

Topology Control in Sensor Wireless Network
INFSCI3966: Class Presentation

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Outline

- Introduction
- Three Papers
 - ASCENT
 - Span
 - Exposure

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Topology Management

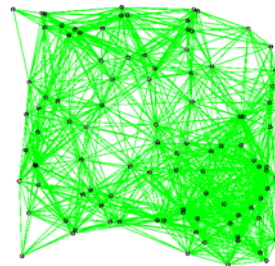
Deciding on

- **which** nodes turn on
- **when** they turn on, and
- at **what** Tx power

.... So that **network connectivity** is maintained.

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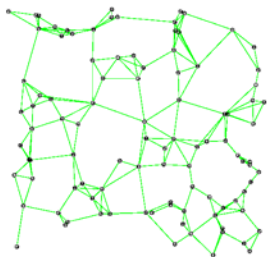
Motivation for Topology Control



- High power
- High interference
- Low Throughput

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Motivation for Topology Control



- Low power
- Low interference
- High Throughput
- Global Connectivity

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Tradeoffs (\Leftrightarrow)

- In sensor nodes, energy conservation desirable

Energy conservation == longer network life

Energy \downarrow \Leftrightarrow node density \uparrow
Energy \downarrow \Leftrightarrow latency \uparrow
Energy \downarrow \Leftrightarrow Tx power \downarrow

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ASCENT

Adaptive Self-Configuring sEnsor Networks
Topologies.

Alberto Cerpa & Deborah Estrin
UCLA

Energy \leftrightarrow Node Density

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ASCENT :

Adaptive Self-Configuring sEnsor Networks
Topologies

- ASCENT ...
 - Not a routing or data dissemination protocol.
 - Simply decides which nodes should join the routing infrastructure.
 - Deploying redundant nodes to extend the system life.
 - Reduction of message loss and increase in energy efficiency.

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Problem Description

- Given an area A, a total number of nodes N distributed with a certain probability distribution in A, we would like to find a subset of nodes that covers area A.

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Centralized Vs Distributed Approach

- Centralized will have scaling and robustness limitations. Also a single node cannot directly sense the conditions of distributed nodes.
- Distributed approaches are more practical for dynamic environments when energy is constraint.

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Problem Space

- **Goal:** exploit the **redundancy** provided by **high density** to extend the system lifetime while providing a basic communication backbone that adapts to application needs
- **Problem:**
 - **few** active nodes:
 - distance between neighboring nodes high \rightarrow increase **message loss**
 - **energy** required to transmit the data over the longer distances will be **prohibitive**
 - **too many** active nodes:
 - at best, **expending unnecessary energy**;
 - at worst the nodes may interfere with one another by **congesting** the channel.

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Distributed sensor network scenario

- Ex) A habitat monitoring sensor network
 - Deployed in a remote forest by dropping sensor nodes from a plane or by placing them by hand
- Ad-hoc deployment
 - Cannot expect the sensor field to be deployed in a regular fashion
 - Uniform deployment does not correspond to uniform connectivity
- Energy constraints
 - Expend as little energy as possible to maximize network lifetime
- Unattended operation under dynamics
 - Preclude manual configuration, pre-configuration

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Assumptions *

- These assumptions will limit ASCENT applications
 - High enough node density to connect the entire region
 - When node density is low, ASCENT mechanism is not applicable (generally, all nodes should be used to form an effective network)
 - Does not consider partition (partition detection and repair techniques are leaved to future work)

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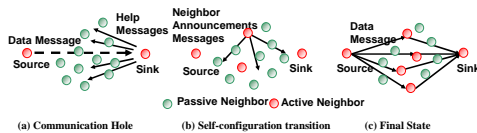
Primary contributions

- Use of adaptive techniques
 - Applications configure the underlying topology based on their needs while trying to save energy to extend network lifetime
- Use of self-configuring techniques
 - React to operating conditions measured locally, not restricted to radio, geographical, or routing.

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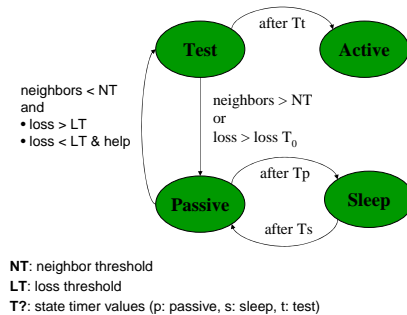
ASCENT Basics

- The nodes can be in **active** or **passive** state.
 - Active nodes are part of the topology (or stay awake) and forward data packets (using an orthogonal routing mechanism).
 - Nodes in passive state can be sleeping or collecting network measurements. They **do not** forward any packets.
- Each node measures the number of neighbors and packet loss **locally**.
- Each node then makes an informed decision to **join** the network topology or to **sleep** by turning its radio off.



