Routing and Transport in Wireless Sensor Networks

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References

- **Adaptive Protocols for Information Dissemination in Wireless Sensor Networks**
  Wendi Rabiner Heinzelman, J. Kulik, and H. Balakrishnan
  Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom 1999), Seattle, Washington, August 15-20, 1999, pp. 174-185.

- **Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks**
  Chalermek Intanagonwiwat, Ramesh Govindan and Deborah Estrin
  Proceedings of the Sixth Annual International Conference on Mobile Computing and Networks (MobiCOM 2000), August 2000, Boston, Massachusetts.

- **Rumor Routing Algorithm For Sensor Networks**
  David Braginsky and Deborah Estrin
  First Workshop on Sensor Networks and Applications (WSNA), September 28, 2002, Atlanta, GA.

- **Highly Resilient, Energy Efficient Multipath Routing in Wireless Sensor Networks**
  Deepak Ganesan, Ramesh Govindan, Scott Shenker and Deborah Estrin
  Mobile Computing and Communications Review (MC2R), Vol 1., No. 2. 2002.

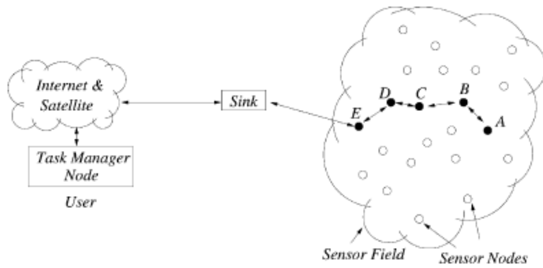
- [redacted]

- **Energy-efficient Communication Protocol for Wireless Microsensor Networks**
  Wendi Heinzelman, Anantha Chandrakasan, Hari Balakrishnan
  Proceedings of the Hawaii International Conference on Systems Science, January 2000, Maui, HI.

- **A Two-tier Data Dissemination Model for Large-scale Wireless Sensor Networks**
  Fan Ye, Haiyun Luo, Jerry Cheng, Songwu Lu, Lixia Zhang
  Proceedings of the Eighth Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCOM 2002), September 2002, Atlanta, GA.

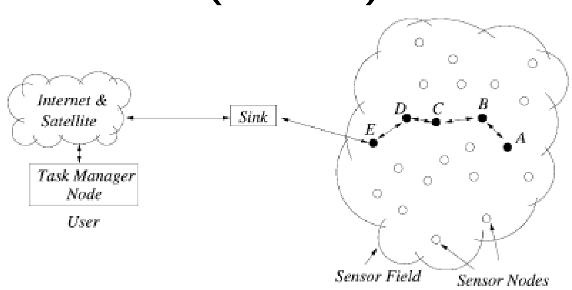
- [redacted]

Model



- Sensor nodes perform sensing tasks and report back data to user (via the "sink")
- Sensor nodes are resource-constrained (limited battery power, processing power, memory, etc.)
- High transmission error rate and low bandwidth when nodes communicate over wireless

Model (cont'd)



- Data flowing from sources (sensors) to "sink" is usually loss-tolerant
  - E.g., sensing temperature, light, acoustic, etc.
- Data flowing from "sink" to sensors is usually loss-sensitive
  - E.g., sensor management: re-tasking or re-programming sensors

Application-specific Protocols

- Data aggregation opportunities
  - Remove duplicate or redundant data
  - "Beamforming" or fusion
- Routing and transport intertwined
  - Data centric

- Want a long-lived, robust, low-latency network ...
  - that scales to large number of sensors, sinks, and high mobility

Protocol Design Goals

- Low Energy
  - Minimize communication
    - ⇨ Aggregate data in network
  - Low Node Duty Cycle
    - ⇨ Minimize individual node responsibility
    - ⇨ Traffic spreading / Load balancing
    - ⇨ Shut down nodes when possible
- Robust
  - Adapt to unpredictable environment without intervention
- Scalable
  - Rely on localized algorithms - no centralized control
- Low Latency
  - Must meet application latency and accuracy requirements
- Small Footprint
  - Must run on hardware with severe memory and computational power constraints

