G 364: Mobile and Wireless Networking

CLASS 13, Mon. Feb. 23 2004

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M-W, 11:40am-1:20pm, 109 Rob

Why New Protocols for Sensor Networks?, 1

- Not just MANET with static nodes!
- Several issues
  - Severe energy constraints
  - Large scale
  - Potential to exploit mobility
  - Applications involve real-time constraints and control loops

Why New Protocols for Sensor Networks?, 2

- Purpose is to estimate function of a physical phenomenon, and not just to move bits
  - E.g. entire map, average, some event etc.
  - Don't really care *which* node provides that
  - Three implications:
    - no longer name or address nodes
    - collaborative computation instead of communication
    - data correlation can be exploited

Wireless Sensor Network Protocols

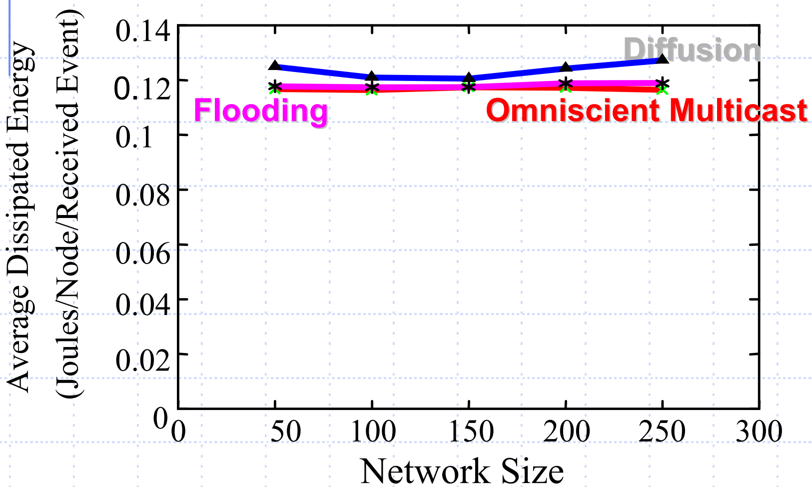
- Building long-lived, massively-distributed, physically-coupled systems:
  - Coordinating to minimize duty cycle and communication
    - Adaptive MAC
    - Adaptive Topology
    - Routing
  - In-network processing
    - Data centric routing
    - Programming models

MAC in Sensor Nets

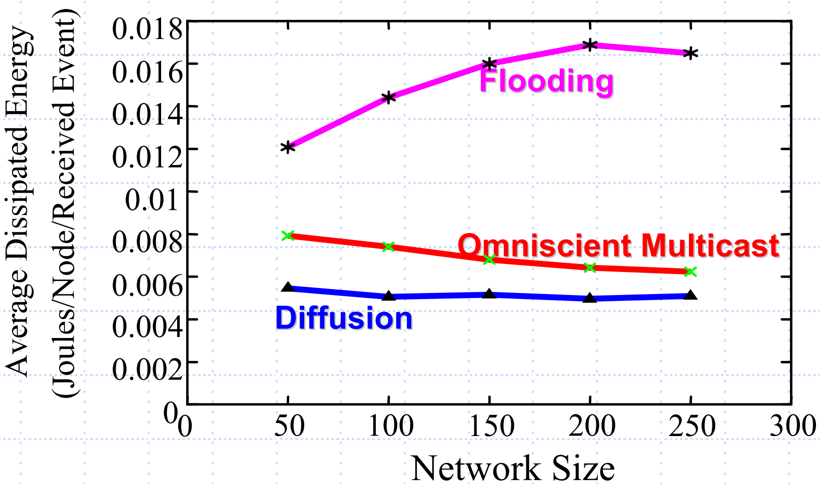
- Important attributes of MAC protocols
  1. **Collision avoidance**
  2. **Energy efficiency**
  3. **Scalability in node density**
  4. Latency
  5. Fairness
  6. Throughput
  7. Bandwidth utilization

MAC Impact on Networks

- Major sources of energy waste
  - Idle listening when no sensing events, Collisions, Control overhead, Overhearing

