Wireless Networks without Infrastructure

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Overview

- Motivation
- Ad-hoc networks
- Application-layer mobility
- Multicast mobility for Internet radio and TV
Motivation

- spectrum is very expensive:

<table>
<thead>
<tr>
<th>Location</th>
<th>what</th>
<th>cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>3G</td>
<td>$590/person</td>
</tr>
<tr>
<td>Germany</td>
<td>3G</td>
<td>$558/person</td>
</tr>
<tr>
<td>Italy</td>
<td>3G</td>
<td>$200/person</td>
</tr>
<tr>
<td>New York</td>
<td>Verizon (20 MHz)</td>
<td>$220/customer</td>
</tr>
</tbody>
</table>

- does not include any base stations

- 3G bandwidth is decreasing (2 Mb/s ↓ 64 kb/s)
An alternate universe

- metrics: $/customer or b/s/area
- “picocellular” 802.11: about 100 Mb/s/km$^2$
- cellular: about 2 Mb/s/km$^2$ (?)

- but:
  - not suited for high-speed mobility
  - no power control $\Rightarrow$ battery, interference
  - no predictable QoS due to L1/L3 interference
802.11 access infrastructure for NY

- each base station covers 100 m radius
- New York: 8m people in 800 km$^2$ $\Rightarrow$ need 80,000 base stations
- assume $500/base station
- about $5/person
- instead of tower, donate an SDSL, CM or Ethernet connection to 80,000 lucky New Yorkers
Opportunities

- multiple wireless networks
  - low-rate, wide-area (e.g., GPRS)
  - high-rate in high-density areas
  - incremental cost may be small
- Internet approach
- also, 3G hybrid CO/PS high complexity
- 3G – a physical and link layer with “network envy” (cf. ATM, BlueTooth)
7DS

- “seven degrees of separation”
- generalization of InfoStation concept
- similar to P2P, but emphasis on data spreading, not searching
- requires zero infrastructure
- however, cooperative systems
- sporadically Internet connected
- power/energy-constrained mobile nodes
- may relay queries, ad-hoc network-style
7DS applications

- any Internet content: web pages, video, music, games
- (original) URL
- keywords (news, weather, map)
- location-based: “map of where I am”, “map of Boston”
- content with advertising
- GPS time & location advertisement
- see also HP Cooltown
7DS mobility model

Randway model:

pause

0.25 m/s
0.5 m/s
1 m/s
1.5 m/s

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7DS implementation

- initial Java implementation on laptop
- to be done for Compaq Ipaq (Linux or WinCE)
- Inhand Electronics ARM RISC board
  - low-power
  - PCMCIA slot for storage, network or GPS
7DS implementation

~1W

802.11b

ARM RISC processor

magnet

~1W

802.11b

ARM RISC processor

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7DS implementation

- to browser, standard proxy cache
- explicit cache management by user – public/private, expiration
- cache is indexed to allow keyword-based searches
- cache objects expire based on query frequency
- however, may serve expired objects since no origin server
- requestor can choose best match(es)
Future work: 7DS data gathering

- mobile sensors (cameras, biomedical, …) submit data to mobile nodes
- mobile nodes “deposit” at nearest Internet AP
- encrypted and signed
- how many – survival vs. energy, network and storage load
- postcard vs. certified mail
Cooperation strategies

**Mobility:** carrier can be fixed or mobile

**Querying:** listen (passive) or active

**Power conservation:** only enable periodically

**Forwarding:** relay queries and responses to extend range
### Performance evaluation

<table>
<thead>
<tr>
<th>Querying</th>
<th>cooperation strategy</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>no</td>
</tr>
<tr>
<td></td>
<td>forwarding</td>
</tr>
<tr>
<td></td>
<td>sharing</td>
</tr>
<tr>
<td></td>
<td>sharing + forwarding</td>
</tr>
<tr>
<td>active</td>
<td>MIS, FIS</td>
</tr>
<tr>
<td>passive</td>
<td>FIS-NDS</td>
</tr>
<tr>
<td></td>
<td>FIS-NP, FIS-NP</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>power cons.</th>
<th>peer-peer</th>
<th>server-client</th>
</tr>
</thead>
<tbody>
<tr>
<td>disabled</td>
<td>NP</td>
<td>FIS, MIS, FIS-NP, FIS-NDS</td>
</tr>
</tbody>
</table>
# Simulations