Example Network Models

Sensors (Sources)	Users (Sinks)	Event	Interest Propagation	Data Dissemination
Stationary	Stationary	Query	Static	Unicast
		Continuous	Unicast	Multicast
Mobile	Mobile	Target Detection	Multicast	Broadcast
			Broadcast	

Protocols

- Flooding
- Gradient
- Clustering
- Reliable
- Geographic

Flooding Based Approaches

- Flooding
- SPIN - Sensor Protocol for Information via Negotiation

"Adaptive Protocols for Information Dissemination in Wireless Sensor Networks," Wendi Rabiner Heinzelman, J. Kulik, and H. Balakrishnan, *MobiCom 1999.*

How did we review papers?

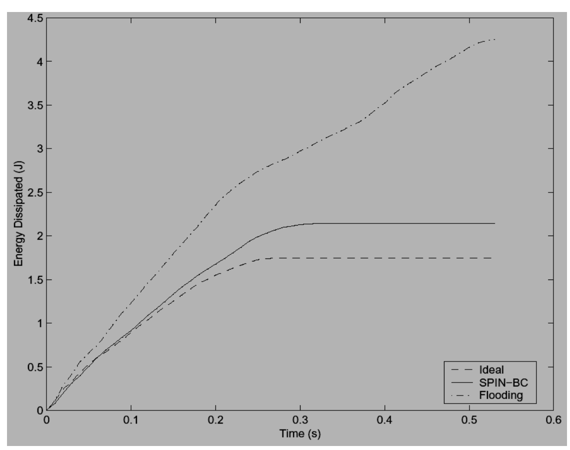
- Motivation of the work
- Single major idea in paper
- Model provided in paper
- Related work
- Advantages of the work
- Improvements to the work
- Single major result
- Future research

SPIN

- Motivation of the work
  - Overcome limitations of classic flooding
- Single major idea in paper
  - Describe data at a high level (meta-data) and use it for negotiation
  - Do in-network processing to eliminate redundancy
- Model provided in paper
  - Dissemination to all sensors
  - meta-data smaller than data
- Related work
  - NNTP: news servers use names and timestamps as meta-data

SPIN

Energy Dissipation:



Which one, flooding or SPIN, you expect to converge faster?

SPIN

Sensors (Sources)	Users (Sinks)	Event	Interest Propagation	Data Dissemination
Stationary	Stationary	Query	Static	Unicast
		Continuous	Unicast	Multicast
Mobile	Mobile	Target Detection	Multicast	Broadcast
			Broadcast	

SPIN

- Advantages of the work
  - Simple: ADV - REQ - DATA
  - scalable: only local interactions
  - Low latency and energy-efficient
  - Robust to failures and mobility
- Improvements to the work
  - Consider network losses and queuing delays
- Single major result
  - More energy efficient than flooding and close to ideal dissemination
- Future research
  - Can we do efficient dissemination without requiring all nodes to be up all the time?

Gradient Based Approaches

- Directed Diffusion

  "Directed Diffusion: A Scalable and Robust Communication Paradigm for Sensor Networks," Chalermek Intanagonwiwat, Ramesh Govindan and Deborah Estrin, *MobiCOM 2000.*

