Fast-handoff Mechanisms for Wireless Internet

Presenter - Ashutosh Dutta
04/12/2005
IRT Group Meeting
adutta@research.telcordia.com
Outline

- Motivation
- Handoff Delay during Wireless Internet Roaming
- Related Work
- Multi-Interface/Inter-Technology Handoff
- Experimental Results
  - MIP-based, SIP-based (binding)
- Proposed Ways to Optimize the handoff
  - Multi-interface mobility management
  - Proactive Handover
  - SIP-based fast-handoff
  - Proxy-based handoff for multicast stream
Motivation

- It is desirable to limit the jitter, delay and packet loss for VoIP and Streaming traffic
- 150 ms end-to-end delay for interactive traffic such as VoIP, 3% packet loss is allowed
- Delay due to handoff takes place at several layers
  - Layer 2 (handoff between AP), Layer 3 (IP address acquisition, configuration) and Media Redirection
- Rapid handoff will contribute to overall delay and packet loss
- Thus it is essential to reduce the handoff delay introduced at different layers
- We propose several mechanisms to reduce the handoff-delay and packet loss
Mobile Wireless Internet: A Scenario
SIP-centric Wireless Internet Roaming

**Visited Domain**
- **AAA**
- **QoS**
- **SIP Server**
  - **DHCP/PPP**
  - **DNS**

**Home Domain**
- **AAA**
- **QoS**
- **SIP Server**
  - **DHCP/PPP**
  - **DNS**

**SLA/SA**
- **VR**
- **HR**

---

**Network 1 (802.11)**
- **N1**
- **N2**
- **PANA**
- **IP_{ch}**
- **207.3.232.10**
- **128.59.11.6**
- **128.59.10.6**

**Network 2 (CDMA/GPRS)**
- **N2**
- **N1**
- **PANA**
- **ERP**
- **207.3.240.10**

**Notes:**
- **ERG** - Edge Router and
- **MN** - Mobile Node
- **AP** - Access Point
Trajectory of a Packet

Total E-E delay = \( \sum T_i \)
Total Packet Loss = \( P_N - P_1 \)

- \( T_1 = \) Encoding Delay
- \( T_2 = \) Packetization Delay
- \( T_3 = \) Transmission Delay
- \( T_4 = \) Handoff Delay
- \( T_5 = \) Jitter buffer delay
- \( T_6 = \) De-Packetization delay
- \( T_7 = \) Decoding Delay
Handoff Latency

Δ1 - L2 Hand-over Latency Delay
Δ2 – Delay due to IP Address Acquisition and Configuration, authentication, authorization
Δ3 – Binding update and Media Redirection delay
## Sample Delays (L3, L2)

### L3 Delay

<table>
<thead>
<tr>
<th>Method (Linux)</th>
<th>DHCP ARP w/o</th>
<th>DRCP</th>
<th>DHCP (v6) SA</th>
<th>DHCP (v6) SF</th>
<th>PPP 7-8 s</th>
<th>FA COA 1-2 s</th>
<th>Auto IP 4-5 s</th>
<th>Static 100 ms</th>
<th>Proactive IP Under study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Δ2</td>
<td>4-5 s</td>
<td>300 ms - 400 ms</td>
<td>150 ms</td>
<td>160 ms</td>
<td>500 ms</td>
<td>7-8 s</td>
<td>1 - 2 s</td>
<td>4-5 s</td>
<td>100 ms</td>
</tr>
</tbody>
</table>

### L2 Delay

<table>
<thead>
<tr>
<th>H/W - OS</th>
<th>L2 Handoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>AiroNet + Linux</td>
<td>200 – 300 ms</td>
</tr>
<tr>
<td>Orinoco + Linux</td>
<td>100 – 160 ms</td>
</tr>
<tr>
<td>DLink + Linux</td>
<td>400 – 600 ms</td>
</tr>
<tr>
<td>Centrino + Linux (Passive)</td>
<td>300 ms</td>
</tr>
<tr>
<td>Orinoco + Windows</td>
<td>250 ms</td>
</tr>
<tr>
<td>Hostap (Managed)</td>
<td>14 ms</td>
</tr>
</tbody>
</table>
Mobility Optimization - Related Work

