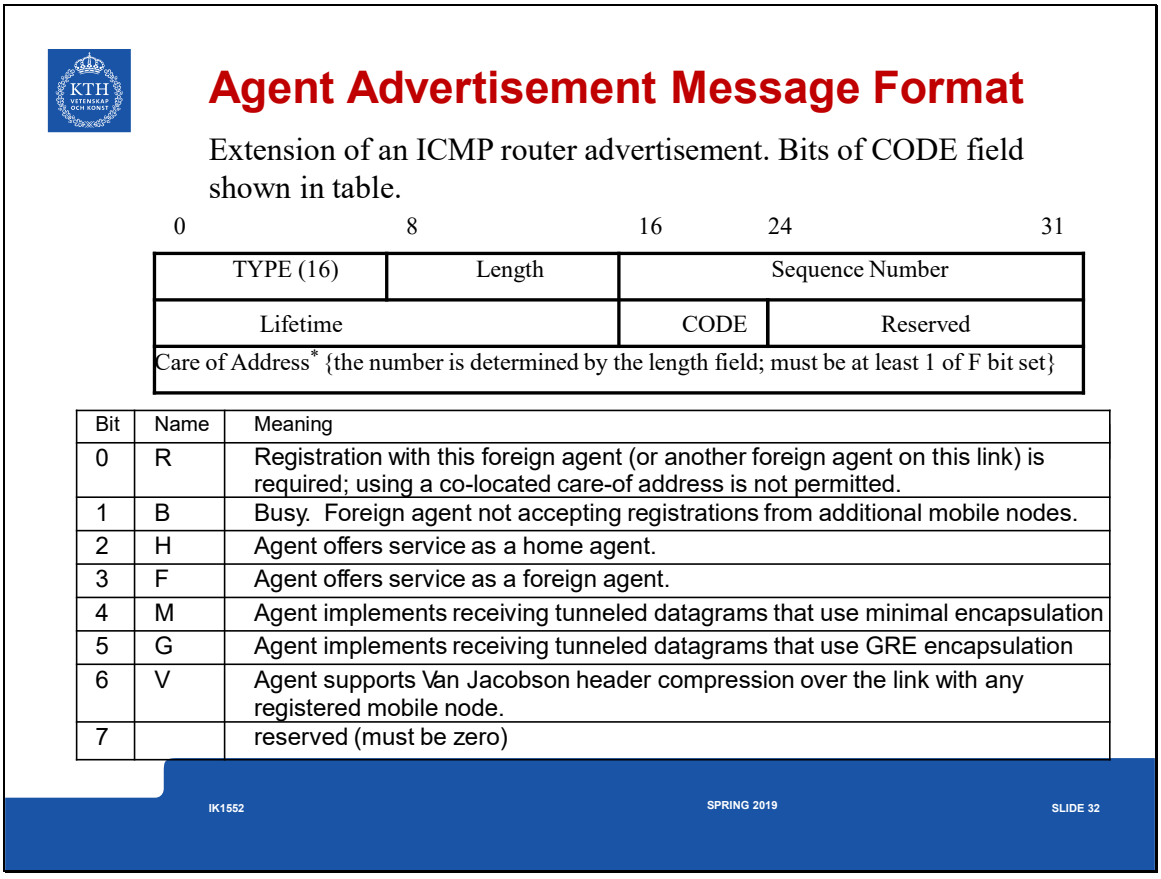
Slide 30



R. Droms, 'Dynamic Host Configuration Protocol', *Internet Request for Comments*, vol. RFC 1541 (Proposed Standard), October 1993, Available at http://www.rfc-editor.org/rfc/rfc1541.txt


Agent Discovery
Why Agent Discovery?
Methods an MN can use to determine whether it is currently at its home network or a foreign network. By:
• Agent Advertisement
• periodic transmissions (beacons) sent by a mobility agent (rate limited to max. 1/s).
• Agent Solicitation
• Send by an MN to discover agents.
MN
node moves
beacons
Solicitation
FA1
FA2
HA
IK1552
SPRING 2019
SLIDE 31

Slide 32



Agent Advertisement Message Format

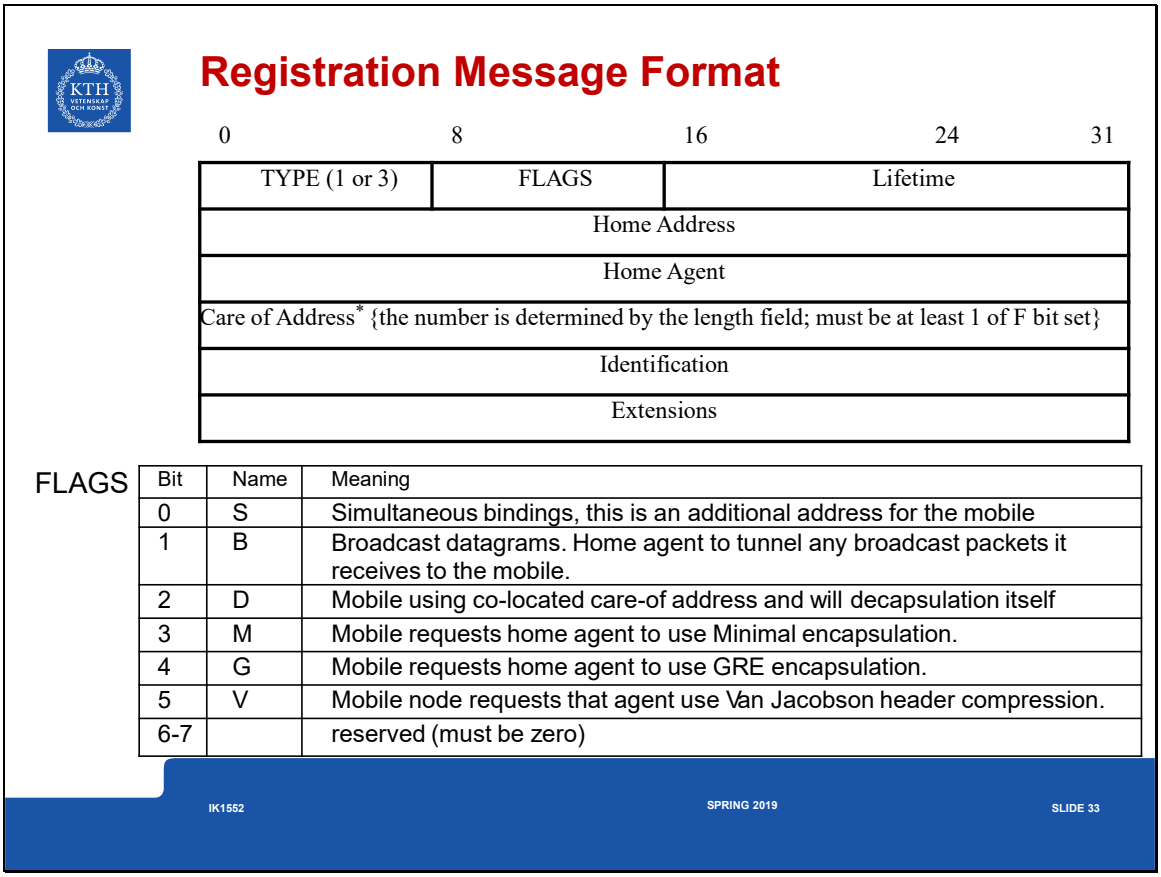
Extension of an ICMP router advertisement. Bits of CODE field shown in table.

0	8	16	24	31
TYPE (16)	Length	Sequence Number		
Lifetime		CODE	Reserved	
Care of Address* {the number is determined by the length field; must be at least 1 of F bit set}				

Bit	Name	Meaning
0	R	Registration with this foreign agent (or another foreign agent on this link) is required; using a co-located care-of address is not permitted.
1	B	Busy. Foreign agent not accepting registrations from additional mobile nodes.
2	H	Agent offers service as a home agent.
3	F	Agent offers service as a foreign agent.
4	M	Agent implements receiving tunneled datagrams that use minimal encapsulation
5	G	Agent implements receiving tunneled datagrams that use GRE encapsulation
6	V	Agent supports Van Jacobson header compression over the link with any registered mobile node.
7		reserved (must be zero)