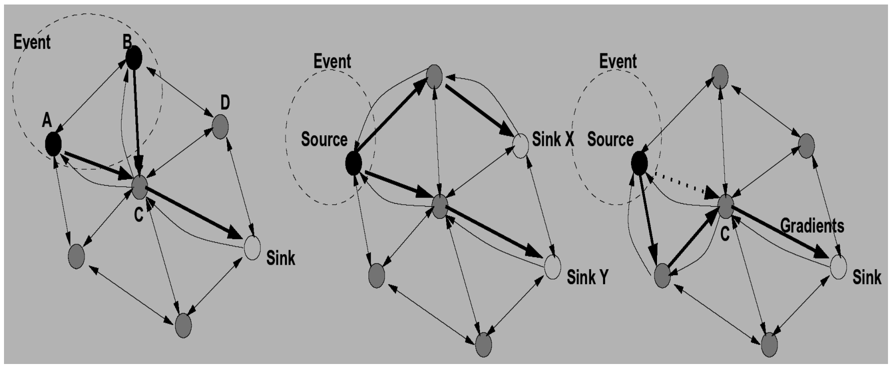
- GRAB - GRadient Broadcast

  "GRAdient Broadcast: A Robust Data Delivery Protocol for Large Scale Sensor Networks," Fan Ye, Gary Zhong, Songwu Lu, Lixia Zhang, ACM Wireless Networks.

Directed Diffusion

- Motivation of the work
  - Distributed sensing and not everyone may be interested in the sensed data
- Single major idea in paper
  - Query-initiated: interests set gradients toward sink
  - Sink reinforces a primary (best) path
  - Interests refreshed periodically and aggregated inside the network
- Model provided in paper
  - Events described by attribute-value pairs
  - Users express interest in certain events
  - Probably works well for long-lived queries
- Related work
  - IP multicast: members join sessions of interest
  - Reliable multicast: local recovery at routers

Directed Diffusion

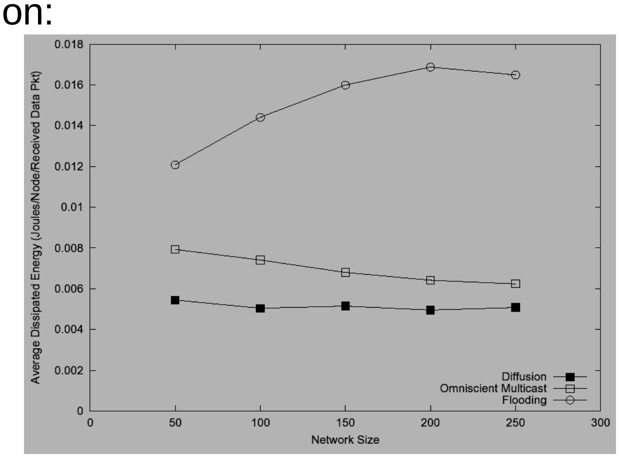


Multiple Sources | Multiple Sinks | Link Failure

Do you see any problem here?

Directed Diffusion

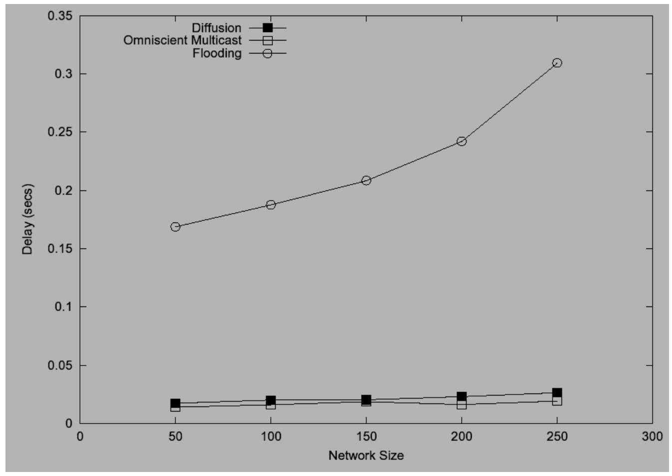
Energy Dissipation:



Why is Diffusion more efficient than Omniscient Multicast?

Directed Diffusion

Latency:



Why does Diffusion have delay comparable to Omniscient Multicast?

Directed Diffusion

- Advantages of the work
  - Robust: only local interactions
  - Low latency: data received along best path
  - Robust: interests refreshed
- Improvements to the work
  - Diffuse interests geographically instead of flooding
  - Consider congestion
  - Data aggregation beyond suppressing duplicates
  - Reinforce multiple paths to avoid energy depletion on primary path
- Single major result
  - More energy efficient than flooding and omniscient multicast (source-rooted tree to all sinks)
- Future research
  - How can we reduce waste in energy due to sink-initiated reinforced paths?
  - Can we analyze stability of selecting reinforced paths?