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pause time</td>
<td>50 s</td>
</tr>
<tr>
<td>Mobile user speed</td>
<td>0...1.5 m/s</td>
</tr>
<tr>
<td>Server advertisement interval</td>
<td>10 s</td>
</tr>
<tr>
<td>Forward message interval</td>
<td>10 s</td>
</tr>
<tr>
<td>Simulation time</td>
<td>25’</td>
</tr>
<tr>
<td>Area</td>
<td>1 km²</td>
</tr>
<tr>
<td>Coverage</td>
<td>230 m (H), 115 m (M), 57.5 m (L)</td>
</tr>
</tbody>
</table>

Measure percentage of data holders after 25 minutes (commute)
Dataholders after 25’

Function of host density:

![Graph showing the function of host density with data points for different categories: P, NP, FW, FIS, FIS-P, FIS-NP, FIS-NDS, MIS. The x-axis represents the number of hosts ranging from 0 to 25, and the y-axis represents the percentage of dataholders ranging from 0 to 100. The graph illustrates the trend of dataholder percentage as the number of hosts increases.]
Dataholders after 25’

Function of host density:
Dataholders after 25’, 5 hosts/km²

Function of query interval:

[Graphs showing dataholders as a function of query interval for high and medium power transmission cases.]

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Dataholders after 25’, 25 hosts/km²

Function of query interval:

![Graph](image-url)
Summary of results

- cooperation and mobility strongly influence results
- P-P outperforms S-C
- forwarding does not help
- host density and query interval don’t influence S-C
Scaling effects

Scheme(power)-(initial data holders, hosts): area

![Graph showing scaling effects with different schemes and initial data holders/host configurations.](image-url)
Analytic model of FIS

- diffusion in a medium with randomly distributed static traps
- particles are absorbed when they enter trap
- $d$ dimensions, $\alpha$ lattice constant, $q$ trap concentration
- hosts that receive data “disappear”
- $q = \pi R^2 N/A$, with $R$ as coverage radius
- survival after $n$ steps: $\log(\phi_n) \approx -\alpha [\log\left(\frac{1}{1-q}\right)]^{2/(d+2)} n^{d/(d+2)}$
Analytic model of FIS

![Graph showing data points and lines for different models over time and data holders.](image_url)

Finite mean-square displacement per square $\leftrightarrow$ randway

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Epidemic model

- carrier is “infected”, hosts are “susceptible”
- transmit to any given host with probability $h\alpha + o(h)$ in interval $h$
- pure birth process
- $T =$ time until data has spread among all mobiles
- $E[T] = \frac{1}{\alpha} \sum_{i=1}^{N-1} \frac{1}{i(N-1)}$
Application-layer mobility

- what is application layer mobility
- SIP as protocol to support application-layer mobility
- different mobility modalities for interactive communications
Application-layer mobility

- mobility = external identifier (URL, identifying IP address) stays constant as lower-layer identifier changes (IP address, routable IP address)

- mobility support:
  - **hide**: keep layer ignorant of change of network attachment point
  - **inband**: TCP connection migration (Snoeren/Balakrishnan)
  - **out of band**: signaling protocol that changes associations

- always need binding update to existing peers *and* registration update for new peers
Application layer mobility

- if connections are short-lived, TCP state maintenance not too important
- need recovery useful for robustness
  - HTTP bytes range
  - ftp partial retrievals
- doesn’t work for telnet and X sessions
- easier to install – separation of bit delivery from mobility
SIP: Session Initiation Protocol

IETF-standardized *peer-to-peer* signaling protocol (RFC 2543):

- locate user given email-style address
- set up session
- (re)-negotiate session parameters
- manual and automatic forwarding ("name/number mapping")
- *personal mobility* ➔ different terminal, same identifier
- “forking” of calls: one call, multiple destinations
- terminate and transfer calls
## SIP Components