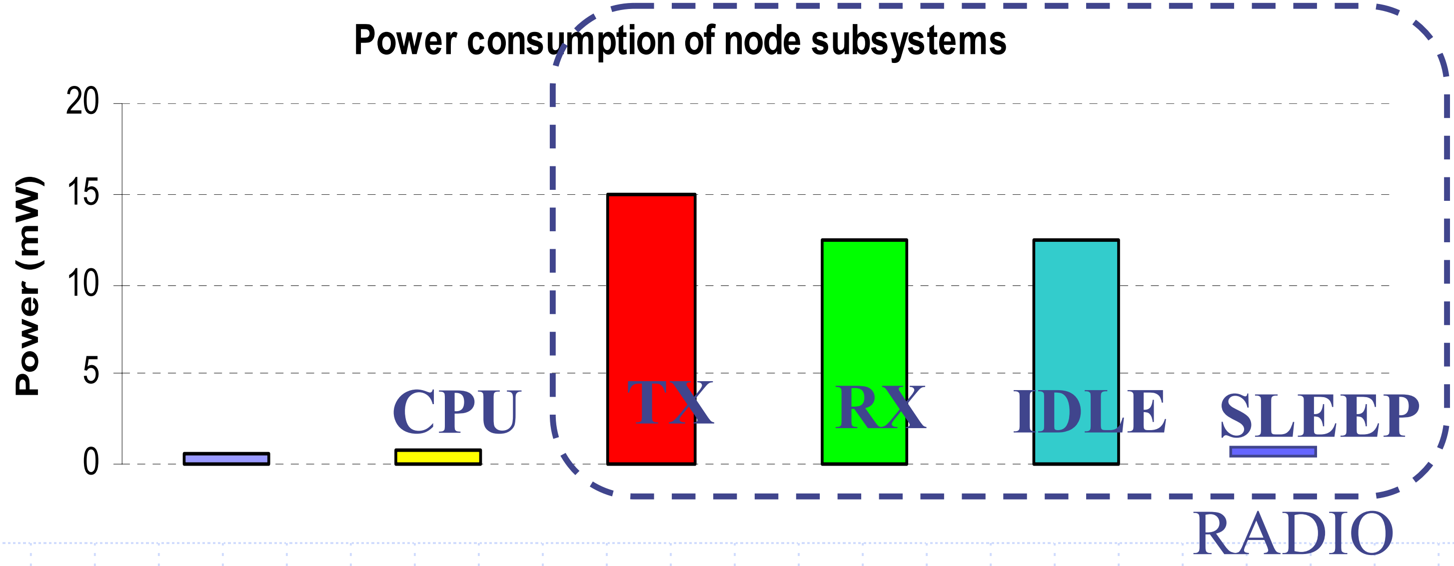


Over 802.11-like MAC



Over energy-aware MAC

Identifying the Energy Consumers



- $E_{TX} \approx E_{RX} \approx E_{IDLE} >> E_{SLEEP}$
- Need to shutdown the radio

Energy Efficiency in MAC

- Major sources of energy waste
  - Idle listening
    - Long idle time when no sensing event happens
    - Collisions
    - Control overhead
    - Overhearing

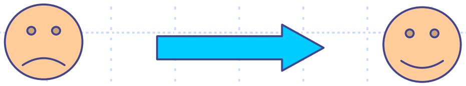
Common to all wireless networks

- Try to reduce energy consumption from all above sources
- TDMA requires slot allocation and time synchronization
- Combine benefits of TDMA + contention protocols

Sensor-MAC (S-MAC) Design (Wei et al. 2002)

- Tradeoffs

Latency
Fairness



Energy

- Major components of S-MAC
  - Periodic listen and sleep
  - Collision avoidance
  - Overhearing avoidance
  - Message passing

