Discovery in Self-Organizing Hierarchical Ad Hoc Wireless Networks and SOHAN Prototype

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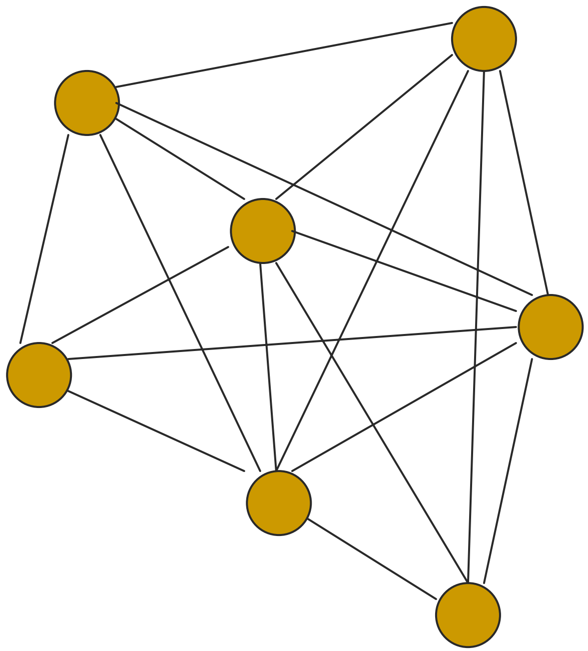
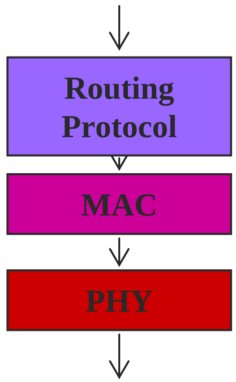
Outline

- Motivation
- Study of discovery mechanisms
  - Centralized and Distributed
- Beacon-Assisted Distributed Discovery Protocol (BEAD)
- Performance of discovery protocols
- Details of prototype implementation (SOHAN)
- Conclusions and Future Work

Existing Ad-hoc Networks



Typical single channel
flat ad-hoc network



Protocol stack
at each node

Topology is defined by the paths chosen by the routing protocol

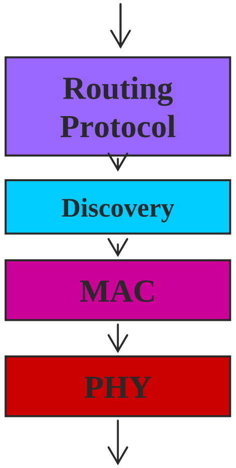
- Proactively using table exchanges
- Reactively using on-demand route-requests

Motivation

- No discovery phase in traditional ad-hoc networks
- Routing protocol responsible for topology formation either using on-demand route requests (e.g. DSR) or proactive exchange of neighbor tables (e.g. DSDV)
  - **For dense topologies, this could generate a lot of routing messages due to 'global' exchange of information**
  - **For multi-channel networks, routing information may need to be propagated across multiple channels**
  - **All nodes assumed to be homogenous and hence use the same routing decision (minimum delay, minimum energy etc)**

Discovery

- Introduce discovery layer between MAC and Routing
  - Filters links made available to the routing protocol based on desired objective function – reduces routing overhead
  - Allows each node to apply a different objective depending on the role it plays
  - Supports multi-channel operation of network



