Managing Mobility in the Future Internet

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> Mario Gerla, CS Dept, UCLA

The Internet is becoming Mobile

- New generation of powerful portable devices:
 - Can support most Internet needs
- Wireless speeds growing constantly:
 - 4G expected to achieve 40Mbps
 - WiFi up to 100Mbps
- Opportunistic ad hoc networking facilitates P2P applications
 - New applications emerging for vehicular and personal P2P networks
 - Social networks extending to the mobile users
- Web browser and web advertisers now targeting the mobile users

Infrastructure vs Ad Hoc wireless Net

Infrastructure Network (cellular or Hot spot)



Ad Hoc, Multihop wireless Network



Paradigm shift in wireless mobility

- 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 (cont)

- Emerging Wireless, Mobile Internet
 - The data is collected by portable devices, and may stay (and be searched) on the devices:
 - Urban sensing (vehicle, people)
 - Multiple hops to other mobiles of to the Access Point
 - This creates new challenges
 - Distributed index (ie, publish/subscribe) to find the data
 - Data sharing among mobiles via opportunistic P2P networking
 - Privacy, security, protection from attacks
 - Intermittent operations (mobile nodes can become disconnected) => delay tolerant applications

New Wireless/Mobile Challenges

Multiplicity of Ad Hoc Networks

- Ad-hoc nets with multiple radio hops to wired Internet useful for various scenarios including mesh 802.11, sensor, etc.
- The challenges: consistent addressing and mobility management
 - Discovery and self-organization capabilities
 - Seamless addressing and routing across wireless-wired gateway
 - Soft handoff
 - Geographic routing options



Cognitive Radios

- Cognitive radio drives consideration of adaptive wireless networks involving multi-hop collaboration between radio nodes
 - Needs Internet support similar to ad-hoc network discussed earlier
 - Rapid changes in network topology, PHY bit-rate, etc. → implications for routing
 - Fundamentally cross-layer approach need to consider wired net boundary
 - High-power cognitive radios may themselves serve as Internet routers…



Sensor Applications: Highway Safety

Sensors in roadway interact with sensor/actuator in cars

- Opportunistic, attribute-based binding of sensors and cars
- Ad-hoc network with dynamically changing topology
- Closed-loop operation with tight real-time and reliability constraints



To address these mobile challenges we organized the …

NSF Mobility in Wireless Networks Workshop

Rutgers, July 31-Aug 1, 2007 Mario Gerla (UCLA) Dipankar Raychaudhuri (Winlab)

http://netlab.cs.ucla.edu/mwnet/usemod10/wiki .cgi?Main

Objectives of the NSF Workshop

- How does "mobility" change the network design?
 - Applications
 - Protocols
 - Mobility models
- What new critical issues emerge?
- What new research is needed to make progress?
- What shape will take the future mobile Internet?

Issues that will drive Future Internet design

Addressing and routing

- Geo-routing
- More generally, attribute based routing
- Mobility support

• Interaction with the infrastructure

- Off loading the wireless internet
- Congestion control assistance
 - The Internet can be used to efficiently propagate congestion information
- Privacy
- Security, protection against attacks

The rest of my talk

- Emerging "mobile" applications and requirements
- Designing architecture and protocols for mobility
- Mobility modeling and its impact on protocol design
- Preliminary protocol evaluation in the Campus Testbed
- The strawman future Mobile Architecture: examining the options
- Case study: vehicle mobility management in the Future Internet

Emerging Mobile Applications

New Generation of Mobile Apps

- Distributed; Integrating heterogeneous infrastructure (e.g., WiFi, cellular, satellite) and ad-hoc networking
- Location-aware
 - Opportunistic, predict, control
- Exploit mobility
 - Homogenous or heterogeneous mobility
 - Individual or swarm mobility
- Location privacy sensitive
- Self-configurable, self-tunable, remotely manageable
- Energy-aware

Emerging Mobile Application

- 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
 - Disaster recovery
- Mobile network management
- Mobile social networking
 - Mobile Facebook

Applications Case Studies

Example: People-to-People Networking

- Downloading newspaper, news clips, music on the way to the subway
 - 7 degrees of separation (Columbia Univ.)

