Advanced Modeling and Simulation of Mobile Ad-Hoc Networks

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Telcordia Contact:
Stephanie Demers
Robert A. Ziegler
ziegler@research.telcordia.com
732.758.5494

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Outline of Today’s Talk

- Overview of ad-hoc networking applications
- Attributes of an ad-hoc network
- Ad-hoc network models
- Simulation of ad-hoc network models
- Detailed simulations and results
  - Goal
  - Design
  - Assumptions
  - Results
- Summary
What is an Ad-Hoc Network?

A rapidly deployable, self-configuring wireless network

- Mobility support
- No requirements for infrastructure
- Flexibility
- Versatility
- Limited scalability
- Limited reliability
- Limited security
- High control overhead

Possible application areas

- Sensor networking
- Military
- Emergency
- Community networking
- Automotive
- Health care
- Entertainment venue
Future Battlefield Networking Concept
Emergency

Local infrastructure is damaged
Emergency Communication Requirements

• General
  – Facilitate primary communications objectives while minimizing risk to emergency workers
    • provide warnings
    • allow communication while in action

• Network
  – ad hoc networking is essential, since infrastructure would be damaged
  – should be robust and survivable in an unpredictable environment
Automotive

Road conditions

Coordination

Weather conditions

In-vehicle entertainment
Automotive

- Objectives
  - Improve traffic efficiency
  - Improve safety
  - Value added services to the drivers and passengers

- Communications requirements
  - Ability to connect to backbone infrastructure
  - Message, data, and speech information types
  - Sufficient bandwidth for all information types

- Ad hoc network deployment
  - Access points may be installed along the highway providing network connectivity, but ad hoc networking is created by vehicles to extend the range
Ad Hoc Network Market
(trying to stand up?)

• Over $200M in Military R&D programs in past 6 years
• Still in an early stage in non-military area
• Standards evolving
• Companies
  – Telcordia
  – BBN
  – SRI
  – Nokia
  – Ericsson
  – INRIA
  – Mesh Networks
  – Socket Communications Inc
  – Etc.

We haven’t seen its face or its body... but we believe it’s not a small baby.
Mobile Ad-Hoc Network Environment

- Significant challenges exist:
  - Routes between nodes constantly change due to
    - Node mobility or node failure
    - Variable reliability of the wireless link (multipath, fading, interference)
  - Resources are scarce
    - Bandwidth is limited over the wireless media
    - High packet error rates on the wireless link may invoke retransmissions, which use even more link bandwidth
  - Infrastructure is unreliable or not available
- MANETs must be robust, so they cannot rely on
  - Fixed topologies
  - Static routes
- In a MANET environment, an ideal routing protocol will
  - offer minimum application latency by quickly updating routing tables in response to node mobility or environment change
  - require minimal message overhead
  - scale gracefully with # of participating nodes
Important Ad-Hoc Network Parameters
(with significant impact on routing performance)

- Network Size (# of nodes)
- Geographical Area
  - relationship to node-to-node link reach (radio performance)
  - implications for density
- Density
  - topological (Connectivity) – e.g. average number of peers per node
- Topology rate of change
  - certain mobility patterns / node distributions may allow specific optimizations
- Link capacity (bits/sec)
  - ... and its relationship to required protocol overheads
- Fraction of unidirectional links
- Data and control traffic distribution
- Fraction/frequency of sleeping nodes
- Node homogeneity
  - power, memory, bandwidth, etc.
Ad Hoc Network Routing Protocols

• Routing protocols for MANETs are evolving
  – No global winner in IETF
  – Limited numbers of prototypes
• Conventional wired-type schemes (global routing, proactive):
  – Distance Vector based: DBF, DSDV, WIRP
  – Link State: OLSR, OSPF, TBRPF, GSR
• On-demand, reactive routing:
  – Source routing; backward learning
  – AODV, TORA, DSR, ABR, ZRP
• Location Assisted routing (geo-routing):
  – DREAM, LAR, LANMAR, etc

• The best choice for a given network depends on its attributes and on the supported applications
Proactive vs. Reactive Routing Protocols

- **Proactive Routing Protocols (e.g. OLSR)**
  - Definition
    - Store route table even before it is required. Use flooding mechanism.
      Exchange topology information with other nodes of the network regularly.
  - Advantages/Disadvantages
    - + Well suited for highly mobile ad-hoc network.
    - + Application delay due to routing table updates is minimized
    - + Well suited for small ad-hoc networks.
    - - Not well suited for large networks; overhead requirement explodes

- **Reactive Routing Protocols (e.g. AODV)**
  - Definition
    - Routing information is only acquired when required
  - Advantages/Disadvantages
    - + Require less bandwidth
    - - Application latency is increased.
    - + Well suited for ad-hoc networks with minimal mobility.
    - + May be better suited for large networks.
Optimized Link State Routing (OLSR)