Collision Avoidance

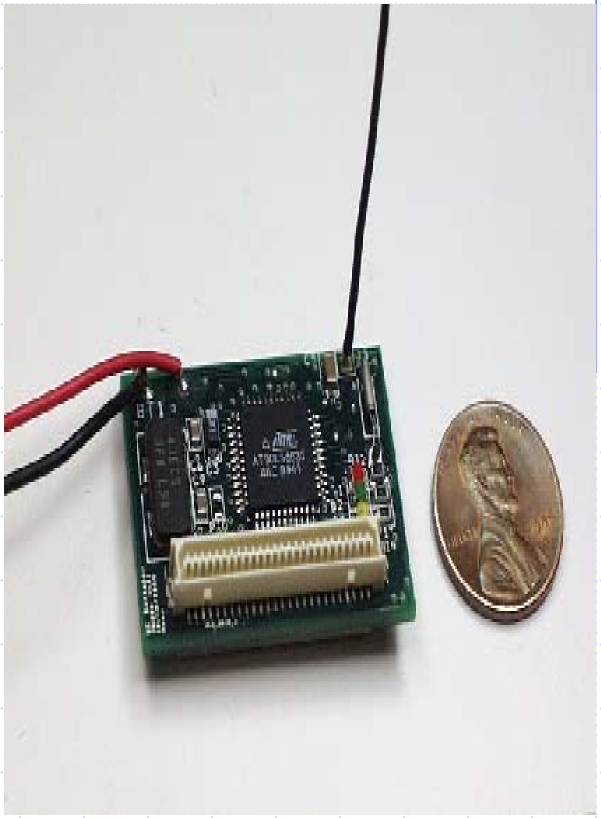
- **Problem:** Multiple senders want to talk
- **Options:** Contention vs. TDMA
- **Solution:** Similar to IEEE 802.11 ad hoc mode (DCF)
  - Physical and virtual carrier sense
  - Randomized backoff time
  - RTS/CTS for hidden terminal problem
  - RTS/CTS/DATA/ACK sequence

Overhearing Avoidance

- **Problem:** Receive packets destined to others
- **Solution:** Sleep when neighbors talk
  - Basic idea from PAMAS (Singh 1998)
  - But we only use in-channel signaling
- Who should sleep?
  - All immediate neighbors of sender and receiver
- How long?
  - The *duration* field in each packet informs other nodes the sleep interval

Testbed Nodes

- Platform
  - Motes (UC Berkeley) :
    - 8-bit CPU at 4MHz,
    - 8KB flash, 512B RAM
  - TinyOS: event-driven
- Compared MAC modules
  - IEEE 802.11-like protocol
  - Message passing with overhearing avoidance
  - S-MAC (2 + periodic listen/sleep)
  - URL: http://www.isi.edu/scadds/smac/

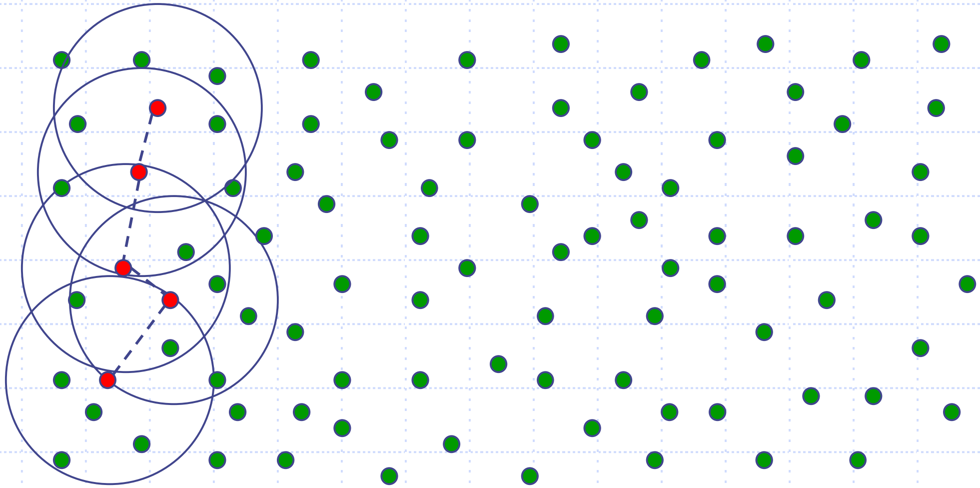


Adaptive Topology (AT)

