Hybrid 3G and 802.11 Network for the Open-Access Research TestBed for Next-Generation Wireless Networks (ORBIT)

Dr. Sanjoy Paul (sanjoy@lucent.com)
Research Director
Wireless Networking Research
Bell Laboratories
Lucent Technologies
(Team: John Lin, Sampath Rangarajan, Li Li, Xue Li)
Outline of the Presentation

- ORBIT Testbed

- Field Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network

- Conclusion
What is ORBIT?

- ORBIT stands for Open-Access Research Testbed for Next-Generation Wireless Networks
- NSF-funded project for 4 years
- Collaboration between industry and academia

Two components of ORBIT
- Testbed
  - Experiments on the Testbed

Two components of Testbed
- Lab Emulation
- Field Trial Network
Focus of the Presentation is the Field Trial Network for ORBIT
Field Trial Network
Outline of the Presentation

- ORBIT Testbed
- Field Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture

- Conclusion
When the 802.11 network is unavailable, user requests and responses routed through the 3G Network.

As soon as 802.11 connectivity is established, packets routed through the 802.11 network.
Field Trial Network: Architecture

- Base Station Router (BSR)
- MWG (Mobile Wireless Gateway)
- RP (Rendezvous Point)
- AG (Access Gateway)

Diagram:
- 3G Network
- MWG
- Bus/Train
- RP Network
- RP
- Campus Network
- The Internet
- AG
Access via MWG and 3G

- IP address for MWG assigned by 3G network
- MWG tunnels packets from WiFi mobile to the AG through the 3G Network

MWG

192.168.1.1

192.168.1.200

68.85.1.100 (assigned by 3G)

AG

RP Network

Internet

3G Carrier Networks

WiFi Mobile
Access via MWG and RP

- IP address of MWG assigned by AG
- MWG tunnels packets from WiFi Mobile to the AG through the RP Network

192.168.1.1
192.168.1.200
128.6.1.100 (Campus Net)

WiFi Mobile

MWG

3G Carrier Network

AG

The Internet

Campus Network

RP
Current 3G Network Architecture

- **BTS**: Base Transceiver Station (Radio Interface)
- **BSC**: Base-station Control
- **PCF**: Packet Control Function
- **PDSN**: Packet Data Serving Node – Interface to the IP Network

PPP connection between MWG and PDSN
Outline of the Presentation

- ORBIT Testbed
- Field Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture
- Conclusion
Base-Station Router (BSR)

- PPP connection between MWG and BSR
- Simplifies disparate network integration
- Ideal for hot-spot and in-building high-speed data markets
- Scalable: pico- to wide-area cellular

The Internet
AG

3G Network
MWG

BSR
Radio Interface
IP Interface
MWG

- Forwards packets between a WiFi mobile client and the 3G Network or the 802.11 Network (the RP network)
- Can detect a nearby RP if connectivity is available and use it for 802.11 access to the Internet.
- Informs WiFi mobile clients about the availability of the high speed WiFi link so that data can be actively fetched by the client
- Supports mobility of the WiFi client between different RPs

RP

- Forwards packets between the MWG and the wired network.
- Provides support for the WiFi client (and MWG) to move between RPs using micro-mobility protocols.
- Uses IP-in-IP tunneling to the AG (Access Gateway) to support micro-mobility
Access Gateway (AG)

- Packets from/to the mobile routed to the AG by the MWG through the 3G or 802.11 network
- AG can distinguish packets received over the 3G network from packets received over the 802.11 network
  - This decision made on source IP address on packets from the MWG
- Supports micro-mobility protocols by serving as an end point for the IP-in-IP tunnels from the RPs
- Serves as the application (HTTP, e-mail etc.) access gateway for all the WiFi clients.
Outline of the Presentation

- ORBIT Testbed

- Field Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture

- Conclusion
Handoff between Base-Station Routers is a challenge

- Smaller coverage area per base station increases frequency of handoffs
- Re-initiating a PPP connection with the new BSR takes significant time
- Tunneling packets from old BSR to new BSR is inefficient
- Need for PPP state transfer
PPP State Migration: **Call flow**