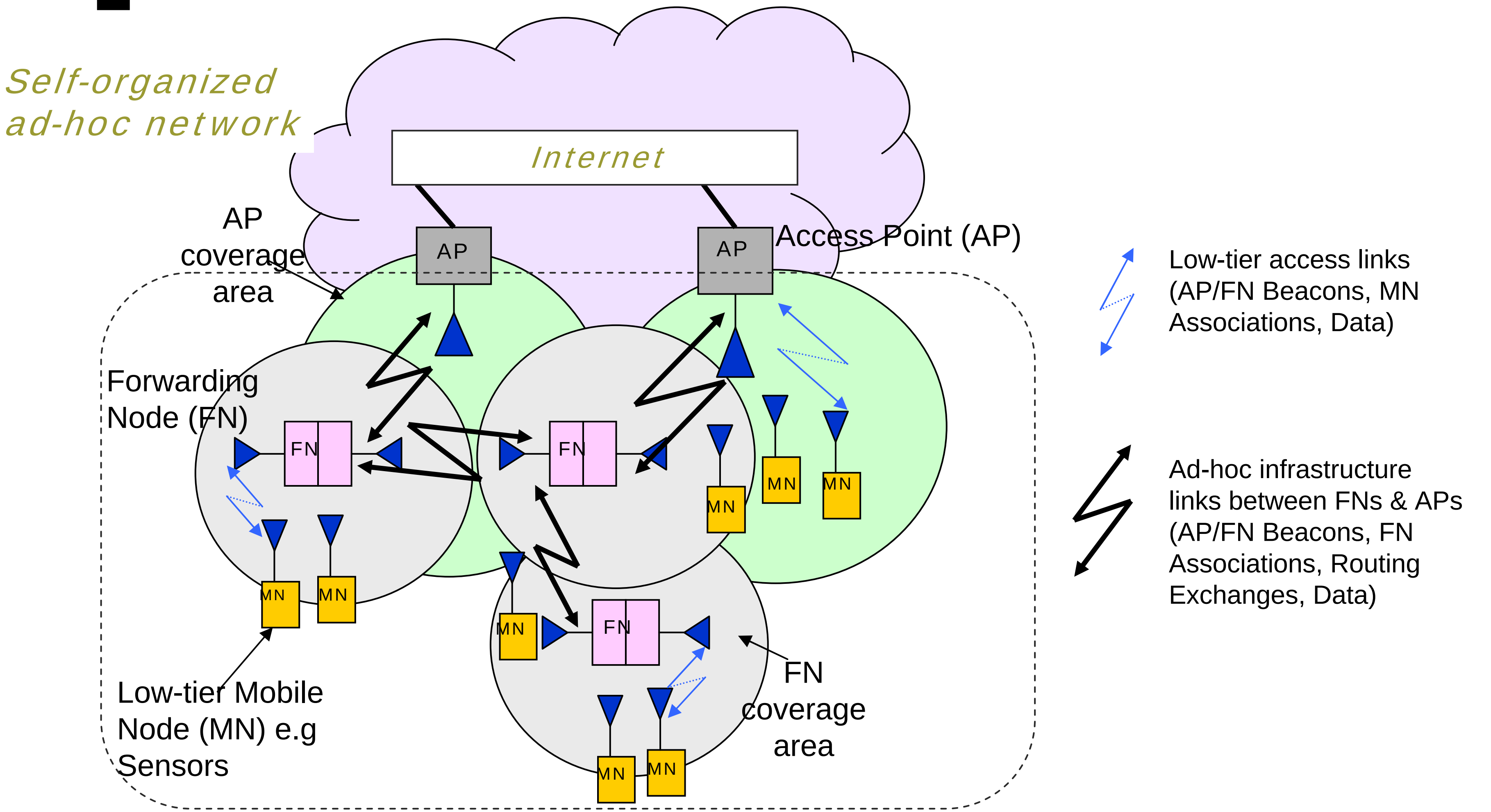
Aim

- Need a distributed mechanism for neighbor discovery that
  - Allows topology control based on desired objective function at each node
  - Supports multi-channel operation
  - Reduces routing overhead

Approach

- Study topologies established by centralized routing strategies for motivating distributed heuristics
- Design a distributed discovery algorithm whose performance is comparable to the centralized strategy
- Study the benefits of the distributed approach in terms of routing overhead compared to a network without discovery