<table>
<thead>
<tr>
<th>Entity</th>
<th>Does</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proxy server</td>
<td>Forward calls</td>
<td>Firewall controller, “call router”</td>
</tr>
<tr>
<td>Redirect server</td>
<td></td>
<td>“application server”</td>
</tr>
<tr>
<td>User agent</td>
<td>End system</td>
<td>SIP phone, gateway, “softswitch”</td>
</tr>
<tr>
<td>Registrar</td>
<td>Location mgmt.</td>
<td>Mobility support</td>
</tr>
</tbody>
</table>

Roles are changeable, on a request-by-request basis
SIP example: redirection

1. INVITE henning@ieee.org
2. 302 Moved temporarily
   Contact: hgs@columbia.edu
3. INVITE hgs@columbia.edu
4. 200 OK
5. ACK henning@ieee.org
6. ACK hgs@columbia.edu
7. 200 OK
SIP example: proxying

1. **INVITE** henning@columbia.edu
2. 200 OK
3. henning hgs@play
4. INVITE hgs@play
5. 200 OK
6. hgs@play
7. 200 OK
8. ACK hgs@play
9. **media stream**
SIP forking proxies

INVITE sales@macrosoft.com
INVITE carol@c.macrosoft.com
INVITE bob@b.macrosoft.com
CANCEL bob@c
INVITE carol@c
200 OK
ACK
200 OK
200 OK
BYE carol@c.macrosoft.com

macrosoft.com

a.wonderland.com
Mobility in an IP environment

**Roaming users:** logging in away from home network: hotel, home office

**Terminal mobility:** terminal moves between subnets

**Personal mobility:** different terminals, same address

**Service mobility:** keep same services while mobile

**Session mobility:** move active session between terminals
Simple mobility: roaming users

- users visit other networks: laptop, PDA, hotel phone, ...
- want to maintain external identity
- usually, just pass IP address to home registrar
- difficult if firewalls and NATs
  - requests need to use local proxy
  - thus, need to register locally
Roaming Users – Dual Registration

Hotel California

DHCP server

SIP: sip.hotelca.com
DNS: hotelca.com
IP: 128.59.16.1

REGISTER sip:sip.hotelca.com
To: eagles%40home.com@sip.hotelca.com
From: eagles%40home.com@sip.hotelca.com

REGISTER sip:home.com
To: eagles%40home.com
From: eagles%40home.com
Contact: sip:eagles%40home.com@sip.hotelca.com

sip.hotelca.com

home.com

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Terminal mobility – mobile IP

- mobile host
- correspondent host
- router with home agent functionality
- router with foreign agent functionality
Terminal mobility – mobile IP difficulties

- domain of IEEE 802.11 (link layer), 3GPP (radio access network), mobile IP (network layer), ...

- network-layer mobility has problems:
  - lack of deployment – home provider has no interest
  - need two addresses – home and visiting
  - dog-legged routing in IPv4
  - may not work with IP address filtering except through triangle routing
  - encapsulation overhead for voice: 8–20 bytes/packet for a 50-byte payload
  - authentication of redirection
SIP terminal mobility overview

- pre-call mobility ➔ SIP proxy, redirect
- mid-call mobility ➔ SIP re-INVITE, RTP
- recovery from disconnection
**SIP terminal mobility: pre-call**

- MH acquires IP address via DHCP
- optional: MH finds SIP server via multicast REGISTER
- MH updates home SIP server – deregister old, register new
- optimization: hierarchical LR (later)
SIP terminal mobility: mid-call

- MH→CH: new INVITE, with Contact header and updated SDP
- re-registers with home registrar
- requires one one-way delay
SIP terminal mobility: multi-stage registration

Don’t want to bother home registrar with each move

1. From: alice@NY
   Contact: 193.1.1.1

2. From: alice@NY
   Contact: alice@CA

3. From: alice@NY
   Contact: 192.1.2.3

CA

Los Angeles
San Francisco

REGISTER

NY

registrar proxy

INVITE

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Personal mobility

alice17@yahoo.com
alice@columbia.edu
7000@columbia.edu
Alice.Cary@columbia.edu

yahoo.com

columbia.edu

alice@host.columbia.edu
(also used by bob@columbia.edu)
tel:12128541111
tel:12015551234

