Exploring Energy-Latency Tradeoffs for Sensor Network Broadcasts

Matthew J. Miller
Cigdem Sengul
Indranil Gupta

University of Illinois at Urbana-Champaign
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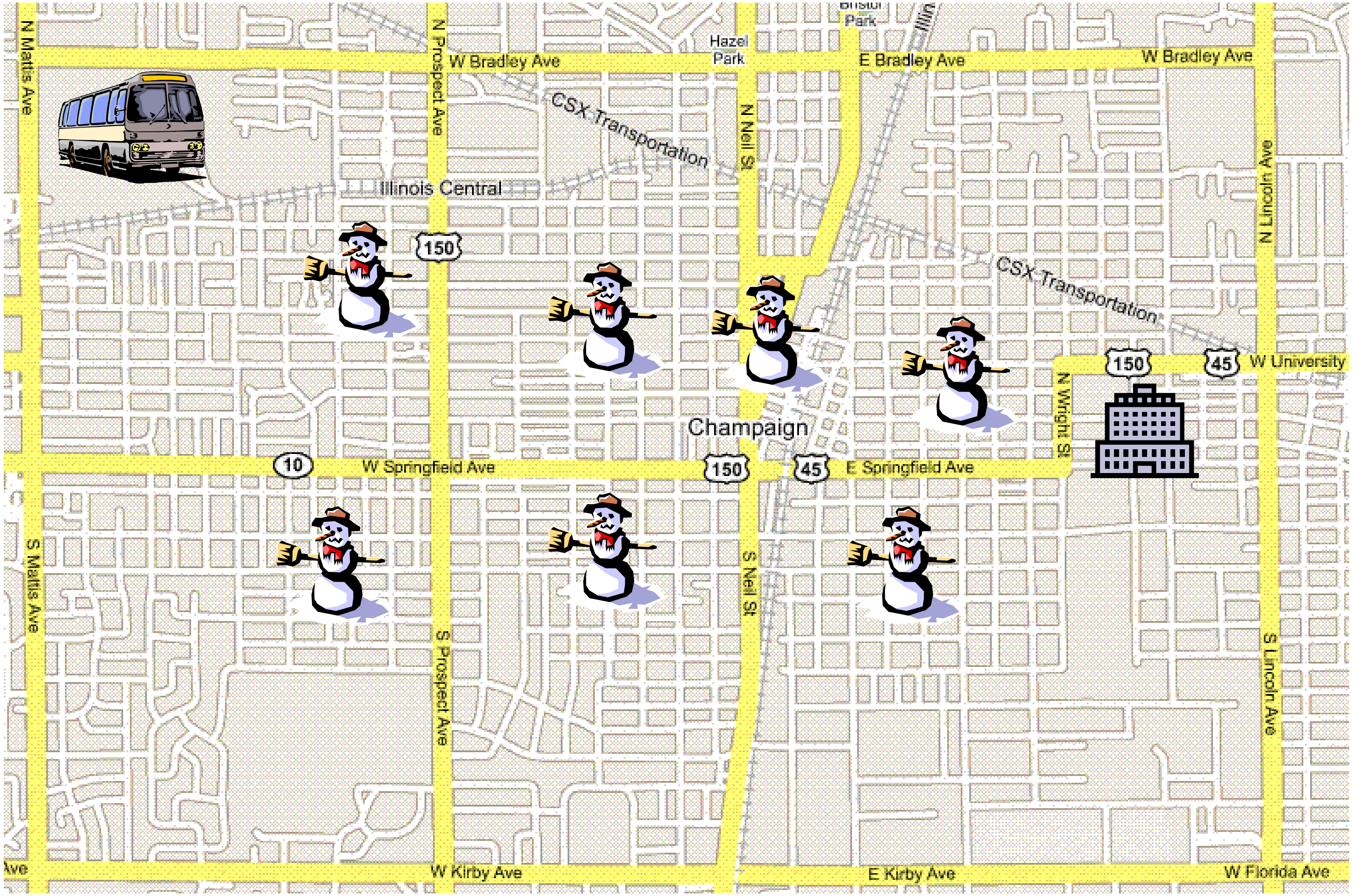
Question???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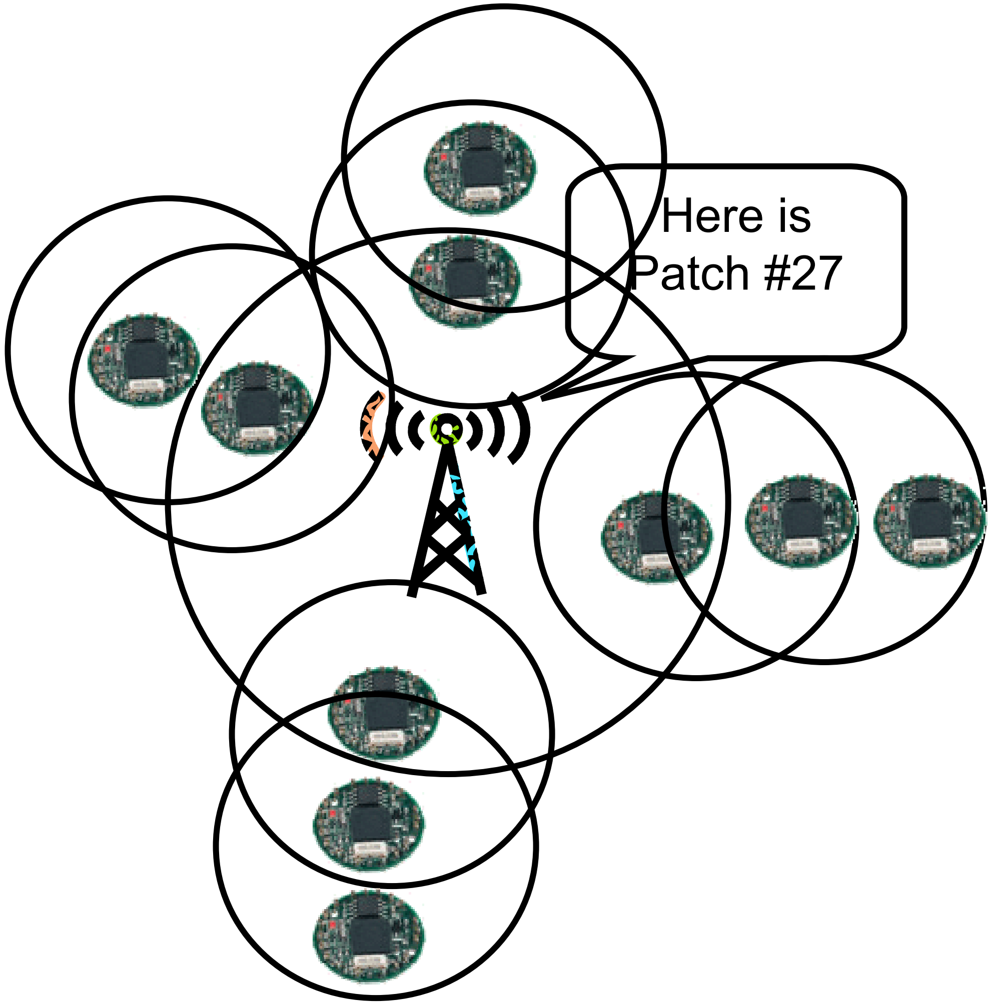
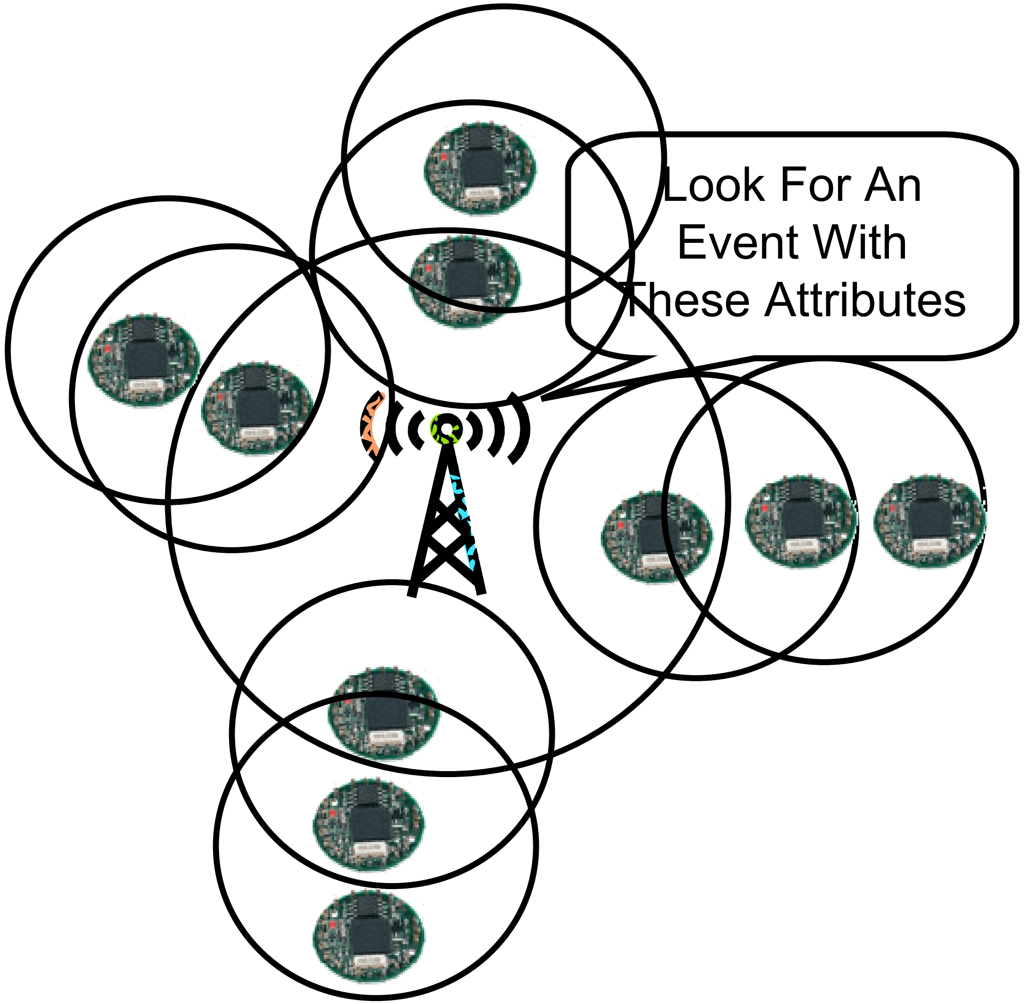
Sensor Application #1