IK1552 SPRING 2019 SLIDE 32

Slide 33



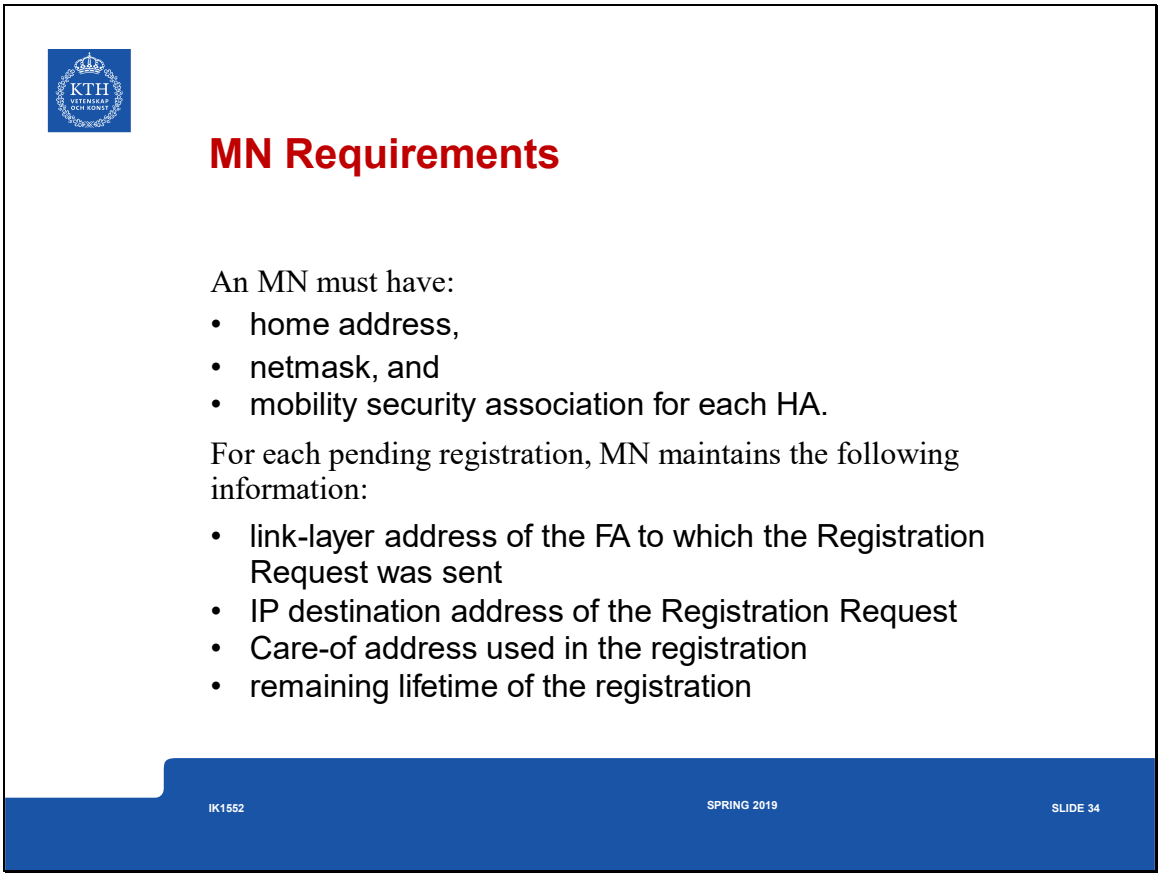
Registration Message Format

0	8	16	24	31
TYPE (1 or 3)	FLAGS	Lifetime		
Home Address				
Home Agent				
Care of Address* {the number is determined by the length field; must be at least 1 of F bit set}				
Identification				
Extensions				

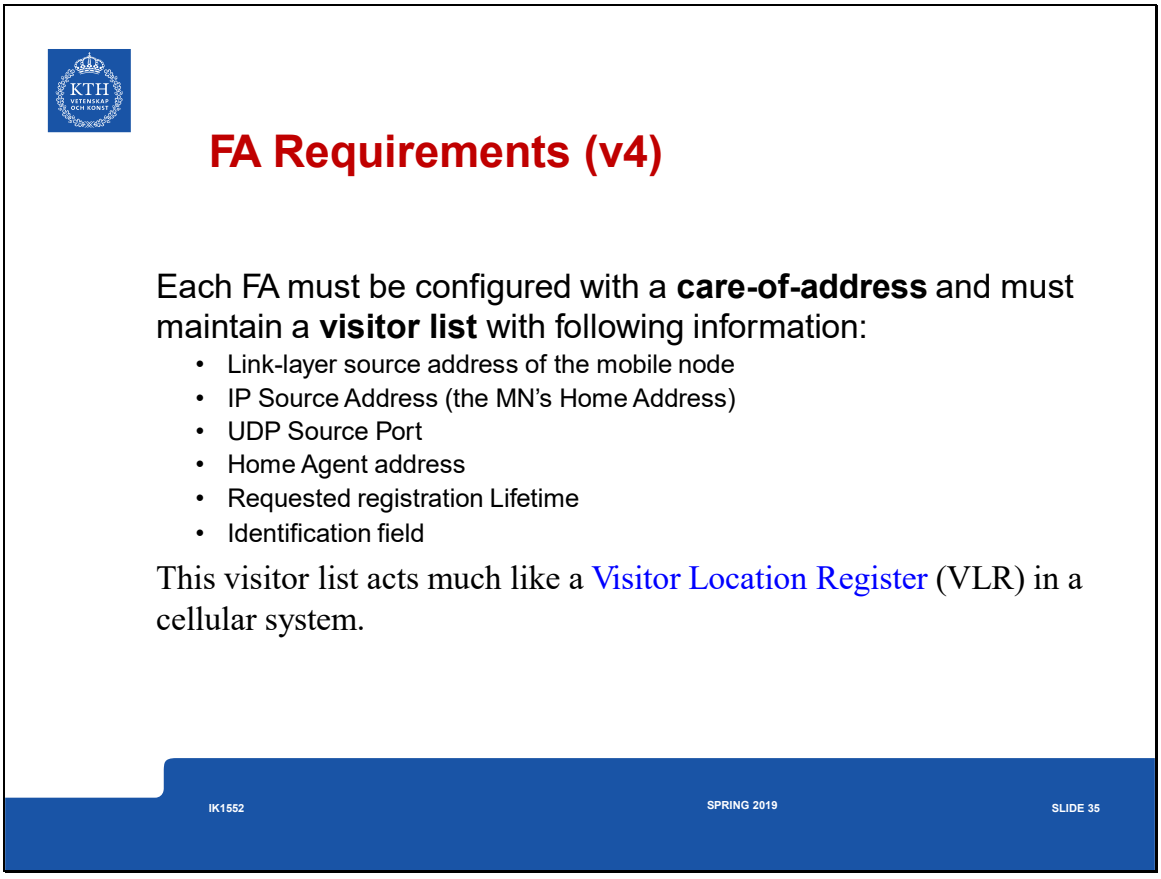
FLAGS

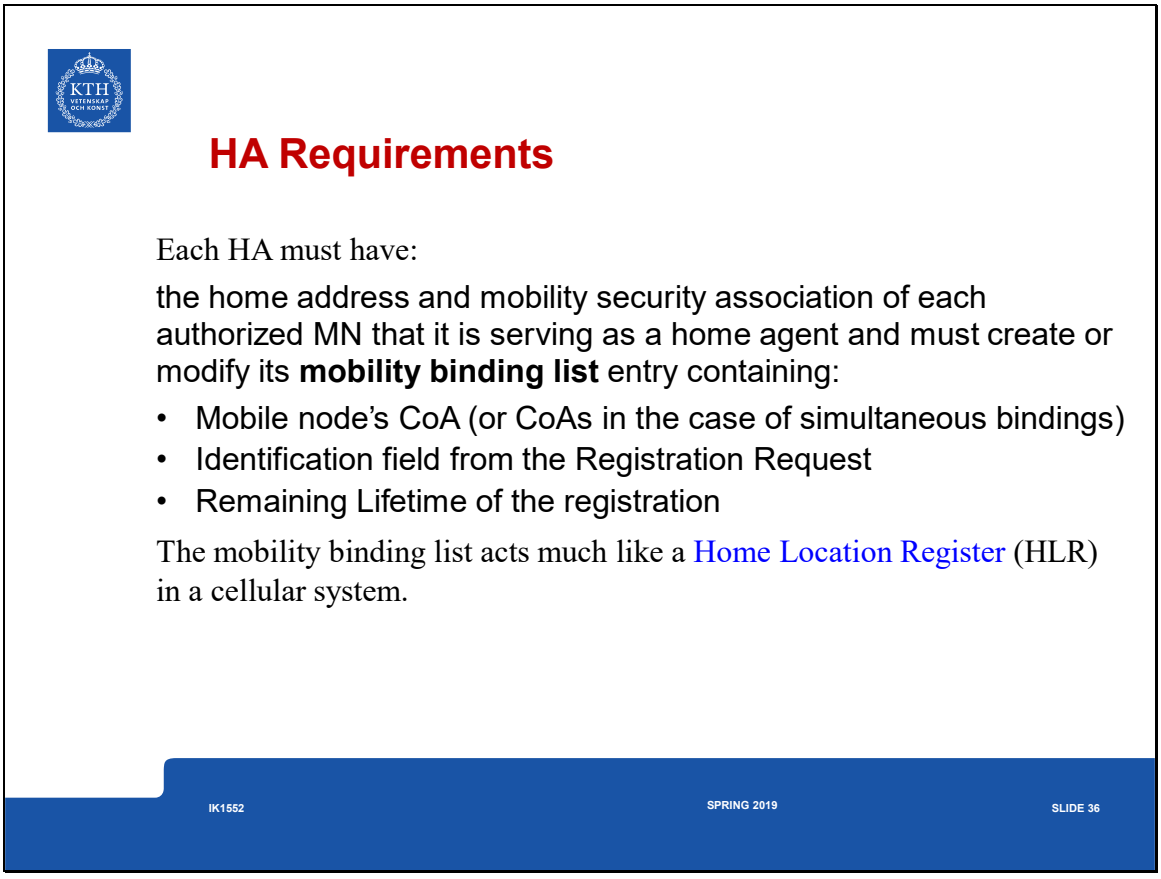
Bit	Name	Meaning
0	S	Simultaneous bindings, this is an additional address for the mobile
1	B	Broadcast datagrams. Home agent to tunnel any broadcast packets it receives to the mobile.
2	D	Mobile using co-located care-of address and will decapsulation itself
3	M	Mobile requests home agent to use Minimal encapsulation.
4	G	Mobile requests home agent to use GRE encapsulation.
5	V	Mobile node requests that agent use Van Jacobson header compression.
6-7		reserved (must be zero)