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State Transitions



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ASCENT parameter tuning

- Choices left to the applications
- NT (neighbor threshold)
 - the average degree of connectivity of the network
 - Trade-off between the energy consumed and/or the level of interference vs. the desired sensing coverage
- LT (loss threshold)
 - The maximum amount of data loss that an application can tolerate
 - Application dependent
 - temperature measurements vs tracking of a moving target
- Tt, Tp (timer of test state, passive state)
 - Trade-off of power consumption vs. decision quality
- Ts (timer of sleep state)
 - Trade-off of energy saving vs. reaction time to dynamics

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Neighbor and data loss determination

- Neighbor: A node from which we receive a certain percentage of packets over time.
- Data loss: is measured locally by each node while in passive and test state
 - Each node increase the sequence number when each packet transmitted
 - When a sequence number is skipped, loss is detected
 - Assumes application data packets also have some mechanism to detect losses

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Neighbor and data loss determination (cont'd)

- The number of active neighbors (N)
 - The number of neighbors with link packet loss smaller than the neighbor loss threshold (NLS)
 - NLS = $1 - (1/N)$
 - This formula worked best
 - N : the number of neighbors calculated in the previous cycle
 - NLS : neighbor loss threshold
- Average data loss rate (DL)
 - Calculated based on the application data packets
 - Data losses are detected using data sequence numbers
 - If the message was not received from any neighbor, it is considered a data loss
 - Control messages are not considered
 - Help, neighbor announcement and routing control

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ASCENT interactions with routing

- ASCENT
 - Is not a routing or data dissemination protocol, decides which nodes should join the routing infrastructure
 - Nodes become active or passive independent of routing protocol
 - Does not use state gathered by the routing protocol
 - Does not require changing the routing state
- Test state (actively routing packets) → passive state (listen-only)
 - Cause some packet loss
 - Improvement :
 - Traffic could be rerouted in advance by informing the routing protocol of ASCENT's state changes

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Energy Usage – Important Metric *

- Energy consumption of the radio dominates that of the sensors and CPU
 - perform event detection continuously
- Observation:** radios consume about the same energy in idle state than Tx and Rx state.
- The only energy efficient mode of the radio is the sleep mode
 - put radio to sleep as often as possible

Radio mode	Power (mW)
Transmit	36
Receive	9
Idle	9
Sleep	0.015

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Energy Savings Analysis *

$$ES(n) = \frac{n * Idle}{NT * Idle + (n - NT) * Idle * \frac{Tp}{Tp + Ts} + (n - NT) * Sleep * \frac{Ts}{Tp + Ts}}$$

NT: # nodes that have radio on.
 Tp: passive state timer
 Ts: sleep state timer
 $\alpha = Tp/Ts$
 $\beta = Power_{Sleep}/Power_{Idle} = 0.004$

$$ES(n) = \frac{n}{NT + (n - NT) * \frac{\alpha + \beta}{\alpha + 1}}$$

$$\lim_{n \rightarrow \infty} ES = \frac{\alpha + 1}{\alpha + \beta}$$

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Adaptive Timers *

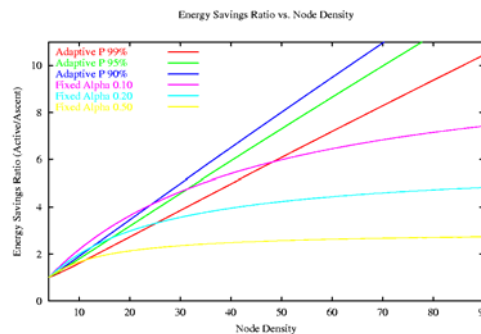
$$Pk(\text{at least } k \text{ passive nodes}) = 1 - \left(\left(\frac{1}{\alpha - 1} \right)^n * \left(\frac{\alpha^k - 1}{\alpha - 1} \right) \right)$$

e.g., for $k = 1$;