- Cellular IP, HAWAII - Micro Mobility
- MIP-Regional Registration, Mobile-IP low latency, IDMP
- HMIPv6, FMIPv6 (IPv6)
- Yokota et al - Link Layer Assisted handoff
- Shin et al, Velayos et al - Layer 2 delay reduction
- Gwon et al, - Tunneling between FAs, Enhanced Forwarding PAR
- DHCP Rapid-Commit, Optimized DAD - Faster IP address acquisition
- DFA, MOM (Multicast)
Possible Handover Scenario

- Handover between 802.11 and 802.3 networks
- Handover between 802.3 and 802.16 networks
- Handover between 802.11 and 802.16 networks
- Handover between 802.11 and 802.11 networks, across ESSs.
- Handover between 802.3 and Cellular networks
- Handover between 802.11 and Cellular networks
- Handover between 802.16 and Cellular networks
Single Radio Interface Roaming Scenario
Handoff with Single Interface (802.11-802.11)

Example
Multiple Radio Interface Roaming Scenario

Cellular Network
(CDMA/GPRS)

IEEE 802.11 LAN

WLAN: Activated
Cellular: deactivated

The mobile detects
Cellular starts the
connection, WLAN: 
deactivated

Mobile
Detects 802.11
may disconnect
cellular
Effect of handoff delay on audio (Non-Optimized)

Figure 1. Single Interface Case (802.11b – 802.11b) – SIP as mobility

Figure 3. Multiple Interface Case (802.11b – CDMA1XRTT) – MIP as mobility

Figure 3. Multiple Interface Case (802.11b – CDMA1XRTT) – SIP as mobility
**SIP-based subnet and domain Mobility handoff**

(Experimental Results)

![Diagram showing SIP-based mobility handoff](image)

**Fig 1. Handoff Factors for SIP-based mobility**

Table 1. subnet/domain handoff Experimental values

<table>
<thead>
<tr>
<th>Operation</th>
<th>DRCP Δ2</th>
<th>PANA Δ3</th>
<th>SIP Δ3</th>
<th>Media RTP Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subnet Handoff</td>
<td>79 ms</td>
<td>2 ms</td>
<td>228 ms</td>
<td>1490 ms</td>
</tr>
<tr>
<td>Domain Handoff</td>
<td>81 ms</td>
<td>45 ms</td>
<td>289 ms</td>
<td>1656 ms</td>
</tr>
</tbody>
</table>

Handoff timing with more granularity

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.521 - 10.1.4.162</td>
<td>RTP1</td>
</tr>
<tr>
<td>00.478</td>
<td>RTP1</td>
</tr>
<tr>
<td>00.652</td>
<td>RTP2</td>
</tr>
<tr>
<td>00.701 - 10.1.1.130</td>
<td>RTP2</td>
</tr>
<tr>
<td>00.938</td>
<td>RTP2</td>
</tr>
<tr>
<td>00.949</td>
<td>DRCP DISCOVER</td>
</tr>
<tr>
<td>00.960</td>
<td>DRCP OFFER</td>
</tr>
<tr>
<td>01.031</td>
<td>DRCP ACK</td>
</tr>
<tr>
<td>(De-REG+REG) (01.049, 01.052)</td>
<td>PANA</td>
</tr>
<tr>
<td>01.151</td>
<td>Re-INVITE</td>
</tr>
<tr>
<td>01.37</td>
<td>OK</td>
</tr>
<tr>
<td>01.52 – 10.1.1.130</td>
<td>RTP1</td>
</tr>
</tbody>
</table>
Inter-domain Secured Mobility

Domain 2 (Foreign network)

DIAMETER Server (AAA Foreign)

PANA Agent w/ Firewall
DRCP
IPSec

AP

MN

RTP Key

Domain 1 (Home network)