1. PPP Migration Request
2. PPP Migration Response
3. PPP Migration Confirm
4. PPP Migration Ack
5. MIP Agent Adv
6. MIP Registration Request
7. MIP Registration Reply

**Research work of:**
Sarit Mukherjee
Anand Kagalkar
Sampath Rangarajan

*From Bell Labs*
### PPP State Info for Migration

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Size (Linux Implementation)</th>
<th>Frequency of change</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCP</td>
<td>70 Bytes (approx)</td>
<td>Once during setup</td>
</tr>
<tr>
<td>PAP*</td>
<td>100 Bytes (approx)</td>
<td>Once during setup</td>
</tr>
<tr>
<td>CHAP*</td>
<td>150 Bytes (approx)</td>
<td>Once during setup (may change during session)</td>
</tr>
<tr>
<td>CCP</td>
<td>10 Bytes (approx)</td>
<td>Once during setup</td>
</tr>
<tr>
<td>IPCP</td>
<td>30 Bytes (approx)</td>
<td>Once during setup</td>
</tr>
<tr>
<td>Header Compression</td>
<td>Depends on Compression Scheme</td>
<td>With every data packet</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>About 300 Bytes</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Only one is used in a session*
PPP State Migration: **Data flow**

1. **PPP Migration Request**
   - Holds PPP frames from MS

2. **PPP Migration Response**
   - Recreates and activates PPP state
   - Processes PPP frames on hold and those coming new from MS
   - Sends IP packets to Old-Serving BSR

3. **PPP Migration Confirm**
   - Sends IP packets on hold and those coming new from HA

4. **PPP Migration Ack**
   - Standard message

5. **MIP Agent Adv**
   - New message

6. **MIP Registration Request**
   - Standard message

7. **MIP Registration Reply**
   - New message

**Data flow**
- IP Packets in Tunnel
- PPP frame in GRE
- P-P Release
PPP State Migration vs Re-initiation

PPP State Migration is significantly faster than PPP new session initiation (50 ms vs. 5000 ms)
Even considering IPCP negotiation, PPP State Migration is significantly faster than PPP new session initiation (250 ms vs. 5000 ms).
Outline of the Presentation

- ORBIT Testbed

- Filed Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture

- Conclusion
Fast Layer 3 Handoff between RPs is a Challenge

Access Gateway (AG)

The Internet

Campus Network

128.6.230.1
128.6.231.1
128.6.232.1

10.1.1.1 10.1.1.2 10.1.1.3

Mobile: 10.2.1.1
Default Router: 10.0.0.1
A new micro-mobility protocol

- Mobile-IP or one of its variants not a feasible approach for inter RP mobility.

Our Implementation:

- Mobiles keep a constant IP address and a constant default IP router IP address, both acquired from the AG (DHCP server)
- AG maintains location information in a location table
- Once Layer 2 handoff is completed
  - RP sends a gratuitous ARP to the mobile and takes over as default router.
  - RP updates location of the mobile at the AG.
- Layer 3 handoff in the order of sub msec.
  - \( \text{max}(\text{one-way delay to the AG, one-way delay to the mobile}) \)

**Key Idea:** Use Ethernet address as a key to the Location Table at the AG.
Handoff latency using firmware (default) Layer-2 (L2) handoff

Re-association of the mobile with a new access point (AP) is the dominant component of the delay (L2 handoff)

T1 = L2 handoff delay due to re-association with new AP
T2 = Time to update ARP cache at mobile
T3 = Ping latency between sending the first probe and getting the ping response from AP
Handoff latency using manual Layer-2 handoff

T1 = L2 handoff delay due to re-association with new AP
T2 = Time to update ARP cache at mobile
T3 = Ping latency between sending the first probe and getting the ping response from AP

Manual Re-association of the mobile with a new Access Point (AP) reduces L2 handoff delay from 350ms to 4ms
Packet loss count for each experiment during handoff

Faster L2 handoff reduces Ping Replay packet loss dramatically.
Reasons for packet loss: (1) weak signal strength (20%); (2) wrong physical address of the destination
## Mobility Protocol Comparison