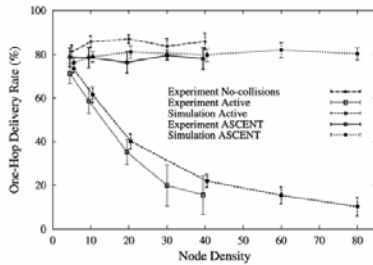
$$\alpha(n) = 10 \left(\frac{\log(1 - Pk)}{n} \right) - 1$$

- For any given probability target Pk and given the # of passive nodes in the area, nodes can calculate the optimal relation between the passive and sleep timers (α)
- Larger the Pk target, the larger the alpha for any given density
- Larger the k, the larger the alpha (although it grows slowly)₂₃

Adaptive vs Fixed Timers

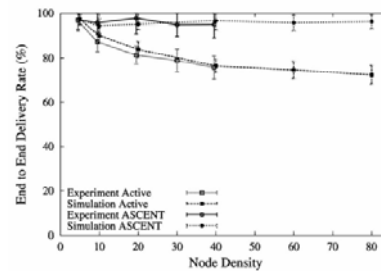


Simulation and Experimental Results



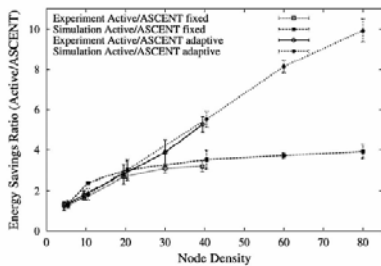
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Simulation and Experimental Results



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Simulation and Experimental Results



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Energy consumption measurements*

- In this paper the values are not direct measurements of energy consumption but indirect measurements using the time the nodes spent in the different ASCENT's states.
- Did not consider the energy consumed by the CPU!!

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System Overhead *

- In ASCENT each node adds sequence number to each packet (including data and control packets).
- The value of the filter constant (for estimating packet loss) is locally estimated and periodically exchanged between active and test nodes.

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Active mode *

- A node in active state continues forwarding data and routing packets until it runs out of energy.
- This means that once you are active there is no way back!!

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Reaction to Dynamics *

- The sensors in the experiment were fixed and none of them was moved.
- There are no obstacles or environment effects!

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Conclusion

- ASCENT has the potential of
 - significant reduction of packet loss
 - Increase in energy efficiency
- ASCENT mechanisms were
 - responsive and stable under systematically varied conditions

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Exposure In Wireless Ad-Hoc Sensor Networks

Seapahn Meguerdichian
Computer Science Department
University of California, Los Angeles

Farinaz Koushanfar
Department of EE and CS
University of California Berkeley

Gang Ou
Electrical and Computer
Engineering Department
University of Maryland

Miodrag Potkonjak
Computer Science Department
University of California, Los Angeles

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Exposure

- Topology control that pertains to coverage.
- Previous two papers: ASCENT & SPAN performed topology control through connectivity.

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Road Map

- Background: Coverage, path exposure
- Theoretical Formulation of path exposure.
- Computation of path exposure
- Results
- Critique
- Implications and opportunities
- Conclusions.

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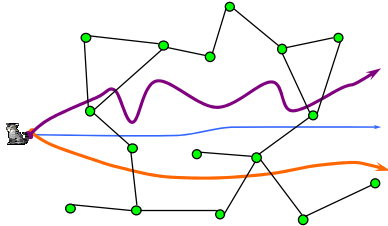
Contributions

- Exposure:
 - Definition
 - Algorithm
 - Centralized Implementation
- Algorithm:
 - Generalized grid approximation
 - Application of graph search algorithms
- Ad-hoc wireless sensor networks:
 - Coverage
 - Quality of Service
- Research:
 - Numerous interesting open problems

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Background : Coverage

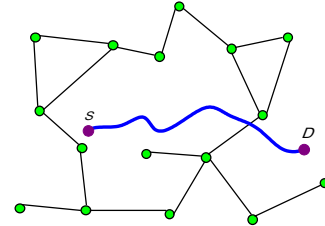
- How well a sensor network can monitor or track a target in the network area.



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Path Exposure

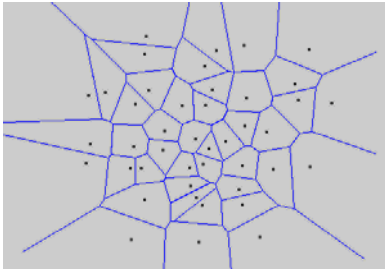
- Informally defined as a sensor network's ability to observe an object moving on an arbitrary path in the sensor network area.



