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Advanced Modeling and Simulation of Mobile Ad-Hoc Networks

Prepared For:
UMIACS/LTS Seminar
March 3, 2004

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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

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What is an Ad-Hoc Network?

A rapidly deployable, self-configuring wireless network

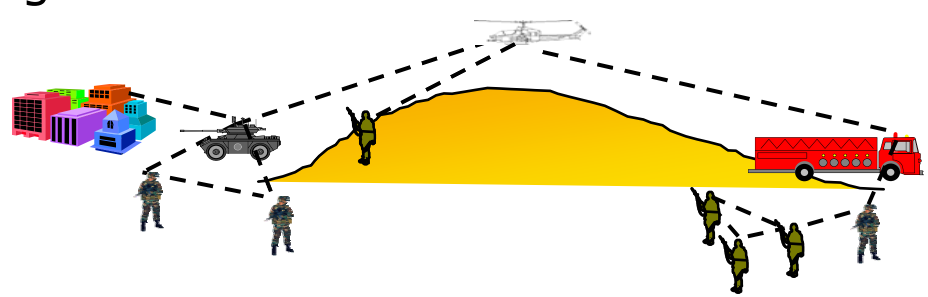
- Mobility support
- No requirements for infrastructure
- Flexibility
- Versatility

- Limited scalability
- Limited reliability
- Limited security
- High control overhead

Possible application areas

– Sensor networking
– Military
– Emergency
– Community networking

- Automotive
- Health care
- Entertainment venue



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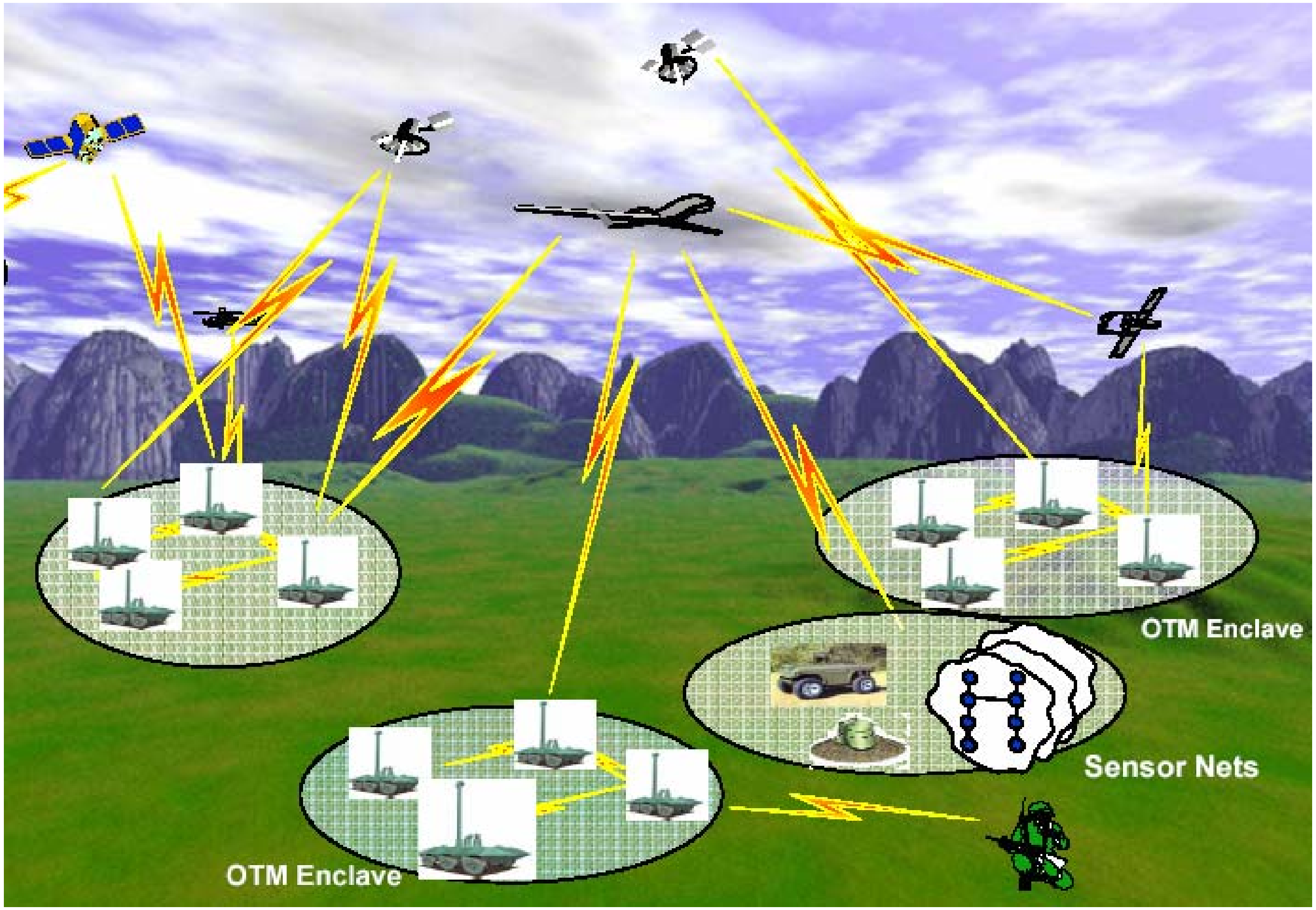
Future Battlefield Networking Concept



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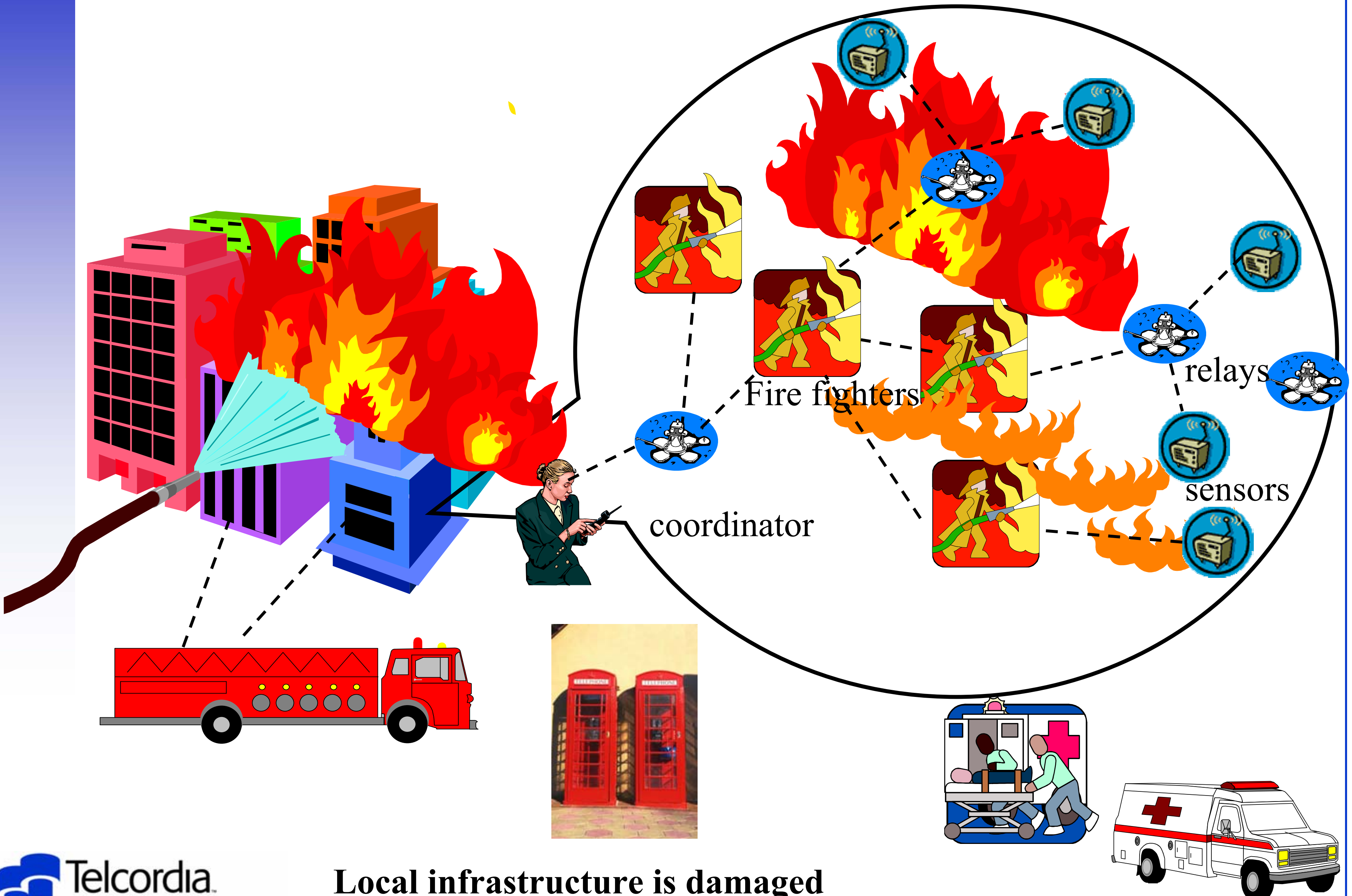
Emergency



Local infrastructure is damaged

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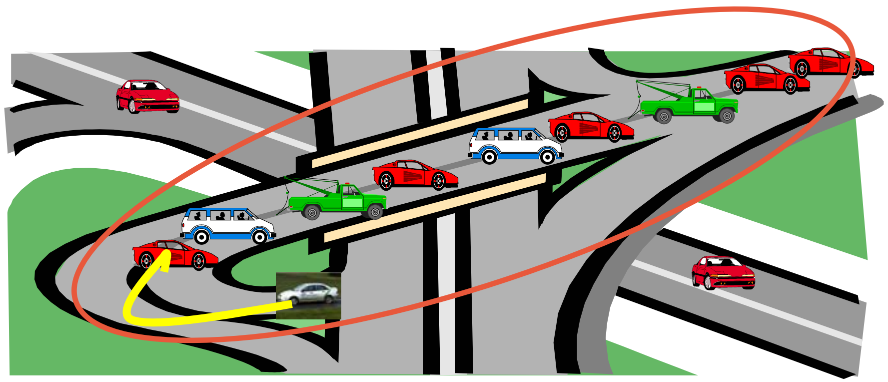
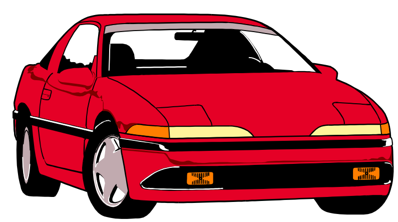
Emergency Communication Requirements

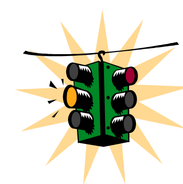
- General
  - Facilitate primary communications objectives while minimizing risk to emergency workers
    - provide warnings
    - allow communication while in action
- Network
  - ad hoc networking is essential, since infrastructure would be damaged
  - should be robust and survivable in an unpredictable environment

Automotive

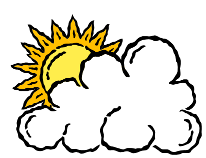


Road conditions

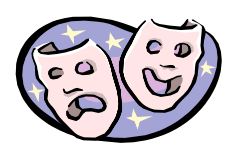




Coordination



Weather conditions



In-vehicle entertainment

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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

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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.