IK1552 SPRING 2019 SLIDE 33


MN Requirements
An MN must have:
• home address,
• netmask, and
• mobility security association for each HA.
For each pending registration, MN maintains the following information:
• link-layer address of the FA to which the Registration Request was sent
• IP destination address of the Registration Request
• Care-of address used in the registration
• remaining lifetime of the registration
IK1552
SPRING 2019
SLIDE 34

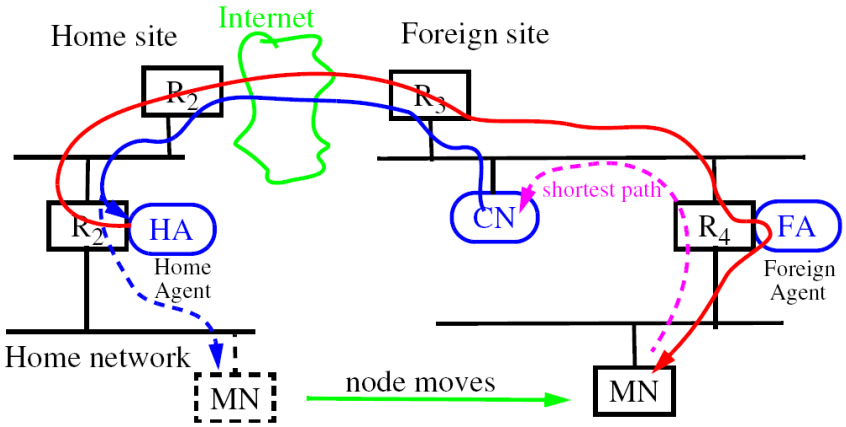
Slide 35


FA Requirements (v4)
Each FA must be configured with a care-of-address and must maintain a visitor list with following information:
• Link-layer source address of the mobile node
• IP Source Address (the MN's Home Address)
• UDP Source Port
• Home Agent address
• Requested registration Lifetime
• Identification field
This visitor list acts much like a Visitor Location Register (VLR) in a cellular system.
IK1552
SPRING 2019
SLIDE 35


HA Requirements
Each HA must have:
the home address and mobility security association of each authorized MN that it is serving as a home agent and must create or modify its mobility binding list entry containing:
• Mobile node's CoA (or CoAs in the case of simultaneous bindings)
• Identification field from the Registration Request
• Remaining Lifetime of the registration
The mobility binding list acts much like a Home Location Register (HLR) in a cellular system.
IK1552
SPRING 2019
SLIDE 36

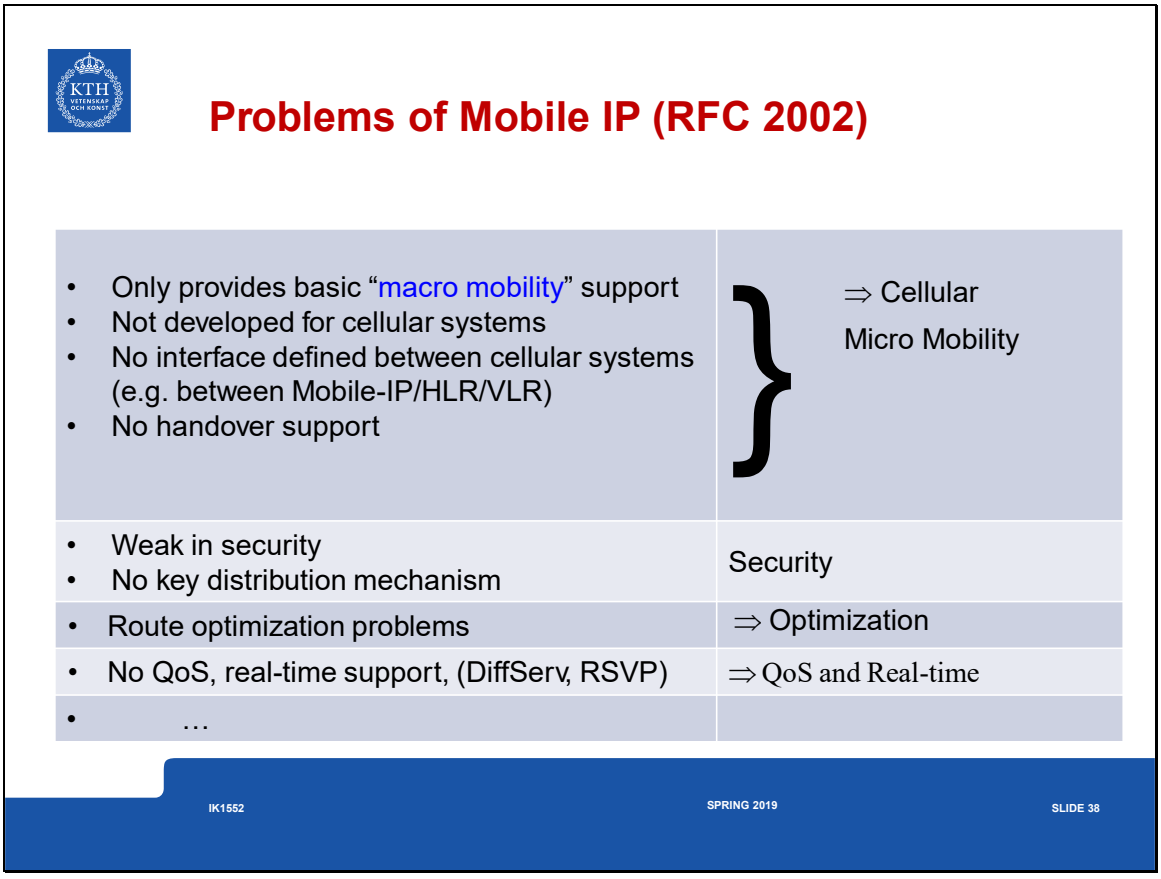
Slide 37

Optimization Problem



We can **not** follow the shortest path in Mobile IPv4 because the CN will always send it via our home network. However, we may be able to use the shortest path from the MN to the CN.

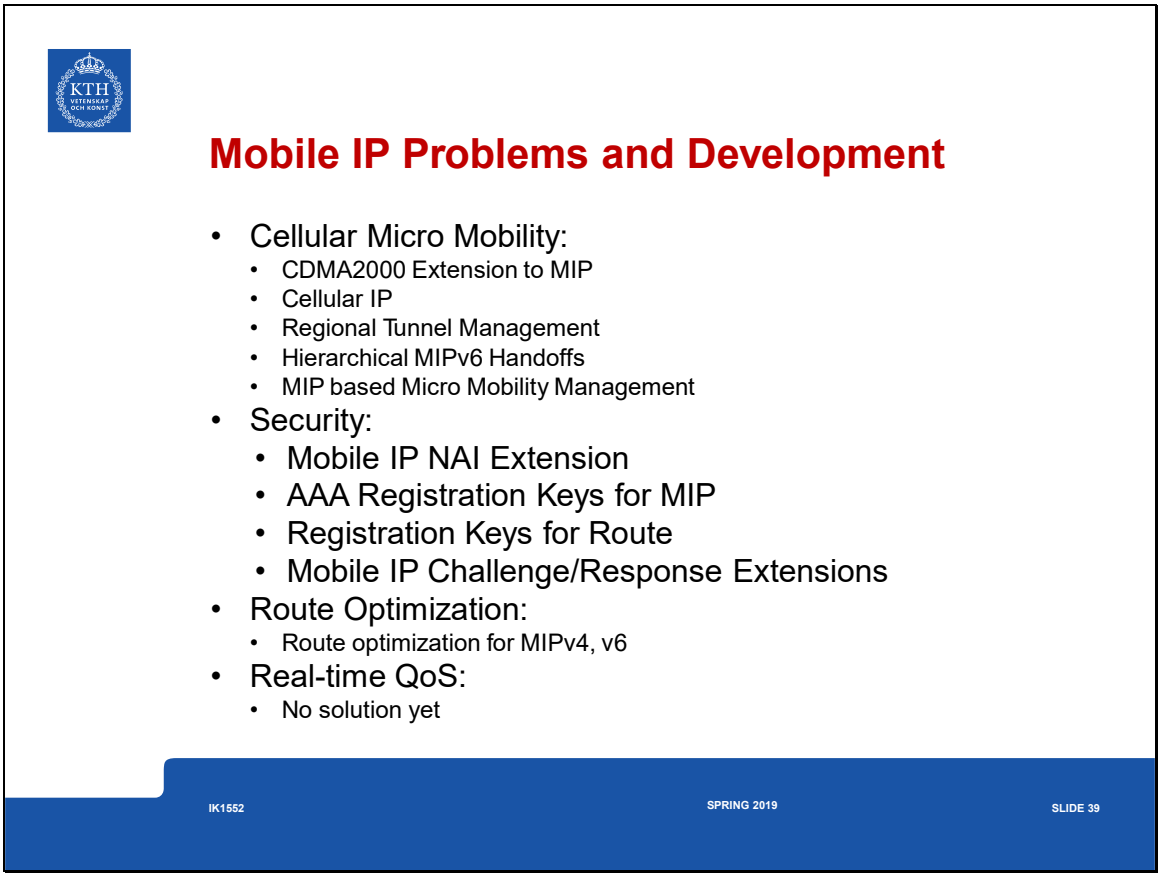
Slide 38



C. Perkins, 'IP Mobility Support', *Internet Request for Comments*, vol. RFC 2002 (Proposed Standard), October 1996, Available at http://www.rfc-editor.org/rfc/rfc2002.txt