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Well studied: Voronoi Graph

- Polygons with edges that are equidistant from neighboring nodes



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Mathematical Model for Path Exposure

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Two Facts

- Sensing ability decreases as distance increases.
- Sensing ability can improve as sensing time increases.

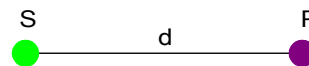


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Sensitivity

- The Sensitivity at point P for a sensor network field with a single sensor S

$$S(s, p) = \frac{\lambda}{[d(s, p)]^k}$$



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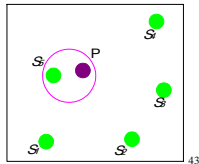
Sensor Field Intensity

- All-Sensor Field Intensity

$$I_A(F, p) = \sum_{i=1}^n S(s_i, p) \quad \text{Is summation the correct operator here?}$$

- Closest-Sensor Field Intensity

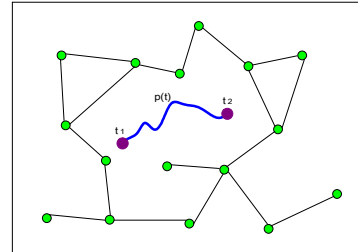
$$I_C(F, p) = S(s_{\min}, p)$$



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Path Exposure

$$E(p(t), t1, t2) = \int_{t1}^{t2} I(F, p(t)) \left| \frac{dp(t)}{dt} \right| dt$$



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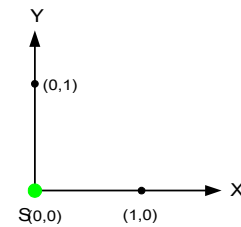
Minimal Exposure Path Algorithm

- Find a path with minimal exposure for the object traveling from starting point S to destination point D.
- Why do we discuss this algorithm?
 - Target side: the worst coverage along this path, good chance to breach
 - Network side: We should add more sensors along the minimal exposure path to improve the coverage..

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Case 1

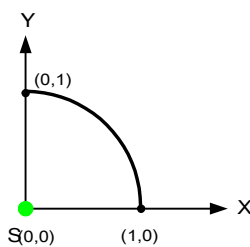
- Single Sensor Model



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Minimal Exposure Path

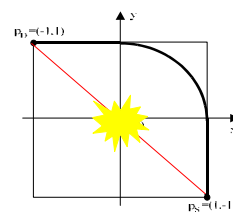
$$(x(t), y(t)) = \left(\cos \frac{\pi}{2} t, \sin \frac{\pi}{2} t \right)$$



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Special Case – One Sensor

Minimal exposure path for one sensor in a square field:



$$S(s(0,0), p(x,y)) = \frac{1}{d(s,p)} = \frac{1}{\sqrt{x^2 + y^2}}$$

$$E = \int_0^1 \frac{1}{\sqrt{x(t)^2 + y(t)^2}} \sqrt{\left(\frac{dx(t)}{dt} \right)^2 + \left(\frac{dy(t)}{dt} \right)^2} dt$$

Min exposure path is a trade off between time and sensing intensity

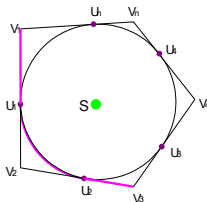
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General Case

- The minimal exposure path from v_i to v_j

$$v_i \rightarrow u_i \rightarrow u_{i+1} \rightarrow u_{i+2} \rightarrow \dots \rightarrow u_{j-1} \rightarrow v_j$$

$$v_i \rightarrow u_{i-1} \rightarrow u_{i-2} \rightarrow \dots \rightarrow u_j \rightarrow v_j$$



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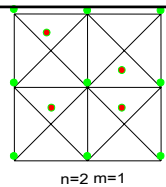
General Exposure Computations

- Analytically intractable.
- Need efficient and scalable methods to approximate exposure integrals and search for Minimal Exposure Paths.
 - Use a grid-based approach and numerical methods to approximate Exposure integrals.
 - Use existing efficient graph search algorithms to find Minimal Exposure Paths.