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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.

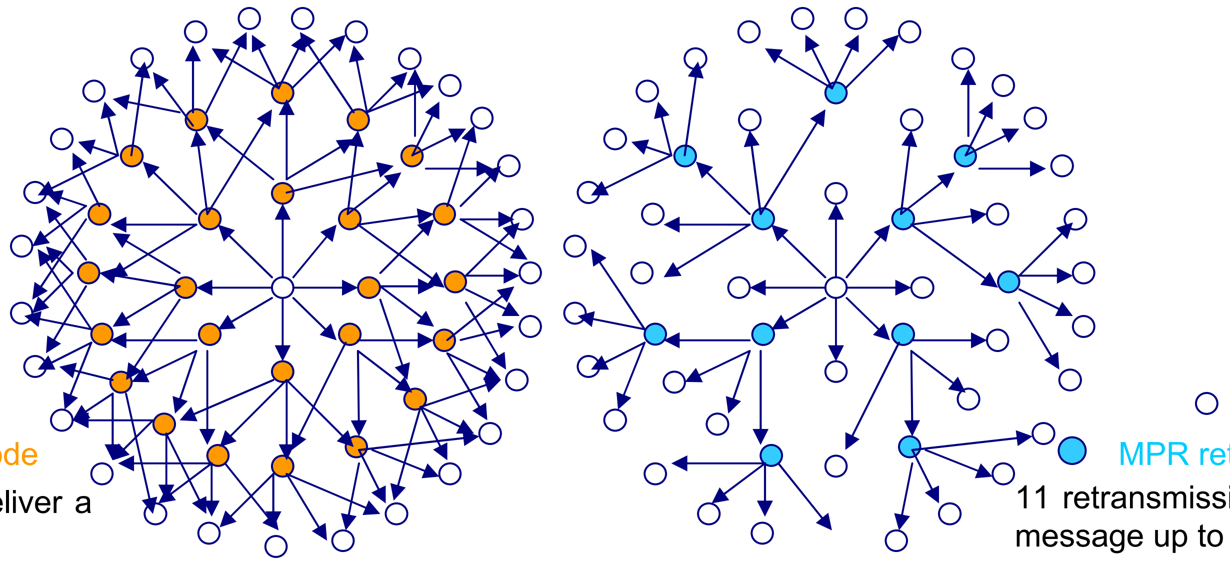
Ad Hoc Network Routing Protocols

- 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)



Re-transmitting node

24 retransmission to deliver a message up to 3 hops

MPR retransmission

11 retransmission to deliver a message up to 3 hops

- 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

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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 → 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

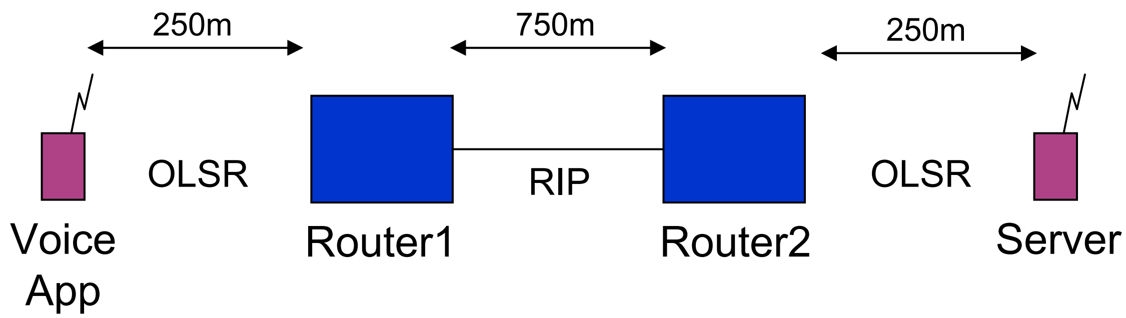
- OPNET Model (version 8.0.C)
  - Based on INRIA LINUX implementation of Optimized Link State Routing Protocol (OLSR) version 3.0
  - Imported in OPNET by Naval Research Laboratory (NRL)
  - Modified by Telcordia based on Boeing LINUX implementation of Host and Network Association (HNA)
- Simulation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

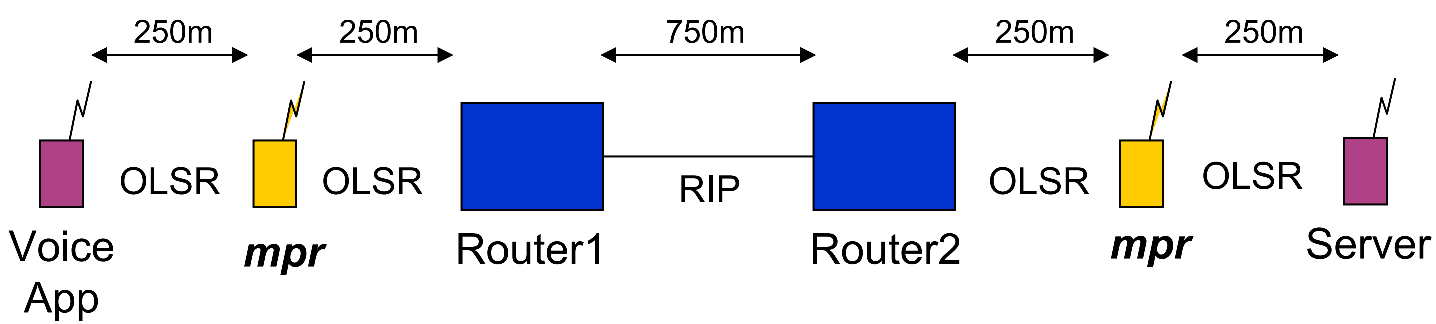
- Investigate the impact of various OLSR settings in a MANET environment on
  - Overhead
  - Route Convergence
- Per IETF OLSR MANET draft, the proposed values for OLSR constants are:
  - HELLO Interval = 2 seconds
  - TC Interval = 5 seconds
  - HNA Interval = TC interval
- Two OLSR constants will be 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



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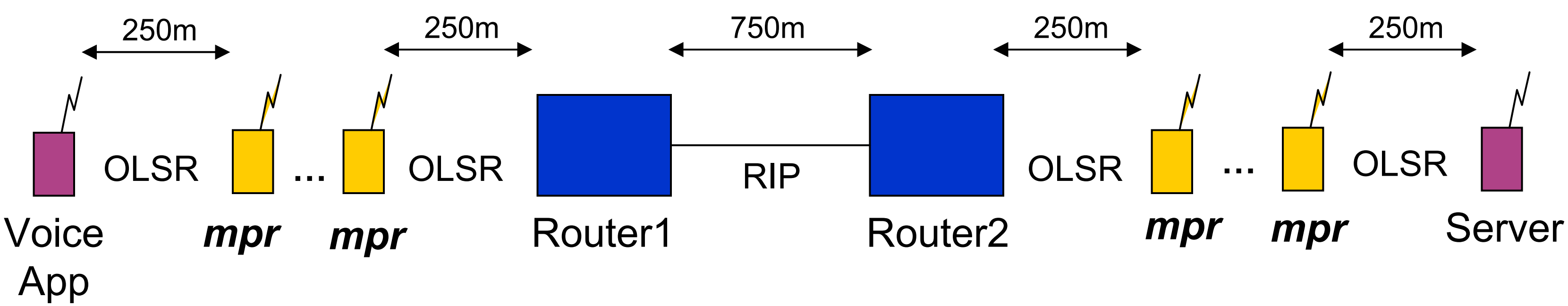
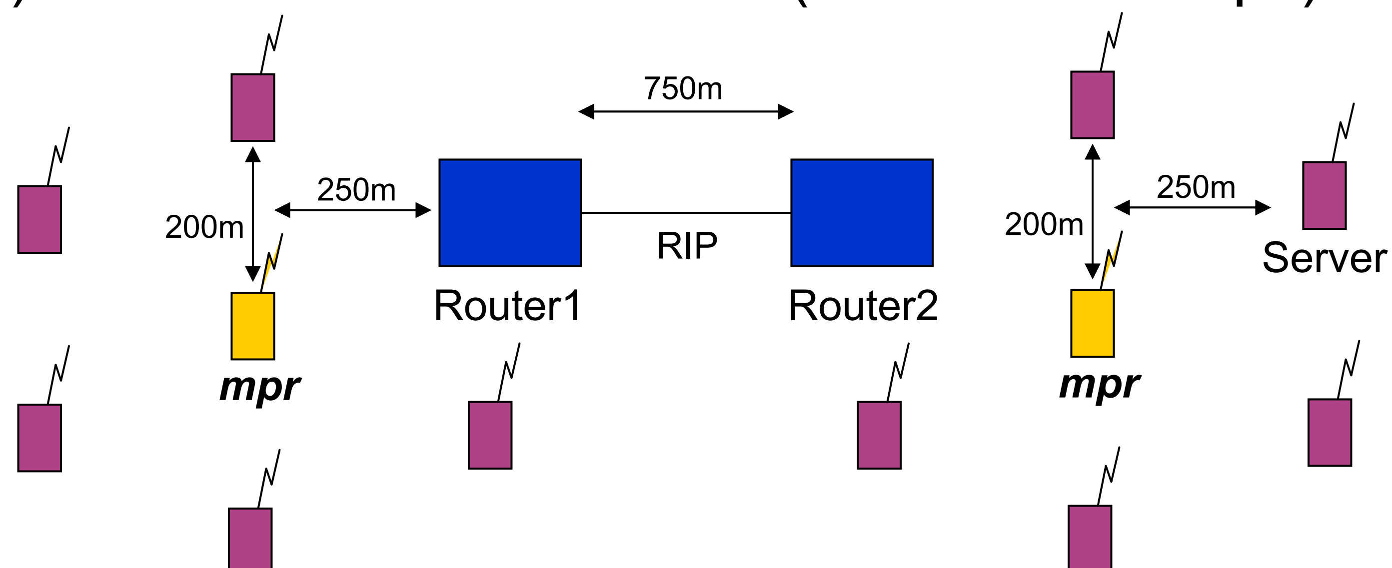
Simulation Scenarios