Directed Diffusion

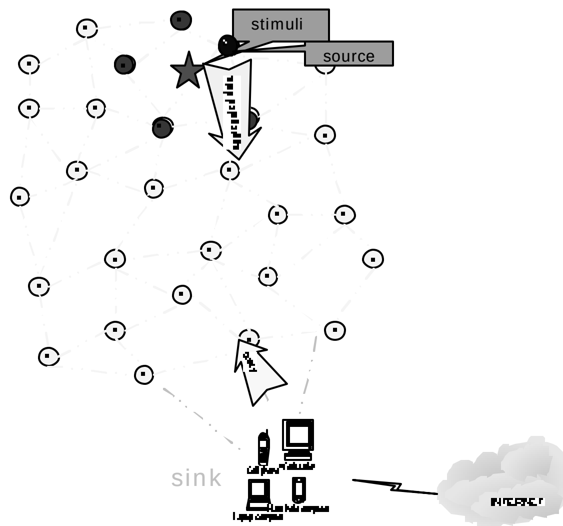
Sensors (Sources)	Users (Sinks)	Event	Interest Propagation	Data Dissemination
Stationary	Stationary	Query	Static	Unicast
		Continuous	Unicast	Multicast
Mobile	Mobile	Target Detection	Multicast	Broadcast
			Broadcast	

GRADient Broadcast: A Robust Data Delivery Protocol For Large Scale Sensor Networks

Fan Ye, Gary Zhong, Songwu Lu,Lixia Zhang
UCLA
ACM WINET

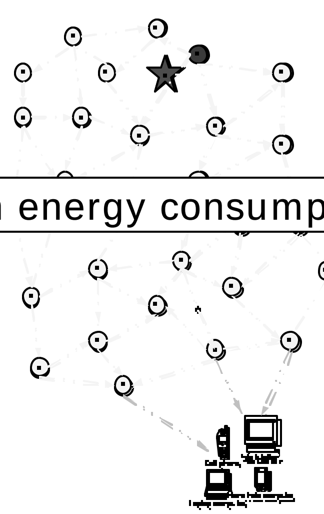
Niky Riga
Sensor Networks Seminar
Fall 2003
Boston University

Setup...



Flow of data (1)

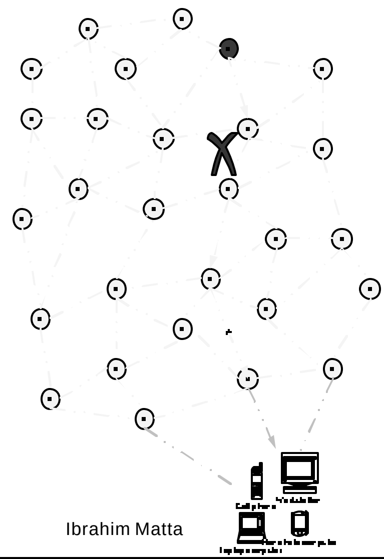
Broadcast



High energy consumption

Flow of data (1)

Single Path



Flow of data (3)

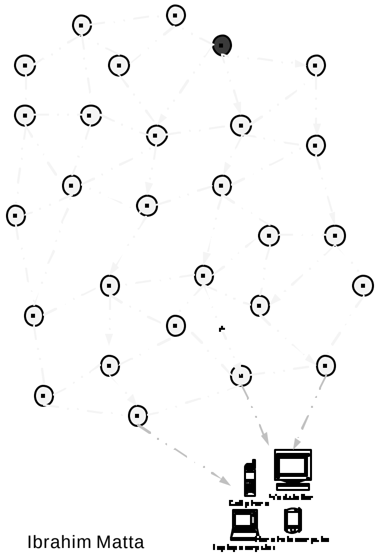
Multipath

Idea : Maintain more than one path from the source to the sink.