- Code Update Application
  - E.g., Trickle [Levis et al., NDSI 2004]
- Updates Generated Once Every Few Weeks
  - Reducing energy consumption is important
  - Latency is not a major concern

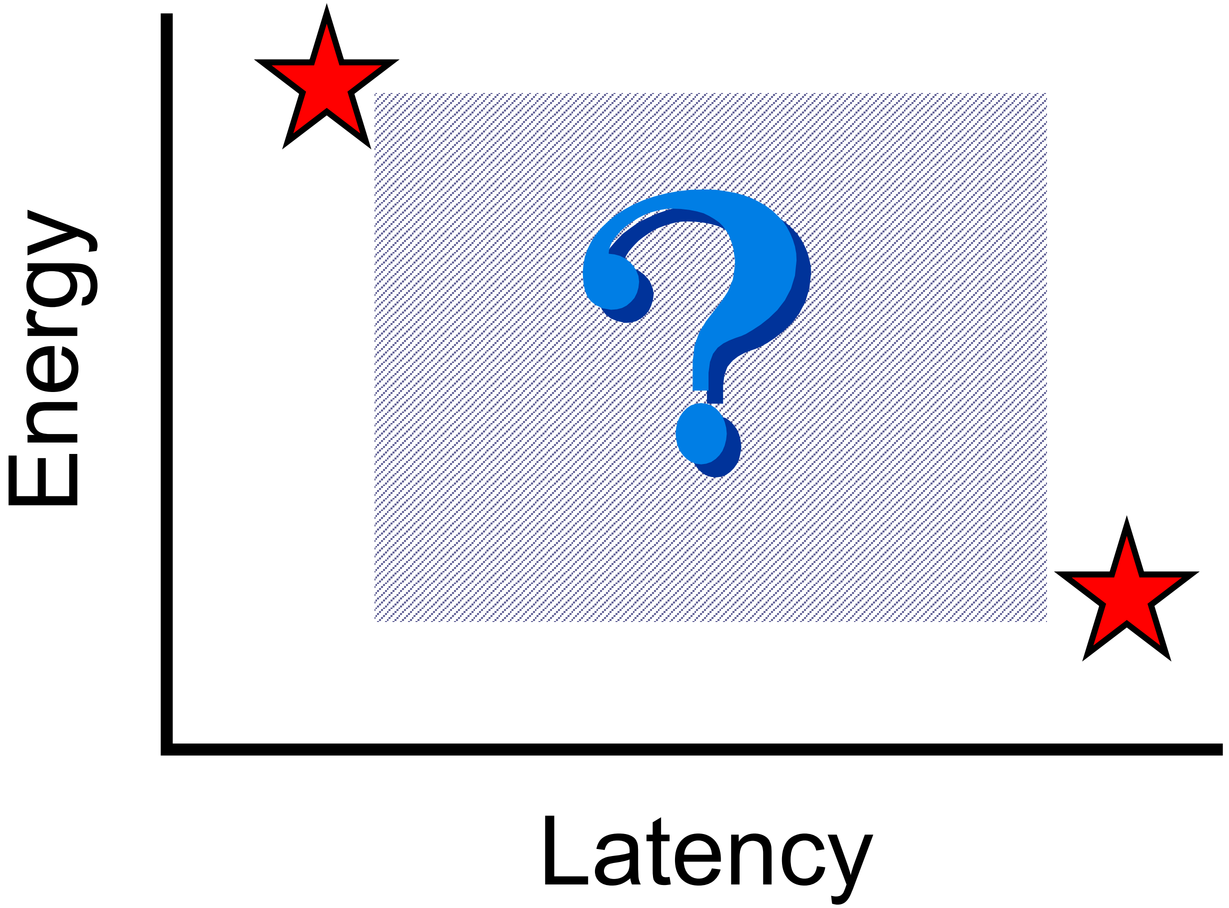


Sensor Application #2

- Short-Term Event Detection
  - E.g., Directed Diffusion [Intanagonwiwat et al., MobiCom 2000]
- Intruder Alert for Temporary, Overnight Camp
  - Latency is critical
  - With adequate power supplies, energy usage is not a concern



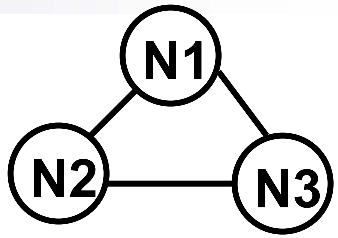
Energy-Latency Options

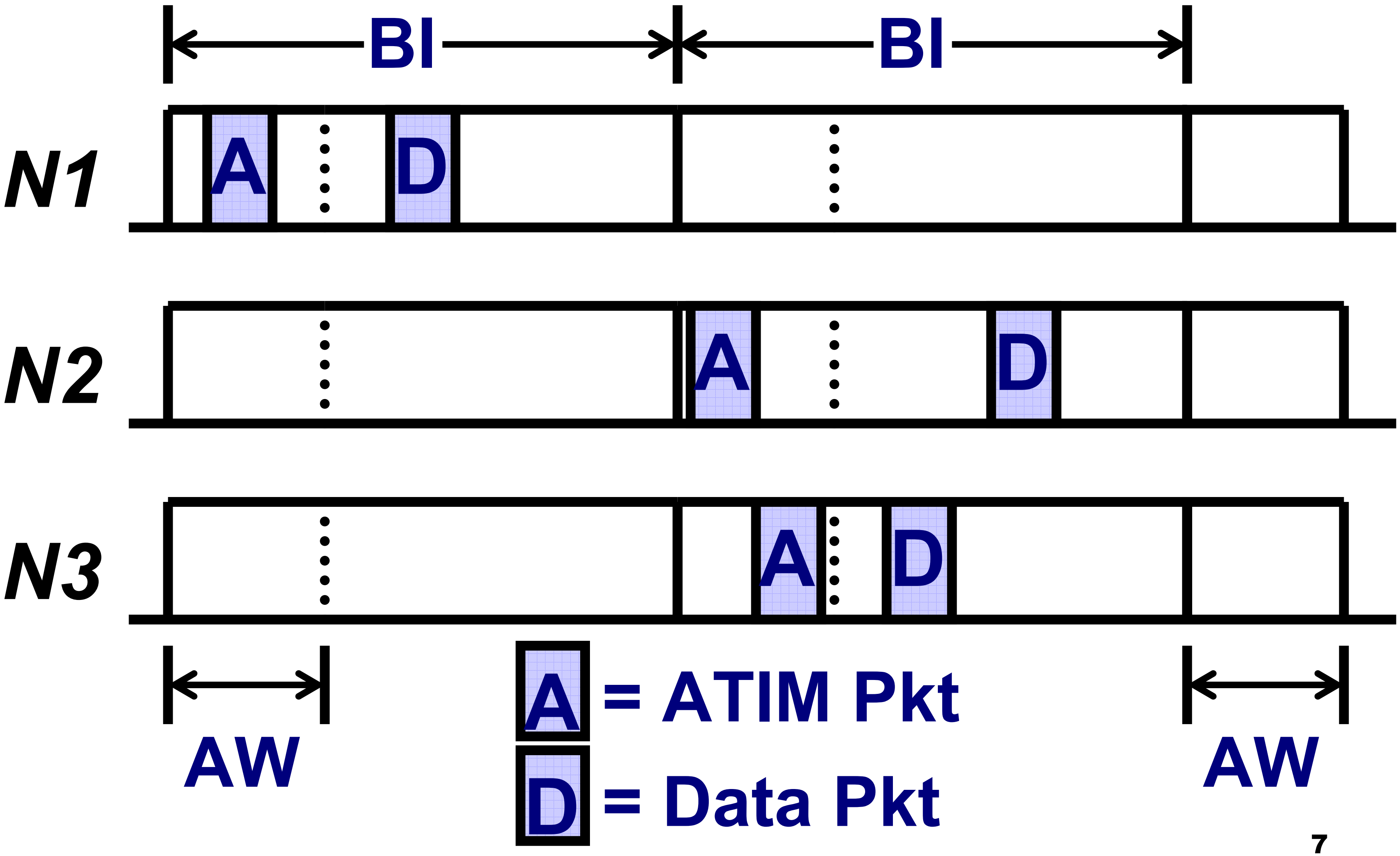


Sleep Scheduling Protocols

- Nodes have two states: active and sleep
- At any given time, some nodes are active to communicate data while others sleep to conserve energy
- Examples
  - IEEE 802.11 Power Save Mode (PSM)
    - Most complete and supports broadcast
    - Not necessarily directly applicable to sensors
  - S-MAC/T-MAC
  - STEM