C. Perkins, 'IP Mobility Support for IPv4', *Internet Request for Comments*, vol. RFC 3220 (Proposed Standard), January 2002, Available at http://www.rfc-editor.org/rfc/rfc3220.txt

Slide 39


Mobile IP Problems and Development
• Cellular Micro Mobility:
• CDMA2000 Extension to MIP
• Cellular IP
• Regional Tunnel Management
• Hierarchical MIPv6 Handoffs
• MIP based Micro Mobility Management
• Security:
• Mobile IP NAI Extension
• AAA Registration Keys for MIP
• Registration Keys for Route
• Mobile IP Challenge/Response Extensions
• Route Optimization:
• Route optimization for MIPv4, v6
• Real-time QoS:
• No solution yet
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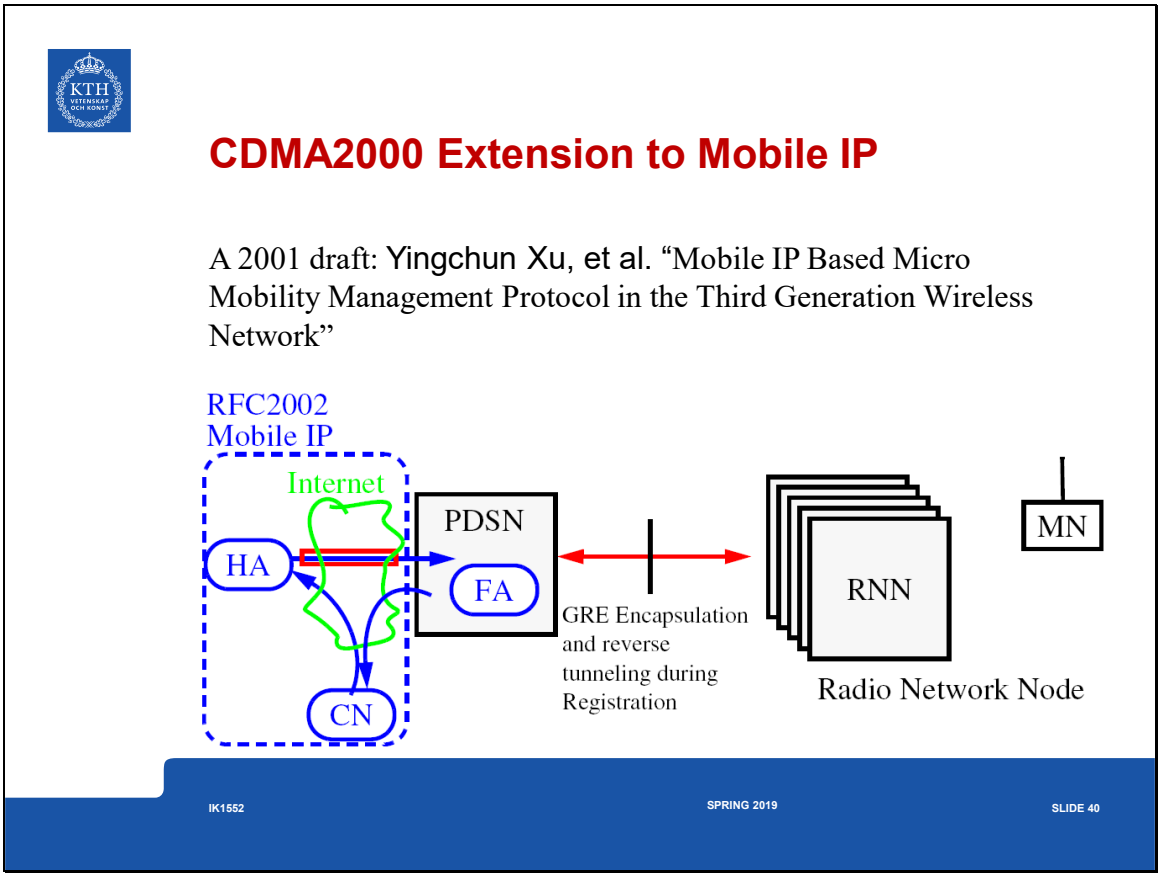
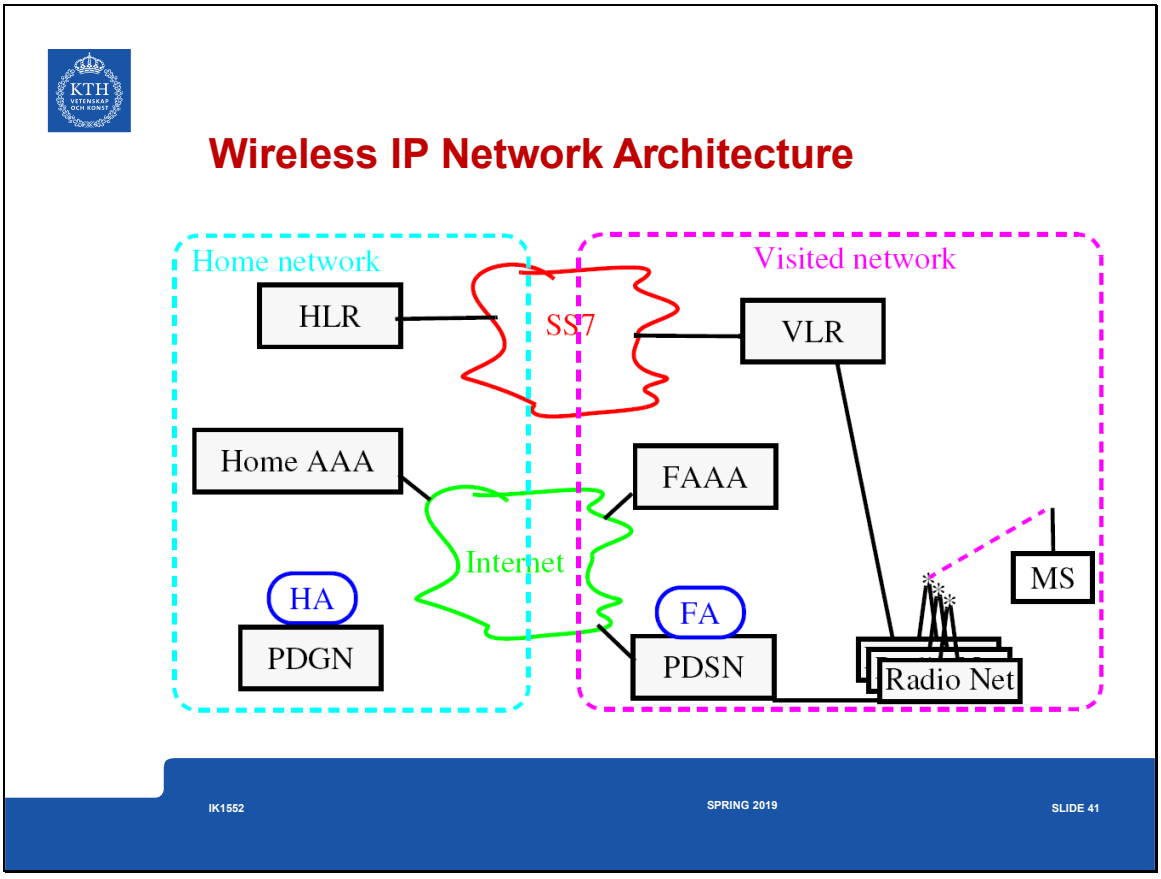
SLIDE 39

