Mobility Architecture in Future Internet

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Mobility in the Internet

• New generation of powerful portable devices:
  – Can support most Internet needs

• Wireless speeds growing constantly:
  – 4G expected to achieve 40Mbps
  – WiFi up to 100Mbps
  – WiMAX up to 45Mbps
  – mmWave up to 3Gbps
Mobility Support Problem

IP Address

Identifier  Locator
Many Solutions

• **Network Layer**
  – Mobile IPv4/v6

• **Transport Layer**
  – SCTP (Stream Control Transport Protocol)
  – TCP-Migrate

• **Application Layer**
  – SIP (Session Initiation Protocol)
Mobile IPv4 (1/2)
Mobile IPv4 (2/2)

Mobile Node

FA

HA

Correspondent Node

Agent Solicitation

Agent Advertisement

Registration Request

Registration Reply

Registration Request

Registration Reply

User Packet

User Packet
Mobile IPv6

Correspondent Node

<Correspondent Address>

<Home Address>

Mobile Node

Home Agent

<Home Address>

Mobile Node

<Correspondent Address> <-> <home address>

Routing option

Route optimization

IP tunnel

Bidirectional tunnelling

<Care-Of Address>
Hierarchical Mobile IPv6 (1/2)

(Home address, RCoA)

HA

Internet

CN

Home BU

MAP domain

MAP (RCoA, LCoA)

Local BU

old AR

new AR

MN

(Home address, RCoA)
Hierarchical Mobile IPv6 (2/2)

(Home address, RCoA)

HA

CN

Internet

MAP domain

old AR

Local BU

new AR

MN

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Many Mobile IP Variants, but...

Scalability

Manageability

Adaptability
New Trends for Mobility Support

• Identifier and Locator Separation

• Network-based Mobility Management

• Scalability

• Adaptability
Identifier/Locator Separation (1/2)

• **Host-based approaches**
  – Host Identity Protocol (HIP)
  – Site Multi-homing by IPv6 Intermediation (SHIMv6)

• **Network-based approaches**
  – Global, Site, and End (GSE)
  – Locator ID Separation Protocol (LISP)
Identifier/Locator Separation (2/2)

- **Host Identity Protocol (HIP)**
  - Identifier: host identity based on public key
  - Locator: IP address

- **IETF Routing and Address Problem (RoAP)**
  - Name-to-identifier
  - Identifier-to-locator
  - Locator-forwarding

- **For Ubiquitous Computing**
  - Geographical addressing?
Network-based Mobility Management (1/2)

• For easy deployment!
  – Driven by device vendors
  – Proxy Mobile IPv6
Network-based Mobility Management (2/2)

<table>
<thead>
<tr>
<th></th>
<th>Mobile IPv6</th>
<th>Proxy Mobile IPv6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deployment</td>
<td>Difficult</td>
<td>Easy</td>
</tr>
<tr>
<td>Robustness/Scalability</td>
<td>No (due to route optimization)</td>
<td>LMA and MAG</td>
</tr>
<tr>
<td>Handoff Performance</td>
<td>Bad</td>
<td>Good</td>
</tr>
<tr>
<td>Packet Delivery Performance</td>
<td>Good</td>
<td>Bad</td>
</tr>
<tr>
<td>Security</td>
<td>Built-in</td>
<td>Needed</td>
</tr>
</tbody>
</table>
Scalability (1/2)

• How to support a few billions of mobile nodes?

• Distributed Hashing Table (DHT)
  – Robust Overlay Architecture for Mobility (ROAM) by UC Berkeley
  – Distributed Home Agent for Robust Mobile Access (DHARMA) by Upenn
  – Scalable Application Mobility Protocol (SAMP) by Seoul Nat’l Univ.
Scalability (2/2)

DHT-based overlay network (e.g., Chord)

Overview of SAMP

Home SIP Server

Anchor SIP Server

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Adaptability (1/2)

• How to support heterogeneous applications and mobile nodes?