DIAMETER Server (AAA Home)

Temp. key for alice@domain1

Pre-shared key for alice@domain1

PANA Agent w/ Firewall
DRCP
IPSec

AP

Mobile Station
PANA Client
NAI=alice@domain1

SIP Proxy

CH

1 Register

2 INVITE

3 302 Moved

4 INVITE

5 Re-INVITE

RTP Key
Effect of multilayer security on handoff - SIP-MIP

Fig 3a. MIP-based secured Inter-domain mobility handoff timing

Fig 3b. MIP-based secured Inter-domain mobility handoff timing
Need for fast-handoff (An example)

- Round trip time from London to Sydney is 540 ms, 28 hops
  - London – Berkley is 136 ms, 22 hops
Fast-handoff mechanisms

**Key Design Principles:**
- Limit the signaling due to Intra-domain Mobility
- Capture the transient packets in-flight and redirects to the mobile
- Obtain IP address proactively and send binding update in the previous network
- Make-before-break in multi-interface case
- Communicates proactively with CH before the handoff takes place by doing pre-authentication
- Have a proxy joins the multicast stream on behalf of the impending client

• Methods currently experimented
  - SIP Registrar and Mobility Proxy-based
  - Proactive secured handoff (MPA)
  - Proxy-based handoff for Multicast Streaming

• Other SIP-based fast-handoff methods for comparison
  - Outbound SIP proxy server and mobility proxy
  - B2BUA and midcom
  - Multicast Agent
SIP fast-handoff mechanism using mobility proxy
Heterogeneous Mobility (Host-based)

MIMM provides innovative techniques and algorithms to support
- Fast handoff among heterogeneous radio systems
- Fast and resource-efficient path quality comparison to allow terminal to pick the interface that best fits is applications’ QoS needs at the lowest power consumption
Multi-Interface Mobility Management - Results

(a) handoff signaling sequence in SIP mobility

(b) handoff signaling sequence in Mobile IP

Figure 1: SIP-based Mobility with MIMM

<table>
<thead>
<tr>
<th>Movement type</th>
<th>Cellular-802.11b</th>
<th>802.11b – Cellular</th>
</tr>
</thead>
<tbody>
<tr>
<td>Handoff Trials</td>
<td>#1</td>
<td>#2</td>
</tr>
<tr>
<td>INVITE -&gt; OK</td>
<td>0.12 s</td>
<td>0.12 s</td>
</tr>
<tr>
<td>INVITE -&gt; 1st Packet</td>
<td>0.39 s</td>
<td>0.41 s</td>
</tr>
<tr>
<td>Re-transmission</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Figure 2: Timing for SIP-based Mobility
SIP Mobility (without make-before-break) 802.11-CDMA

MN

eth0 22.733
eth0 22.772
eth0 22.812

PPP Setup
~16 s

WLAN is gone
PPP0 is coming up

Re-INVITE

Re-INVITE (Re-trans)

OK

ACK

RTP 59961
RTP 59962
RTP 59963

CN

Packets sent at 40 ms interval

CN – 165.254.55.2
MN – WLAN – eth0 – 10.1.10.2
CDMA – PPP0 – 166.157.12.179

Packets sent at 40 ms interval

Delay
18 s

Jitter
In cellular
network

RTP 60402
RTP 60403
RTP 60404
RTP 60405
RTP 60406
SIP Mobility (MIMM) – Make-before-break (802.11 – CDMA)

MN: WLAN - Eth0 – 10.1.10.2
CDMA - PPP0 – 166.157.116.186
CN – 165.254.55.2

• Jitter observed in Cellular Network
• Several Re-INVITE retransmission in CDMA network
• Packets are received in eth0 during SIP Re-INVITE sequence
• No packets are lost during the handoff
Mobility with VPN

Based on its current location, MN dynamically establishes/changes/terminates tunnels without changing current standards of IPsec VPN or Mobile IP.