Slide 40

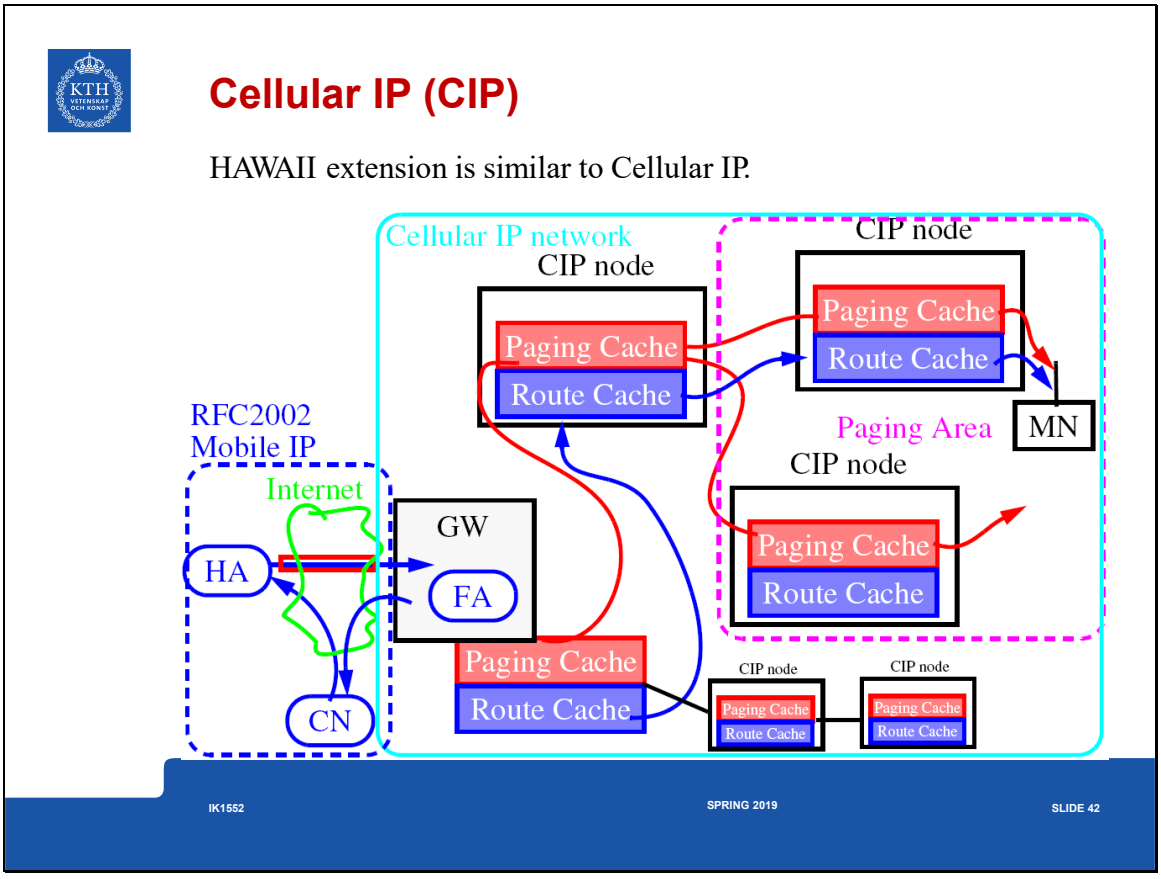


Yingchun Xu, Rajesh Bhalla, Ed Campbell, Karl Freter, Eileen McGrath Hadwen, Gopal Dommety, Kirit Joshi, Parviz Yegani, Takeo Matsumura, Atsushi Teshima, Lee Dong Hyun, Naoto Itoh, Kimihiro Ohki, Byung-Keun Lim, Peter J. McCann, Thomas Towle, Jay Jayapalan, Peter W. Wenzel, Carey B. Becker, James Jiang, Shota Shikano, Woojune Kim, Yong Chang, Bill Semper, Jun Mo Koo, Mark A. Lipford, Frederic Leroudier, and Jim Gately, "Mobile IP Based Micro Mobility Management Protocol in The Third Generation Wireless Network",Internet Draft, May, 2001, Expires Nov. 2001, draft-ietf-mobileip-3gwireless-ext-06.txt http://www.ietf.org/proceedings/52/I-D/draft-ietf-mobileip-3gwireless-ext-06.txt

Slide 41


Wireless IP Network Architecture
Home network
Visited network
HLR
SS7
VLR
Home AAA
FAAA
Internet
HA
PDGN
FA
PDSN
Radio Net
MS
IK1552
SPRING 2019
SLIDE 41

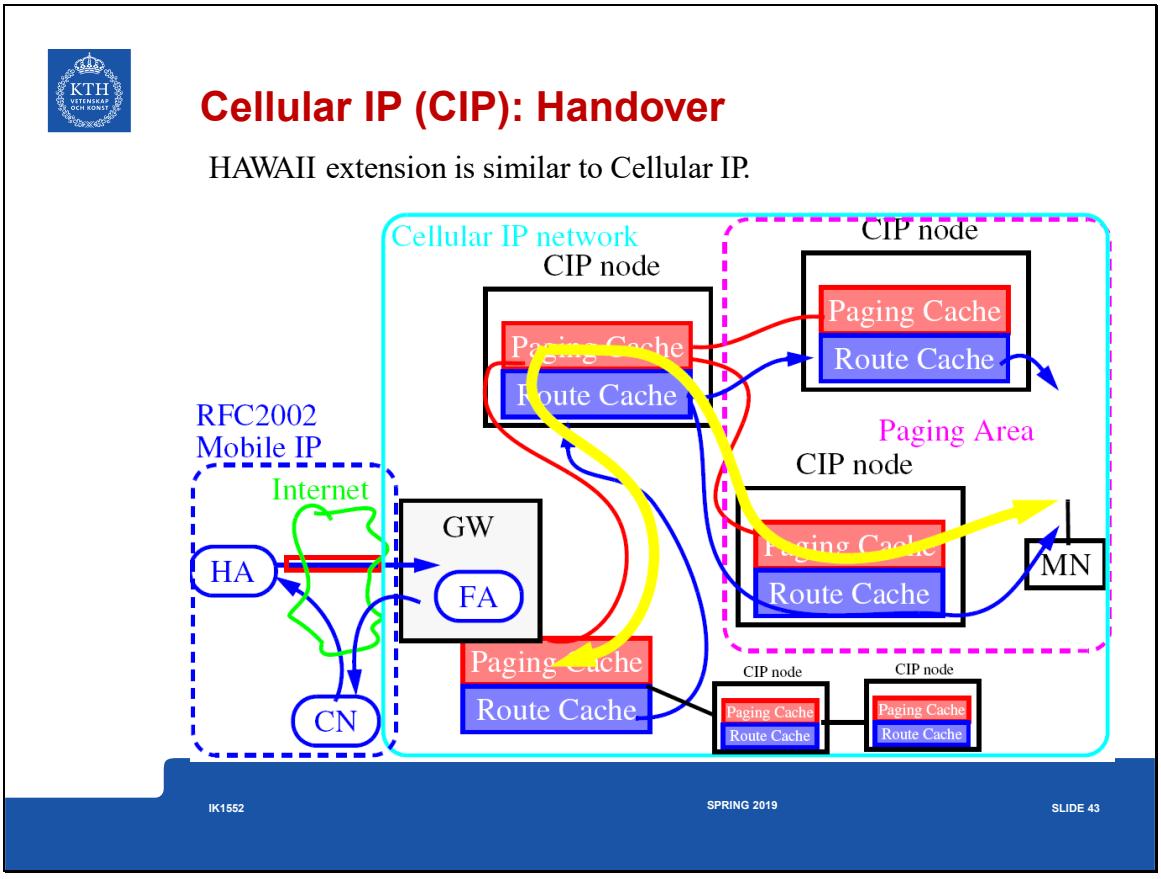
Slide 42



András G. Valkó, 'Cellular IP: A New Approach to Internet Host Mobility', *SIGCOMM Comput. Commun. Rev.*, vol. 29, no. 1, pp. 50–65, Jan. 1999. DOI: 10.1145/505754.505758