• Several Proposals
  – Reconfigurable Architecture and Mobility Management (RAMP)
  – Adaptive Route Optimization (ARO)
Overview of RAMP
Mobility in Future Internet

Protocols, Applications, and Mobility Models
Paradigm Shift (1/2)

• Traditional wireless mobility
  – Last hop connectivity
  – Soft handoff (horizontal, vertical)
  – Most data and services still in the wired Internet
  – Advanced ad hoc networking only in tactical and emergency scenarios
Paradigm Shift (2/2)

• **Emerging Wireless and Mobile Internet**
  – The data is collected by portable devices, and may stay on the devices for a long time:
    • Urban sensing (vehicle, people), Medical monitoring, etc
  – **New challenges**
    • Distributed index (i.e. publish/subscribe) to find the data
    • Data sharing among mobile users via opportunistic P2P networking
    • Privacy, security, protection from attacks
    • Intermittent operations: delay tolerant applications; disruption tolerant networks
Emerging Wireless/Mobile Protocols
Background (1/2)

• Changing the view on mobility
  – Mobility has become an integral attribute of the Internet and we need to design for it.
  – Without mobility support, the Internet cannot be invisible.

• There is a big gap between the opportunities that mobility enables and the practical protocols that can take advantage of it.
Background (2/2)

• Directions
  – Design for mobility requires a clean-slate approach to communication protocols in wireless networks and the Internet
  
  – Design for mobility has direct implications on the Internet design, in-network storage and localization information being key factors
  
  – Standards are needed for benchmarks.
Challenges (1/2)

- **The state of links is a function of mobility**
  - link lifetime, fading, multipath effects, etc.

- **The neighborhood of a node changes with mobility**
  - impacts reliable exchanges and forms of cooperation between senders and receivers (e.g., virtual MIMO, network coding)

- **End-to-end paths change with mobility**
  - impacts path characteristics and the allocation of resources over paths to satisfy application requirements.
Challenges (2/2)

• **Supporting security is more difficult with mobility**
  – Identities of trusted nodes must change
  – Privacy can be compromised with mobility (e.g. node can be tracked by the perceived location of its transmissions)

• **Policy-based dissemination of information is more difficult with mobility**

• **Feedback to control data rate is not as useful if paths change**
Design for Mobility: Requirements

• Some protocols benefit from mobility: group mobility, etc.

• Controlled mobility
  – Nodes move around to improve topology, deliver data, store-carry-forward,
  – Trajectory planning and changing what routes

• Interest-driven “physical” dissemination:
  – How should opportunistic data mules handle data?

• Content-driven routing
A Clean Slate Approach (1/2)

- Exploit broadcast nature of links & in-network storage
- OSI/TCP architecture is no longer “the best”
  - **MAC layer**: MAC should work on broadcast and directional transmissions; support many-to-many rather than one-to-one communication
  - **Network layer**: Attribute-based queries, geo-location is important, resource discovery (no DNS)
  - **Beyond routing**: resource discovery replaces route discovery; need for binding of resources/services on the basis of names;
A Clean Slate Approach (2/2)

- OSI/TCP architecture is no longer “the best”
  - **Opportunistic use of resources**: cooperative x-mit schemes (take advantage of gains at PHY) and incentive mechanisms (battery life, use of spectrum), cooperation using memory, virtual MIMO
  - **Use mobility of nodes to cooperate as data mules**: need for coordination to decide which nodes move
  - **Peer-to-peer opportunistic transmissions**: how to cache and how to route
  - **Tolerance to various forms of disruption** (e.g., no connections)
Changing The Internet Design (1/2)

• Use of storage and location information must be considered in the global routing design.

• Use of location information: IPv6 can be used but we must find anonymous location information in addressing
  – Use of proxies and in-net storage
  – Privacy and security implications
Changing The Internet Design (2/2)

• Mobility creates a stronger focus on security
  – We do not know the local neighborhood!

• Opportunistic mobile routing infrastructures will become important

• Mobility changes the expectations for services (anywhere, anytime), but maintaining performance with seamless mobility is difficult.
Case Study 1: MobiSteer (1/2)

- **MobiSteer**
  - Using Steerable Beam Directional Antenna for Vehicular Network Access
Case Study 1: MobiSteer (2/2)

How to beam steer?
Which is the best AP?
Case Study 2: Controlled Mobility

• Mobile nodes’ mobility can be controlled,
  – e.g., miniature autonomous air-vehicles
  – Benefits
    • Increase network throughput or reduce delays
    • Maintain network connectivity

• Mobile Backbone Architecture

![Mobile Backbone Architecture Diagram]

- Mobile Backbone Node (MBN)
- Regular Node (RN)
Case Study 3: Mobility-Assisted Communications

• Intermittent Connectivity
  – Lack of contemporaneous end-to-end paths
    • Disaster communication, Vehicular ad hoc networks
    • Ad-hoc/Sensor Networks, Inter-planetary networks
Emerging Wireless/Mobile Applications
New Wireless/Mobile Applications