IEEE 802.11 PSM Example With Broadcasts

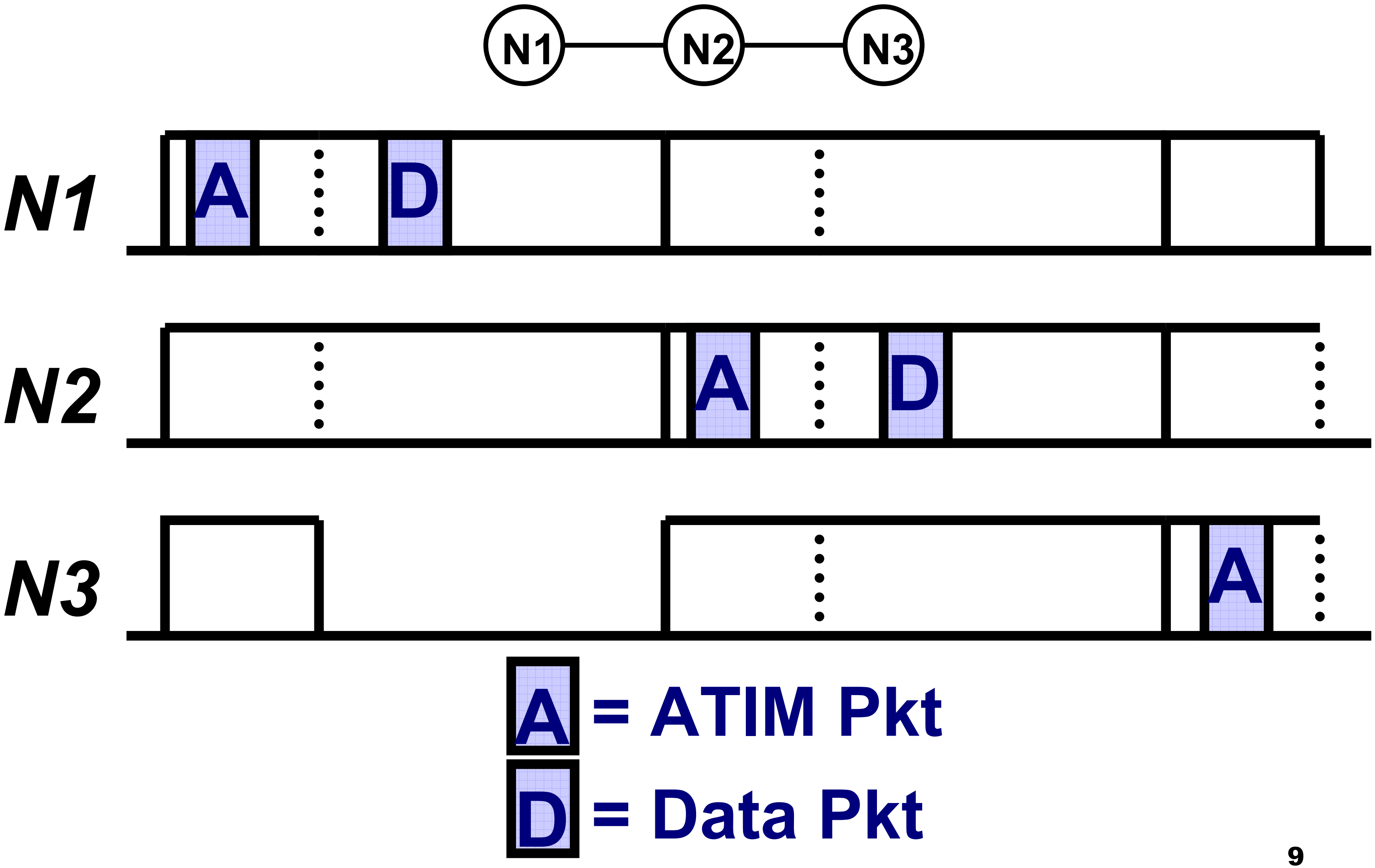




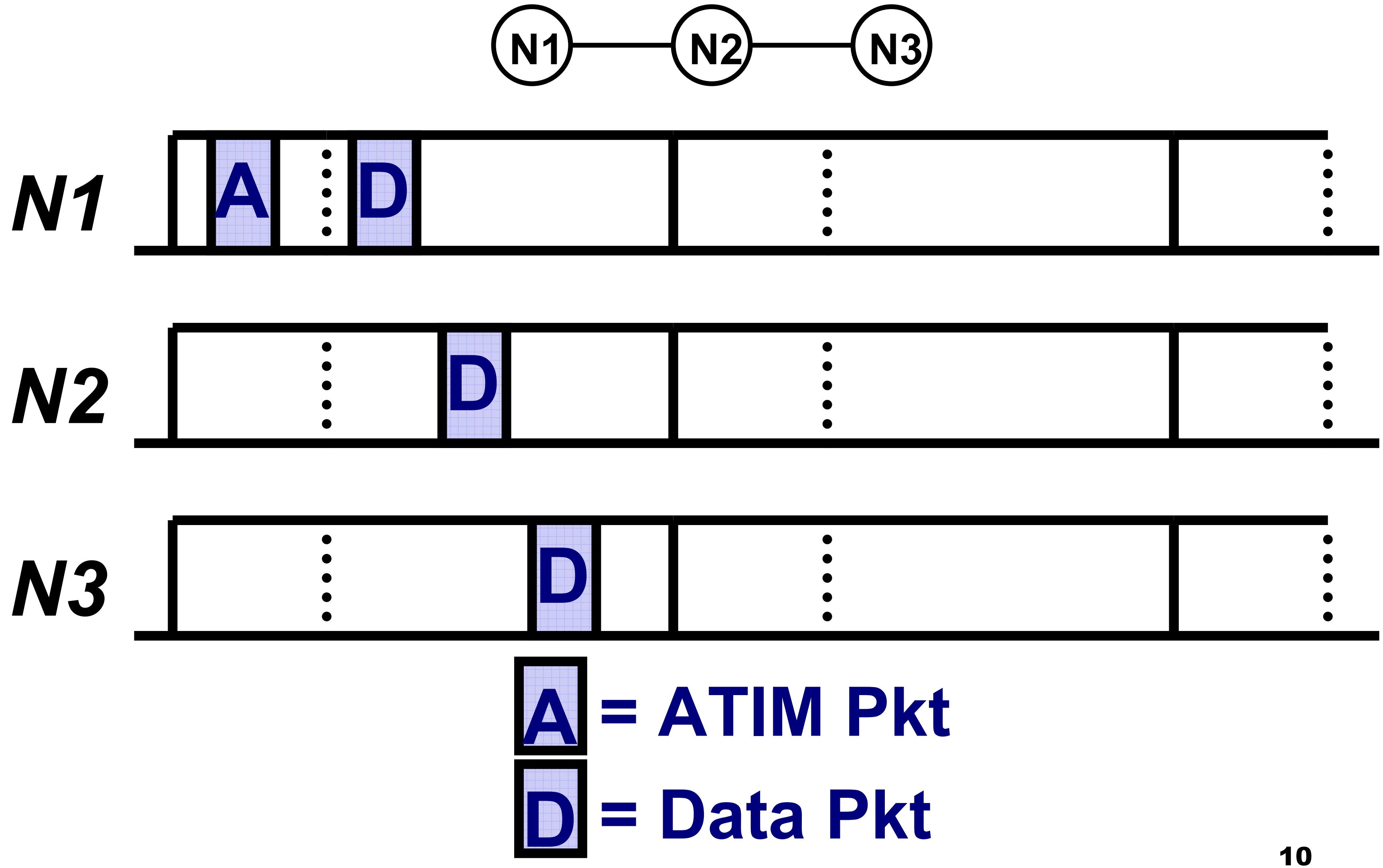
IEEE 802.11 PSM

- Nodes are assumed to be synchronized
- Every beacon interval (BI), all nodes wake up for an ATIM window (AW)
- During the AW, nodes advertise any traffic that they have queued
- After the AW, nodes remain active if they expect to send or receive data based on advertisements; otherwise nodes return to sleep until the next BI

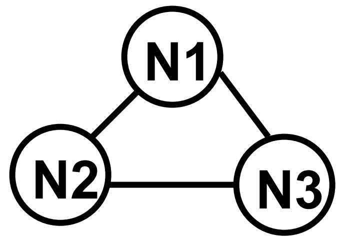
Protocol Extreme #1

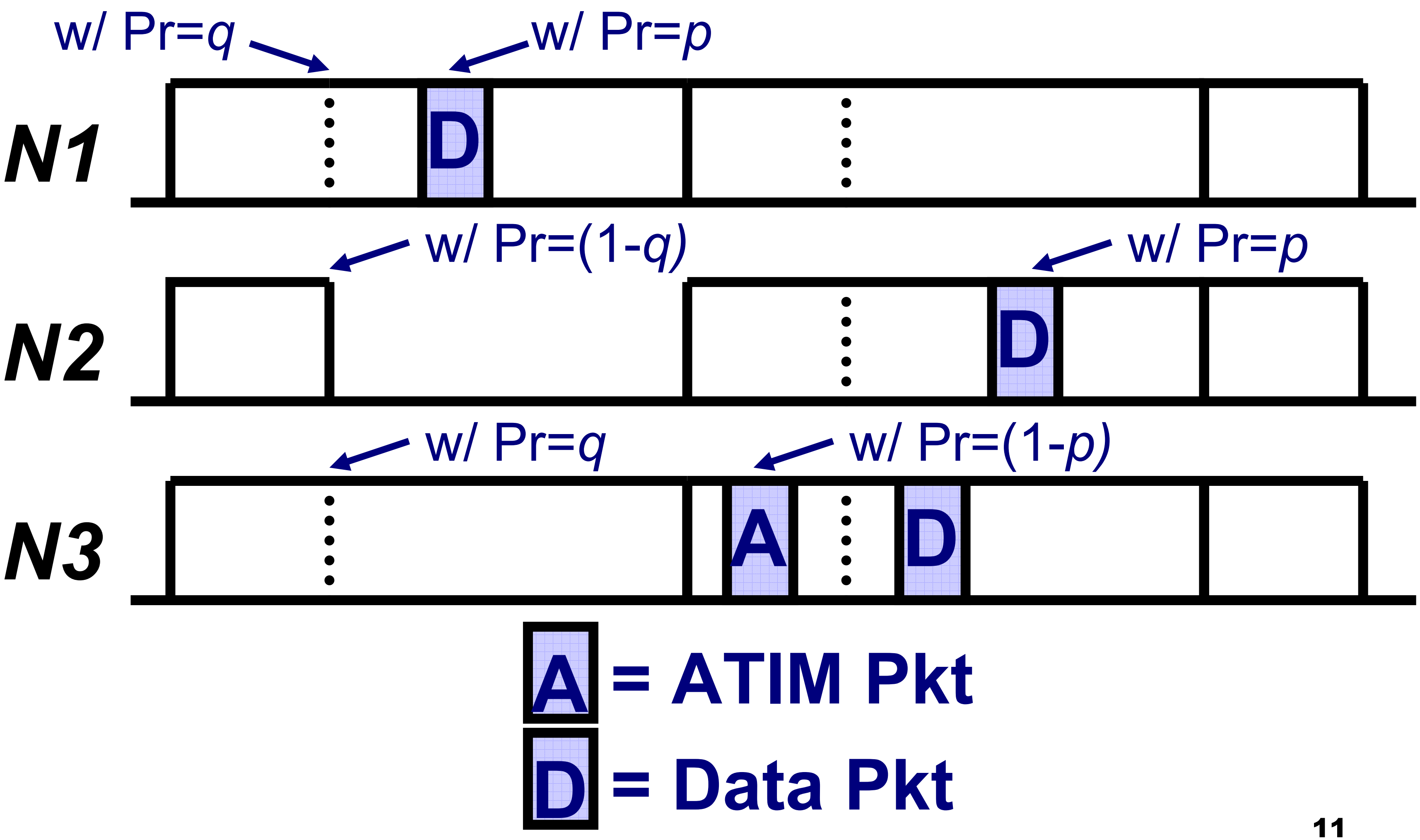


Protocol Extreme #2



Probabilistic Protocol





Probability-Based Broadcast Forwarding (PBBF)

- Introduce two parameters to sleep scheduling protocols: *p* and *q*
- When a node is scheduled to sleep, it will remain active with probability *q*
- When a node receives a broadcast, it sends it immediately with probability *p*
  - With probability (1-*p*), the node will wait and advertise the packet during the next AW before rebroadcasting the packet

PBBF Comments

- p=0, q=0 equivalent to the original sleep scheduling protocol
- p=1, q=1 approximates the “always on” protocol
  - Still have the ATIM window overhead

- Effects of p and q on metrics:

	Energy	Latency	Reliability
$p \uparrow$	---	$\downarrow$ if $q > 0$	$\downarrow$ if $q < 1$
$q \uparrow$	$\uparrow$	$\downarrow$ if $p > 0$	$\uparrow$ if $p > 0$

Analysis: Reliability

- Bond (edge) percolation theory
  - Determines the connectivity of a random graph
  - Different from Haas' Gossip-Based Routing which used site (vertex) percolation theory
- A phase transition occurs when the probability of an edge between two vertices is greater than the critical value
  - In this phase, the probability that an infinitely large cluster exists in a graph is close to one
- A phase transition occurs when the probability of an edge is less than the critical value
  - In this phase, the probability that an infinitely large cluster exists in the graph is close to zero

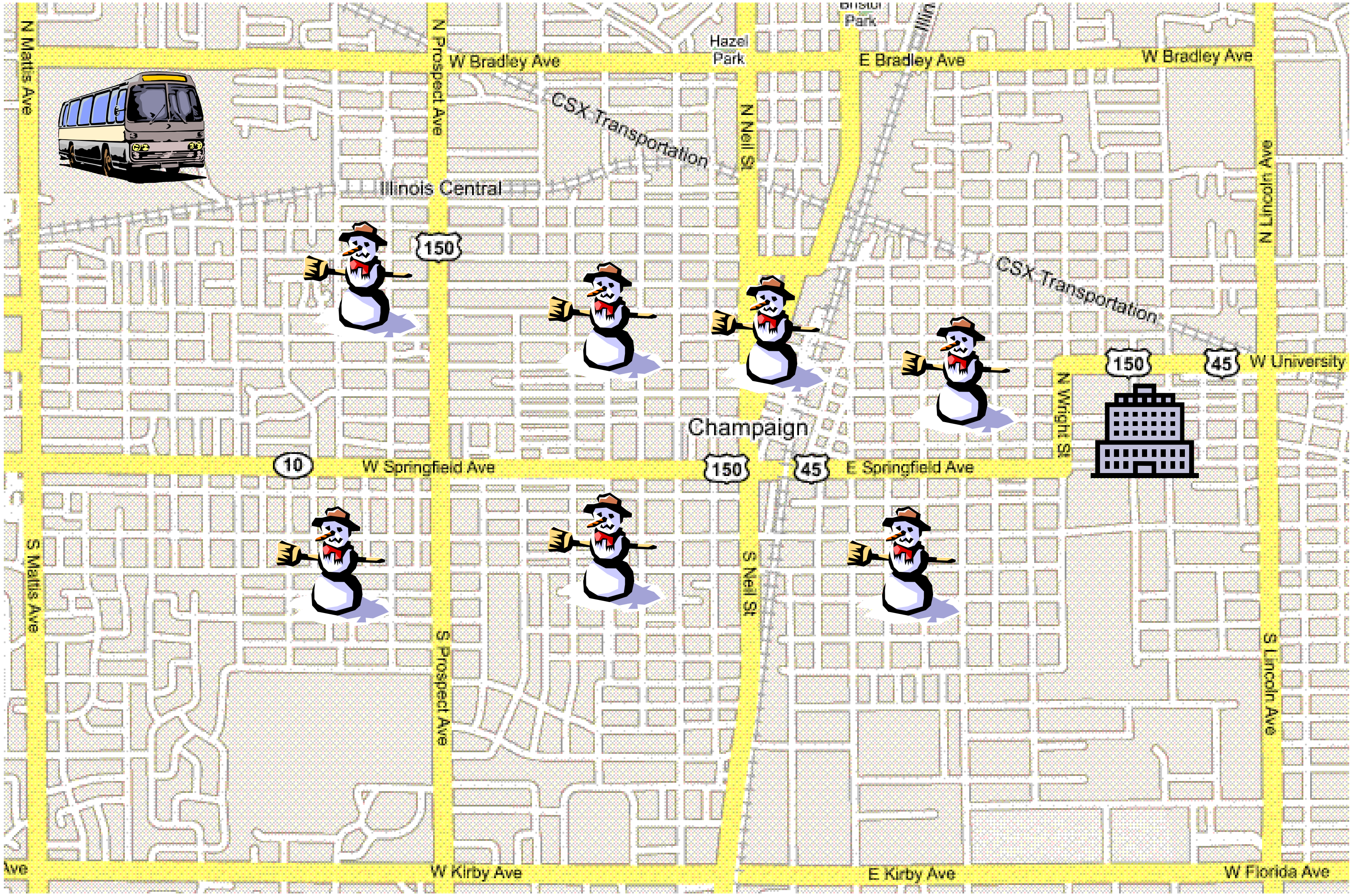
Analysis: Reliability

- In PBBF, the probability that a broadcast is received on a link is:

$$pq + (1-p)$$

- Thus, if $pq + (1-p)$ is greater than a critical value, then every broadcast reaches most of the nodes in the network
- Tested PBBF on grid topology with ideal MAC and physical layers

Answer = 0.5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N Prospect Ave
N Neil St
N Lincoln Ave
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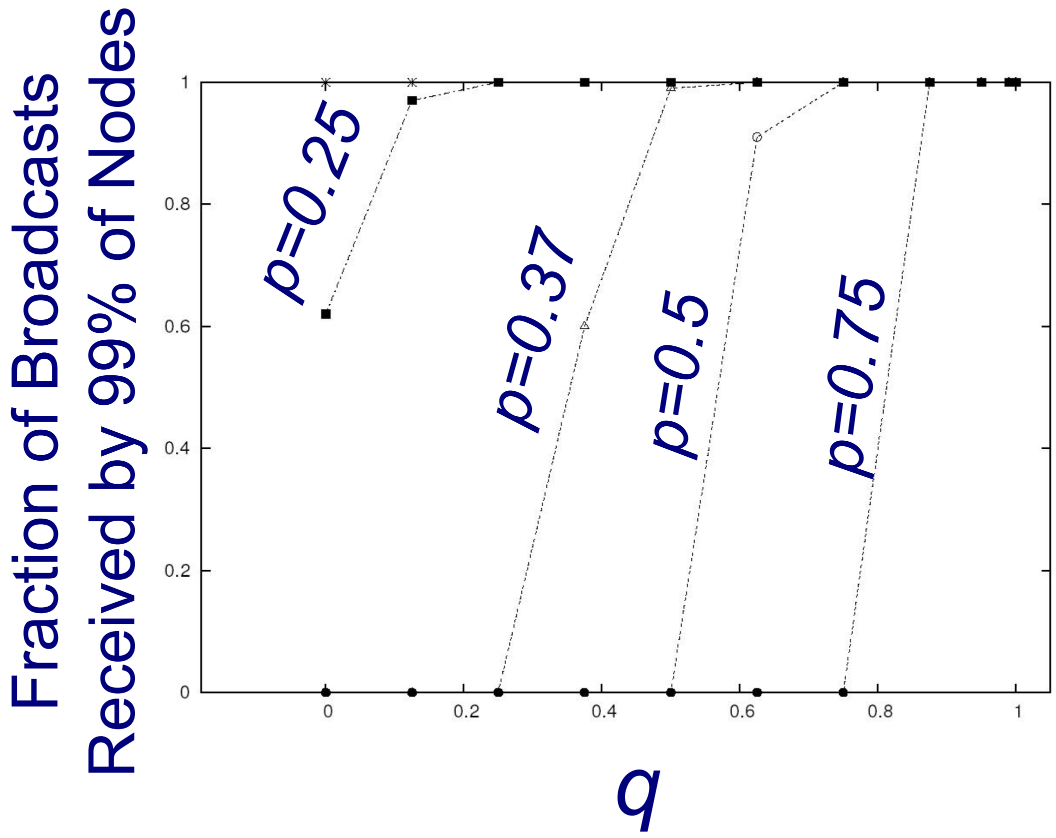
Analysis: Reliability