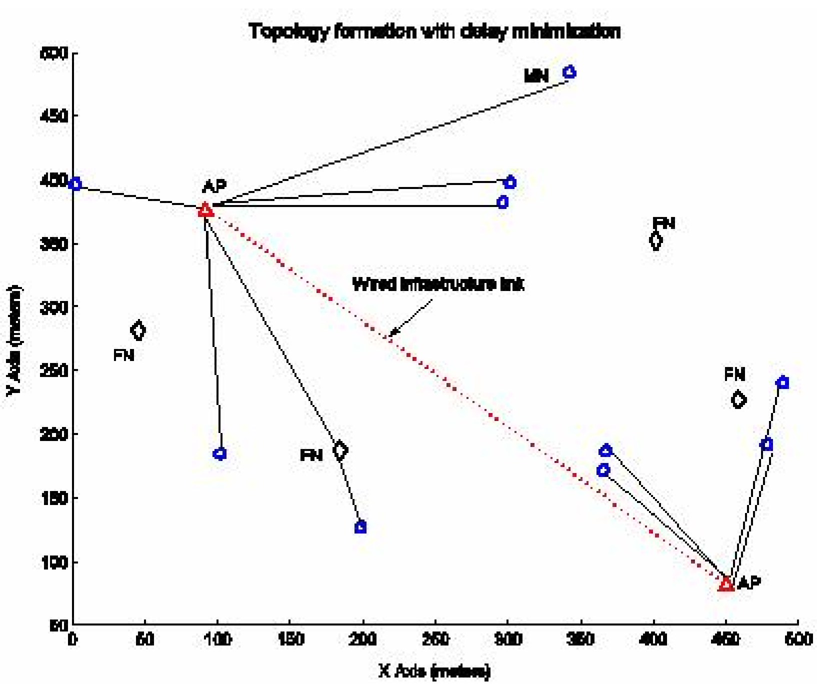
3-Tier Hierarchical Architecture

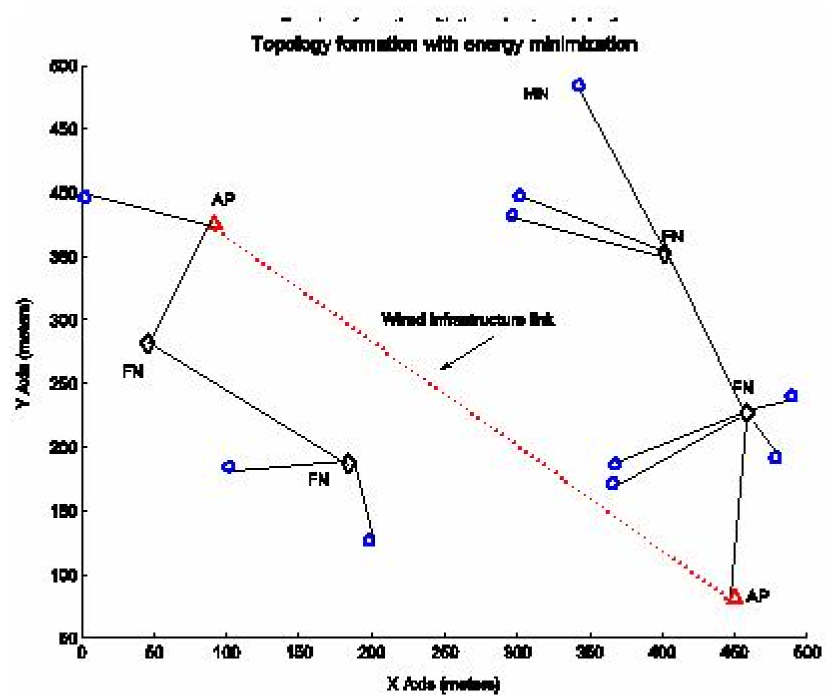


Centralized Discovery Study

- Baseline reference to motivate distributed heuristics and also for comparing performances
- Three basic topologies: minimum energy, minimum delay and maximum throughput
- Using linear programming in MATLAB, study effects of delay and throughput constraints on minimum energy objective function

Centralized Study

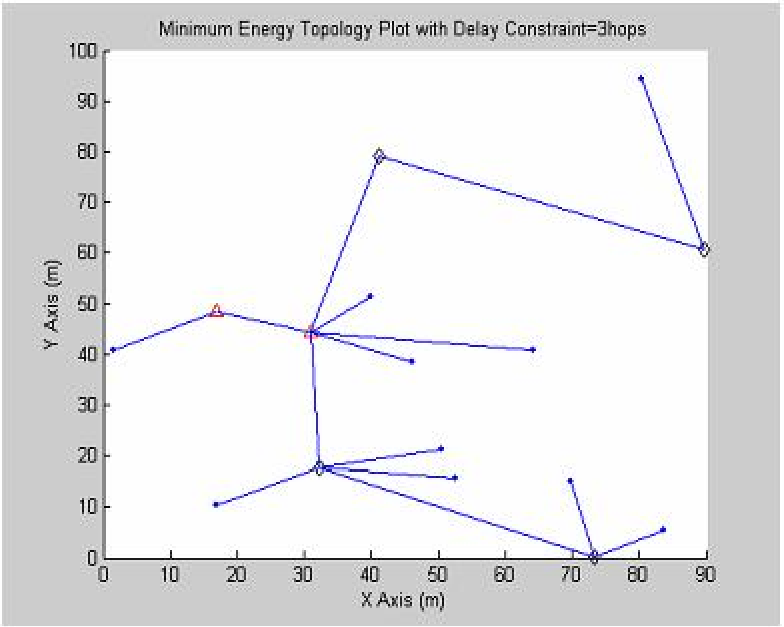




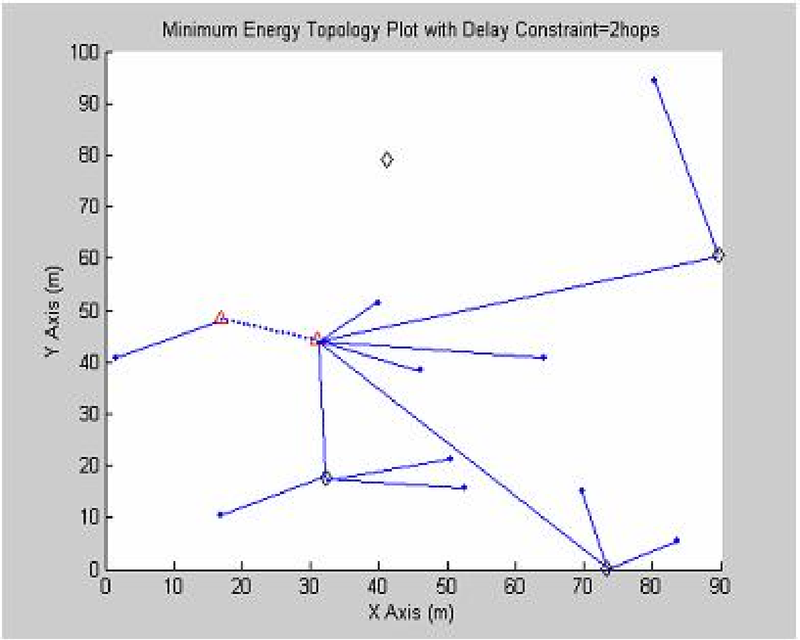
Equivalent to standard
shortest-path routing protocols