• Distributed
• Integrating heterogeneous infrastructure and ad-hoc networking
• Location/Energy/User behavior-aware
• Exploit mobility
• Location privacy sensitive
• Self-configurable, self-tunable, remotely manageable
Examples

• Vehicular applications
  – Safety, traffic information, route planning

• Content-sharing applications
  – Entertainment (video, audio), games

• Mobile external sensing
  – Urban pollution sensing, accident reporting

• Mobile ad-hoc services
  – Relaying to near-field users

• Emergency applications
Case 1: Urban Sensing in VANETs
Case 2: Vehicle-Assisted Data Delivery (VADD)

- Make the best use of the wireless transmission
- Forward the packet via high density area
- Use intersection as an opportunity to switch the forwarding direction and optimize the forwarding path

![Diagram of a road network showing a geographically shortest path and fast speed wireless communication.]

- Geographically shortest path
- Fast speed wireless communication
Case 3: Push-based Data Dissemination

• Deliver the data to all vehicles within a given area

• Applications
  – Transportation control
  – Emergency announcement
Case 4: Mobile Sensor Networks

• Applications
  – Air quality monitoring
  – Flu virus tracking

• Unique characteristics
  – Nodal mobility
  – Sparse connectivity
  – Delay/fault tolerability
  – Limited buffer/memory
Case 5: Traffic View

• Improve driving safety
  – Provides driver with a real-time view of the traffic ahead
• Prototype demonstrated in real traffic conditions
  – http://discolab.rutgers.edu/traffic/tvdemo.html
Research Challenges (1/2)

- **Mobile application design**
  - Location-aware, exploit mobility, gathering feedback and traces

- **Performance and QoS**
  - Delay tolerance, channel variations

- **Cross-layer communication design**
  - Exploit mobile application context information

- **Security issues**
  - Location validation, Location privacy
  - Trust management
Research Challenges (2/2)

• Mobile data management
• Fault tolerance
  – In the presence of mobility
• Remote maintainability
  – Deployment, configuration, upgrade, debugging
• Application and service-oriented protocols
  – Over mobile networks
Mobility Models and Mobile Testbeds
Flexibility in Mobility Model

• Multiple scale models
  – Micro and Macro levels, (e.g., from stop signs to cross town patterns)

• Multi-faceted scenarios
  – Combines motion, data traffic, map, infrastructure
  – Interrelation between data/motion; data caching; aggregation, etc

• Trade off between accuracy and usability
  – Different applications may focus on different parameters
Trace to Models

• Traces:
  – Lack of cellular traces (owned by providers)
  – Lack of vehicular traces (not enough testbeds)
  – Scarcity of urban traces

• Interplay/synergy of:
  – Measured traces
  – Synthetic models/traces
  – Theoretical motion/traffic models
Evaluation Methodology

• Guidelines for community
• Model validation
• Model implementation verification
• Sound statistical analysis of results
Flexibility in Testbeds

• Multi-layer/user vs. single-layer/user testbeds
• Heterogeneous (hardware, protocols, applications)
• Broad range of motion patterns:
  – From pre-scheduled to controlled and spontaneous
• Broad range of devices:
  – From small scale testbeds (motes) to large scale testbeds (vehicles)
Scalability in Testbeds

- Testbed expansion with simulation and emulation
- Integration with real world networks and applications
Measurement Methodology

- Guidelines for the community
- Validation of the model (motion, traffic, etc)
- Verification of the implementation
- Repeatability
- Sensitivity analysis
- Sound statistical analysis
GENI Wireless Mobility Testbeds

- Vehicular networks
- People to people networks
- Small scale - augmented by simulation (hybrid)
- Inter-operation
Campus Vehicular Testbed in UCLA

- **Campus Vehicular Testbed (C-VeT)**
  - A platform to support car-to-car experiments in various traffic conditions and mobility patterns
  - A shared virtualized environment to test new protocols and applications
  - Remote access to C-VeT through web interface
  - Collection of mobility traces and network statistics
  - Experiments on a real vehicular network
  - Full experimental Flexibility but no control on mobility
V2V & V2I Testbed in OSU

- Receiver moved at x km/hr towards the stationary transmitter
- Measured using DSRC radios:
  - Received Power
  - Bit Error Rate
Conclusion

• Mobility is a key consideration in Future Internet!

• Need reconsideration for Internet architecture!

• Long way to go!

Thank you!
References (1/2)

• NSF Workshop on Mobility in Wireless Networks  


References (2/2)


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• [CVeT] [http://www.vehicularlab.org/](http://www.vehicularlab.org/)