- Phase transition when:

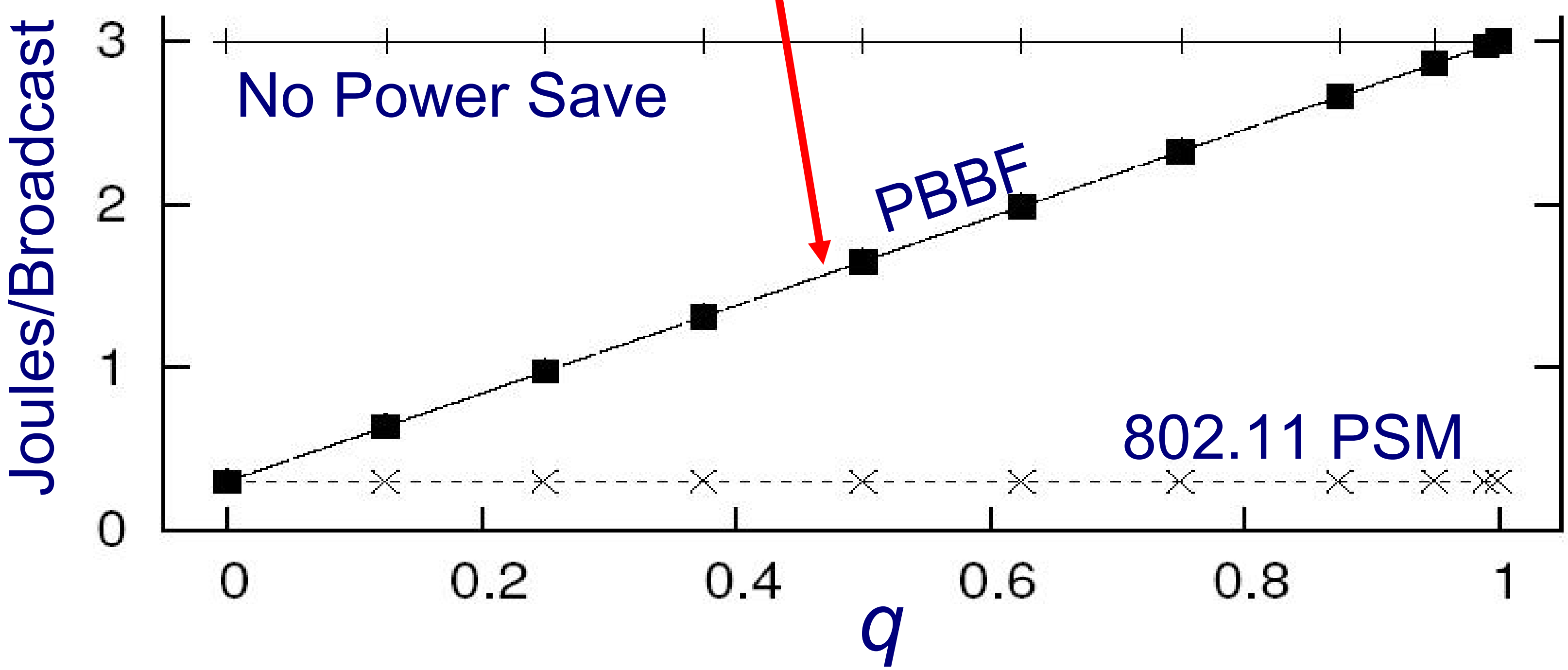
$pq + (1-p) \approx 0.8\text{-}0.85$

- Larger than bond percolation threshold
  - Boundary effects
  - Different metric
- Still shows phase transition