C) Scenario 3: OLSR 4-hops

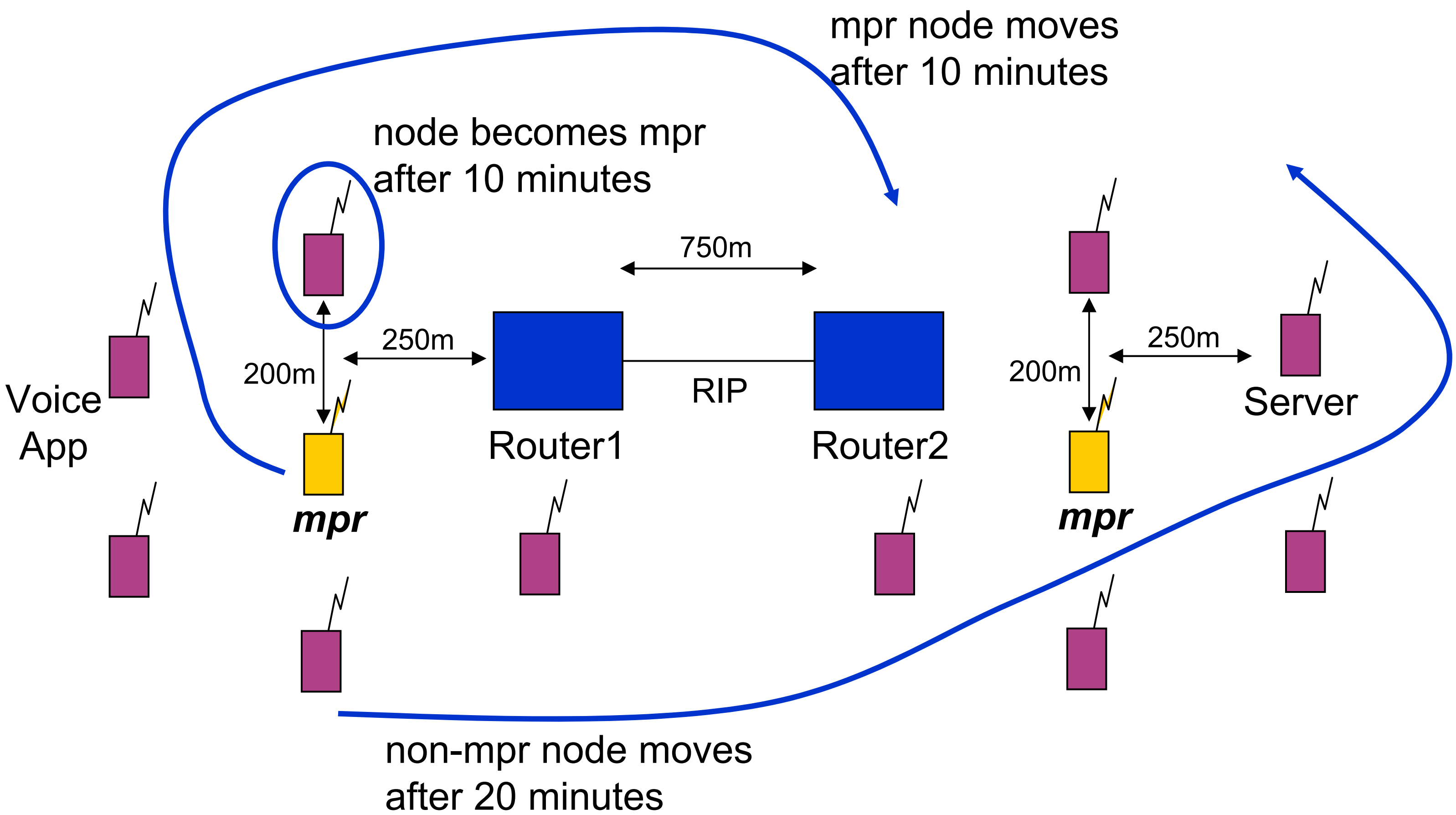


D) Scenario 4: OLSR Clutter (maximum 2-hops)



Simulation Scenarios

E) Scenario 5: OLSR Clutter with mobility



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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

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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

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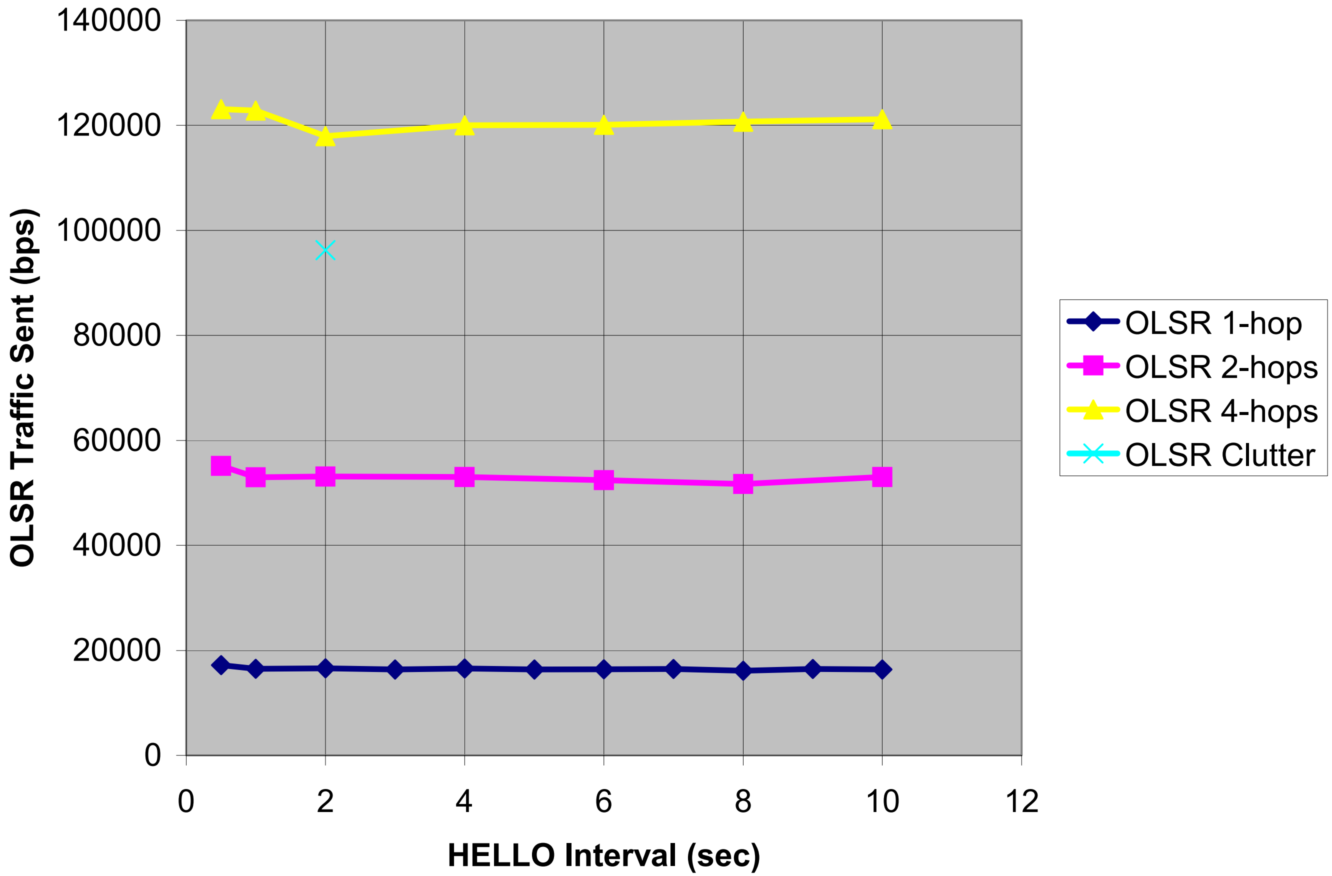
OLSR Traffic Sent