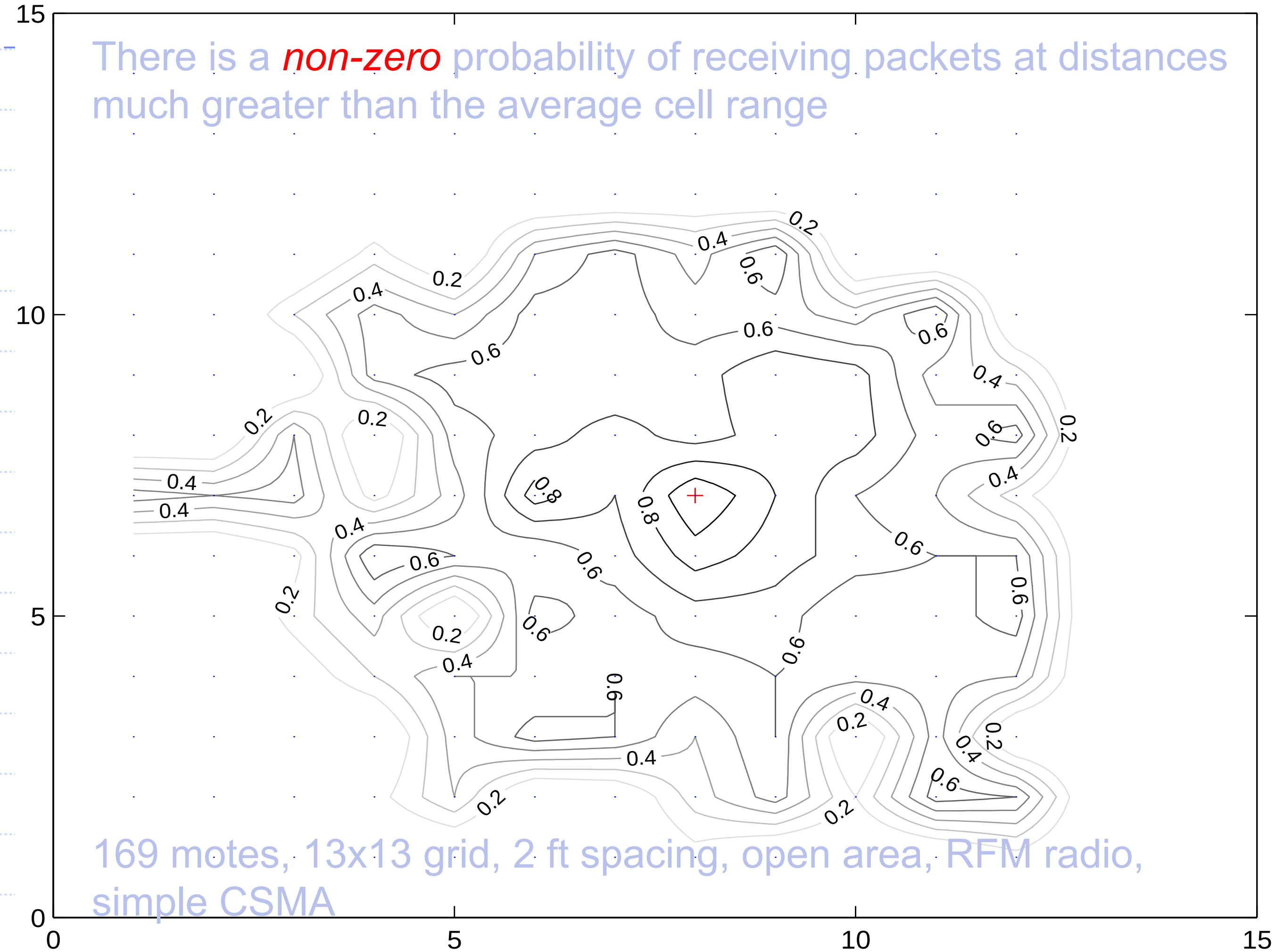
- Can we do more than shut down radio in between transmissions/receptions?
- Can we put nodes to sleep for longer periods of time?
- Goal:
  - Exploit high density (over) deployment to extend system lifetime
  - Provide topology that adapts to the application needs
  - Self-configuring system that adapts to environment without manual configuration

AT: Problem Description

- Simple Formulation (Geometric Disk Covering)
  - Given a distribution of ***N*** nodes in a plane
  - Place a ***minimum*** number of disks of radius ***r*** (centered on the nodes) to cover them
  - Disk represents the radio connectivity (***simple*** circle model)
- The problem is NP-Hard



Connectivity Measurements*



Can't just determine connectivity clusters thru geographic coordinates

For the same reason you can't determine coordinates w/connectivity

***An Empirical Study of Epidemic Algorithms in Large Scale Multihop Wireless Networks**
Ganesan, Krishnamachari, Woo, Culler, Estrin and Wicker, UCLA/CSD-TR 02-0013.