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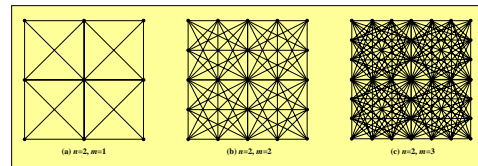
Multiple Sensors

- Construct $(n \times n)$ Grid Squares for a sensor network field
- Place $(m+1)$ equally spaced vertices along each edge, connect the each two vertices
- Force that path can be only the edges
- Compute the exposure for each edge
- Consider each edge's exposure as the weight
- Calculate the minimal exposure path by using Dijkstra's Single-Source-Shortest-Path algorithm. 51



$n=2 \ m=1$

Generalized Grid



Generalized Grid – 1st order, 2nd order, 3rd order ...
More movement freedom → more accurate results

Approximation quality improves by increasing grid divisions with higher costs of storage and run-time.

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Experimental Results

- Minimal exposure path for 50 randomly deployed sensors using the All-Sensor intensity model (IA).



8x8 m=1	16x16 m=2	32x32 m=8
Exposure: 0.7079	Exposure: 0.6976	Exposure: 0.6945
Length: 1633.9	Length: 1607.7	Length: 1581.0

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$P_{\min E}$ – Uniform Random Deployment

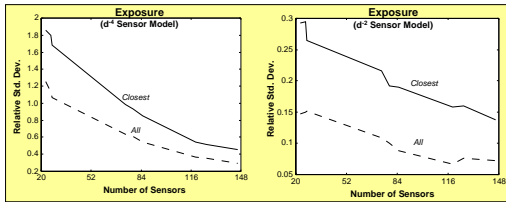
Minimal exposure path for 50 randomly deployed sensors using the All-Sensor intensity model (I_A).



8x8 m=1	16x16 m=2	32x32 m=8
Exposure: 0.7079	Exposure: 0.6976	Exposure: 0.6945
Length: 1633.9	Length: 1607.7	Length: 1581.0

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Exposure – Statistical Behavior



Diminishing relative standard deviation in exposure for $1/d^2$ and $1/d^4$ sensor models.

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Exposure – What's missing?

- Favors centralized implementations
- Performance and cost studies subject to
 - Wireless Protocols (MAC, routing, etc)
 - Errors in measurements
 - Locationing
 - Sensing
 - Numerical errors
 - Computation based on incomplete information
 - Not every node will know the exact position and information about all other nodes

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Related Topics to Path Exposure

- **Death of a Sensor Network:**
 - Qos Perspective
- **Location Discovery**
- **Target tracking**
 - Combine with MAC/Routing layers

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Exposure : Death of a Sensor Network

- Exposure value for the minimum exposure path can be a Qos measure.
- Minimum number of minimum exposure path can be a Qos measure.
- If the sensor deployment cannot guarantee any of the two measures, the sensor network can be considered to be deficient.

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Location of Sensors

- **Deterministic placement**
 - ❖ The sensors are deliberately placed.
 - ❖ Perfect for a centralized implementation
- What about mobile sensors?

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Target Tracking

- Track a target by using the target's some unique characteristics such as acoustic, vibration, thermal, calculate target's next position after a period of tracking time
- Divide the entire space - time region into space - time cells
- Some nodes detect the target, they report to the manager nodes
- The manager nodes use locations of the target at the N successive time instants to predict the location of the target at $M(<N)$ future time instants.

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Conclusions

- It is too complicated to calculate the exposure of an object moving on an arbitrary path under arbitrary sensor intensity field.
- Simplification decreases the algorithms' practical value
- Most of the models are only used for theoretical purpose
- Future work:
Algorithms and models have to be tested in real environment

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Span An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Networks

Benjie Chen, Kyle Jamieson, Hari Balakrishnan, &
Robert Morris

MIT

Energy ↔ Node Density

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Outline

- Motivation
- Approach
- The Span algorithm
- 802.11 Power Saving Mode
- Improvement of 802.11 PSM with Span
- Performance Evaluation
- Conclusions

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Motivation

- Means of data communication
- Dependence on battery power
- Radio consumes power also when node listens or idle.
- Networks lifetime can be prolonged by using smart power management technique.

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Approach

Straightforward:

Turning off the radio of the inactive node will save power.

In practice:

Multi-hop networks require (otherwise idle) nodes to forward packets bound for other hosts.

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The Goal

Turn off as many nodes as possible without *significantly* diminishing the capacity or connectivity of the network.

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SPAN algorithm

- An energy-efficient coordination algorithm for topology maintenance in ad hoc networks.
- Based on the observation: sufficient density of nodes require only small number of them to be on at any time to forward traffic for active connections.