Proximity advertisement

- Listen to music Nokia-EMI
- Advertisement WideRay
- "Reading" billboards CBS
- Exchanging songs, pictures, ads, movie clips
- Social networking Nokia Sensor



From Nokia sensor homepage

Bluetooth P2P Content Sharing



Collaborative Health Monitoring: Health Net



Sensor Applications: Assisted Living

- Emergency event triggers interaction between object sensors and body sensors and initiate external communication
 - Heterogeneous ad-hoc network
 - Sensors used to detect events and specify location
 - Real-time communication with care provider



Example: Vehicular Applications

Safe navigation:

- Forward/Intersection Collision Warning
- Advisories to other vehicles about road perils (e.g., ice on bridge, congestion ahead)

Environment sensing/monitoring:

- Traffic monitoring
- Pollution probing
- Pavement conditions (e.g., potholes)
- Urban surveillance
 - Witnessing of accidents/crimes

Content distribution

- Multimedia-based proximity marketing (e.g., virtual hotel tours, movie trailers)
- In-vehicle software updates and patches (e.g., map data updates in SatNavs)



Collision Warning



Potholes

Vehicular Networks (cont)

Urban data sensing

- Mobile sensors (e.g., GPS, accelerometer, gas sensors, etc.)
 - Including user generated sensor data (e.g., accident video clips)
- E.g., vehicular sensor networks, smartphone-based participatory sensing
- Mobile nodes sense, process sensor data, and publish information

Content distribution

- Files downloaded from *hotspots* or road side *Infostations*
- Sharable sensor data, including user generated multi-media data (e.g., accident video clips)



Vehicular Sensor Networks



The Mobile Challenges

- Urban data sensing:
 - How to search and access "*distributed*" mobile data?
 - Example: Which vehicles were in Wilshire & Westwood intersection at 3PM yesterday?
- Content distribution:
 - How to *distribute* sharable content to mobile users in:
 - People-to-people networks?
 - Highly mobile vehicular networks?
 - Intermittent connectivity?
- Goal: develop mobile data sensing and content distribution protocols in challenged urban wireless environments
 - Challenged urban wireless environments
 - High mobility (esp. vehicular networks)
 - Intermittent connectivity (mobility+user density)
 - Error prone wireless channels (obstacles)

Robust, Motion Resistant Protocols

Mobility driven design

Mobility impacts:

- the conditions in which protocols must operate,
- the state and context that nodes can use to communicate, and
- the problems that protocols must solve.

Examples:

- The state of links is a function of mobility (e.g., link lifetime, fading, multipath effects, direction of a link, etc.)
- The neighborhood of a node changes with mobility, which impacts reliable exchanges, channel division (space, time, code, frequency) among neighbors, and forms of cooperation between senders and receivers (e.g., virtual MIMO, network coding)
- End-to-end paths change with mobility, which impacts path characteristics (in-order delivery, delay, throughput, lifetime of paths, etc.) and the allocation of resources over paths to satisfy application requirements.

Designing for Mobility: A Clean Slate

- MAC issues: MAC should work on broadcast and directional transmissions; support many-to-many rather than one-toone communication
- Network issues: Naming (no need for addresses?), attributebased 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;
- Route binding: "Opportunistic use of resources"; cooperative x-mit schemes (take advantage of gains at PHY) incentive mechanisms (battery life, use of spectrum), cooperation using memory, virtual MIMO
- DTN routing: Use mobility of nodes to cooperate as data mules; need for coordination to decide which nodes move where; Tolerant to various forms of disruption

Mobility Models and Mobile Testbeds

Why Motion Models?