Tradeoff

- How many nodes to activate?
  - ***Few*** active nodes:
    - distance between neighboring nodes high → increased ***packet loss,*** higher ***transmit power and reduced spatial reuse***
    - need to maintain sensing coverage
  - ***Too many*** active nodes:
    - at best, ***expending unnecessary energy***
    - at worst nodes may ***interfere*** with one another by ***congesting*** the channel

Adaptive Topology Schemes

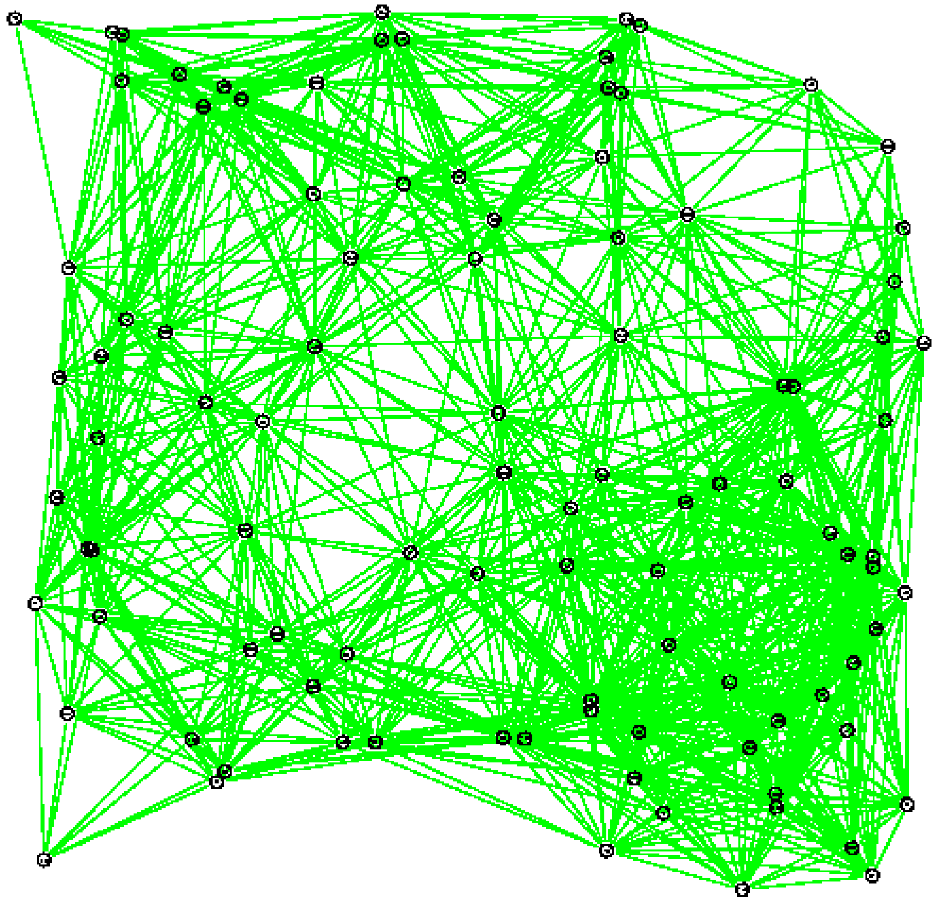
- Mechanisms being explored:
  - ***Empirical adaptation***: Each node assesses its connectivity and adapts participation in multi-hop topology based on the measured operating region, **ASCENT (Cerpa et al. 2002)**
  - **Cluster-based,** load sharing within clusters, **CEC (Xu et al. 2002)**
  - **Routing/Geographic topology based,** eliminate redundant links, **SPAN (Chen et al. 2001), GAF (Xu et al. 2001)**
  - **Data/traffic driven:** Trigger nodes on demand using paging channel, **STEM (Tsiatsis et al. 2002)**