**Triple encapsulation** tunnel is constructed by:

- **i-HA (Internal Home Agent)**: Forwards IP packets to MN’s current internal location
- **VPN GW**: Protects (encrypts and authenticates) IP packets transmitted in external networks
- **x-HA (External Home Agent)**: Forwards IP packets to MN’s current external location
**Demonstration Scenario**

**Step 1:** MN (at its home network over WLAN) and CN start an application session, then MN starts moving
**Demonstration Scenario**

**Step 2:** MN starts preparing alternate path by establishing x-MIP and VPN tunnel over the cellular link, while keeping communication via the home network over WLAN.

![Diagram showing network components and tunnels](Image)
**Demonstration Scenario**

**Step 3:** MN stops using its home WLAN, starts using cellular and establishes i-MIP tunnel, then continues communication with CN
Mobile-IP with VPN Experimental Testbed
Step-by-step protocol flow

PPP setup over CDMA at SNR (S1)

Make-before-break scenario at SNR = S2

Mobile coming back home
Non-make-before-break situation

![Graph showing Non-Make-before-break](image_url)

- RTP Sequence
- Non-Make-before-break
- Cellular
- 802.11 (enterprise)
- Packet Loss Due to Non-make-before-break

IRT TalkI - 31
SUM (make-before-break)
Home-cellular-Hotspot

![Home-Cellular-Hotspot handoff](chart)

- **Home**: 802.11
- **Cellular**: External
- **Hotspot**: 802.11

**RTP Sequence**

**Time in Seconds**

RTP Sequence:
- 0
- 500
- 1500
- 2500
- 3500
- 4500
- 5500
Handoff and delay with multiple Interfaces (MIP-VPN)

(a) Packet Transmission Delay

- Packet Transmission Delay for Voice Traffic
  - Packet Numbers
  - Transmission Delay

Operation | Timing
---|---
PPP setup | 10 sec
X-MIP | 300 ms
VPN Tunnel setup | 6 Sec
I-MIP | 400 ms
I-MIP (Home) | 200 ms
IPSEC | 60 ms
DHCP | 3 Sec
TransmissionDelay | 5 ms 802.11
| 2.5 s cellular

(c) Inter-packet departure and arrival delay variation for VBR (Voice)

(c) Inter-packet departure and arrival delay variation for CBR (Voice)
MOBIKE-flow (802.11-Cellular-802.11)

- VPN traffic in 802.11
- VPN traffic in cellular
- Mobike in cellular
- Mobike in 802.11

IP0 – address of 802.11 interface
IP1 – address of cellular interface

IP0 is primary address

44.948 (PPP is up)
45.232 (Last packet on 802.11)
45.522 (IP1 is primary address)
46.312 (First packet on Cellular)
46.432
46.469
28:44.091
51.894 (802.11)
51.915
28:52.019

Visited Network 1 (802.11)

Visited Network 2 (Cellular)

Make-before-break
No packet loss

Packet Loss
(Break-before-make)

IP0 is primary address

MN moves from 802.11 (hotspot) to Cellular to 802.11 (hotspot)
MOBIKE-flow (Cellular-802.11-Cellular)

- CN to VPN GW: RTP
- VPN GW to MN: Tunnel (RTP)

Visited Network 1 (Cellular)
IP0 = address of 802.11 interface
IP1 = address of cellular interface
IP0 is primary address

Visited Network 2 (802.11)
- 13.342 (802.11 is up)
- 13.377
- 13.554 (First packet on 802.11)
- 13.667 (Last packet on cellular)

No packet loss
Out-of-order-packet
(make-before-break)

- 43.103 (Last packet on 802.11)
- 47.881
- 51.519
- 51.977

Packet Loss
(No-Break-before-make)

MN moves from Cellular to 802.11 (hotspot) to Cellular
MPA-assisted Seamless Handoff (a scenario)

CTN – Candidate Target Networks
TN – Target Network

Information Service (e.g., 802.21) mechanism can help locate the neighboring network elements in the candidate target networks (CTN)
Functional Components of MPA