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Mobile-IP Compliant</th>
<th>Anticipation of Link-Layer Handoff</th>
<th>Wireless Mode</th>
<th>Protocol Layer</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daedalus</td>
<td>No</td>
<td>Yes</td>
<td>Infrastructure</td>
<td>Network</td>
<td>8-15 ms</td>
</tr>
<tr>
<td>MosquitoNet</td>
<td>Modified</td>
<td>No</td>
<td>-----</td>
<td>Network</td>
<td>&gt; 250ms</td>
</tr>
<tr>
<td>Domain Foreign Agent</td>
<td>No</td>
<td>Yes</td>
<td>Infrastructure</td>
<td>Network</td>
<td>~10ms</td>
</tr>
<tr>
<td>NeighborCasting</td>
<td>Modified</td>
<td>Yes</td>
<td>Infrastructure</td>
<td>Network</td>
<td>NA</td>
</tr>
<tr>
<td>End-to-End Approach</td>
<td>No</td>
<td>No</td>
<td>-----</td>
<td>Transport</td>
<td>RoundTrip (peer-to-peer)</td>
</tr>
<tr>
<td>Dynamics Mobile-IP</td>
<td>Yes</td>
<td>Yes</td>
<td>Ad-hoc</td>
<td>Network</td>
<td>10-50 ms</td>
</tr>
<tr>
<td>FSHWI</td>
<td>Modified</td>
<td>Yes</td>
<td>Infrastructure</td>
<td>Network</td>
<td>~10ms</td>
</tr>
<tr>
<td>Low-Latency Handoff</td>
<td>Yes</td>
<td>No</td>
<td>Infrastructure</td>
<td>Link &amp; Network</td>
<td>&lt; 100ms</td>
</tr>
<tr>
<td>Our protocol</td>
<td>No</td>
<td>No</td>
<td>Infrastructure</td>
<td>Link &amp; Network</td>
<td>&lt; 1ms (within a campus)</td>
</tr>
</tbody>
</table>
Outline of the Presentation

- ORBIT Testbed

- Filed Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture

- Conclusion
Handoff between 3G BSR and 802.11 RP

- MWG hides transport-level Mobility
- MWG terminates PPP while Handset terminates TCP
- When MWG moves from 3G to 802.11 network, it gets a new IP address but that is transparent to the handset
- IP address of TCP End-points remain the same
Outline of the Presentation

- ORBIT Testbed

- Filed Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
  - Handoff between 3G cellular and 802.11 network
  - Potential Extensions to the Architecture

- Conclusion
Extending the Field Trial Network: Ad-hoc Relays

3G Carrier Network

AG

The Internet

RP

RP Network

MWG (3G Proxy)

MWG (RP Proxy)

3G Network

Ad-Hoc Network
Extending Field Trial Network with Ad-Hoc Network

- When the 802.11 network is unavailable, user requests and responses routed through the 3G Network.
- As soon as 802.11 connectivity is established, packets routed through the 802.11 network.

- An Ad-Hoc 802.11 network will
  - Extend the coverage for 3G and Fixed 802.11 Networks
  - Make the 3G access more efficient by routing packets through proxy node(s) that have the best channel quality to the 3G base-station.
Outline of the Presentation

- ORBIT Testbed
- Field Trial Network: Hybrid 3G and WiFi
  - Architecture
  - Components
  - Handoff in 3G cellular network
    - PPP State Migration
  - Handoff in 802.11 network
    - New Micro-mobility Protocol
- Conclusion
Conclusion

- **ORBIT Testbed:**
  - Hybrid 3G and WiFi Network is operational in Bell Labs Holmdel Lab where 3G is currently emulated using 802.11 access
  - Hybrid 3G and WiFi Network with 3G Base Station Router (BSR) is expected to be operational in Bell Labs Holmdel Lab by early 2005
  - Field Trial Hybrid 3G and WiFi Network is expected to be operational in Rutgers campus by mid 2005

- **Several New Research ideas:**
  - Fast handoff in 3G BSR architecture using PPP state migration
  - Micro-mobility in outdoor WiFi Networks
  - Extending WiFi networks using Ad-Hoc networks
  - Multicast in Hybrid 3G/WiFi networks