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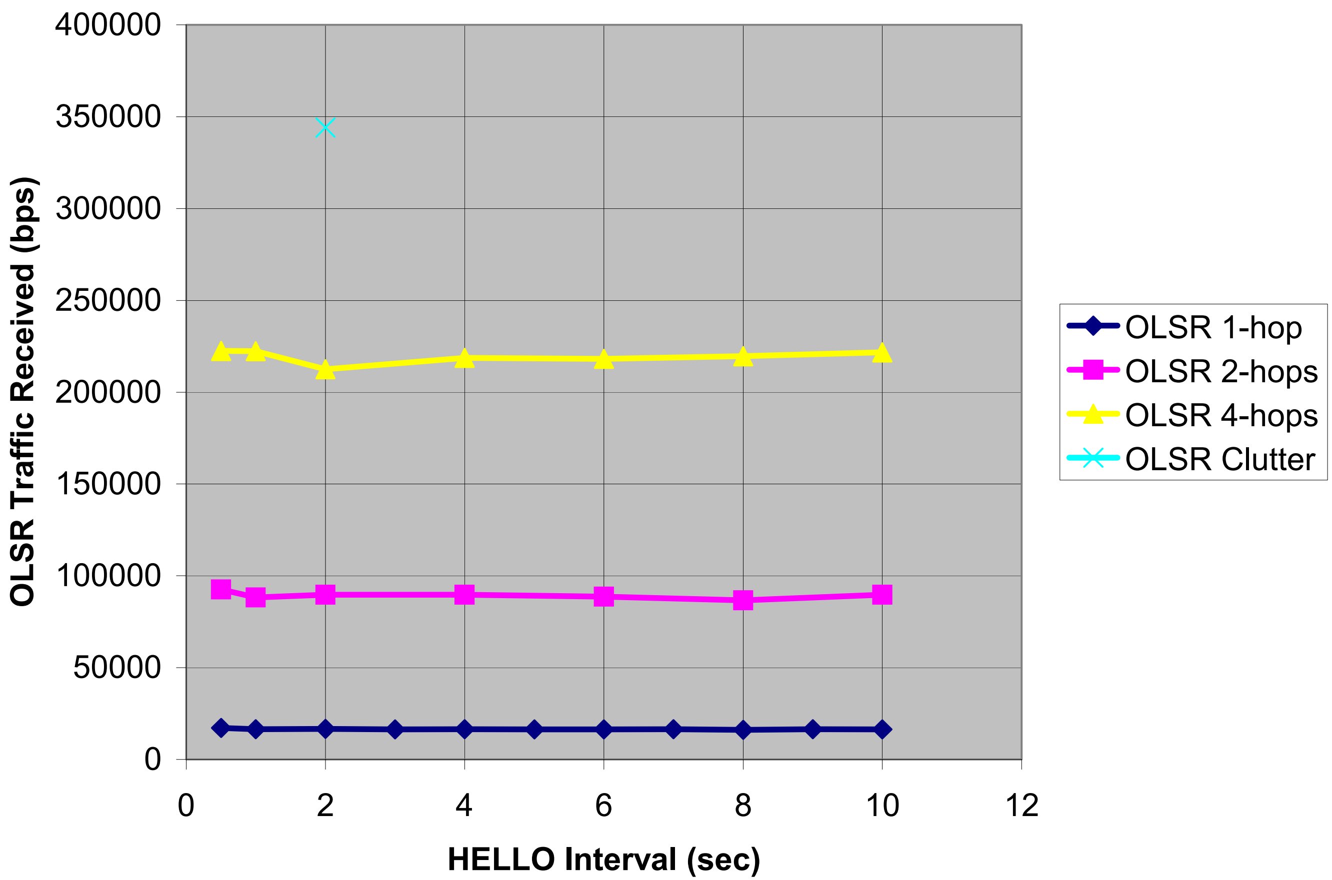
OLSR Traffic Received



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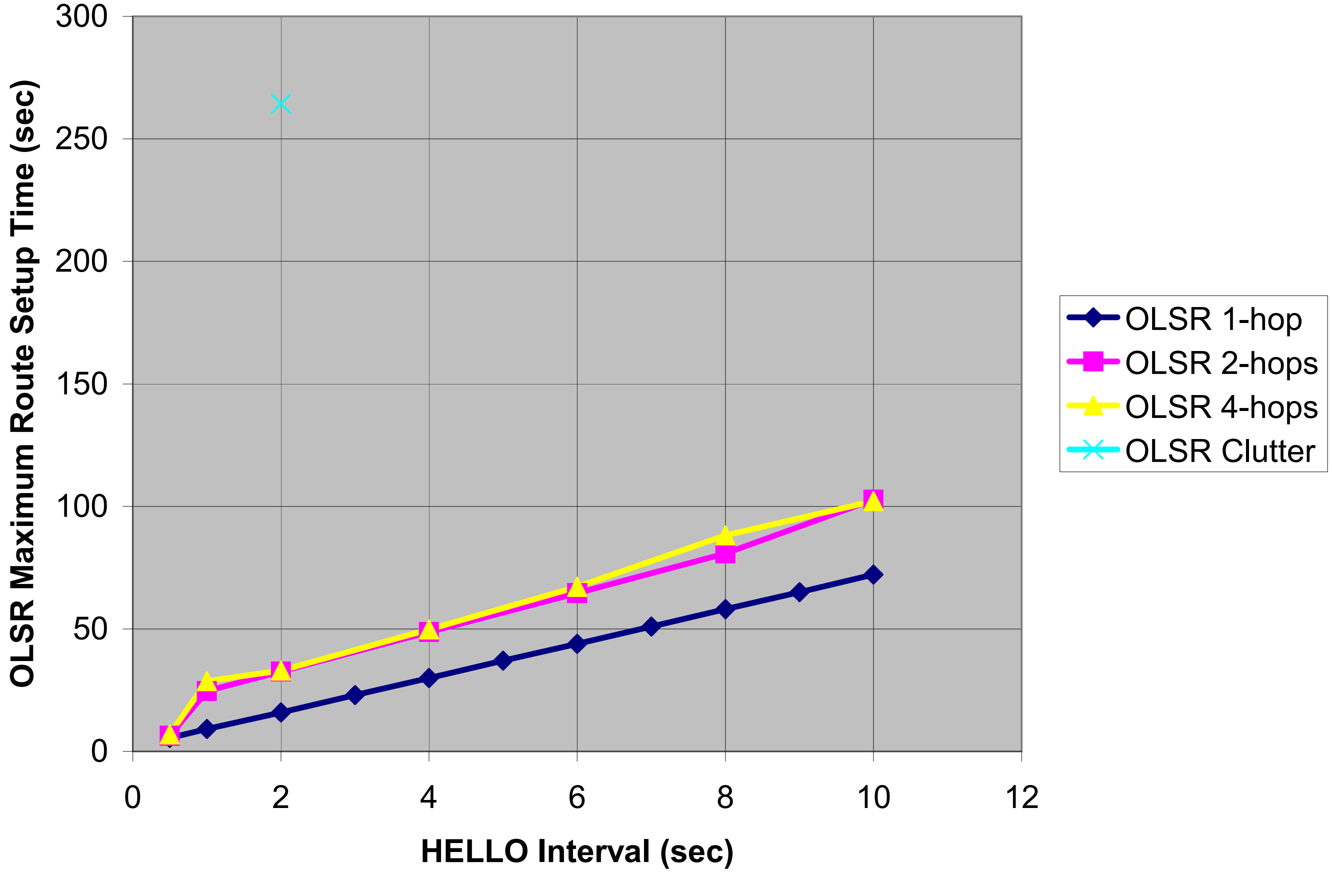
OLSR Maximum Route Setup Time



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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

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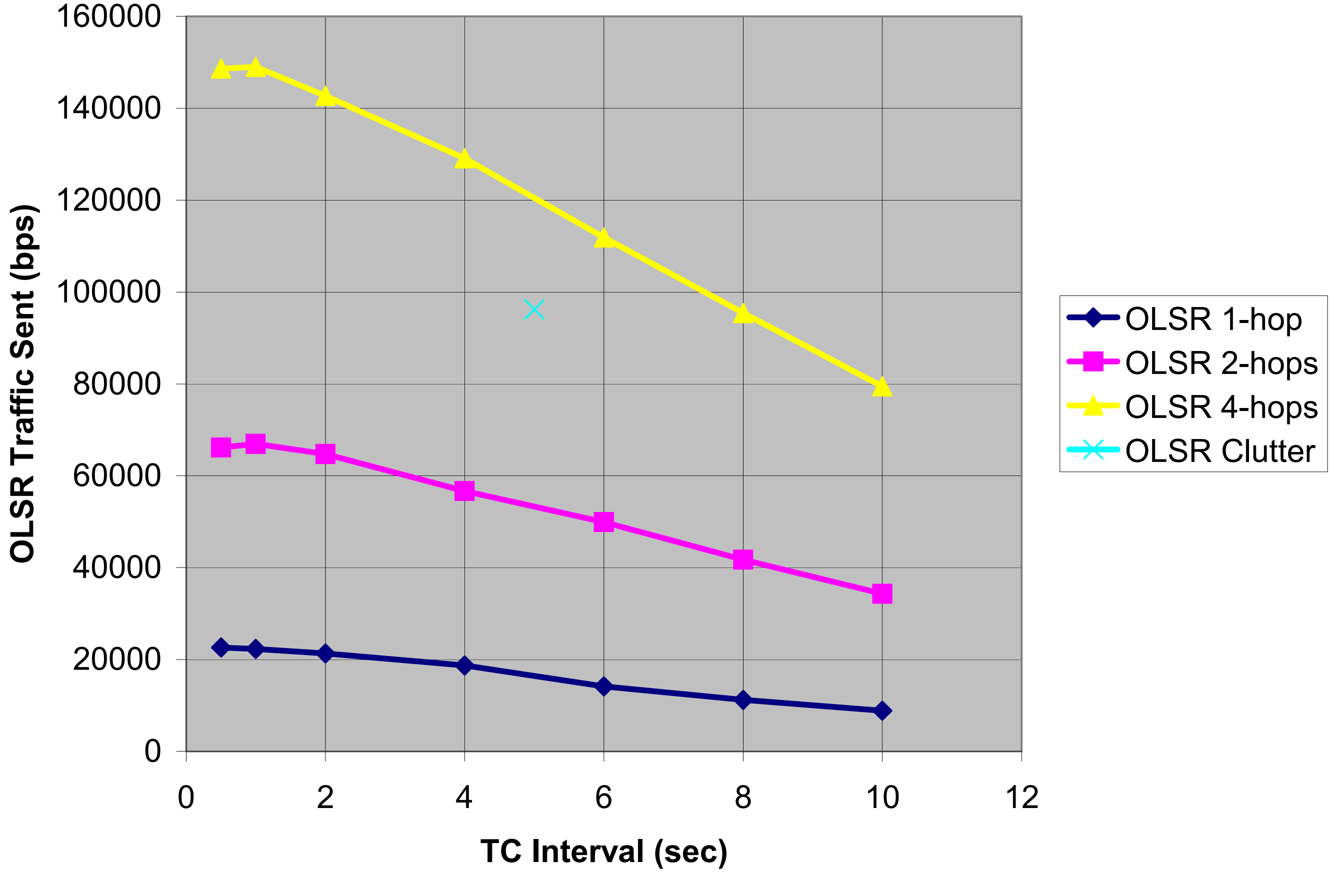
TC Interval Study