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The main ideas of Span

- Each node is either a coordinator or a non-coordinator .
- Traffic routed only by coordinators.
- Maintain connected backbone - preserve connectivity.

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The main ideas of Span– cont.

- Minimize the number of coordinators.
- Rotate the roles of coordinator amongst all nodes.
- A node with higher utility and energy level is more likely to become a coordinator.
- Decisions based on local information only.

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How Span works

Each node periodically broadcasts HELLO messages:

- Status (coordinator / non-coordinator)
- Current Coordinators
- Current Neighbors

Maintain a local database !

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Span and its database

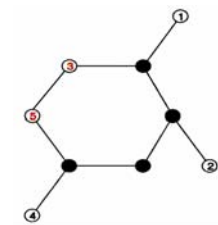
From Hello messages each node constructs:

- a list of node's neighbors and coordinators
- for each neighbor a list of its neighbors and coordinators

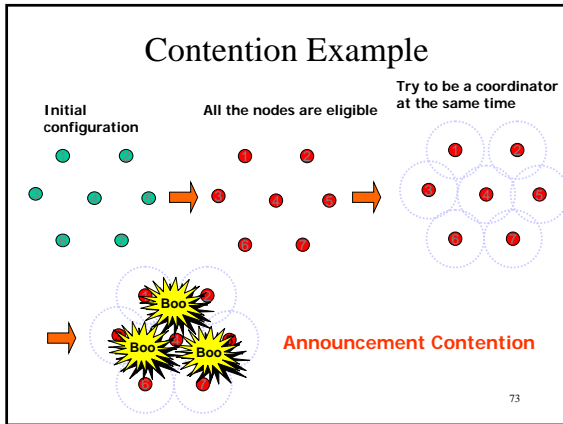
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Coordinator Eligibility Rule

- A non-coordinator decides to become a coordinator if it discovers that two of its neighbors cannot communicate with each other directly or via one or two coordinators.



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- ### Randomized back-off delay
- Each node periodically evaluates its eligibility
 - Announcement contention resolved by delaying coordinator announcements with a randomized back-off delay
 - After the delay volunteers if and only if the eligibility rule still holds
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- ### Randomized back-off delay – cont.
- The delay reflects “cost”
 - % of consumed battery charge
 - % of neighbors in need of node
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First case – equal energy

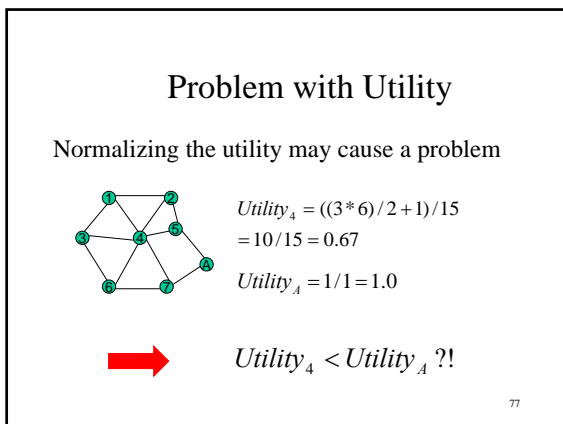
All the nodes have equal energy at their battery.

$\frac{C_i}{\binom{N_i}{2}}$ - The utility of node i

Packet round-trip delay

$$\text{delay} = \left[\left(1 - \frac{C_i}{\binom{N_i}{2}} \right) + R \right] \times N_i \times T$$

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- ### Possible Solution
- Use C_i instead of the utility.
 - Still need to normalize C_i
 - For normalization use the maximum possible number of neighbor pairs.
- The new *Utility* :
- $$\frac{C_i}{\binom{N_{\max}}{2}}$$
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The New Equation

Utility_{A,1,2,3,5,6,7} = $\frac{1}{\binom{N_{\max}}{2}}$

Utility₄ = $\frac{10}{\binom{N_{\max}}{2}}$

Delay₄ = $\left[\left(1 - \frac{10}{\binom{N_{\max}}{2}} \right) + R \right] \times N_{\max} \times T$

Delay_A = $\left[\left(1 - \frac{1}{\binom{N_{\max}}{2}} \right) + R \right] \times N_{\max} \times T$

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Second case – Energy concern