Multipath

Disjoint Paths

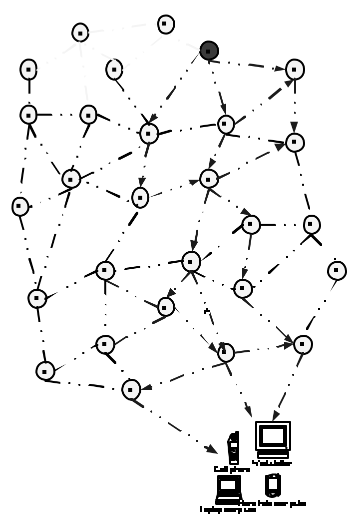
For each two paths all the nodes along the path are different except the source and the sink



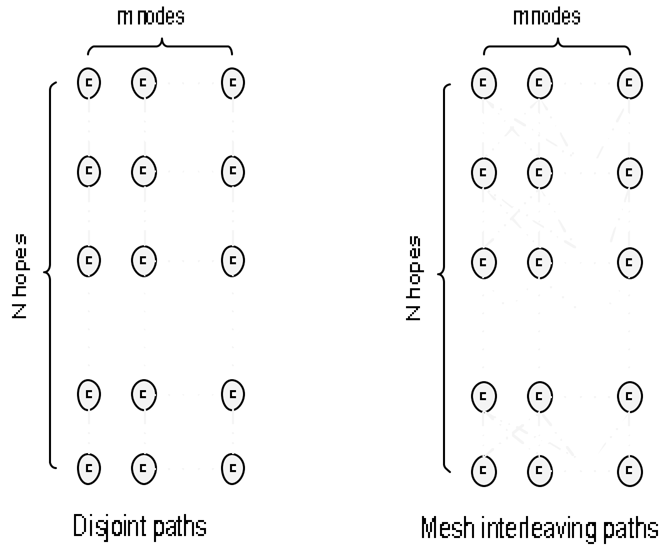
Multipath

Braided Paths

Two different paths from the source to the sink differ in at least two nodes



Braided VS Disjoint multipaths



Proof

f : probability of node failure on a link

$P^{d}_{fail}(N)$: probability that a packet fail to reach the destination after N hops in disjoint

$P^{g}_{fail}(N)$: probability that a packet fail to reach the destination after N hops in mesh

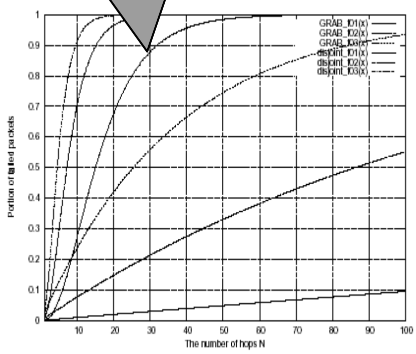
Proof (e=0)

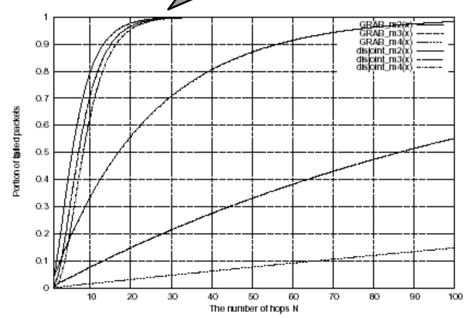
Probability that a packet fails to reach hop N for different node failure rate