Also available from:
http://ccr.sigcomm.org/archive/1999/jan99/ccr-9901-valko.ps

Slide 43


Cellular IP (CIP): Handover
HAWAII extension is similar to Cellular IP.
Cellular IP network
CIP node
CIP node
Paging Cache
Route Cache
Paging Area
CIP node
RFC2002
Mobile IP
Internet
GW
FA
HA
CN
MN
Paging Cache
Route Cache
CIP node
CIP node
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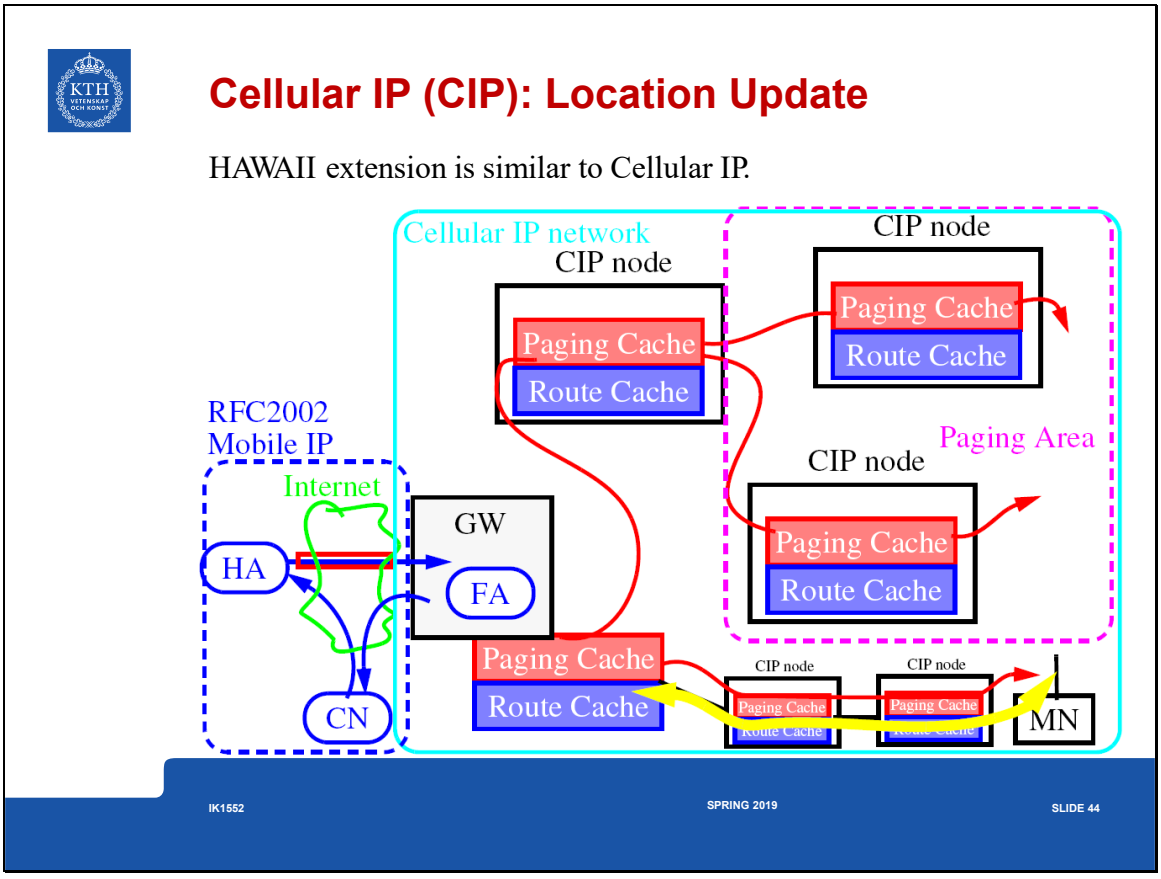
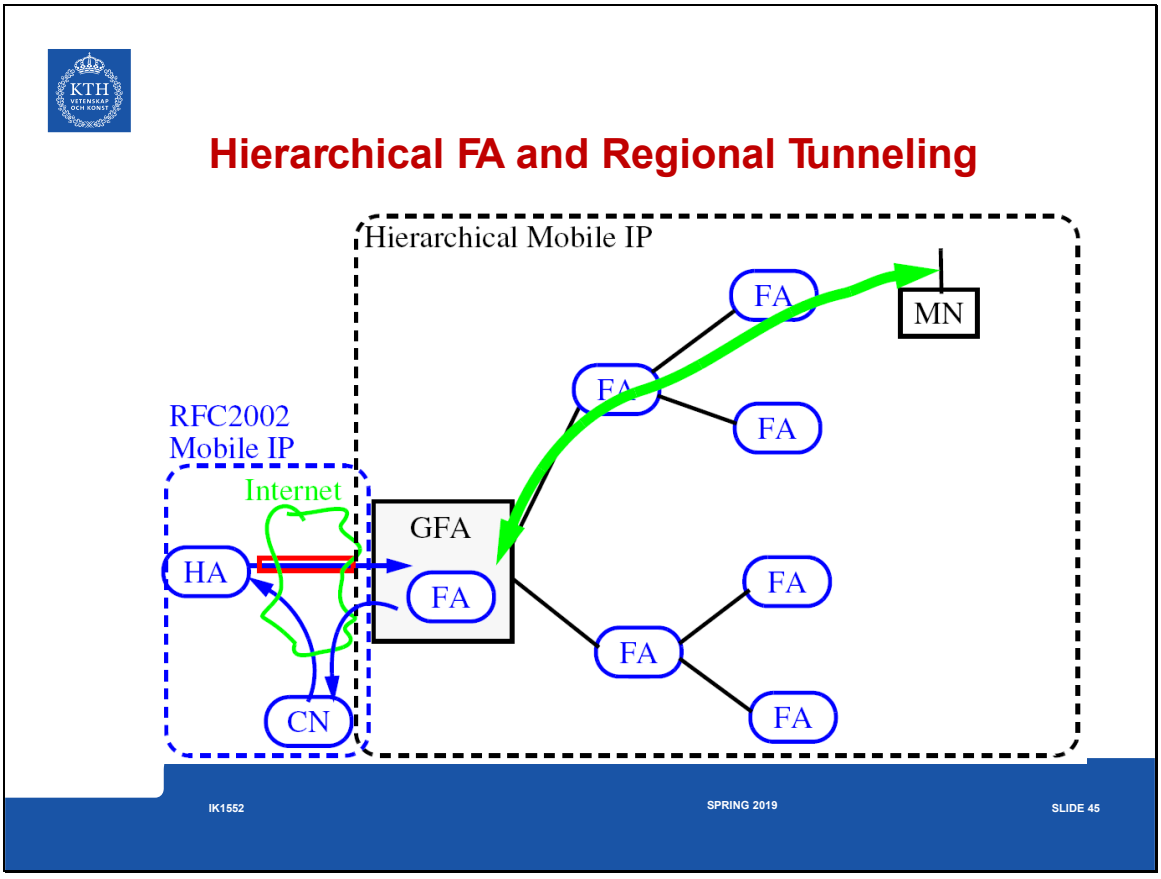
SPRING 2019
SLIDE 43


Cellular IP (CIP): Location Update
HAWAII extension is similar to Cellular IP.
Cellular IP network
CIP node
Paging Cache
Route Cache
CIP node
Paging Cache
Route Cache
RFC2002
Mobile IP
Paging Area
CIP node
Paging Cache
Route Cache
Internet
GW
HA
FA
CN
Paging Cache
Route Cache
CIP node
CIP node
MN
IK1552
SPRING 2019
SLIDE 44