Topology Control

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

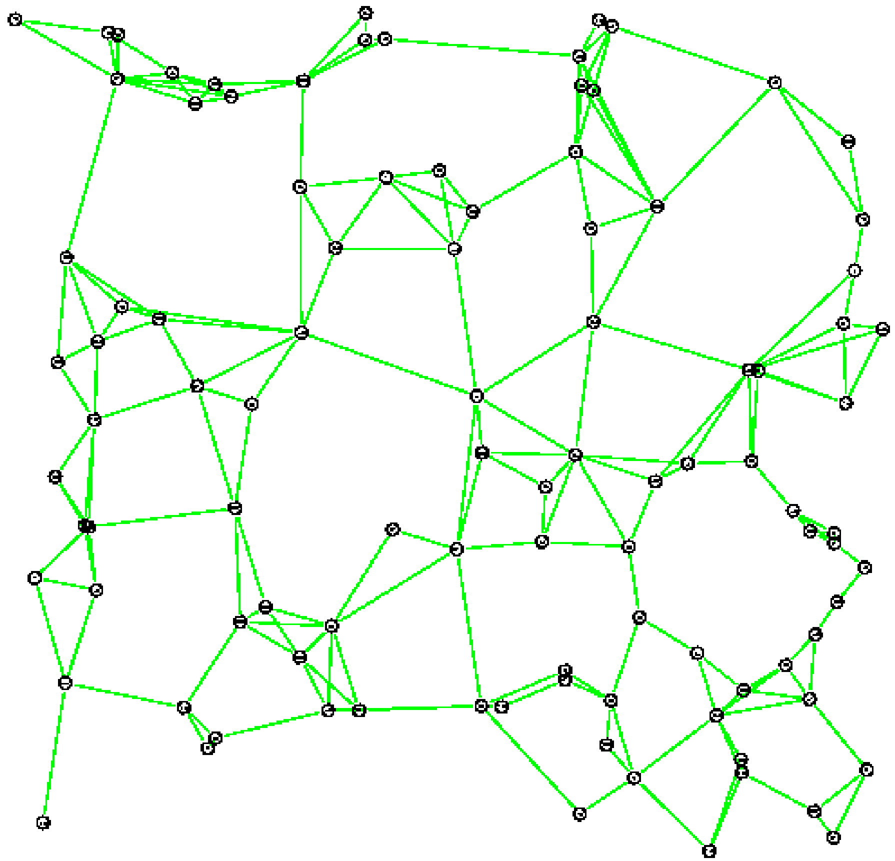
So that **desired network connectivity** is maintained

Motivation for Topology Control, 1



- High power
- High interference
- Low Throughput

Motivation for Topology Control, 2



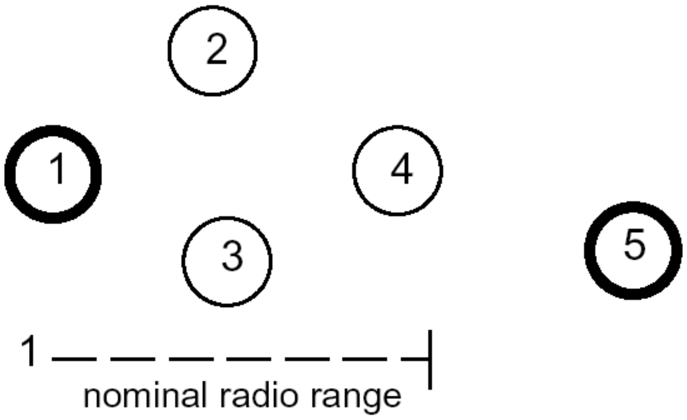
- Low power
- Low interference
- High Throughput
- Global Connectivity