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Personal mobility

- switch between PDA, cell phone, PC, Ethernet phone, Internet appliance, …
- several “generic” addresses, one person/function, many terminals
- e.g., tel:2129397042, hgs@cs.columbia.edu, schulzrinne@yahoo.com or support@acme.com
- SIP is designed for that – proxying and redirection does translation
- but: need mapping mechanisms to recognize registrations as belonging to the same person
- some possible solutions:
  - dip into LDAP personnel database or /etc/passwd to match phone number and variations of name (J.Doe, John.Doe, Doe)
  - need dialing plan to recognize 7042@cs.columbia.edu and tel:2129397042 as same
Service mobility

Examples:

- speed dial & address book
- media preferences
- special feature buttons (voice mail, do-not-disturb)
- incoming call handling instructions
- buddy lists
- features in home provider server

→ independent of terminal (including pay phone!), across providers
Service mobility

- REGISTER can retrieve configuration information (e.g., speed dial settings, distinctive ringing or voice mail settings)
- but needs to be device-independent
- most such services (e.g., voicemail forwarding, call filtering) should remain on server(s)
- use SIP Route mechanism to direct path of outgoing calls via home server

Route: <sip:alice@home.net>, <sip:alice@services-r-us.com>
Service mobility – call handling

- need uniform basic service description model → Call Processing Language (CPL)
- CPL for local call handling
- update CPL from terminal: add telemarketer to block list
- harder: synchronize CPL changes across multiple providers
- one possibility: REGISTER updates information, but device needs to know that it has multiple identities
- merging of call logs
SIP and mobility: issues

- doesn’t work for TCP applications – solutions:
  - punt: “don’t type and drive”
  - application-layer awareness: restart web, email, ftp transfer – need for deep fade anyway…
  - TCP redirect (Snoeren/Balakrishnan)
  - NAT-style boxes controlled by SIP (see Telcordia ITSUMO project)
- fast hand-off via SIP proxies with media translators
- but: works nicely for “vertical handoff” between different technologies - e.g., transfer call from mobile handset to office videophone when arriving at work
Conclusions for application-layer mobility

- uniform solution for wired and wireless multimedia terminals
- network-layer mobility neither sufficient nor available
- many common services don’t need network-layer support
- application-layer mobility for sessions
- one SIP-based approach for multimedia sessions, presence & events
Internet radio

- multicast in LANs widely available
- insert local content and advertisements
- caching if Internet not multicast-enabled
- mobility issues
Internet radio
## Multicast handoff

<table>
<thead>
<tr>
<th>Mobile Client</th>
<th>Base station(s)</th>
<th>Multicast Switch</th>
<th>Local Server</th>
<th>Edge Multicast Router</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer 2 hand-off</td>
<td>Beacon from BS1</td>
<td>Binds to BS2</td>
<td>CGMP (Leave/Join)</td>
<td>Multicast stream S1</td>
</tr>
<tr>
<td>New BS</td>
<td></td>
<td></td>
<td></td>
<td>Router Advertisement</td>
</tr>
<tr>
<td>Join the same group in new cell (same subnet)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layer 3 hand-off and IP configuration</td>
<td></td>
<td></td>
<td></td>
<td>DHCP DISCOVER</td>
</tr>
<tr>
<td>Join the same group in new subnet</td>
<td></td>
<td></td>
<td></td>
<td>RTCP Join</td>
</tr>
<tr>
<td>Leaves that subnet</td>
<td></td>
<td></td>
<td></td>
<td>IGMP join</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DHCP OFFER</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RTCP BYE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IGMP leave</td>
</tr>
</tbody>
</table>

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Internet radio

- can either use scoped multicast or re-assign multicast via scoped SAP

- mobility issues:
  - hand-off detection
  - address acquisition
  - IGMP leave latency (bandwidth)
  - IGMP join latency
Conclusion

- next-generation wireless expensive, late, slow
- non-traditional mobility
- non-traditional infrastructure
- sporadic connections
- complementary mobility at the application layer
- mobility for multicast, not just unicast