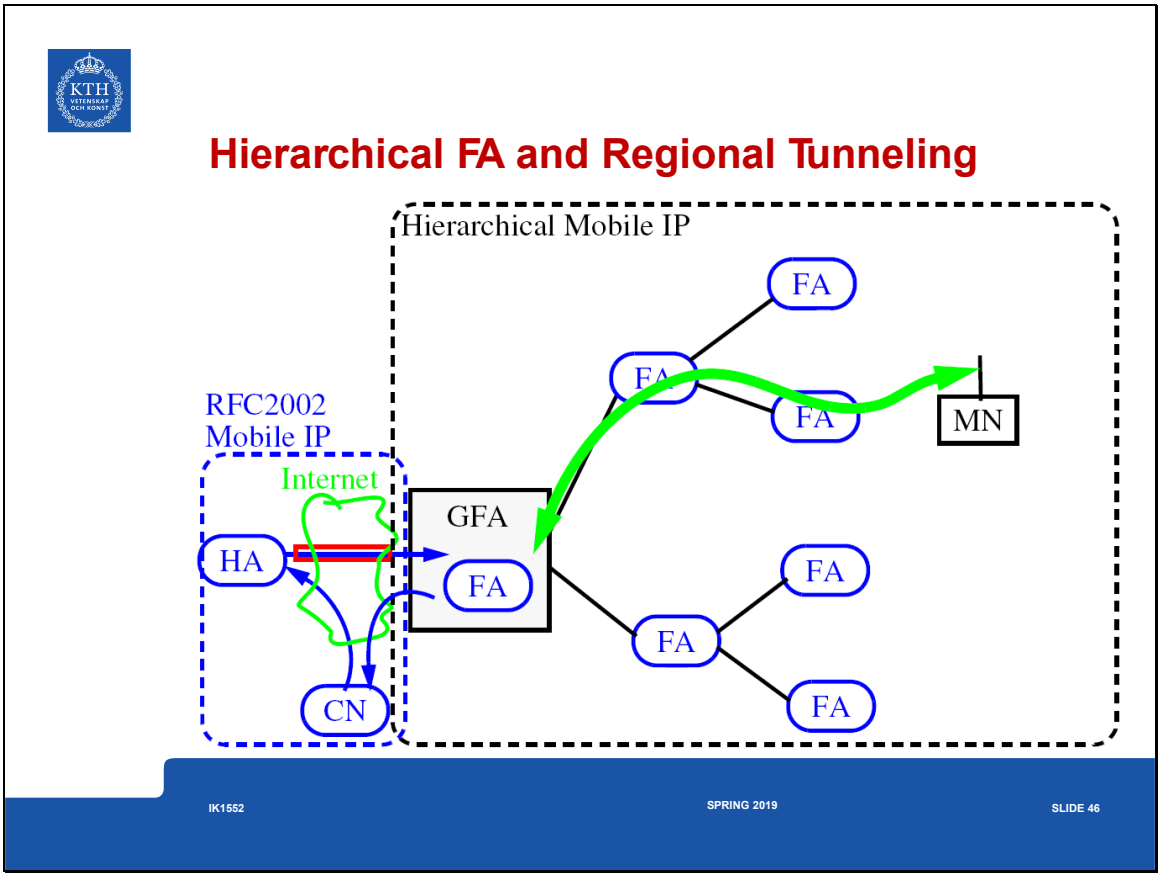
Slide 45



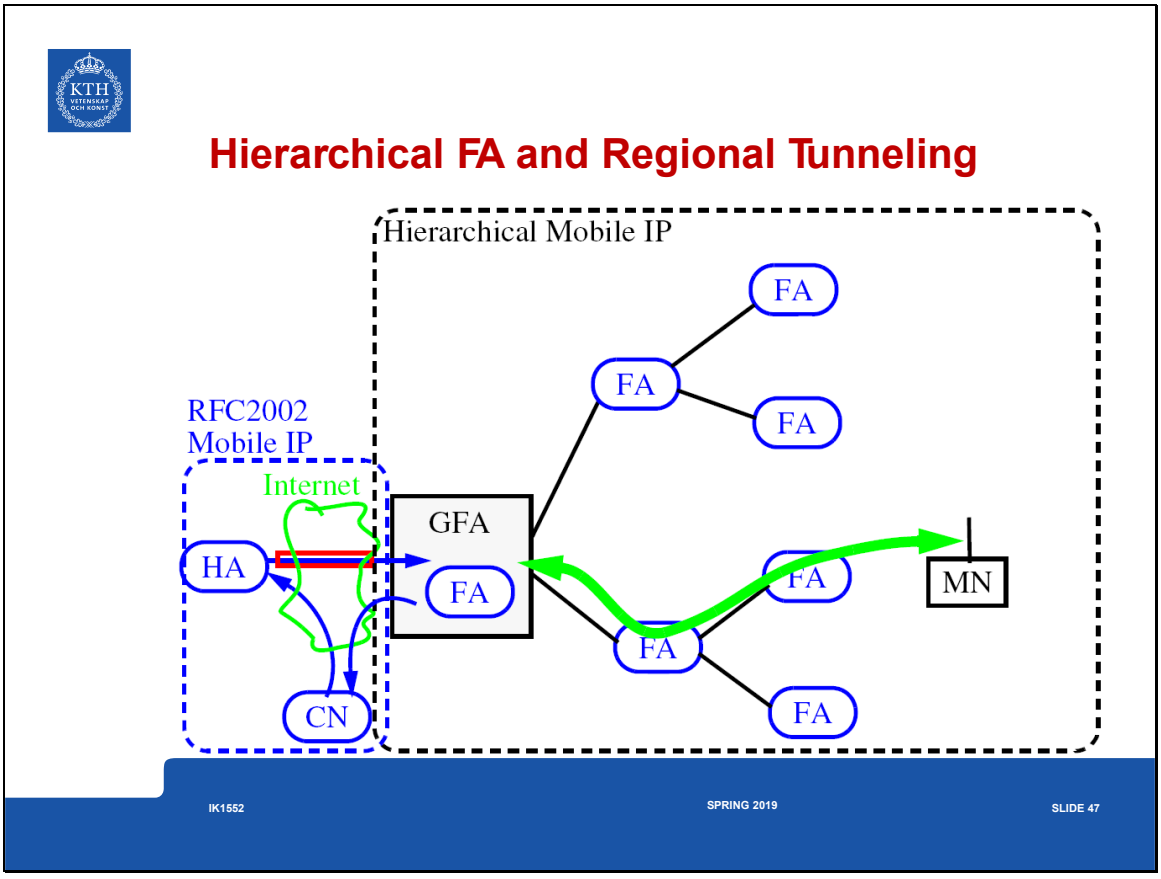
H. Soliman, C. Castelluccia, K. E. Malki, and L. Bellier, 'Hierarchical Mobile IPv6 Mobility Management (HMIPv6)', *Internet Request for Comments*, vol. RFC 4140 (Experimental), Aug. 2005 [Online]. Available: http://www.rfc-editor.org/rfc/rfc4140.txt

C. Castelluccia, 'HMIPv6: A Hierarchical Mobile IPv6 Proposal', *SIGMOBILE Mob. Comput. Commun. Rev.*, vol. 4, no. 1, pp. 48–59, Jan. 2000. DOI: 10.1145/360449.360474

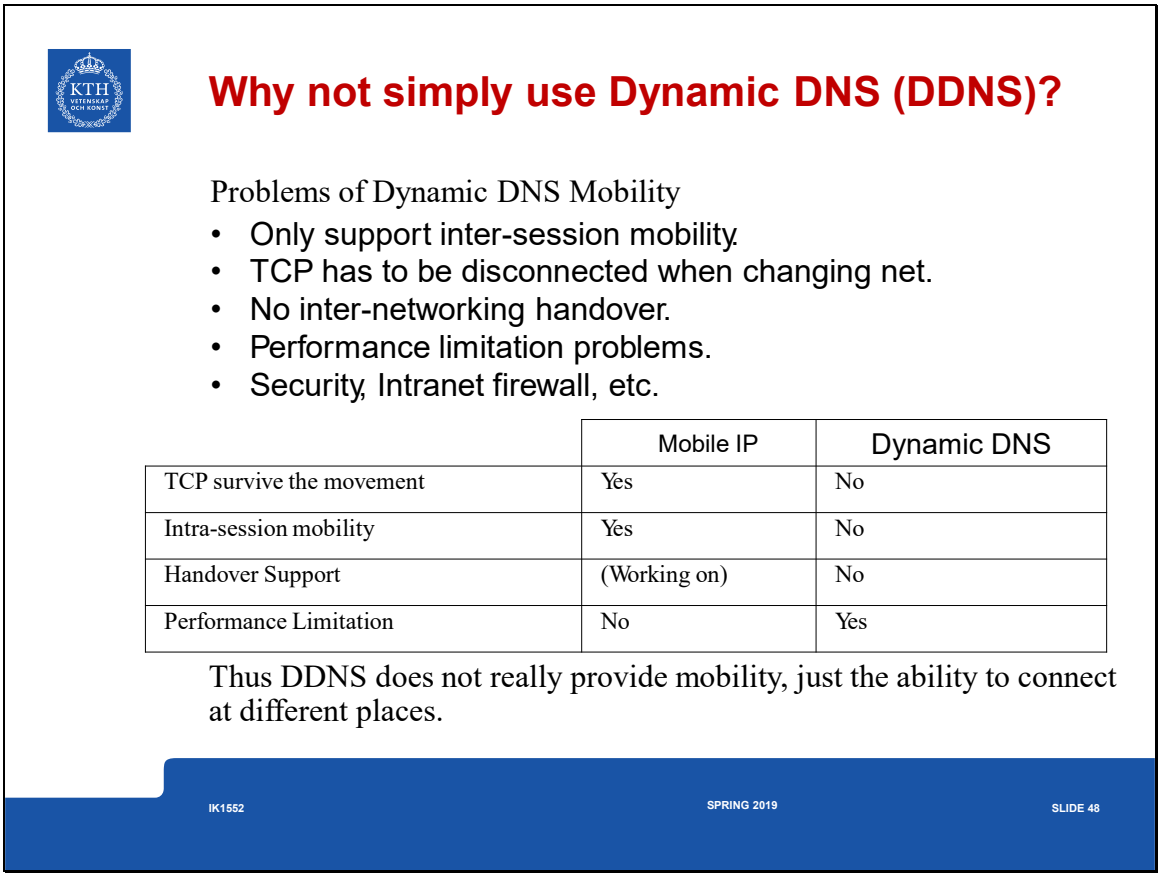
Slide 46


Hierarchical FA and Regional Tunneling
Hierarchical Mobile IP
RFC2002
Mobile IP
Internet
HA
GFA
FA
FA
FA
FA
FA
FA
FA
MN
CN
IK1552
SPRING 2019
SLIDE 46

Slide 47


Hierarchical FA and Regional Tunneling
Hierarchical Mobile IP
FA
FA
FA
RFC2002
Mobile IP
Internet
GFA
HA
FA
FA
MN
FA
CN
FA
IK1552
SPRING 2019
SLIDE 47

Slide 48



Why not simply use Dynamic DNS (DDNS)?

Problems of Dynamic DNS Mobility

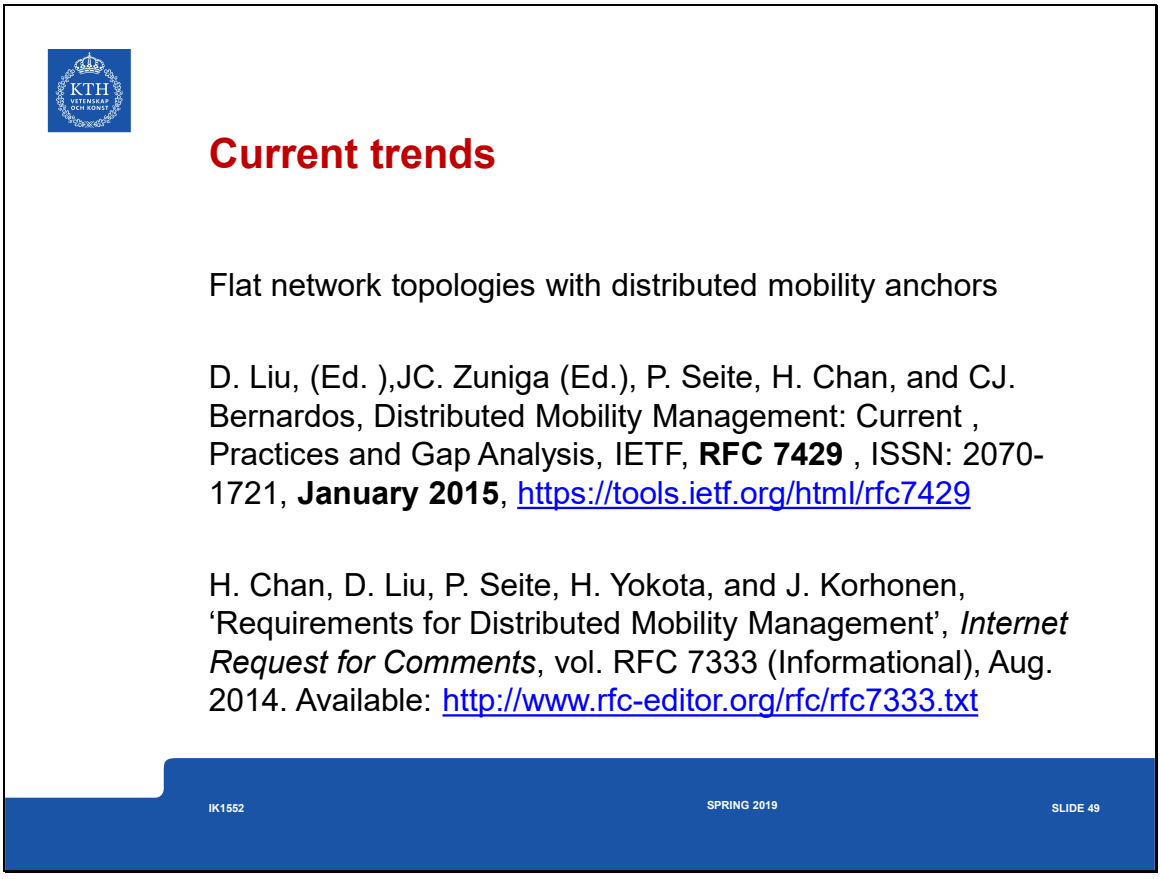
- Only support inter-session mobility.
- TCP has to be disconnected when changing net.
- No inter-networking handover.
- Performance limitation problems.
- Security, Intranet firewall, etc.