Minimum Energy with Delay Constraint

Delay constraint = 3 hops



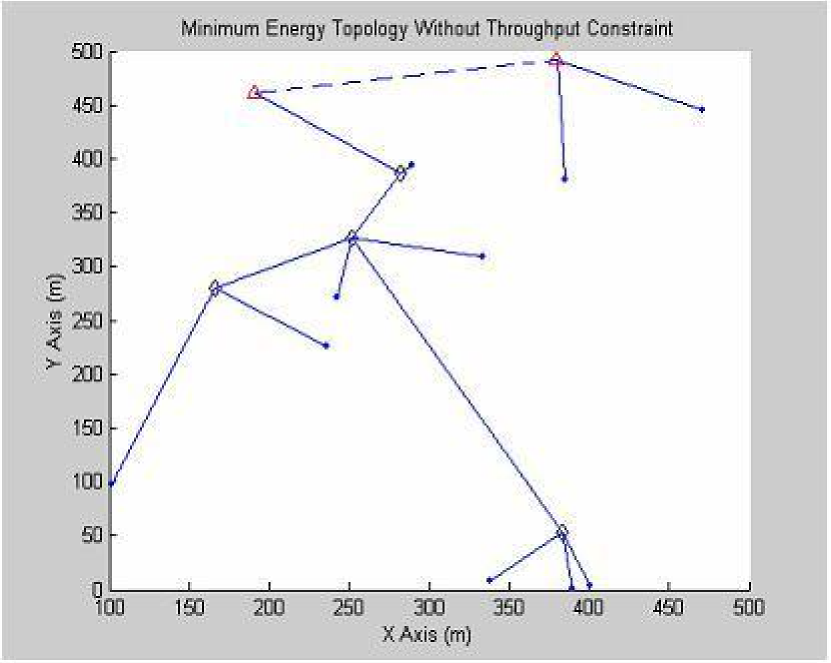
Delay constraint = 2 hops



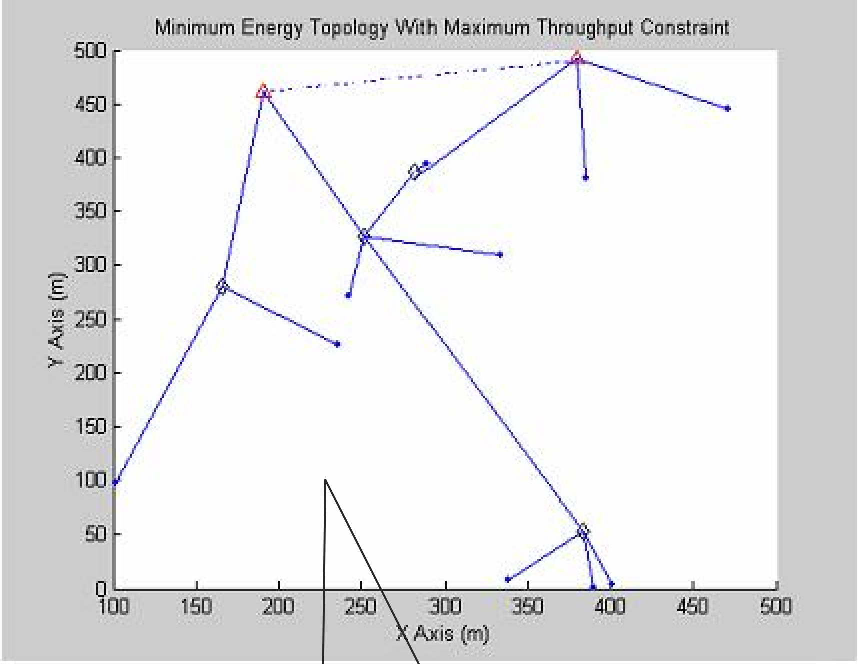
Objective: Minimize energy to AP subject to delay constraint of 'n' hops

Minimum Energy with Throughput Constraint

Without throughput constraints



With throughput constraints



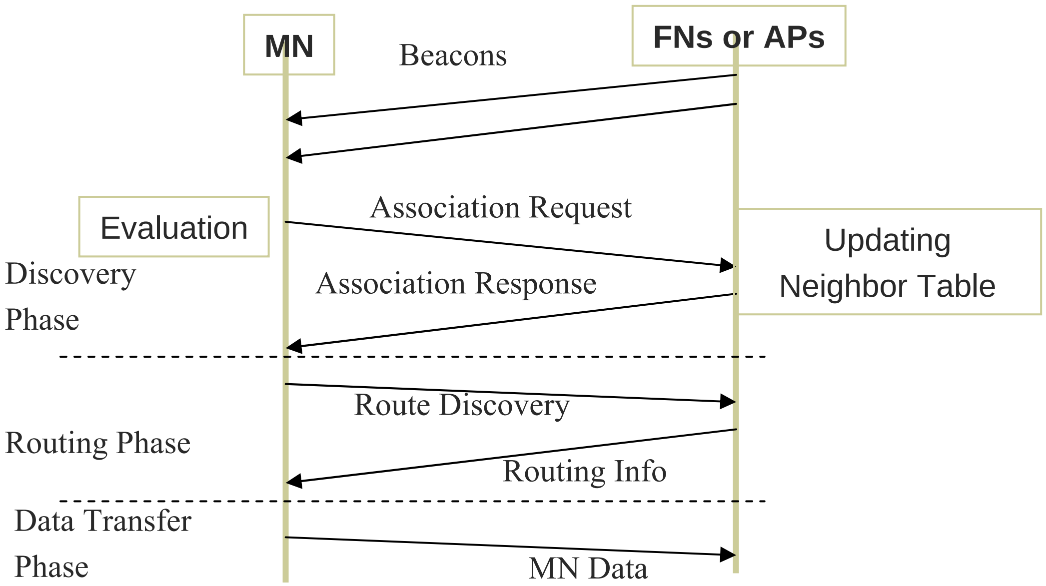
FN's achieve AP load balancing

Objective: Minimize energy to AP subject to throughput constraints or R kbps

Distributed Discovery Algorithms

- Previous centralized study is used as a baseline and is not suitable for actual deployment
- Need a mechanism that matches the performance of centralized scheme and is distributed as well

Beacon-Assisted Distributed Discovery Protocol (BEAD)