OLSR Traffic Sent



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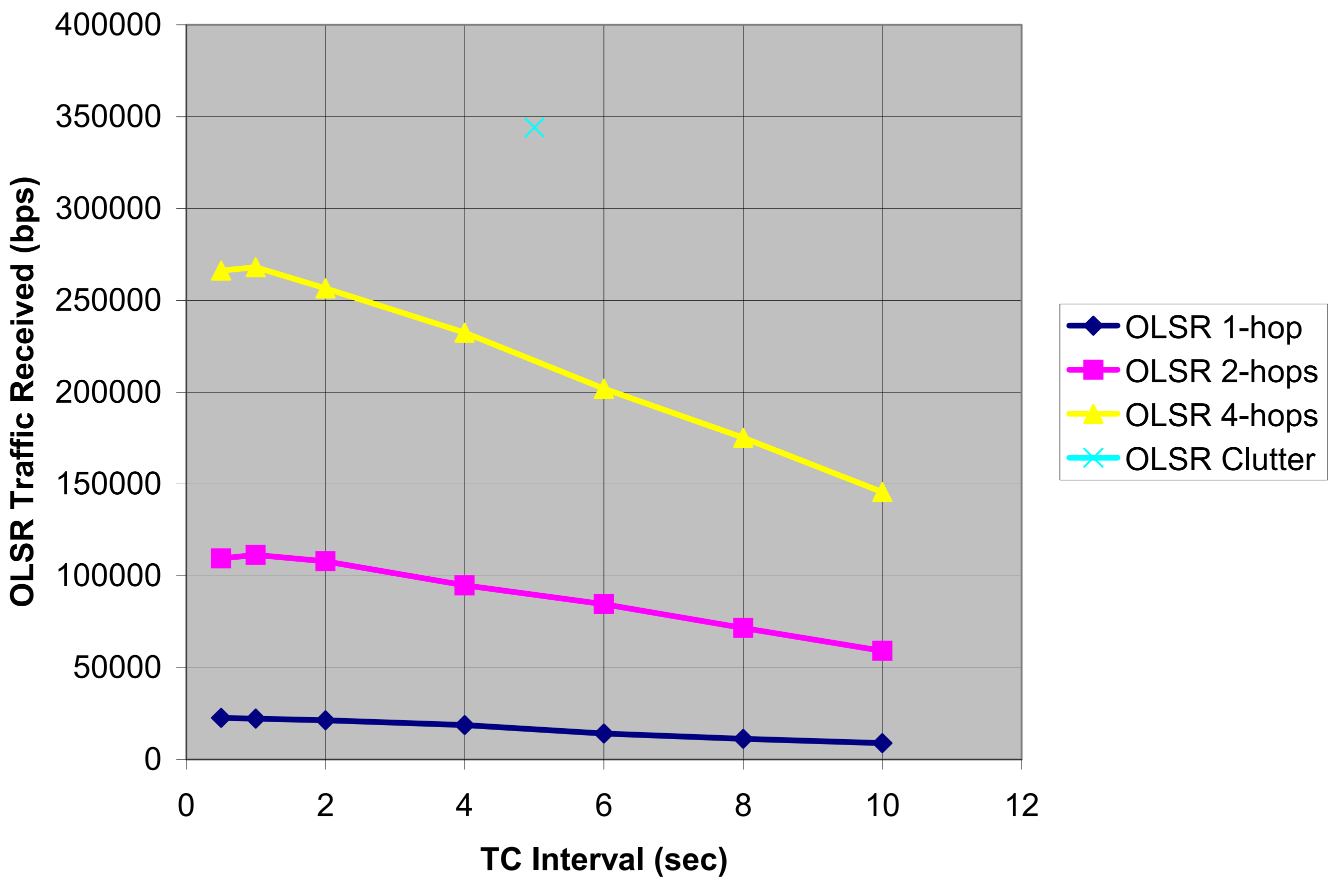
OLSR Traffic Received



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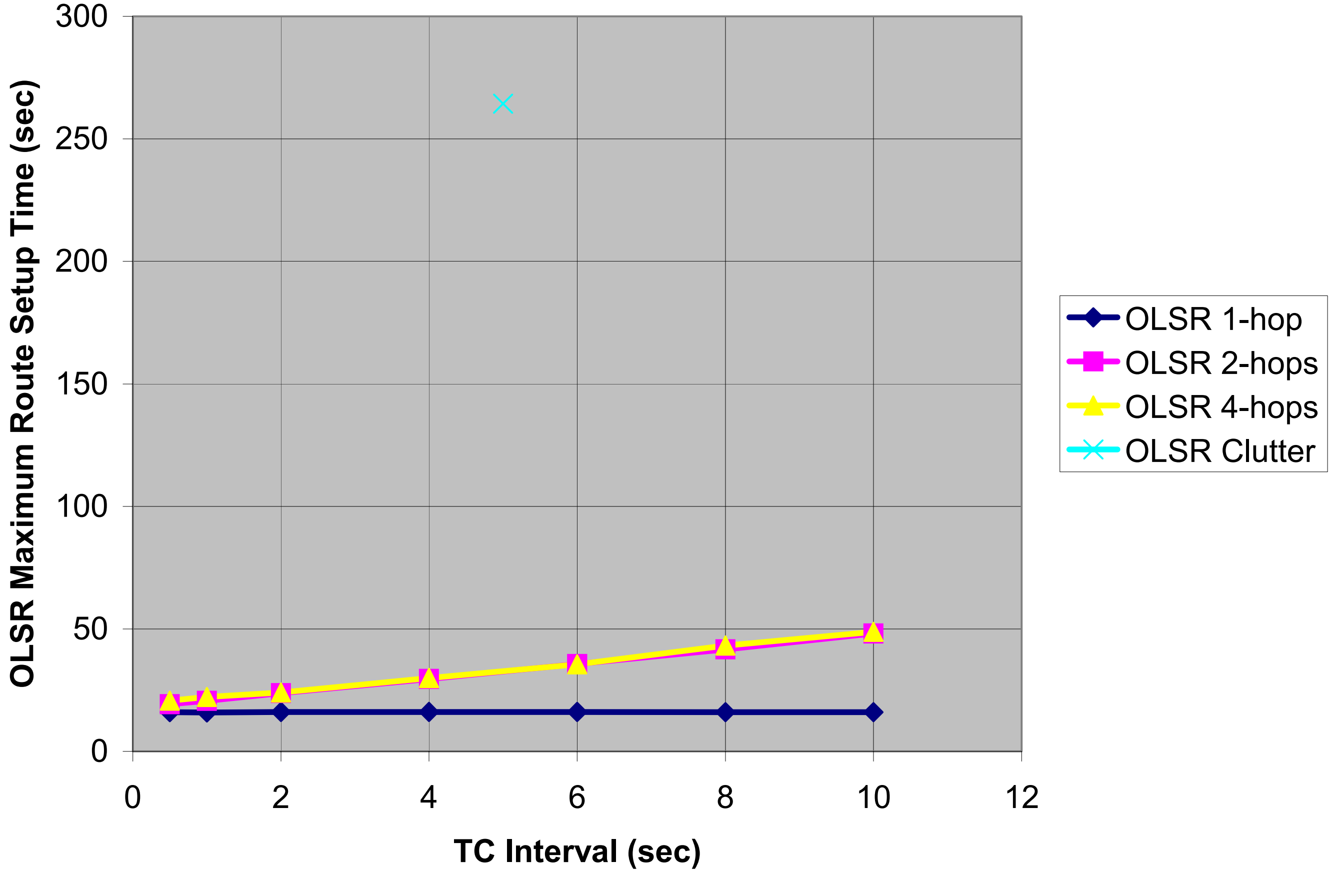
OLSR Maximum Route Setup Time



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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

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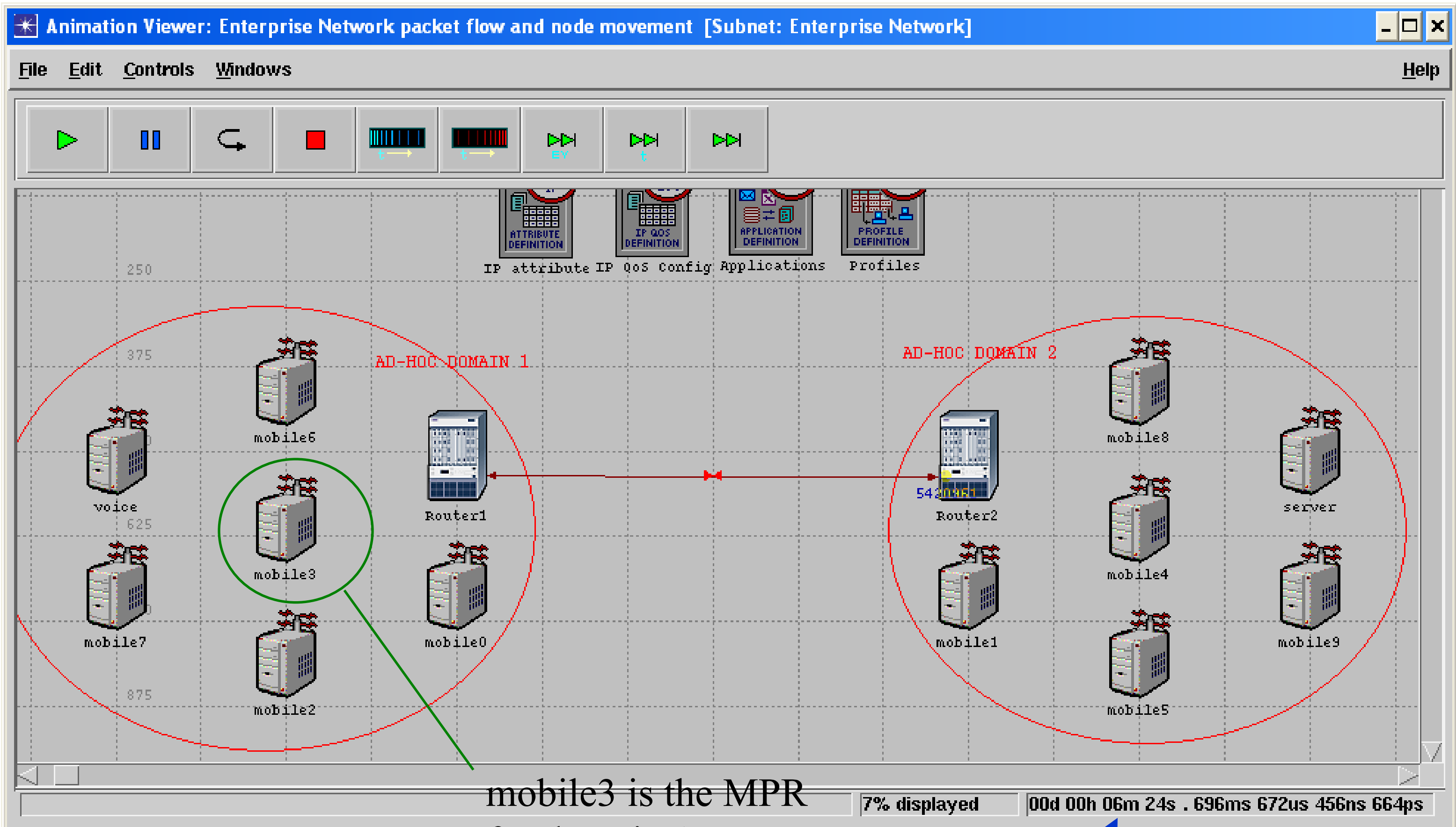
MPR and Mobility Study