	Mobile IP	Dynamic DNS
TCP survive the movement	Yes	No
Intra-session mobility	Yes	No
Handover Support	(Working on)	No
Performance Limitation	No	Yes

Thus DDNS does not really provide mobility, just the ability to connect at different places.

IK1552 SPRING 2019 SLIDE 48

Slide 49



Current trends

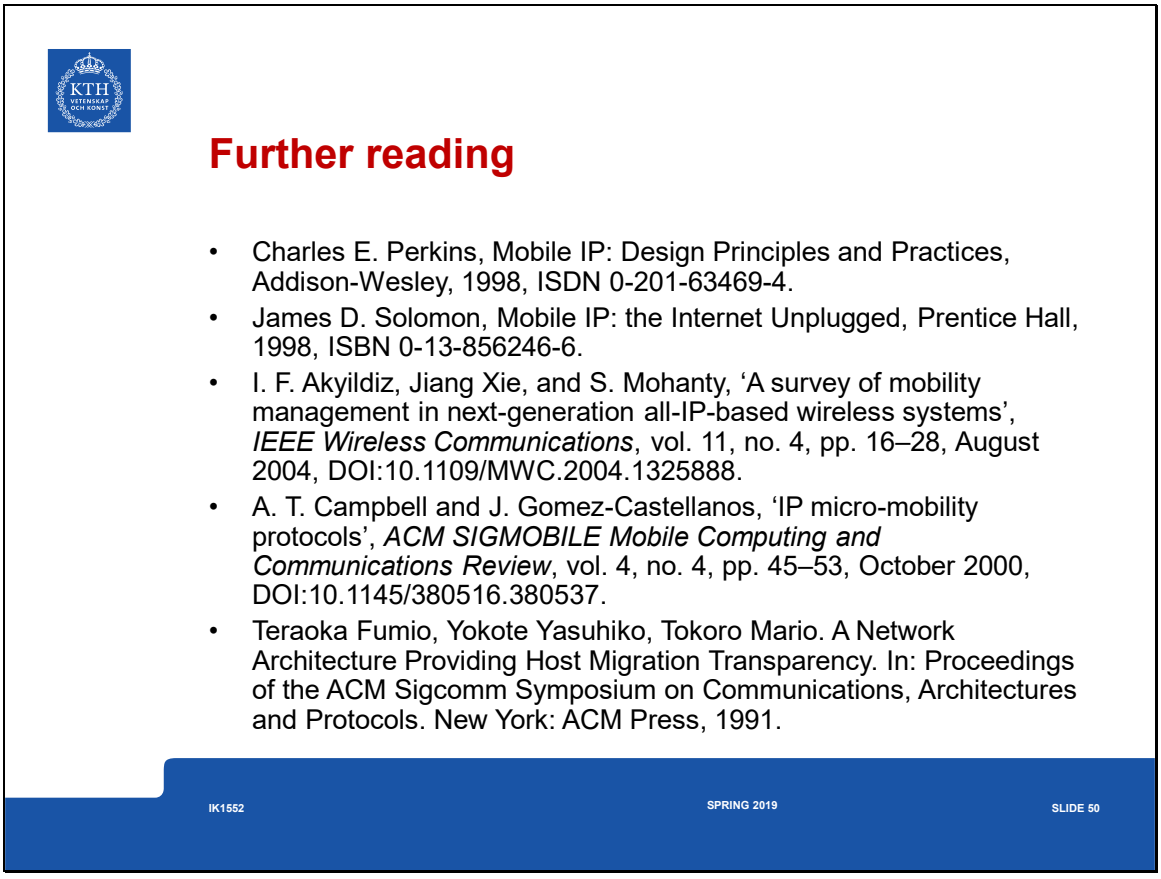
Flat network topologies with distributed mobility anchors

D. Liu, (Ed.),JC. Zuniga (Ed.), P. Seite, H. Chan, and CJ. Bernardos, Distributed Mobility Management: Current , Practices and Gap Analysis, IETF, **RFC 7429** , ISSN: 2070-1721, **January 2015**, https://tools.ietf.org/html/rfc7429

H. Chan, D. Liu, P. Seite, H. Yokota, and J. Korhonen, 'Requirements for Distributed Mobility Management', *Internet Request for Comments*, vol. RFC 7333 (Informational), Aug. 2014. Available: http://www.rfc-editor.org/rfc/rfc7333.txt

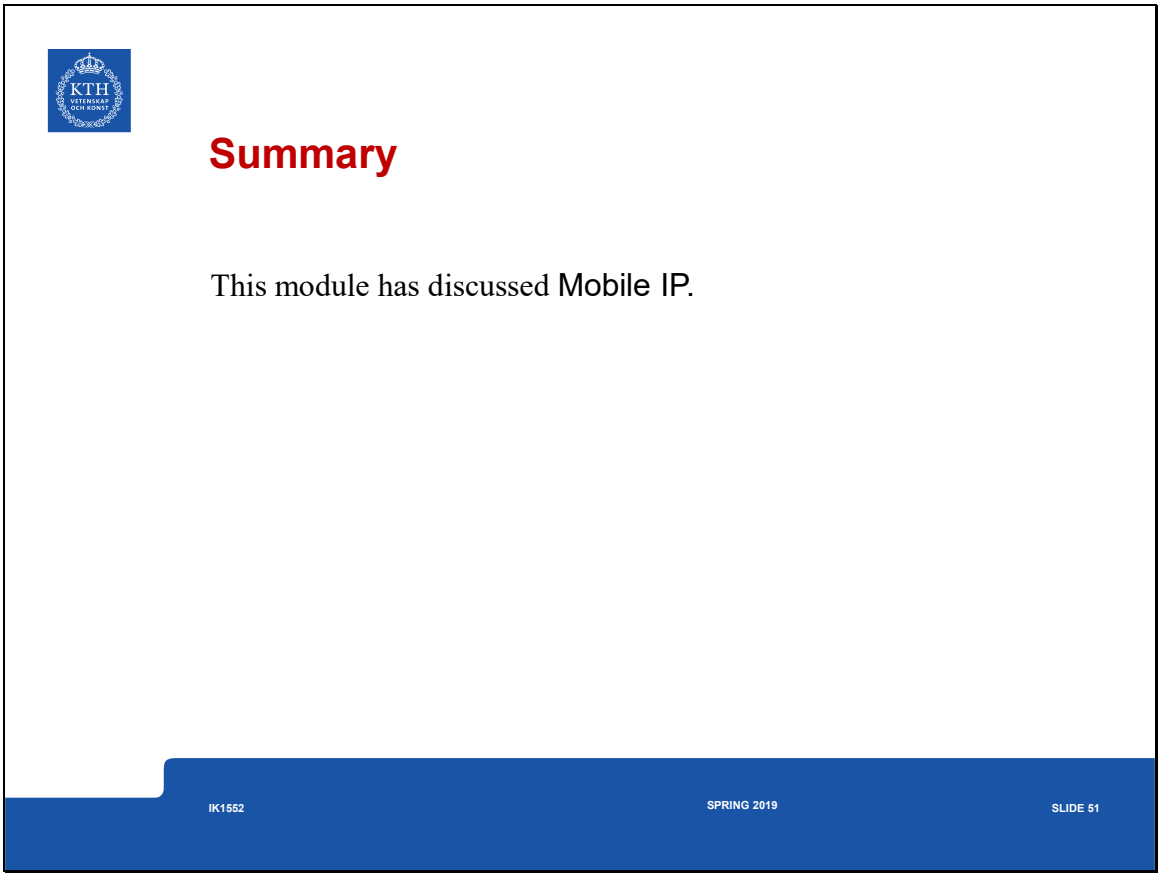
IK1552 SPRING 2019 SLIDE 49

Slide 50



Zhang Hongke, The Status Quo and Future of Mobile Internet Technologies, ZTE Communications, 2005, No.1, http://wwwen.zte.com.cn/endata/magazine/ztecommunications/2005year/no1/articles/200503/t20050324_162313.html

Slide 51


Summary
This module has discussed Mobile IP.
IK1552
SPRING 2019
SLIDE 51

Slide 52