- Three-way handshake to form associations
- Routing phase occurs *after* discovery is complete
- Route requests are forwarded only over links formed during discovery

Distributed Algorithms

- ME – Transmit power minimization at MN layer and delay minimization at FN layer
  - Suggested by observations of centralized analysis

- MD – Delay minimization at both MN and FN layers
  - Standard objective of routing algorithms

NS-2 Simulation Parameters

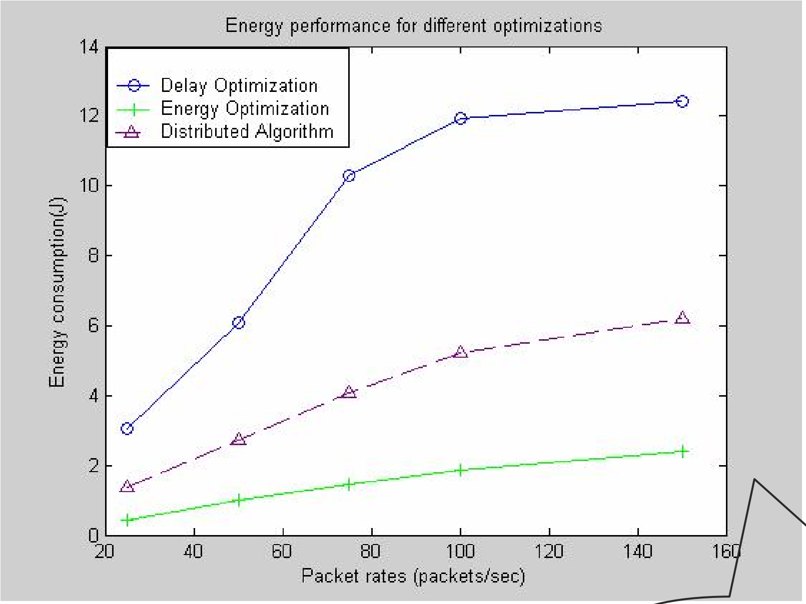
- Data Type - CBR/UDP
- Packet Size - 64 bytes
- Beacon Interval - 100ms
- Missed beacons permitted - 5
- Rescan timer (Number of Beacon Intervals) - 50
- Routing protocol - AODV
- MAC Protocol - 802.11
- Maximum data rate -1Mbps
- 1000x1000m area unless otherwise mentioned

Comparison with Centralized Study

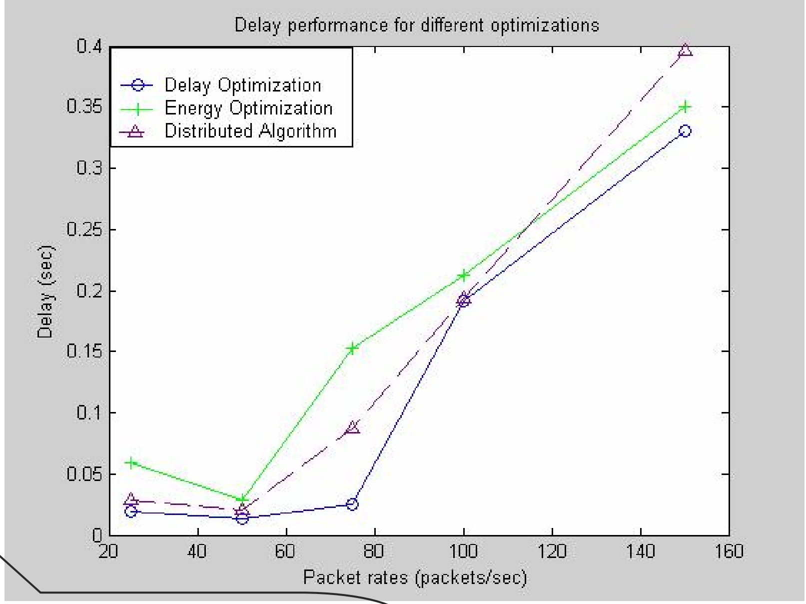
Algorithm Used for comparison: ME

(minimize energy consumption at MN's, minimize delays at FN's.)