1) Pre-authentication/authorization
   - Used for establishing a security association (SA) between the mobile and a network to which the mobile may move
   - L2 pre-authentication can also be enabled based on the established SA

2) Pre-configuration
   - Used for establishing contexts specific to the network to which the mobile may move (e.g., nCoA)
   - The SA created in (1) are used to perform secured configuration procedure

3) Secured Proactive Handover
   - Used for sending/receiving IP packets based on the pre-authorized contexts by using the contexts of the current network
Expected Result

Conventional Method

Detect new AP in different subnet

L2 handoff starts

L3 auth/authz starts

L3 handoff starts

L2 auth/authz, starts

L3 auth/authz completes

L3 handoff completes

MPA

Detect new AP

Pre-auth/Pre-authz starts

L3 handoff starts

L2 auth/authz, starts

L2 handoff starts

L2 handoff completes

L3 auth/authz completes

L3 handoff completes

Critical period (communication interruption can occur)
Pre-Authentication

SIP mobility is just an example mobility protocol. MPA works for any mobility management protocol.

DATA[CN<->A(X)]

Subnet X

pre-authentication

Subnet Y

CN: Correspondent Node
MN: Mobile Node
AA: Authentication Agent
CA: Configuration Agent
AR: Access Router
Pre-authorization

IP address: A(X)
Current subnet: X
Status: Pre-authentication done
Action: pre-authorization

MN-CA key

DATA[CN<->A(X)]

CN: Correspondent Node
MN: Mobile Node
AA: Authentication Agent
CA: Configuration Agent
AR: Access Router
Proactive Handover: Initial Phase

- **DATA[CN<->A(X)]**
- **MN-AR key**
- **Secure Proactive Handover tunnel establishment procedure**

**subnet X**
- MN
- IP address: A(X), A(Y)
- Current subnet: X
- Status: Pre-authorization done
- Action: PH Initiation

**subnet Y**
- AA
- CA
- AR

**CN**: Correspondent Node
**MN**: Mobile Node
**AA**: Authentication Agent
**CA**: Configuration Agent
**AR**: Access Router
Proactive Handover: Tunneling Phase

DATA[CN<->A(X)]

MN-AR key

Re-Invite[CN<->A(Y)]

SIP Re-Invite over proactive handover tunnel [AR<->A(X)]

IP address: A(X), A(Y)

Current subnet: X

Status: PH tunnel established

Action: SIP Re-Invite

CN: Correspondent Node
MN: Mobile Node
AA: Authentication Agent
CA: Configuration Agent
AR: Access Router
Proactive Handover: Completion Phase

IP address: A(X), A(Y)
Current subnet: X
Status: SIP Re-Invite done
Action: PH Completion

DATA [CN<->A(Y)]
over proactive handover tunnel [AR<->A(X)]

Subnet X

Subnet Y

Proactive handover stop procedure
L2 handoff procedure

CN: Correspondent Node
MN: Mobile Node
AA: Authentication Agent
CA: Configuration Agent
AR: Access Router
MPA Communication Flow

1. Found CTN

2. High probability to switch to the CTN

3. Determined to switch to The CTN

4. BU completion and Ready to switch

5. Switching

Pre-authentication [Authentication Protocol]

Pre-configuration [Configuration Protocol to get nCoA]

Pre-configuration [tunnel management protocol to establish PHT]

Secure Proactive Update Phase
Binding Update + data Transmission over PHT using nCoA

Secure proactive handover pre-switching phase [tunnel management protocol to delete PHT]

Post Switching Phase: Reassignment of nCoA to its physical Interface

New Data using nCoA

Candidate Target Network

Existing session using oCoA

MN

oPoA

nPoA

AA

CA

AR

CN
MPA Optimization Issues

• Network Discovery
  – Discover the neighboring network elements (e.g., Routers, APs, Authentication Agents)
  – 802.21 (Information Service), 802.11u, WIEN SG, CARD, DNS/SLP