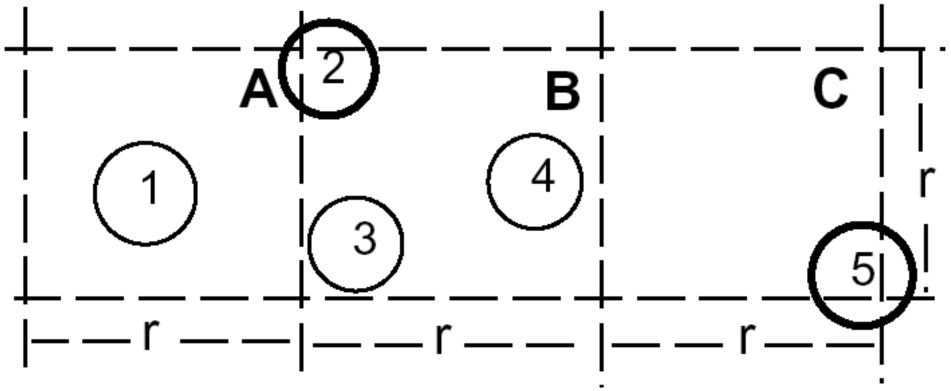
GAF: Geographic Adaptive Fidelity

- Geography-informed Energy Conservation for Ad Hoc Routing
  - Ya Xu, John Heidemann, Deborah Estrin USC/ISI, UCLA

Energy ⇔ Node Density

Node Redundancy in Ad Hoc Routing

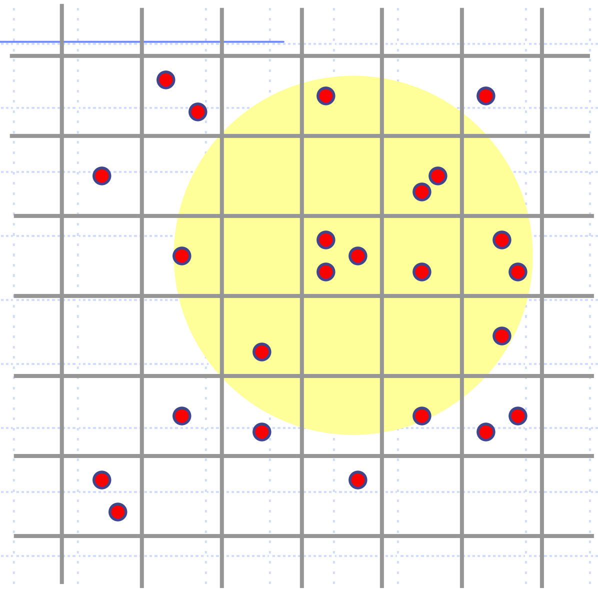




$$r^2 + (2r)^2 \leq R^2$$

$$r \leq \frac{R}{\sqrt{5}}$$

GAF: Geographic Adaptive Fidelity



Energy ⇔ Density

- Conserve traffic forwarding capacity
- Divide network in virtual grids of size r <= radio_range/sqrt(5)
- Each node in a grid is equivalent from a traffic forwarding perspective
- Keep **1 node awake in each grid** at each time

- GAF reduces the energy by a factor ***M'***
- This factor is a function of the average number of nodes in a grid: ***M***