Energy consumption



Delay



Distributed heuristic performance is comparable to centralized topologies

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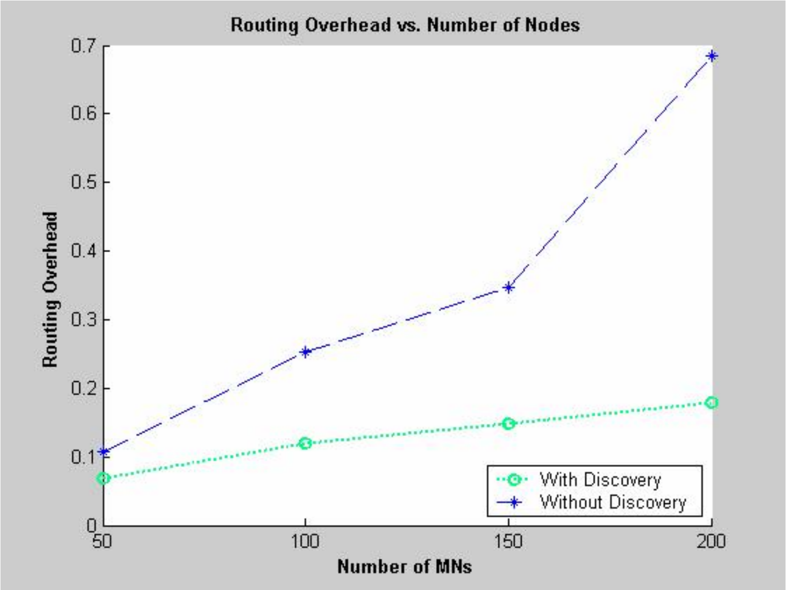
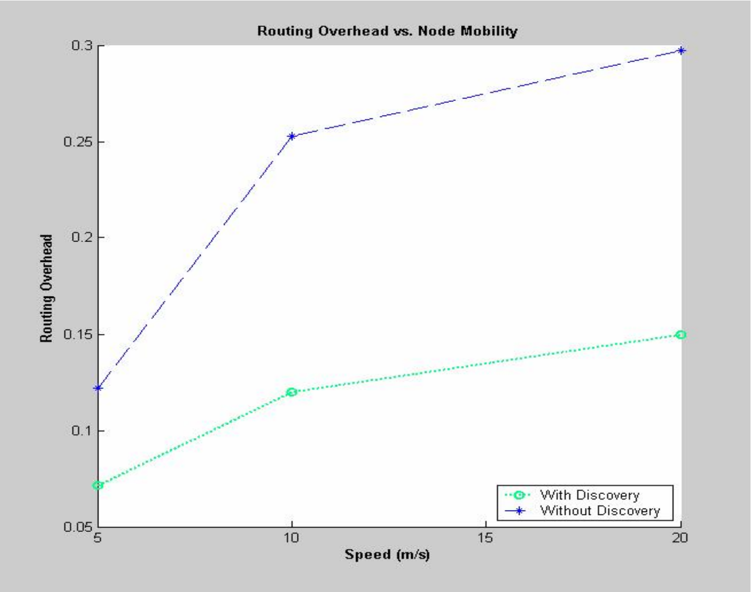
Effects on Routing Overhead

Routing overhead vs. number of nodes



Routing overhead vs. mobility



The discovery protocol significantly reduces routing overhead

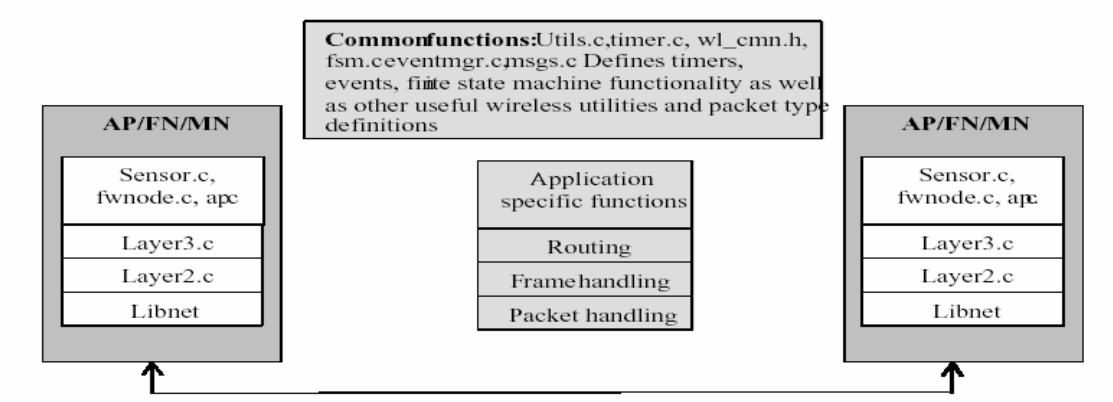
Prototype details

HARDWARE

Access Point	Forwarding node	Sensors
US Robotics 2450 AP	Compulab 586 CORE	Intrinsyc Cerfcube
AMD Elan SC400 processor	AMD Elan SC520 CPU	Intel PXA 250 (XScale processor)
1 MB Flash, 4 MB RAM	2 MB NOR flash + 64 MB NAND Flash on board	CF-based wireless support
Prism-2 based PCMCIA card	Dual PCMCIA slots	