- Nodes with more energy should volunteer to be coordinator more quickly.
- The scaled energy level of the node is:
 - $\frac{E_r}{E_m}$ — amount of energy remained at the node
 - E_m — maximum amount of energy available at the same node
- A linear decreasing function: $1 - \frac{E_r}{E_m}$ works the best

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Putting it all together

The final Equation for the back-off delay is:

$$\left[\left(1 - \frac{E_r}{E_m} \right) + \left[1 - \frac{C_i}{\binom{N_{\max}}{2}} \right] + R \right] \times N_{\max} \times T$$

Annotations: Remaining energy (E_r), Maximum amount of energy (E_m), Number of new connections (C_i), Random between [0,1] (R), Packet round-trip delay (T), Neighbors number (N_{max})

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Coordinator Withdrawal

- If all of its neighbors can reach each other directly or via other coordinators
- If it has been a coordinator for some period of time and every pair of neighbor nodes can reach each other via some other neighbors (even if they are not coordinators yet)

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Span in protocol stack

Routing Layer	GPSR	DSR	AODV
	Span		
MAC/PHY	802.11		

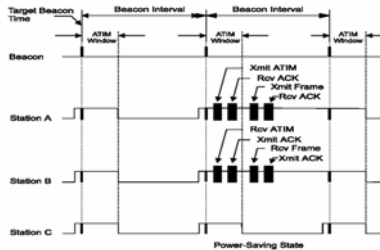
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802.11 Ad Hoc Power saving Mode

- Periodic beacons to synchronize nodes
- ATIM (ad hoc traffic indication message) window
- Nodes Acks if there is a packet directed to it
- Node turns itself off until next beacon period.

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Power Saving Mode - flow



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802.11 Disadvantages

- Decreased channel capacity
- Long packet delivery latency (without Span)
- The beacon period and ATIM window size greatly affect routing performance.
- Beacon period of 200ms and ATIM window of 40 ms proved to be a good balance

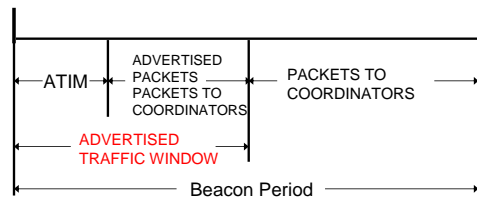
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Improving 802.11 using Span

- No advertisements for packets between the coordinators.
 - Individually advertise each broadcast message.
 - New advertised traffic window
- Span doesn't require these modifications, but does better when they implemented.

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Last improvement for 802.11

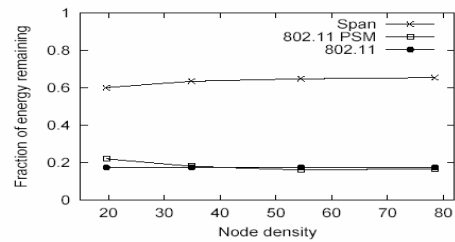


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Performance Evaluation

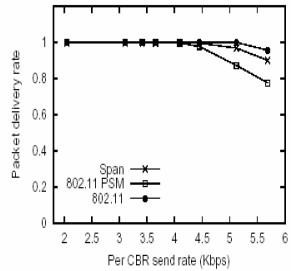
89

Power Savings



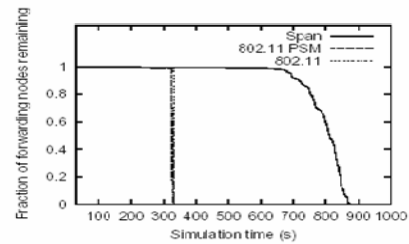
90

Capacity Preservation



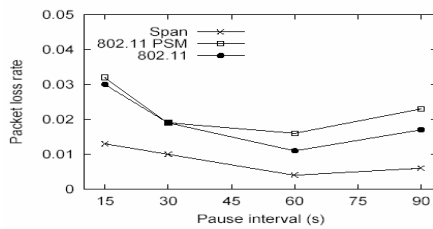
91

Node Lifetime



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Effects of mobility



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Summary

- System lifetime with Span is approximately a factor of two better than without Span.
- Span preserves connectivity, capacity.
- Span has a lower loss rate than both 802.11 and 802.11 PSM when the node density is low.

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Things to improve

- The amount of energy saved by Span increases only slightly as density increases.
- Routing layer has to be modified to route through coordinators.
- Rotation can maintain the network topology longer, but introduce more state switches.

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