- Motion models are critical for the design of:
 - Applications
 - Network Protocols
 - MAC Protocols
 - Cross layer strategies
- Realistic motion models are embedded in Vehicular simulators
 - Can handle medium scale urban scenario's (hundereds of vehicles)
 - Can be validated with Testbeds in small scale scenarios (dozens of vehicles)
 - Enable algorithm scalability studies (to the thousands of mobiles) by validation with analytic models

Model Flexibility

- 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

Metrics and Parameters

- Motion Impact on Data Performance:
 - How are the data performance metrics (throughput, delay) impacted by the particular motion patterns,
 - How do the motion patterns impact the data traffic,
- Consider new "mobility" measures:
 - Inter-contact time, neighborhood change rate, partitioning, clustering, spontaneous group formations, etc
 - Ideally, a few *motion "primitives"* that can cover most scenarios and allow cross comparison of test experiments

Motion Study: Portland Access Point effectiveness for V2V comms

1 x 2 km area in Downtown Portland, Oregon



Marfia et al: "VANET: On Mobility Scenarios and Urban Infrastructure. A Case Study" MOVE workshop 2007

Three Mobility Models

- Random Waypoint
 - Each node randomly moves on the plane (no road constraint)
 - Inputs: speed interval, stop time interval
- CorSim (Corridor Simulator)
 - Inputs: detailed road maps, traffic lights and traffic signs, speed limits, *traffic flows*
- Transims traces
 - Generated from Census data by Los Alamos TRANSIMS large scale micro-simulator
 - Inputs: detailed road maps, traffic lights and traffic signs, speed limits, activity locations

Simulation Set-up

Qualnet simulator; 200 sec runs

- Transims:
 - 7AM (avg vehicles/avg speed/avg stop time):
 - 270/45 kmph/3.2 sec
 - 8AM:
 - 371/45 kmph/5.7 sec
- Corsim:
 - same average values across field as Transims, BUT UNIFORM pattern instead of the exact Transims pattern
- RWP:
 - same avg values as Transims, but RANDOM motion pattern

Routing: AODV + Opportunistic short cuts via AP's

DATA Traffic: Load is increased by increasing fraction of transmitting pairs

Transims results



Performance drop at congested freeway ramp (at rush hour) -12% load -> 60% of overhead traffic AP infrastructure helps by Reducing congestion

Results: RWP



Randomness, in this case, improves performance Freeway access ramp effect has disappeared!

Results: Corsim



Uniform traffic pattern cannot predict access ramp It also badly underestimates AP improvement

Ideal synthetic motion model?

- Faithful end to end traffic pattern
 - Both RWP and Corsim failed this!
- Accurate average speeds
- Realistic velocity variance/ acceleration
- Must capture correlation between vehicles
- Must be simulation resource efficient

Accuracy vs run time efficiency trade-off

Testbeds

Why a Testbed?

- Designer needs more than simulation
- Testbed helps understand:
 - Realistic user behavior in reaction to motion, data etc
 - Realistic channel behavior with new advanced radios (MIMO, SDR)
 - Real implementation/HW constraints
- Helps Uncover:
 - interactions between layers
 - Incorrect common beliefs
- Helps Assess:
 - HW, SW, Mgmt costs

C-VeT Campus Vehicular Testbed

E. Giordano, A. Ghosh, G. Marfia, S. Ho, J.S. Park, PhD System Design: Giovanni Pau, PhD Advisor: Mario Gerla, PhD

Vehicle Fleet

• We plan to install our node equipment in:

- A dozen private cars: customized experiments
- Up to 20-30 Campus Facilities operated vehicles (including shuttles and facility management trucks).

Experiments:

- Controlled motion experiments with private cars
- Campus vehicle experiments (locally or remotely initiated) on random motion patterns
- Opportunistic ad hoc and infrastructure synergistic experiments



The vehicular radio:

• In the final deployment:

- Industrial PC (Linux OS)
- 2 x WLAN Interfaces
- 1 Software Defined Radio (FPGA based) Interface
- 1 Control Channel
- 1 GPS





Initial Demos:

• Equipment:

- 6 Cars running in Campus
- Clocks are in synch with the GPS
- OLSR for the WLAN routing
- 1 EvDO interface in the Lead Car
- 1 Remote Monitor connected through the Internet

• Experiments:

- Connectivity map though OLSR
- Rough loss analysis though ping.
- On/OFF traffic using lperf
- Bit Torrent content sharing
- Opportunistic multihop access to AP's

The V2V testbed



6-Car Caravan on CAMPUS communicating via OLSR



On Going Vehicular Research at UCLA

- V2V communications for safe navigation:
 - Emergency Multimedia Information streaming
- V2V communications for content/entertainment:
 - Car torrent, Code torrent, Ad Torrent
 - Car to Car Internet games
- V2V for urban surveillance:
 - Pervasive, mobile sensing: MobEyes
 - Emergency Networking
 - Evacuation
- Test bed support is critical