PLATFORM

SOFTWARE

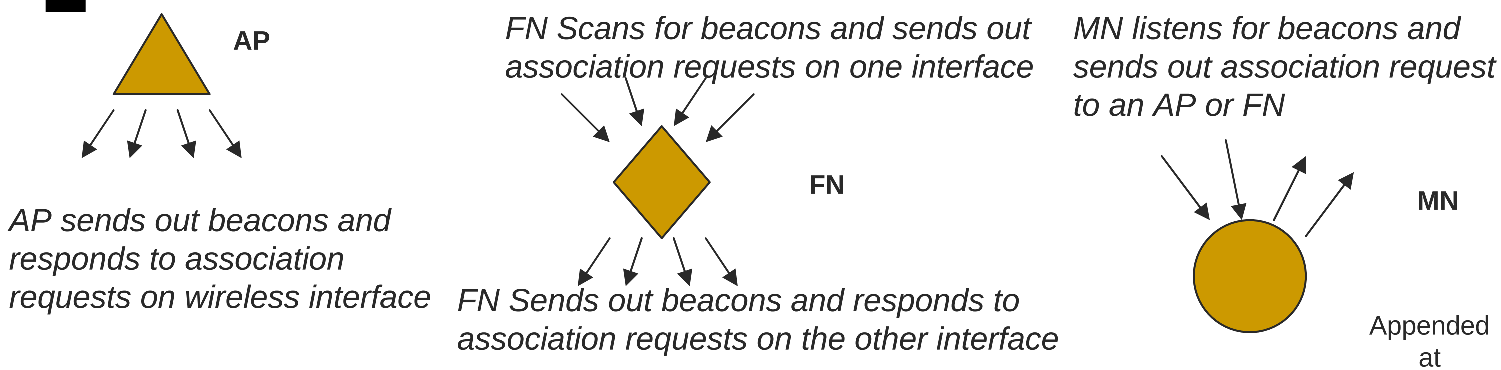


802.11b ad-hoc mode

Prototype Components

- Initial bootstrapping (channel allocation and transmit power levels using scripts)
- Discovery (BEAD) Implementation
- Distance-vector based routing protocol
- Data transfer from MN’s to AP’s upon association

BEAD Implementation



Beacon

Appended at Transmitter: Transmit Power · Appended at Receiver: Recv Power

Frame Control	Duration	Broadcast MAC	Source MAC	Node ID	Node Type	Hops to AP	Packet Type (Beacon)	BSSID	Transmit Power	fcs	Recv Power

Association Request

Frame Control	Duration	Destination MAC	Source MAC	Node ID	Node Type	Hops to AP	Packet Type (Assoc)	fcs

Association Response

Frame Control	Duration	Destination MAC	Source MAC	Node ID	Node Type	Hops to AP	Packet Type (Assoc_rep)	Transmit Power	BSSID	fcs

Neighbor table maintained at each node

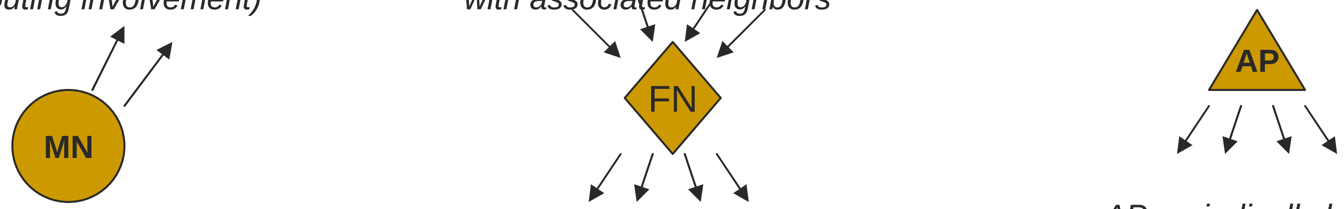
Neighbor MAC	Node ID	Node Type	Channel	Interface	Transmit Power	Recv Power	Hops to AP	Refresh Timer	Seq Num	BSSID

Each entry is a link in the topology available to routing protocol

Routing Protocol

MN simply sends data to parent (no routing involvement)

FN periodically exchanges routing table with associated neighbors



Neighbor table forms basis for initial routing table entries and updates

AP periodically broadcasts neighbors tables

Routing table at an FN/AP

Destination Node ID	Destination MAC	Node Type	Channel	Interface	Next Hop MAC	Cost (Hop Count)	Refresh Timer

Node ID used to avoid confusion between multiple FN interfaces

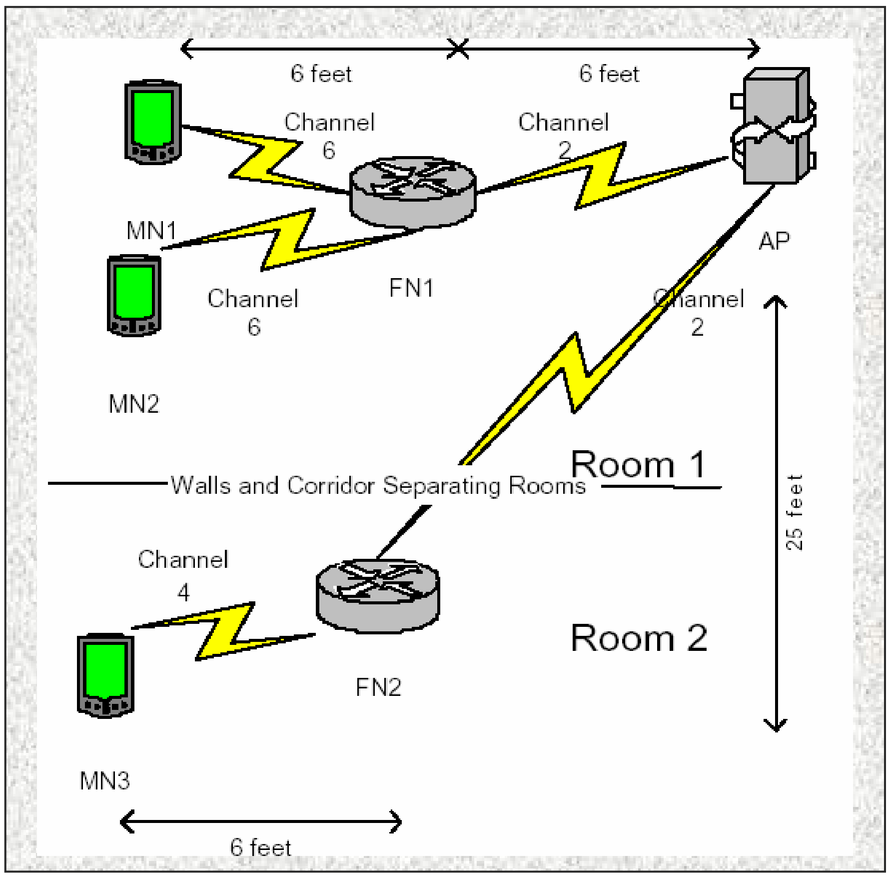
Hop count is used at FN/ AP layer

Stale entries are purged (renewed by discovery)