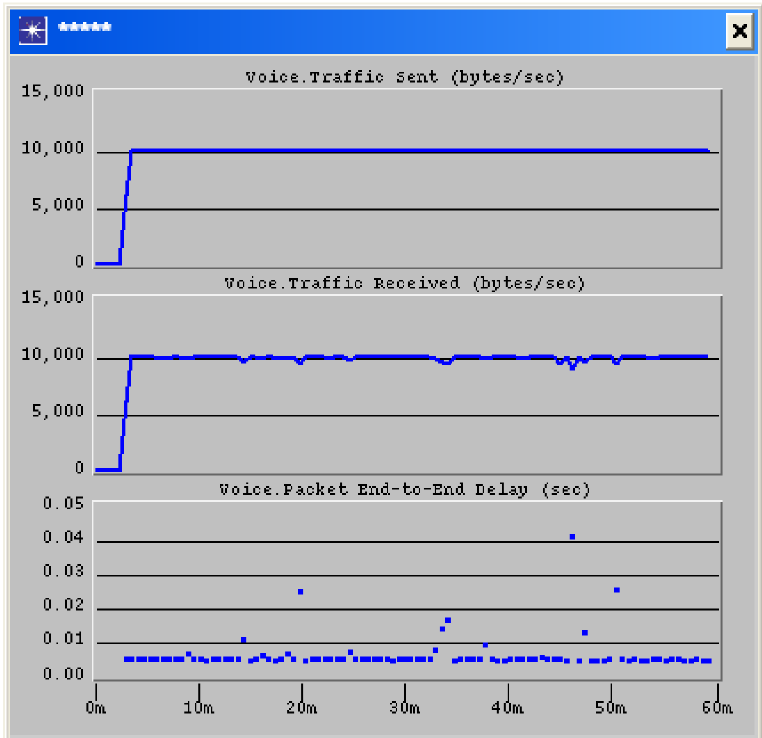
Initial Cluster Topology

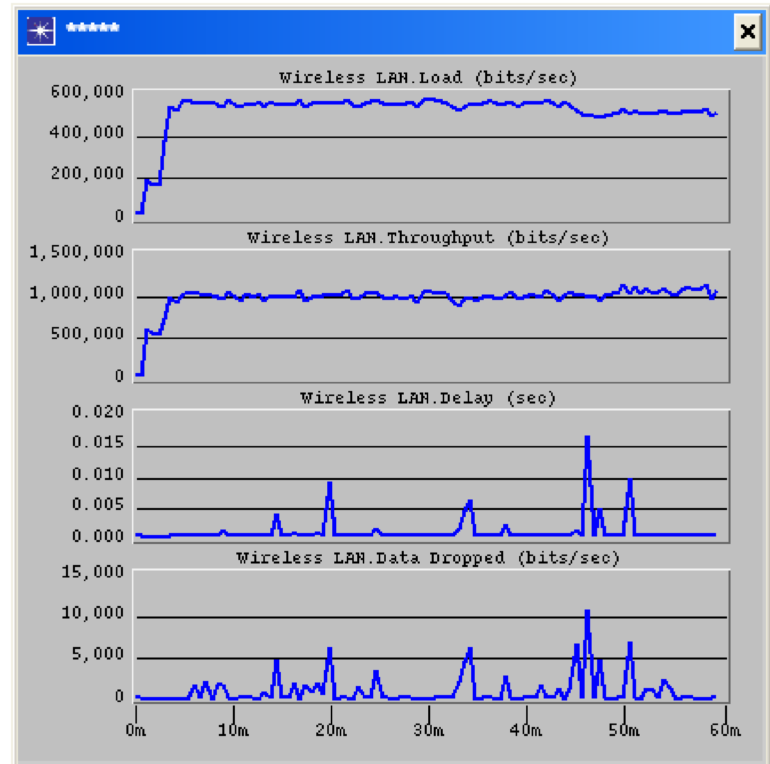


mobile3 is the MPR for domain 1

simulation time

Static Network Performance
Cluster Topology





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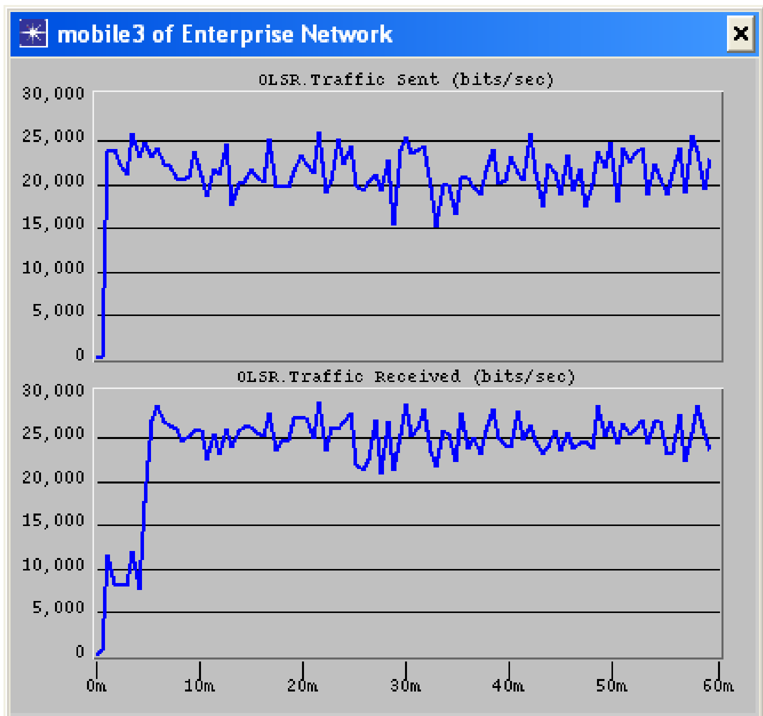
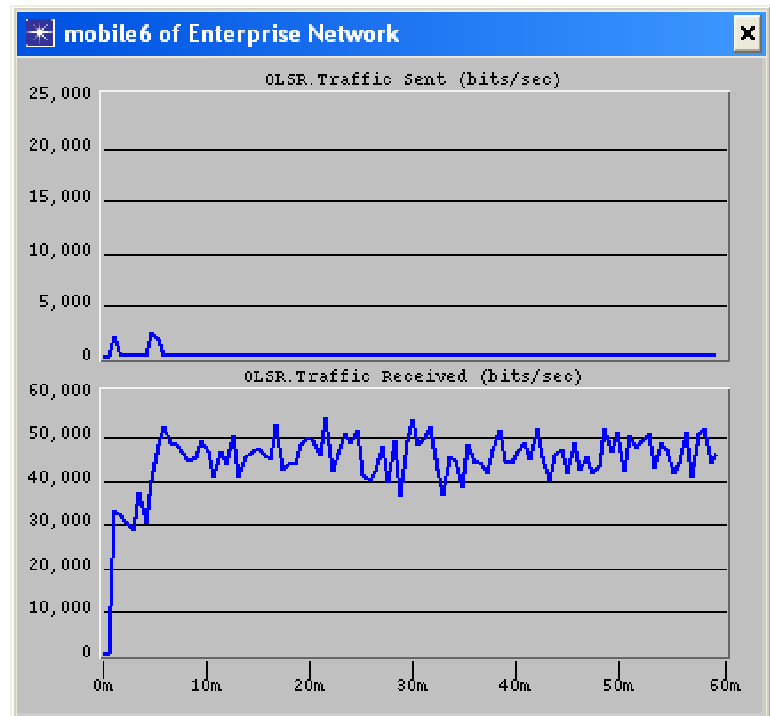
Static Network Performance
Cluster Topology



mobile3 (mpr)



mobile6 (non-mpr)