$$P^d_{fail}(N) = (1-(1-f)^N)^m$$

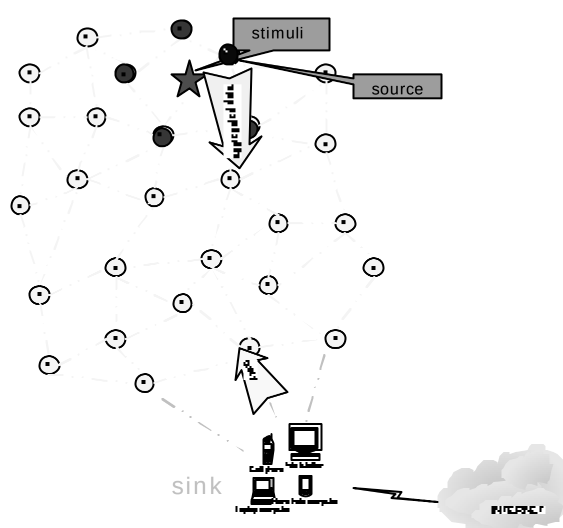
$$P^g_{fail}(N) = (1-(1-f^m)^N$$

Probability that a packet fails to reach hop N for different number of nodes m





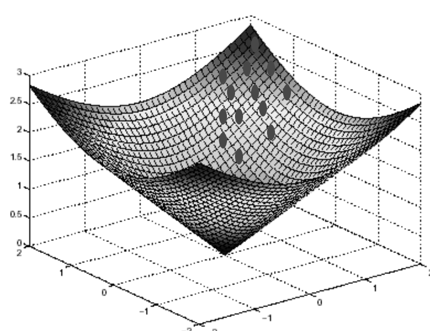
GRAB model



GRAB

- To build paths between the source and the sink, the sinks creates a *cost field.*
- The cost at each node is the minimum energy overhead to forward a packet from the node to the sink.

Cost Field



- Sink broadcasts an ADV with cost 0
- Initial cost for the nodes 8
- Each node when receives an ADV add the cost advertised with the cost from the sender to the node. It keeps the smaller cost between the new and the old.
- Event driven updates

GRAB forwarding algorithm

Packet carries except from the data:

- *a : credit defined by source*
- C_{source} *:cost from source to sink*
- $P_{consumed}$*:amount consumed until this node*
- C_{sender} *:the cost from current sender to sink*

Source creates the packet .

Each node with $C_{receiver}<C_{source}$ *calculates :*

$$R_a = \frac{a - a_{used}}{a}, a_{used} = P_{consumed} + C_{receiver} - C_{source}$$

$$R_{thresh} = \left(\frac{C_{receiver}}{C_{source}}\right)^2$$

If $R_a > R_{thresh}$ forwards the message.

Complexities of GRAB

- Kept state O(n), *n* number of sinks
- Packet analysis in each node O(1)
- Energy overhead
  - Forwarding O(k),k number of data reports
  - Cost field building proportional to #updates and #sinks

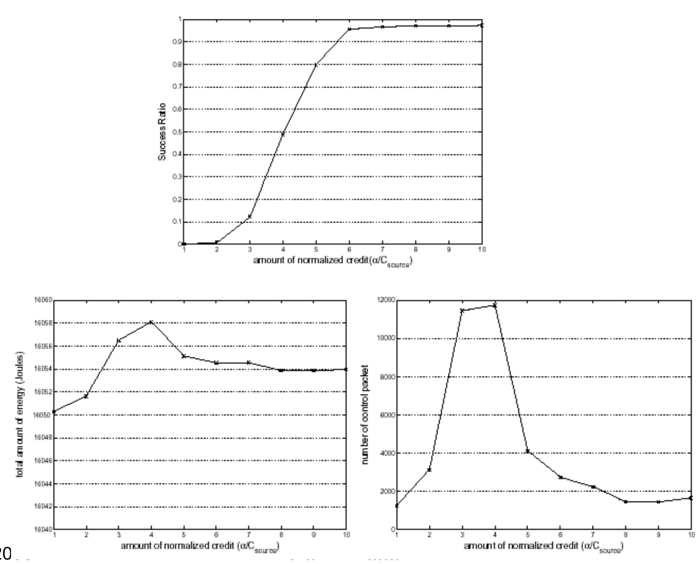
Evaluation
Criteria

- Success ratio

$$\text{Success ratio} = \frac{\#\text{packets sent by source}}{\#\text{packets received in sink}}$$