• Proactive IP Address Acquisition

• Proactive Duplicate IP address Detection

• Proactive Address Resolution

• Proactive Tunnel Management

• Proactive Mobility Binding Update

• Bootstrap Link-layer Security in CTN using L3 Pre-authentication
## Protocol Set for the MPA demonstration

<table>
<thead>
<tr>
<th>Protocol Type</th>
<th>Protocol(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-authentication protocol</td>
<td>PANA</td>
</tr>
<tr>
<td>Pre-configuration protocol</td>
<td>PANA, DHCP</td>
</tr>
<tr>
<td>Proactive handover tunneling protocol</td>
<td>RelayIP</td>
</tr>
<tr>
<td>Proactive handover tunnel management protocol</td>
<td>PANA</td>
</tr>
<tr>
<td>Mobility management protocol</td>
<td>SIP</td>
</tr>
<tr>
<td>Link-layer security</td>
<td>Mobility None</td>
</tr>
</tbody>
</table>
Experimental Network in the Lab.

Network 1

- R1
  - eth0
  - 10.10.40.52/24
  - DHCP Server
- AP1 (Channel 6)
- ITSUMO network
- SIP with VIC/RAT Application
- MN
  - IP0: 10.10.40.20

Network 2

- R2
  - eth0
  - 10.10.10/24
  - DHCP Server
- AP2 (Channel 9)
- MN
  - IP1: 10.10.10.223

Network 3

- AA
- Relay/Client Proxy
- Network 2
- IP2
- CN
  - 10.10.30.25

Move

AP1, AP2: Access Point
R1, R2: Access Router
MN: Mobile Node
CN: Correspondent Node
IP0, IP1: IP address of MN
Protocol flow for MPA

1. Assign IP0 to Physical I/F
2. Assign IP1 to Tunnel I/F
3. PANA (Pre-Authentication and pre-configuration to obtain IP1)
4. Tunnel (IP0-IP1)
5. SIP Re-invite with IP1
6. Deletes Tunnel with
7. L2 handover
8. Assign IP1 to Physical I/F
9. Data
10. Address acquisition Using DHCP relay
Optimized handoff delay (Single IF/ Multiple I/F)

Figure 3: Multi-Interface with MIP (802.11-CDMA)

Figure 4: Multi-Interface with SIP (802.11-CDMA)

Figure 5: Proactive with SIP mobility (Single Interface 802.11-802.11)
Fast-handoff for Multicast Stream (General Scenario)
Multicast Mobility with multiple servers

Objective: Reduce Join/Leave Latency during Mobile’s movement

- Fast-handoff for the mobiles

Sources
p1 S1
S1
p2 S2

Backbone

M-Proxy

IGMP

Local Server

RTSP

Ad server (a1,a2)

Local Program

BS0

RTCP

P1,a1

BS1

P2,a2

P2,a3

BS2

P2,a2

Local Server

RTSP

Ad server (a3)

Local Program
IGMP Join/Leave latency vs. Proxy-based handoff in 802.11 environment

There is no JOIN Latency but Leave latency inherent

JOIN Latency is about 60 seconds

JOIN latency is almost zero Leave latency is still an issue

Maximum leave latency is about 3 min.
Conclusions

- Rapid Handoff in an IP-based cellular network has adverse effect for interactive and streaming traffic
  - Introduces delay, jitter and packet loss
- Experimental results were presented involving handoff between homogeneous and heterogeneous access networks
  - 802.11-802.11, 802.11 – CDMA
- Both SIP-based and MIP-based mobility were used for experiment
- Optimized Handoff Schemes were presented with some results for each scheme
- Optimized handoff schemes seem to be more prominent for
  - Proactive Handover
  - When the distance between CH and MH is much larger
  - Proxy-based handoff for multicast stream
- Future Work
  - Comparison with other fast-handoff mechanisms
  - Network Selection/Discovery Mechanism
  - Buffering Scheme for MPA assisted handoff