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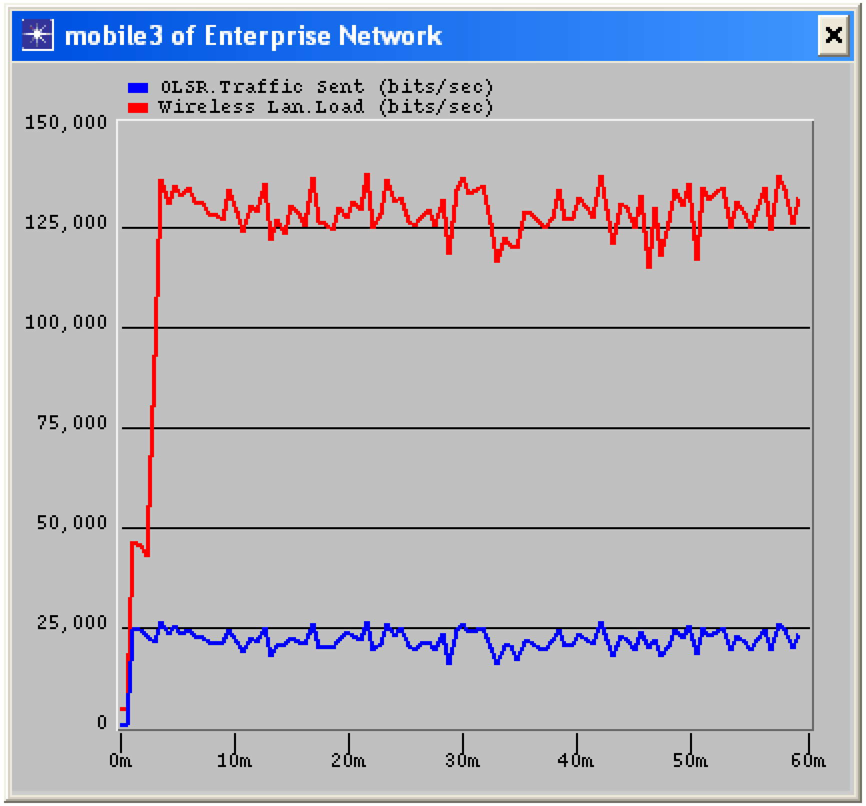
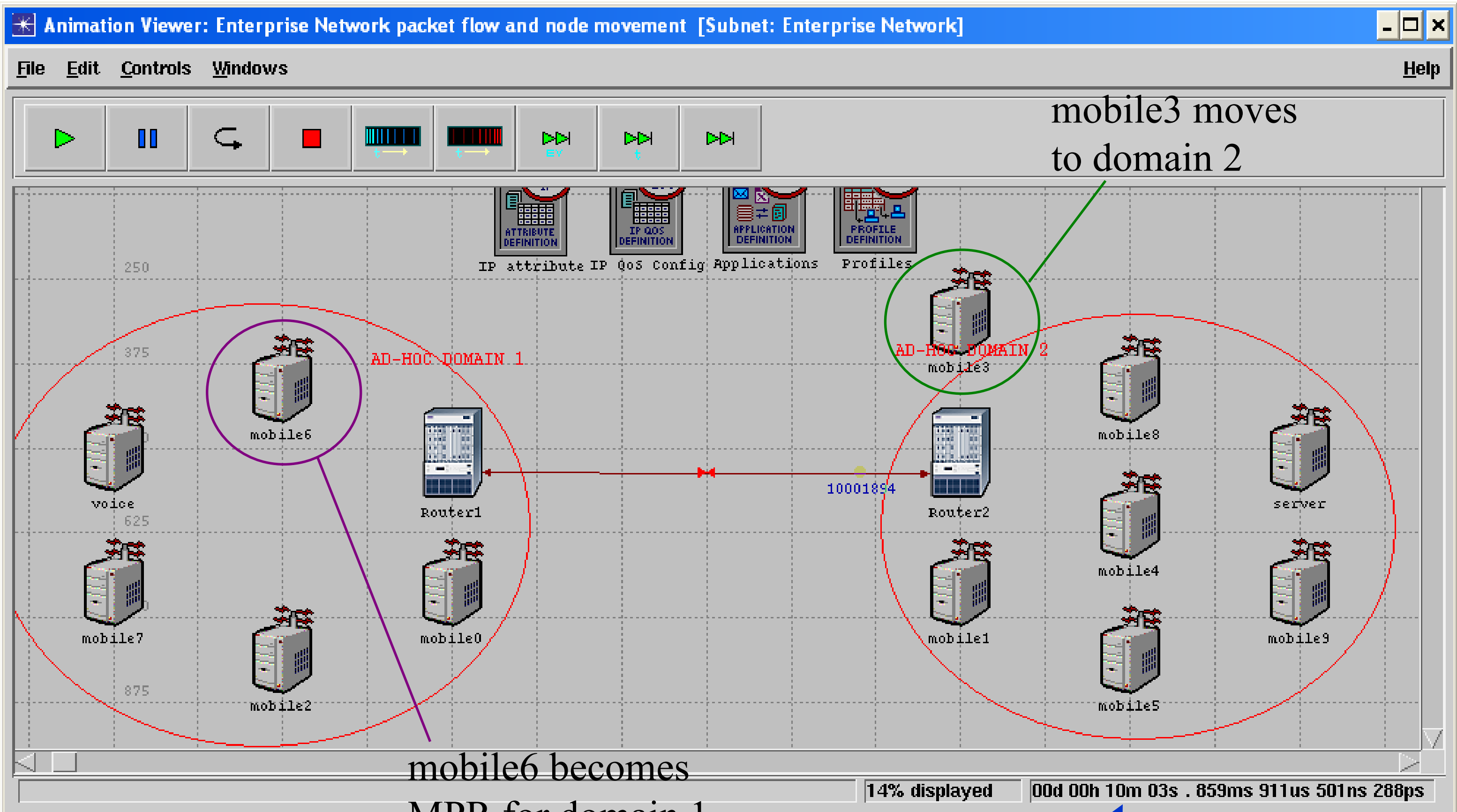
Static Network Performance
Cluster Topology



mobile3 (mpr)

Cluster Topology
Mobility at 10 minutes



mobile3 moves to domain 2

mobile6 becomes MPR for domain 1

simulation time

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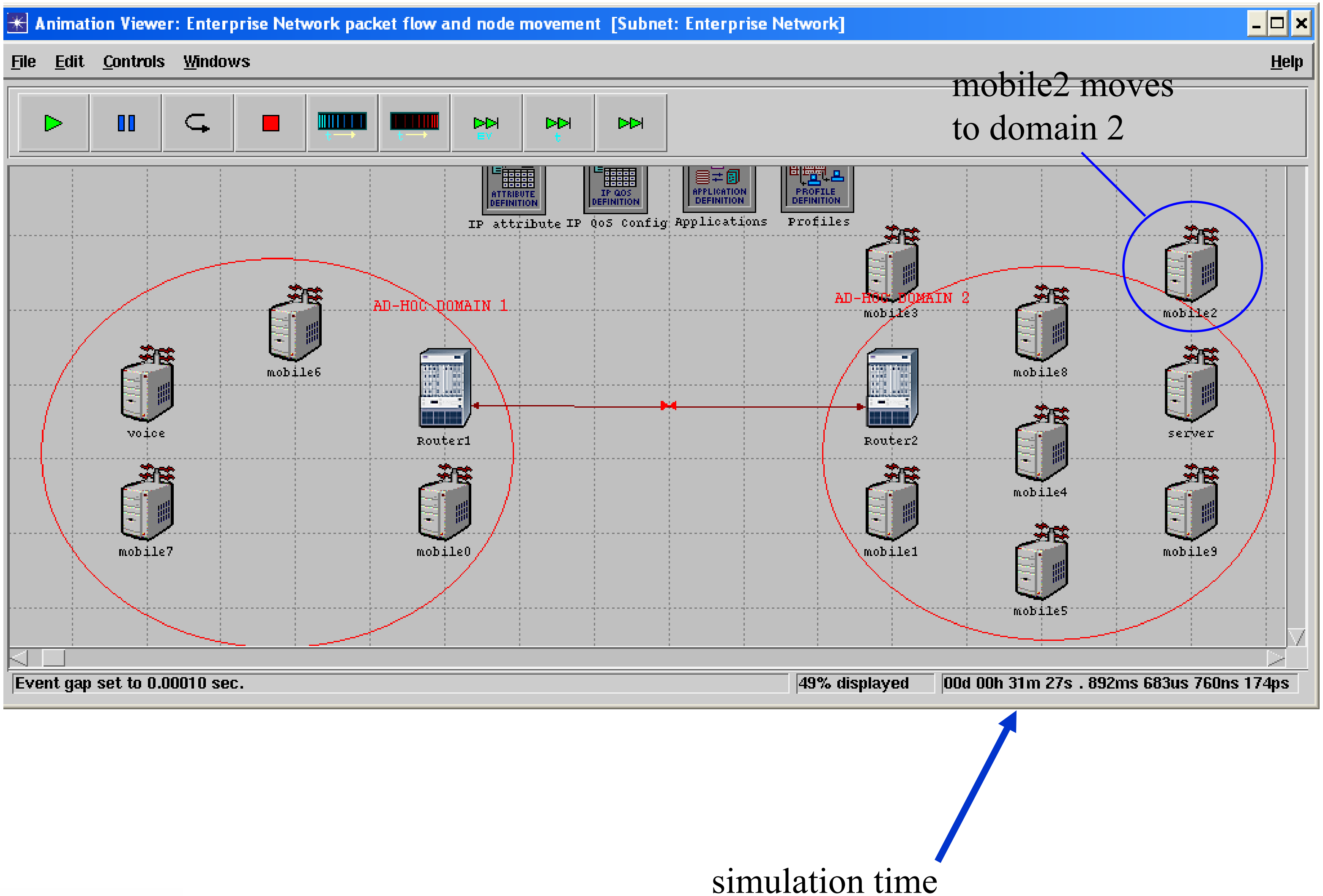
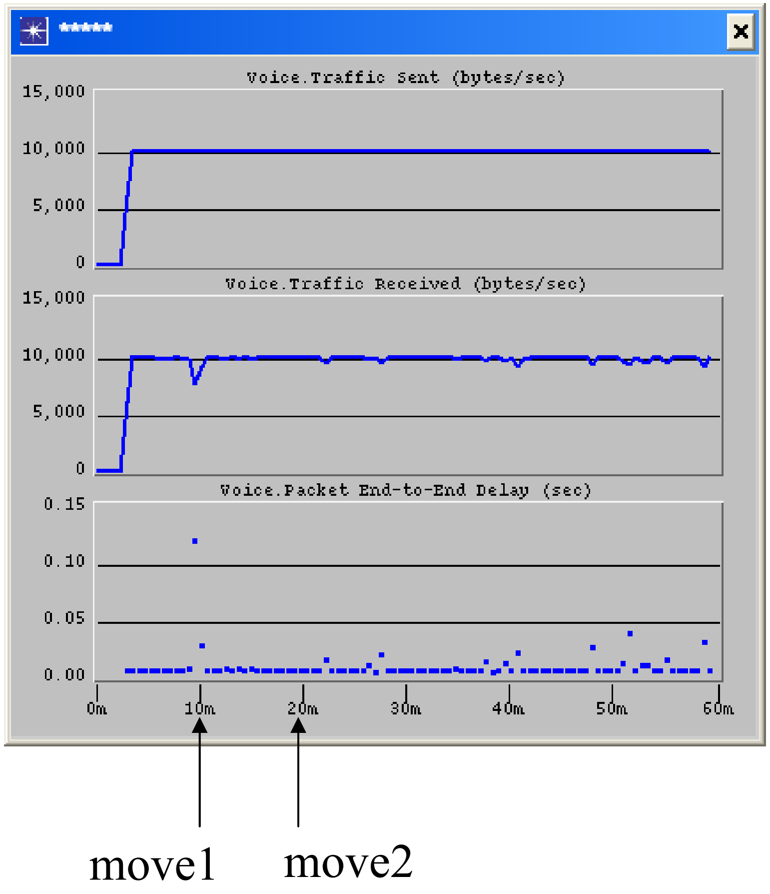
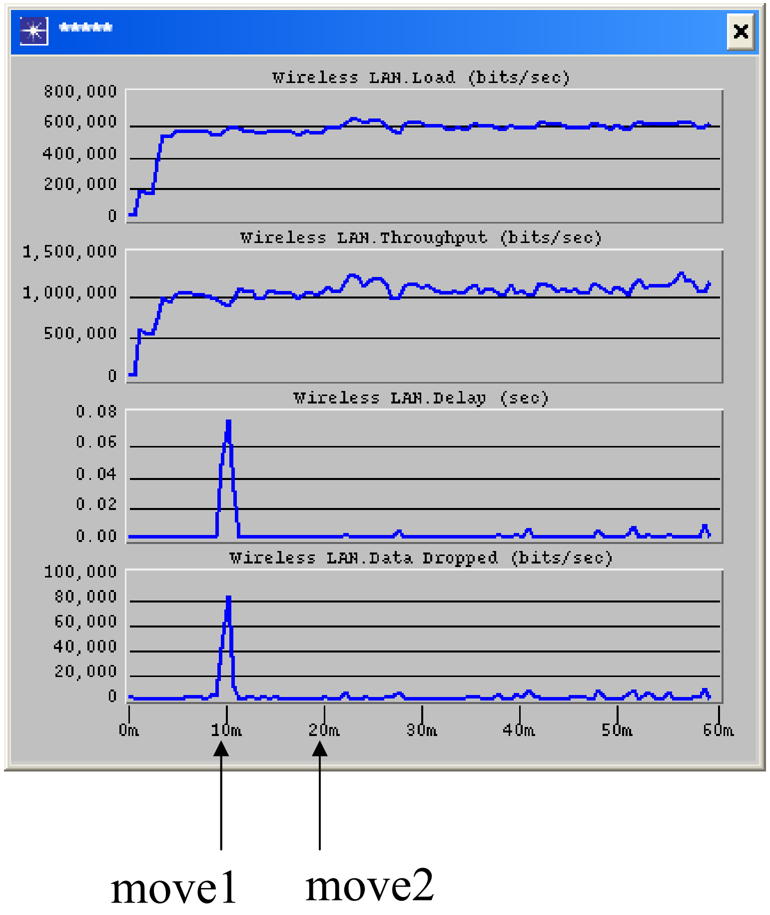
Cluster Topology
Mobility at 20 minutes