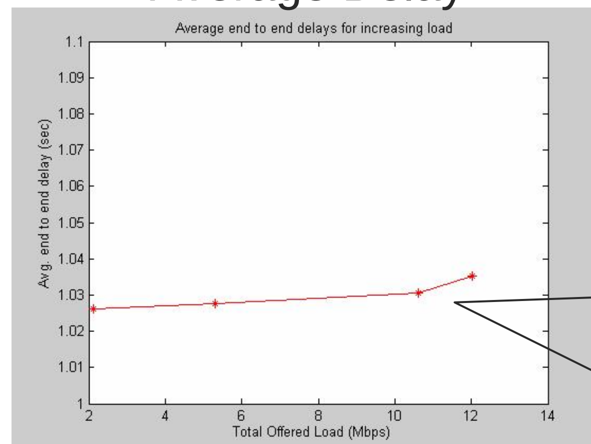
Distance-Vector Based Protocol

Initial Benchmarking Results

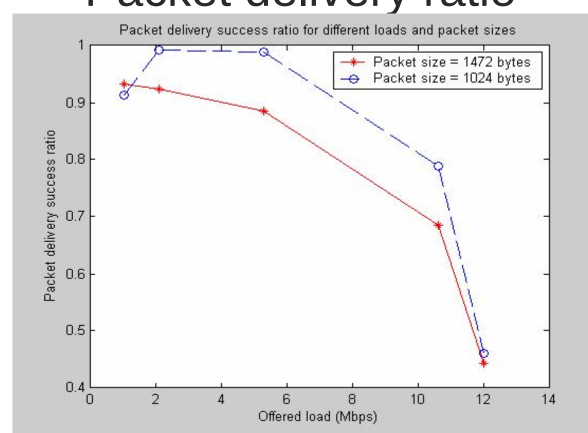
Experimental Setup



Average Delay



Packet delivery ratio



Average delay does not increase dramatically even with increasing load

Future Work

- Study inter-layer interactions between MAC, discovery and routing protocols
- Look into tradeoff between robustness and sparseness of topology
- Using the ORBIT platform, perform experiments with a larger number of nodes to study the effects of scale on the proposed architecture

Minimum Energy with Delay Constraint

Objective function:

$$\min \sum_{i=1}^{N} \sum_{j=1}^{N} P_{ij} X_{ij}$$

Flow Conservation:

$$\sum_{i=1}^{N} X_{ij} - \sum_{i=1}^{N} X_{ji} = 0 \forall j, j \in \Omega$$

$$\sum_{i=1}^{N} X_{iI} - \sum_{i=1}^{N} X_{Ii} = 1$$

$$\sum_{i=1}^{N} X_{ji} - \sum_{i=1}^{N} X_{ij} = 1, \forall j \in \Psi$$

Delay Constraint:

$$\sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij} \leq D$$

Limit on all flows:

$$X_{ij} \geq 0$$

N is the number of nodes in the system

P_{ij} represents the power consumed per bit over the link between node i and node j

($P_{ij} = P_{t(i \rightarrow j)}$ * Maximum Data Rate^{-1})

P_t represents the transmit power cost along a link

X_{ij} represents the flow over the link between node i and node j and is either 0 or 1

Ω represents the set of forwarding nodes and access points in the system

I is the Internet represented by a single node acting as the destination for all sensor traffic

Ψ is the set of all sensors in the system

D is the maximum permissible end-to-end delay

Minimum Energy with Throughput Constraint

Objective function:

$$\min \sum_{i=1}^{N} \sum_{j=1}^{N} P_{ij} x_{ij}$$

Flow Conservation:

$$\sum_{i=1}^{N} x_{ij} - \sum_{i=1}^{N} x_{ji} = 0 \forall j, j \in \Omega$$

$$\sum_{i=1}^{N} x_{i\mathrm{I}} - \sum_{i=1}^{N} x_{\mathrm{I}i} = \sum_{s \in \Psi} T_{s\mathrm{I}}$$

$$\sum_{i=1}^{N} x_{ji} - \sum_{i=1}^{N} x_{ij} = \mathrm{T}_{j\mathrm{I}}, \forall j \in \Psi$$

Limit on all flows:

$$x_{ij} \leq 0$$

Wireless medium sharing:

Flows through arcs incident at a node sum up to the maximum available data rate

N is the number of nodes in the system

P_{ij} represents the power consumed per bit over the link between node i and node j

($P_{ij} = P_{t(i \rightarrow j)}$ * Maximum Data Rate^{-1})

P_t represents the transmit power cost along a link

x_{ij} represents the flow over the link between node i and node j

Ω represents the set of forwarding nodes and access points in the system

I is the Internet represented by a single node acting as the destination for all sensor traffic

Ψ is the set of all sensors in the system

T_{ij} is the traffic destined from node i to node j; the traffic is CBR