- Total energy consumption
- Control packet overhead

Evaluation
Credit a

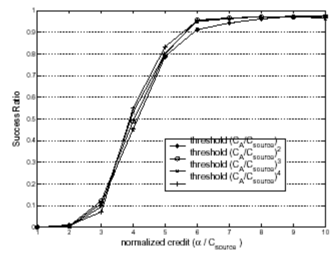


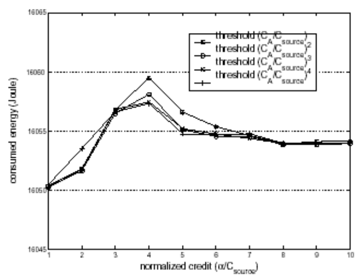
Evaluation

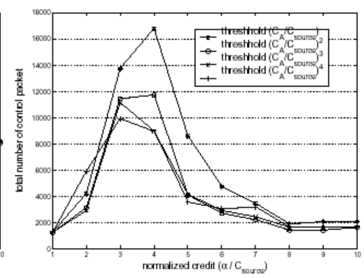
Threshold functions

$$f_1 = \frac{C_A}{C_{source}}, \quad f_2 = \left(\frac{C_A}{C_{source}}\right)^2$$

$$f_3 = \left(\frac{C_A}{C_{source}}\right)^3, \quad f_4 = \left(\frac{C_A}{C_{source}}\right)^4$$

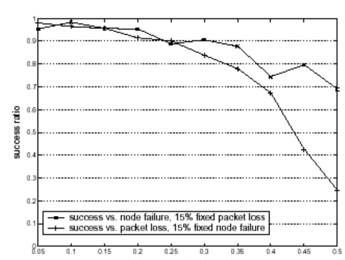


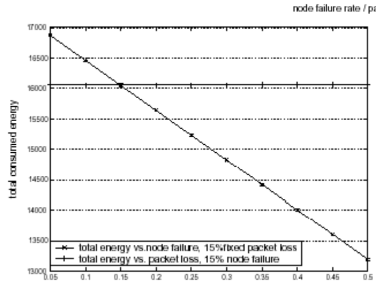


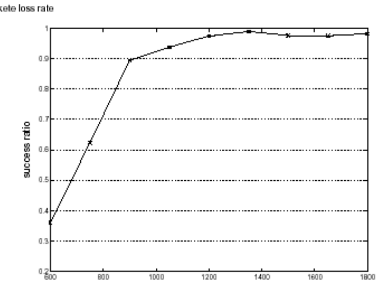


Evaluation

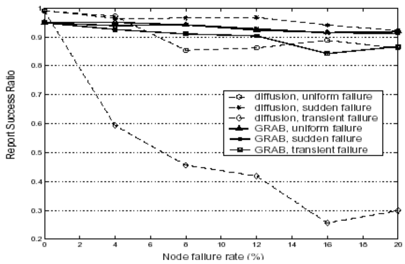
Environmental Settings

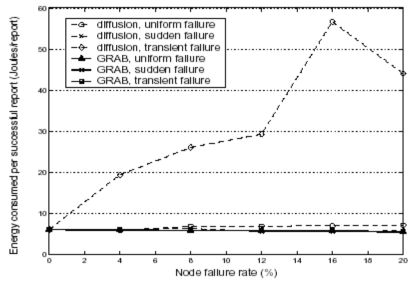






Evaluation
GRAB vs Directed Diffusion





Related Work

- Directed diffusion, braided-diffusion,
  - Scalar vs. vector routing states
  - Receiver-decided vs. Sender-appointed
  - Multiple interleaving paths vs. single path
- gradient routing
  - Both receiver-decided, scalar routing states
  - Controllable mesh vs. cost field only
- energy aware routing(piconet)
  - Both scalar routing states
  - Receiver-decided vs. sender-probabilistically-appointed

Summary

- A forwarding mesh of multiple interleaving paths ensures robustness
  - A sender does not bind the forwarding to any specific neighbor
  - Multiple receivers decide on their own whether to forward
- Per-packet credit builds mesh on-the-fly
  - Dividing credit among all hops for robustness
  - No state maintained about which node is in mesh

Future Work

- Adaptive credit assignment
- Sink inform source about data quality
- Sink mobility

Questions??

Thank you ☺