Cluster Topology
Network Performance with Mobility





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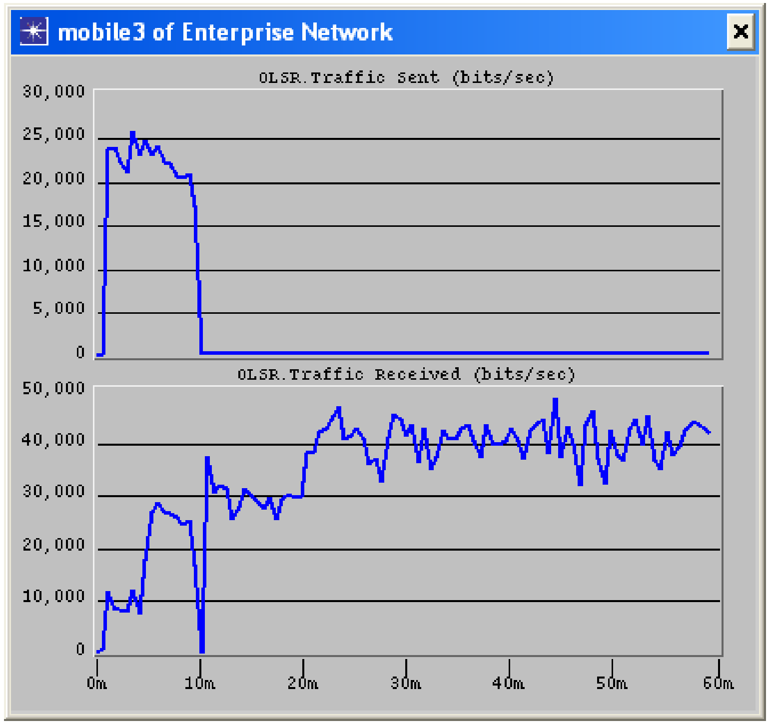
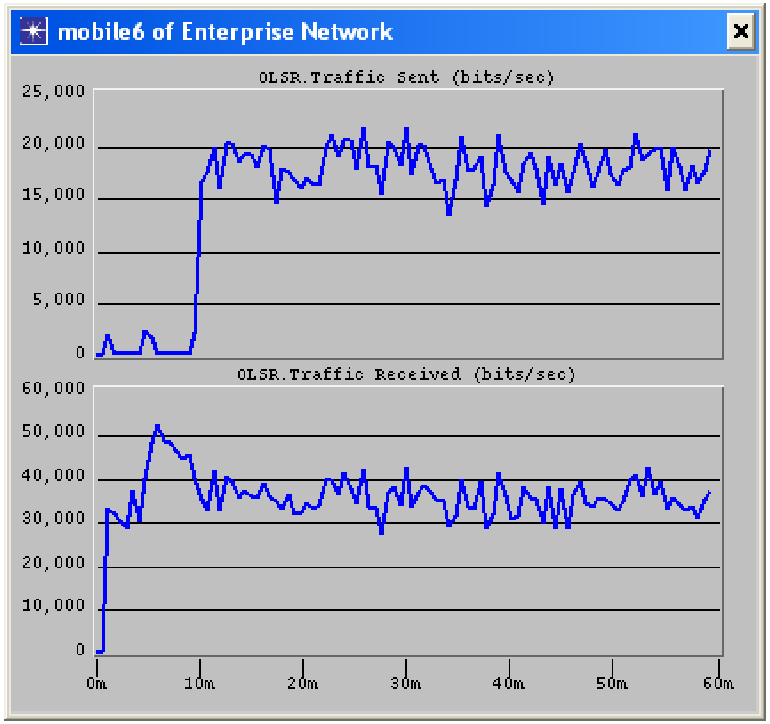
Cluster Topology
Network Performance with Mobility



mobile3 (mpr 0-10min)



mobile6 (mpr 10-60min)

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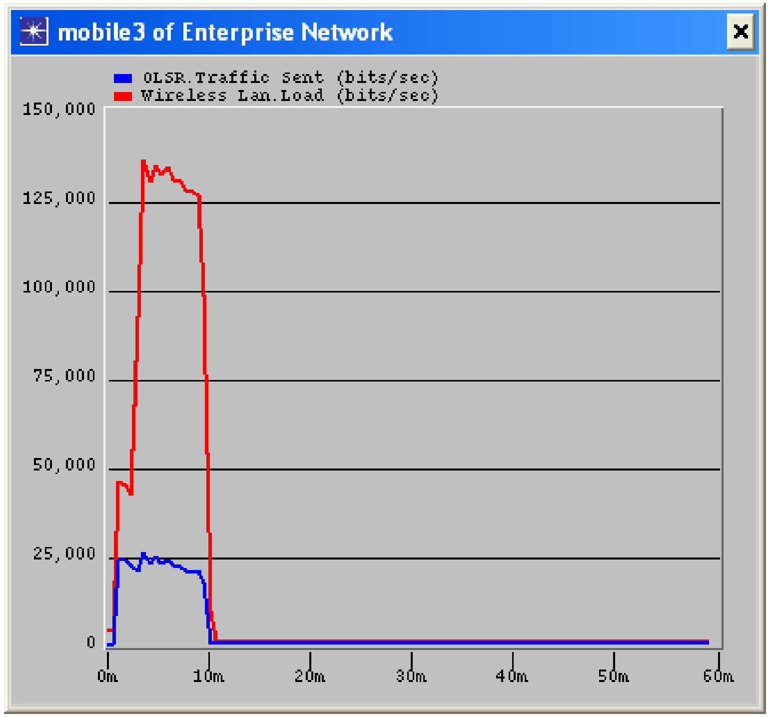
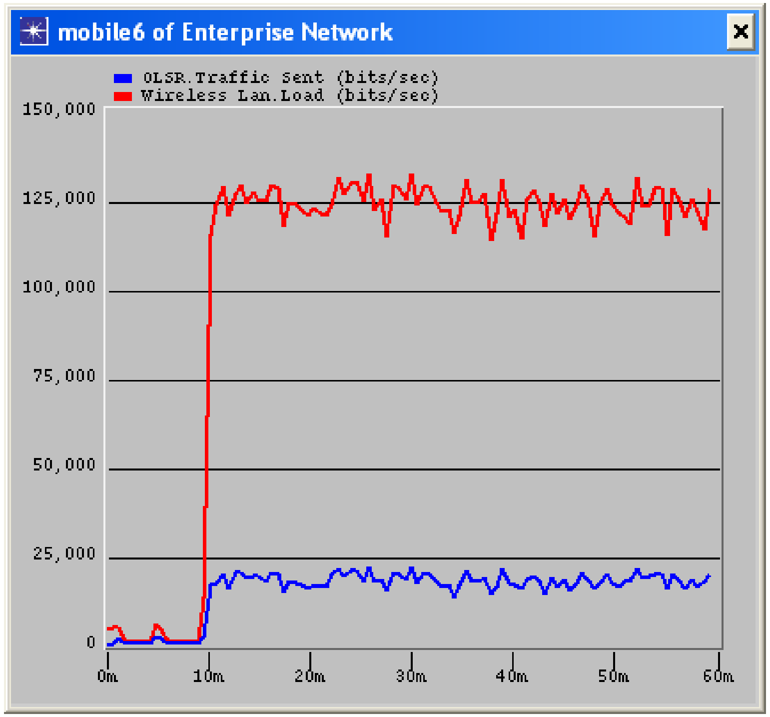
Cluster Topology
Network Performance with Mobility



mobile3 (mpr 0-10min)



mobile6 (mpr 10-60 min)

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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)

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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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