Future Work

- Integration with Mobile-IP
- Integration with IP multicast
- Integration with AIRMAIL
- Using location information from level 1 to improve level 2 handoff
Conclusions

• Very fast local handoff is possible (3-5 ms)
• Buffering is beneficial and has low overhead
• Tradeoff between beacons and buffering:
  **TCP:** 120 ms beacon period and 5-10 packets of buffer gives 98-99% of throughput without handoff
  **UDP:**
  - Human ear sensitivity allows delay budget of 100-200 ms
  - Application playout buffer hides jitter

So a beacon period around 100 ms with 5-10 packets of buffer (to avoid loss) seems a good choice
UDP Delay Jitter

Inter-packet Arrival Time (ms) vs Packet Sequence #

bp=120ms, buf=8
UDP Duplicate Packets

![Graph showing the relationship between buffer size and number of duplicate packets for different buffer periods (bp=20ms, bp=120ms, bp=500ms).]
UDP Packet loss

![Graph showing UDP packet loss with different buffer sizes (bp=20ms, bp=120ms, bp=500ms). The x-axis represents buffer size in terms of packets, and the y-axis represents the number of packets lost. The graph shows a decrease in the number of packets lost as the buffer size increases.]
TCP Throughput with handoff

Throughput with handoff (%)

Buffer size (# packets)

- bp=20ms
- bp=120ms
- bp=1000ms

Throughput with handoff (%) vs Buffer size (# packets)
TCP benchmark: ttcp
- Bulk-transfer applications (such as WWW)
- 2048 8 KB segments from local source to MH
- 2 handoffs in ~20 sec. duration

UDP benchmark: udpbench
- Simulate a real-time application (vat audio stream)
- pcm: 20ms inter-packet spacing, 78 Kbps (200 byte average packet size)
- Playout delay: allows trading off buffer size for beaconing frequency
  - local conference: ~100 ms
  - remote conference: ~4-5 sec.
- Negligible reordering of packets
- Delay jitter due to retransmission
Experimental Results

- Used separate ethernet instead of wireless network
- Cisco router ignores ICMP redirects, so used source on local net
- Simulated handoff with no cell overlap (eg. IR networks)

Basic handoff mechanism:

- Rendezvous time: depends on beacon period (varied from 20 ms to 1 sec)
- Handoff time: 3-5 ms
- Buffering overhead: negligible (a few pointer manipulations)
- Beaconing overhead:
  - 42 byte packet => 336 bps (1 sec beaconing) to 16.8kbps (20 ms beaconing)
  - ttcp throughput: 1-2% decrease in the worst case
Implementation

Solaris 2.4 in-kernel implementation

Protocol messages:
- 42 bytes in size (ICMP packets)
- Generated and processed by the IP driver
- REDIRECT: special ICMP Redirect to gateway
- Periodic beaconing helps ensure reliability

Buffer module:
- Streams module that can be pushed/popped using modified `ifconfig`
- Automatically registers itself with IP
- Buffers packets using `dupmsg`
- To retransmit, it sends packets back to IP for re-routing
Advantages:
• IP vs. ATM: Per-mobile processing rather than per-connection
• Portable: independent of underlying network
• But easy to move to MAC layer: learning bridges instead of IP layer processing
• Can use location information from level 1 to improve level 2 handoff

Disadvantages:
• No QoS guarantees (but applications can adapt)
Light-weight handoff protocol

Old BS  →  Router/MA  ←  REDIRECT

Old beacon  →  New beacon

Old BS  ←  FWD_REQ  →  New BS

FWD_ACK

MH

GREET

GREET_ACK
**Old BS:** on getting FWD_REQ
- Switches routing entry for MH
- Re-transmits buffered packets
- Sends FWD_ACK to old BS
- Sends REDIRECT to router (not in critical path)

**Level 2:**
- Each BS broadcasts MA advertisements onto wireless network
- Rest of handoff processing identical to Mobile-IP
Handoff Protocol

Level 1:

Periodic beacons from Basestations (BS)

**MH:** on getting new beacon
- Changes default gateway
- Sends GREET to new BS

**New BS:** on getting GREET
- Switches routing entry for MH
- Sends FWD_REQ to old BS
- Sends GREET_ACK to MH
Network Architecture

Level 1:
- Within the same administrative/security domain
- Basestations with fast wired connectivity
- Hides local mobility from the outside world
  - reduced update traffic
  - reduced update load on mobility agents (MA)
- Light-weight handoff

Level 2:
- Mobile-IP to handle movement across subnets
Motivation

- Locality in user mobility
- Survey: about 75% of professionals are “mobile”. 50% of them mainly stay within the building
- Continuous-media applications require fast handoff (a few 10s of ms)
- Mobile-IP is a heavy-weight protocol
  - security
  - interaction with home agent
  - encapsulation
- Need for a light-weight handoff mechanism at the local level
Problem Definition

**Wireless LAN** (Example: WaveLAN):

- Multiple microcells cover an office environment
  - Better frequency reuse, lower power
  - Increased handoff frequency
- Applications of interest:
  - TCP-based (such as WWW browsing)
  - UDP-based (such as packet telephony)

**Goals:**

- Develop an architecture for supporting mobility efficiently in wireless networks
- Quantify performance
Outline

- Problem Definition
- Motivation for a 2-level Architecture
- Design and Implementation of the first level
- Experimental Results
  - ttcp (TCP benchmark)
  - udpbench (UDP benchmark)
- Conclusions and Future Work
An Architecture to Support Fast Handoffs in Wireless Networks

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