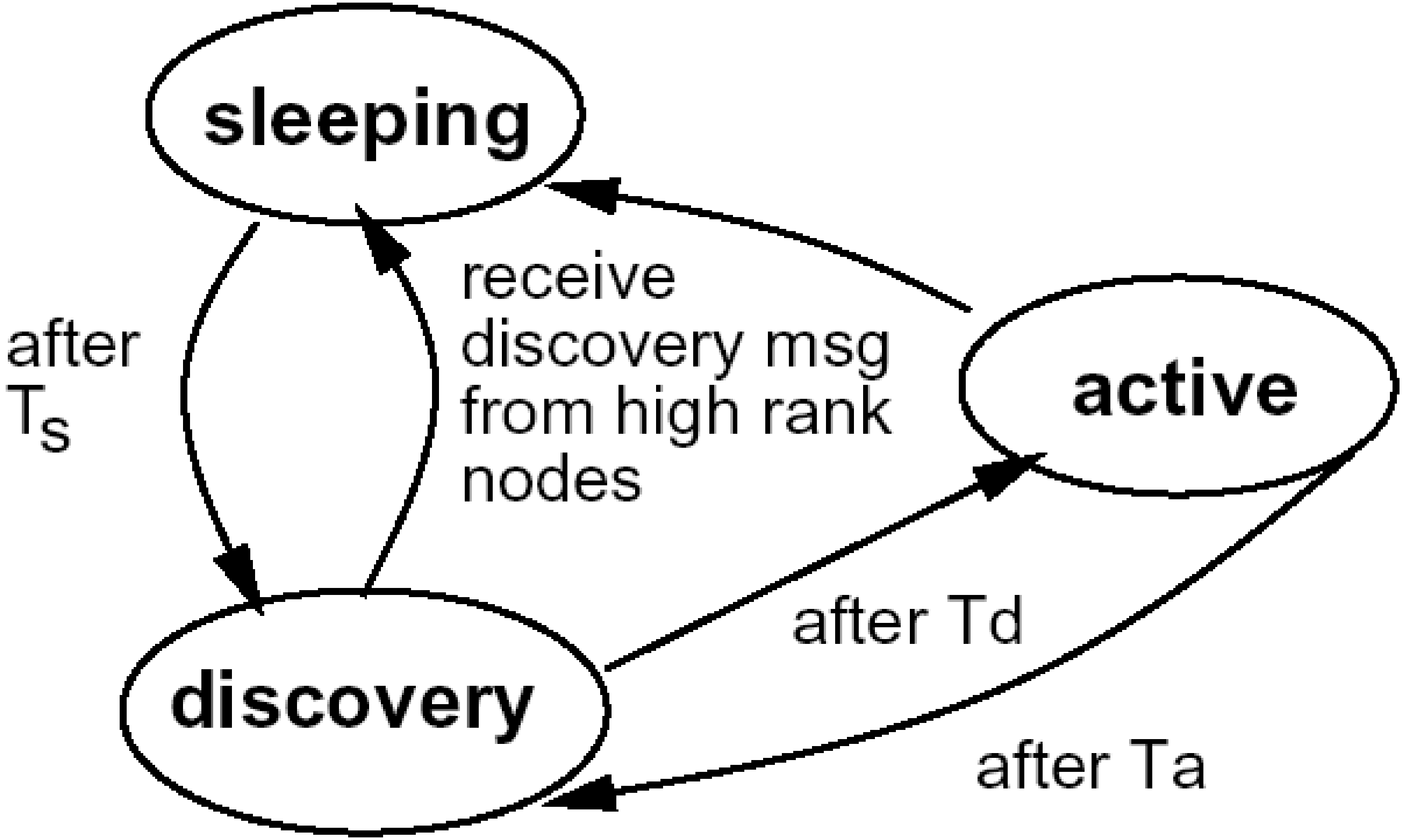
$$M' = \frac{M}{1 - e^{-M}}$$

for uniformly random node deployment

M'	M	λ
1.0	0	0
1.5	0.87	13.7
2.0	1.59	25.0
2.5	2.22	35.0
3.0	2.82	44.3

Average number of neighbors of a node

GAF State Machine



Topology Control: Other solutions

- ASCENT: Adaptive Self-Configuring sEnsor Networks Topologies
  - Cerpa & Estrin, UCLA
- Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Networks
  - Chen, Jamieson, Balakrishnan & Morris, MIT
- STEM: Sparse Topology and Energy Management
  - Schurgers, Tsiatsis, Ganeriwal &Srivastava, UCLA

Routing in Sensor Networks

- Given a topology, how to route data?
  - The MANET way: Reactive, proactive, and geo-enabled routing …
- **Building on Geo Routing**
  - GRAB (Lu et al 2002)
  - Routing on curve (Badri 2002)

Directed Diffusion (DD): Data Centric Routing, 1

- Basic idea
  - name data (not nodes) with externally relevant attributes
    - Data type, time, location of node, SNR, etc
  - diffuse requests and responses across network using application driven routing (e.g., geo sensitive or not)
  - support in-network aggregation and processing
  - optimize path with gradient-based feedback

DD, 2

- Data sources publish data, data clients subscribe to data
  - However, all nodes may play both roles
    - A node that aggregates/combines/processes incoming sensor node data becomes a source of new data
    - A sensor node that only publishes when a combination of conditions arise, is a client for the triggering event data
  - T*rue peer to peer system*
- Linux (32 bit proc) and TinyOS (8 bit proc) implementations

Assignments

- Download the survey on sensor nets
- Updated information on the class web page:

  www.ece.neu.edu/courses/eceg364/2004sp