Future Testbed Experiments

- Realistic assessment of radio, mobility characteristics
- Account for user behavior
- Interaction with (and support of) the Infrastructure
- Content P2P sharing
- Urban sensing

The Future Mobile Internet Architecture

Changing the Internet Architecture: Previous Failures and Lessons Learned

- Attempts at upgrading IPv4 did not have expected results:
 - IPv6 standardized but not widely deployed...
 - Little progress with end-to-end QoS in the Internet
 - Mobile IP for first wave of wireless not broadly implemented
- Attempts at utopian new network architectures also failed:
 - B-ISDN/ATM did not take off (...complexity, lack of organic growth model)
 - Problems with 3G wireless
- Lesson: encourage *bottom-up transformation* without loss of investment in legacy system:
 - Evolutionary strategies preferable
 - New approaches to protocol standards: hierarchies, modularity, opensource,..
 - Economic incentives for deployment

Internet Architecture: Strategies for Change

Evolutionary approach

- Design a new wireless, ad-hoc and sensor "low-tier IP network profile to be "compatible" with IP global network (e.g. IPv6, BGP routing, MPLS, etc.)
- As wireless service needs proliferate, new low-tier IP may replace current IP intra-network



Internet Architecture: Strategies for Change

Overlay approach

- new wireless, ad-hoc or sensor access nets interwork across *global overlay* network
- IP is pushed down to a "layer 3-" service, while overlay is "3+"
- Permits significant flexibility in advanced service features,
- However, tight optimization of packet overhead more difficult due to IP encapsulation



Internet Architecture: Strategies for Change

Revolutionary approach

- Specify a new "beyond IP" network optimized for mobile/wireless/sensor
- Build a prototype nationwide network and offer it for experimental use
- Use this network for emerging mobile data and real-time sensor actuator applications with demanding performance and efficiency requirements



What Mobile Users need from Future Internet Infrastructure

- Mobility support
 - Location tracking; Geo Location Service
 - User profiling
- Vehicle data traffic/routing management
 - Least Cost Routing: vehicle grid or infrastructure
 - Inter AP/cell connectivity awareness
 - Congestion monitoring/protection
 - Path Quality estimation
- Intermittent vehicle connectivity support (DTN)
 - Destination temporarily disconnected;
 - Internet stores/forwards (Cache Forward Net);
- Security authentication (PKI) support
 - Certificate authority; Tracking trouble makers across continents..
- Vehicle network monitoring/management
 - When Infrastructure fails (eg. Katrina) switchover to Vehicle Grid standalone operation

Case Study: Geo Location Service

- Why Geo-routing?
 - Most scalable (no state needed in routers)
 - GPS readily available; local coordinates used in blind areas (tunnels, parking lots, urban canyons)
- Geo Location Service
 - First option: Infrastructure overlay support
 - Distributed implementation backup (eg GHT)
 - Other option: transparent Internet geo route support in virtualized router

Infrastructure based Overlay Location Service (OLS)



Vehicular ID hashed into overlay DHT Mapping: Vehicular ID <=> location

Georouting through the infrastructure

• IPv6 addressing (xy coordinates in header extension)



- How to make the system resilient to failures/attacks?
 - If access points fail, use GLS implemented in grid

Infrastructure routing support

The trade off: grid short paths vs Internet fast wires

- Baseline: Shortest path routing
 - Short connections should go grid
 - Packets to remote destinations on infrastructure
- Enhanced: Access Points and Overlay assist in the decision
 - Propagation of congestion info from Overlay to wireless using 3 hop beaconing (say) every second

Summary

- The Future Internet must be designed to support mobile users as "first class" citizens
 - Most access will be from mobiles
 - Most data will be collected by mobiles
 - Much of the data will "stay on mobiles"
- Internet Overlays designed for wireless demands appear to be the best evolution strategy
- Long term solution will lead to fully integrated IP
 - However, still too early to design integrated IP
 - Must wait until mobile applications stabilize
 - Must wait for better/cheaper wireless+sensor technology

THE END

THANK YOU