- Sources build routes **proactively** by MPR link advertisements
- MPR (Multi-Point Relay) for efficient flooding and limited link advertisements
- Uniform control overhead independent of traffic
OLSR Routing Protocol – Details

• Node N broadcasts HELLO messages every HELLO interval to its one hop neighbors for neighbor sensing:
  – Determine the link status (symmetric, asymmetric, or MPR) of each of its one hop neighbors
  – HELLO message contains list of known one-hop neighbors
• Node N builds neighbor table that includes all its 1-hop and 2-hop neighbors
  – Node N selects its multipoint relay (MPR) nodes among its one hop neighbors such that it can reach all the nodes that are 2 hops away.
  – MPR selection requires symmetric link to node N
• MPR node broadcasts Topology Control (TC) messages every TC interval to advertise link states
  – TC message contains list of one hop neighbors who have selected this MPR
  – Only MPR nodes can forward TC messages \(\Rightarrow\) more efficient flooding
  – TC messages are used for routing table calculation
• Node with non-MANET interfaces broadcasts HNA messages every HNA interval (\(=\) TC interval)
Modeling and Simulation Considerations

- High-fidelity protocol simulation captures key network performance measures
- It’s impractical to simultaneously model the physical layer with high fidelity (e.g. bit accuracy)
  - Use simple packet loss models
  - Parameterize with node-to-node distance as path loss
  - Capture of traffic-proportional interference traffic is harder
- Simulations are event-driven
  - E.g., transmit message, receive message, protocol timer expiration
  - Mobility / node degradation / node failure
- Protocol instantiations need to captured as finite state machines
- Protocol modeling should be validated against real implementation
  - Use actual implemented code in simulation environment, when possible
- Flexible simulation platforms are invaluable to intensive trade studies
  - OPNET Family
  - QualNet
  - NS (Network Simulator)
General Goals for Modeling and Simulation

• Analyze performance of protocols and overall network
  – Throughput
  – Latency
  – Utilization
  – Robustness

• Study engineering tradeoffs involved
  – Evaluate high-level design decisions
    • E.g. proactive vs. reactive routing protocol
  – Optimize parameter values
  – Quantify parameter sensitivities

• Identify any bottlenecks, i.e. inefficiencies or areas for improvement in protocol and network design
Simulation of OLSR Routing Protocol

• OPNET Model (version 8.0.C)
  – Based on INRIA LINUX implementation of Optimized Link State Routing Protocol (OLSR) version 3.0
  – Imported in OPNET by Naval Research Laboratory (NRL)
  – Modified by Telcordia based on Boeing LINUX implementation of Host and Network Association (HNA)

• Simulation caveat – separate network power-up transient effects from routing studies
  – OLSR is only started after the network has been configured
    • Node configuration protocols are also important but beyond the scope of this talk
  – An application is only started once the entire network has been properly initialized with all its protocols (including routing)
    • Network initialization time depends on the number of nodes in the network
Specific Simulation Goals

• Investigate the impact of various OLSR settings in a MANET environment on
  – Overhead
  – Route Convergence

• Per IETF OLSR MANET draft, the proposed values for OLSR constants are:
  – HELLO Interval = 2 seconds
  – TC Interval = 5 seconds
  – HNA Interval = TC interval

• Two OLSR constants will be varied
  – HELLO Interval = 0.5, 1, 2, 4, 6, 8, 10 while TC Interval = 5 seconds
  – TC Interval = 0.5, 1, 2, 4, 6, 8, 10 while HELLO Interval = 2 seconds
Simulation Scenarios

A) Scenario 1: OLSR 1-hop

B) Scenario 2: OLSR 2-hops
Simulation Scenarios

C) Scenario 3: OLSR 4-hops

D) Scenario 4: OLSR Clutter (maximum 2-hops)
E) Scenario 5: OLSR Clutter with mobility

node becomes mpr after 10 minutes

mpr node moves after 10 minutes

non-mpr node moves after 20 minutes

Voice App

Router1

Router2

Server

mpr

mpr

mpr

mpr
Specific Simulation Assumptions

• Simulated voice traffic
  – AF11 QoS requirement
  – Destination
    • One-way, node to server
  – Continuous traffic
    • Starts 150-200 seconds into simulation
    • Continue until end of simulation

• Routing Protocol
  – OLSR between ad-hoc nodes
  – RIP between border gateways (wireline nodes)

• Node-to-Node Links
  – Standard IEEE 802.11 links, link protocols from OPNET standard library
  – Assumed link data rate: 1 Mbps
  – PHY abstraction
    • Packet loss from free space propagation model
    • Maximum node-to-node communication range of 300m
Simulation Performance Definitions

- **OLSR Route Setup Time**
  - Time elapsed between the time a node gets its new IP address (initially or after a move with auto-configuration protocols) to the time OLSR finishes updating its routing table.

- **Average aggregate OLSR Traffic Sent / Received**
  - Sum of HELLO, TC and HNA packet traffic

- **Wireless LAN Load**
  - Load (in bps) submitted to the wireless LAN layer by all other higher layers in this node.

- **Wireless LAN Throughput**
  - Total traffic (bps) sent up to higher layer protocols from the wireless LAN

- **Other measurements**
  - Application throughput
  - Application latency
  - Packet drop rates
Simulation Studies

• HELLO Interval Impact
  – Recall: HELLO packets are sent by all nodes to sense neighbors

• TC Interval Impact
  – Recall: TC (topology control) packets are sent only by MPR nodes to advertise link states and allow routing table calculation

• MPR Node Selection Impact
  – How much more traffic must MPR nodes handle?

• Node Mobility Impact
  – Consequences? Particularly for mobile MPR nodes.
Hello Interval Study
OLSR Traffic Sent

![Graph showing OLSR Traffic Sent over HELLO Interval (sec)]

- OLSR 1-hop
- OLSR 2-hops
- OLSR 4-hops
- OLSR Clutter

OLSR Traffic Sent (bps)

HELLO Interval (sec)
OLSR Traffic Received

![Graph showing OLSR Traffic Received](image)

- OLSR 1-hop
- OLSR 2-hops
- OLSR 4-hops
- OLSR Clutter
HELLO Interval Study Results

• No significant change in total OLSR traffic sent/received as a function of HELLO interval
  – HELLO packets are small compared to TC packets
• Large increase in route setup time when increasing HELLO interval
  – Multiple HELLO exchanges are required to ascertain one- and two-hop topology, and select MPR nodes
TC Interval Study
OLSR Traffic Sent

![Graph showing OLSR Traffic Sent over time]

- OLSR 1-hop
- OLSR 2-hops
- OLSR 4-hops
- OLSR Clutter

OLSR Traffic Sent (bps) vs. TC Interval (sec)
OLSR Traffic Received

![Graph showing OLSR Traffic Received over TC Interval (sec). The graph includes lines for OLSR 1-hop, OLSR 2-hops, OLSR 4-hops, and OLSR Clutter.]
OLSR Maximum Route Setup Time

- OLSR 1-hop
- OLSR 2-hops
- OLSR 4-hops
- OLSR Clutter
TC Interval Study Result

- Large reduction in OLSR traffic sent/received
  - TC packets dominate total OLSR traffic due to their relative size
- Relatively small impact on OLSR route setup time when increasing TC interval
MPR and Mobility Study
Initial Cluster Topology

Mobile3 is the MPR for domain 1

Simulation time
Static Network Performance
Cluster Topology

Voice Traffic Sent (bytes/sec)
Voice Traffic Received (bytes/sec)
Voice Packet End-to-End Delay (sec)

Wireless LAN Load (bits/sec)
Wireless LAN Throughput (bits/sec)
Wireless LAN Delay (sec)
Wireless LAN Data Dropped (bits/sec)
Static Network Performance
Cluster Topology

mobile3 (mpr)
mobile6 (non-mpr)
Static Network Performance
Cluster Topology

mobile3 (mpr)
Cluster Topology
Mobility at 10 minutes

- mobile3 moves to domain 2
- mobile6 becomes MPR for domain 1
- simulation time
Cluster Topology
Mobility at 20 minutes

mobile2 moves to domain 2

simulation time
Cluster Topology
Network Performance with Mobility
Cluster Topology
Network Performance with Mobility

mobile3 (mpr 0-10min)  mobile6 (mpr 10-60min)
Cluster Topology
Network Performance with Mobility

mobile3 (mpr 0-10min)  mobile6 (mpr 10-60 min)
MPR & Mobility Study Results

- There is a 200 to 1 ratio in OLSR traffic carried on MPR nodes (~20 kbps) versus non-MPR nodes (100 bps) in the clutter scenario simulation.
- There is a small delay in setting up the new OLSR routing tables. During that time, voice traffic is dropped if the node that moved was used to route the voice traffic.
- **Comment**: moving the application node (in this case, node *voice*) across domains may incur additional application latencies (e.g. TCP connection reestablishment)
Closing Remarks

• Smaller scenarios shown here only hint at network scales that can be reasonably modeled and simulated
  – Telcordia has simulated networks with $O(80)$ to $O(100)$ nodes
  – “Super-sizing” simulations to $O(1000)$ nodes requires further advances
    • Parallel simulation (but models and simulation must be designed for parallel implementation)
    • Co-simulation (mix of “real” network and protocol processing with simulation)

• There are many other protocol considerations in a complete MANET modeling and simulation exercise
  – Node configuration
  – Mobility management
  – Quality of service
  – Security
  – Fail-safe redundancy considerations for service nodes
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