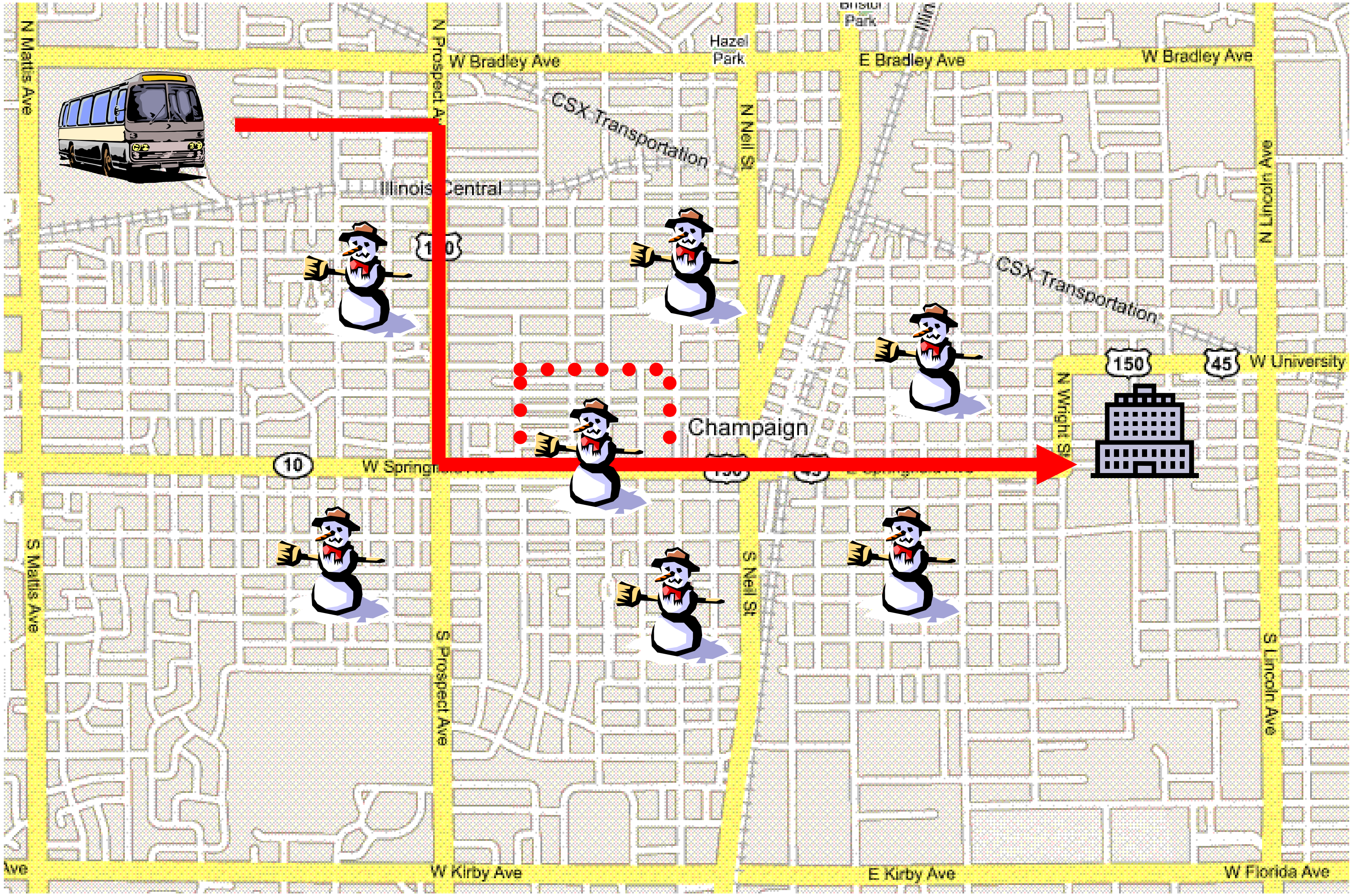


Analysis: Energy

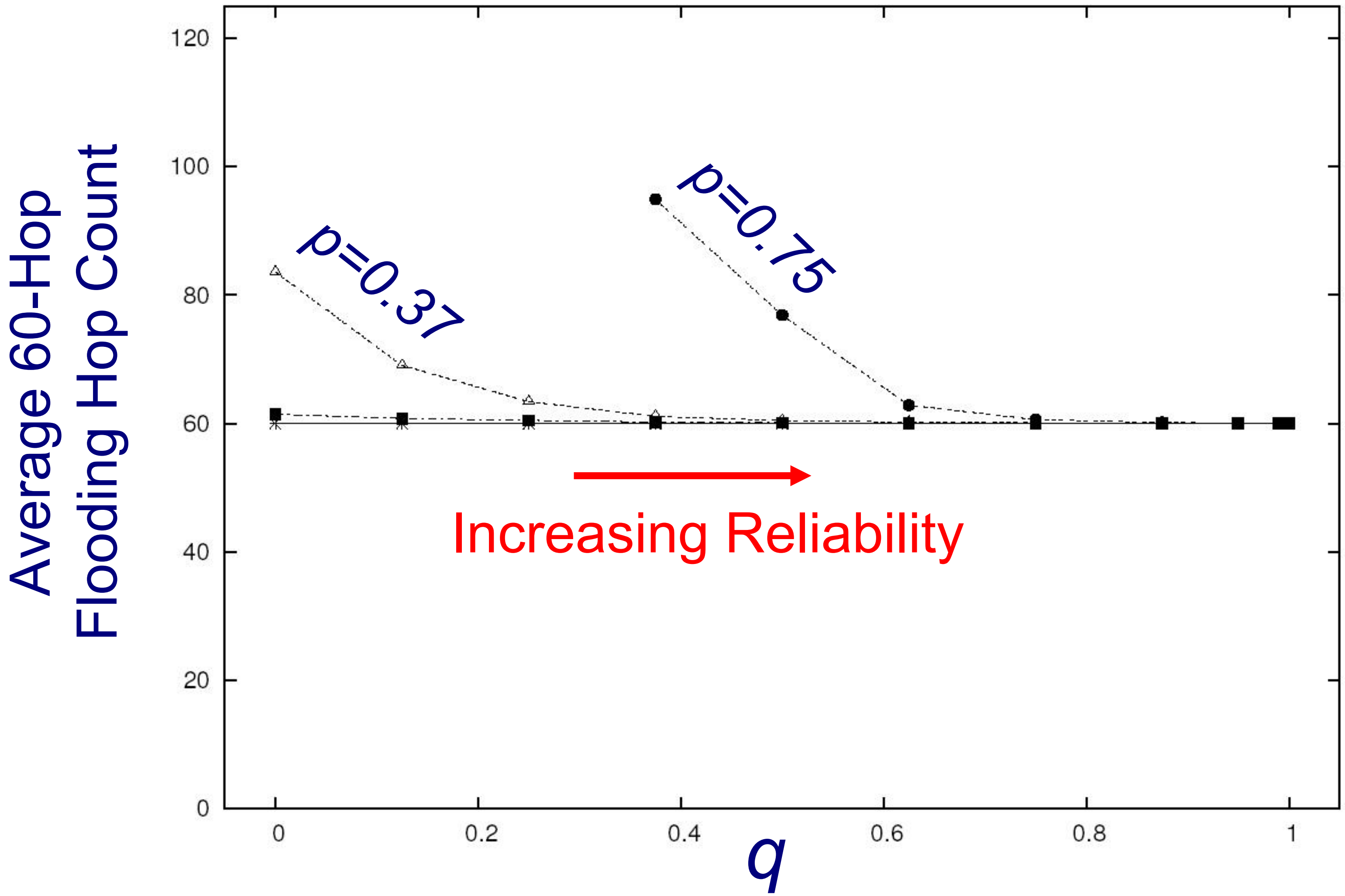
≈ 1 + *q* * [(BI - AW)/AW]



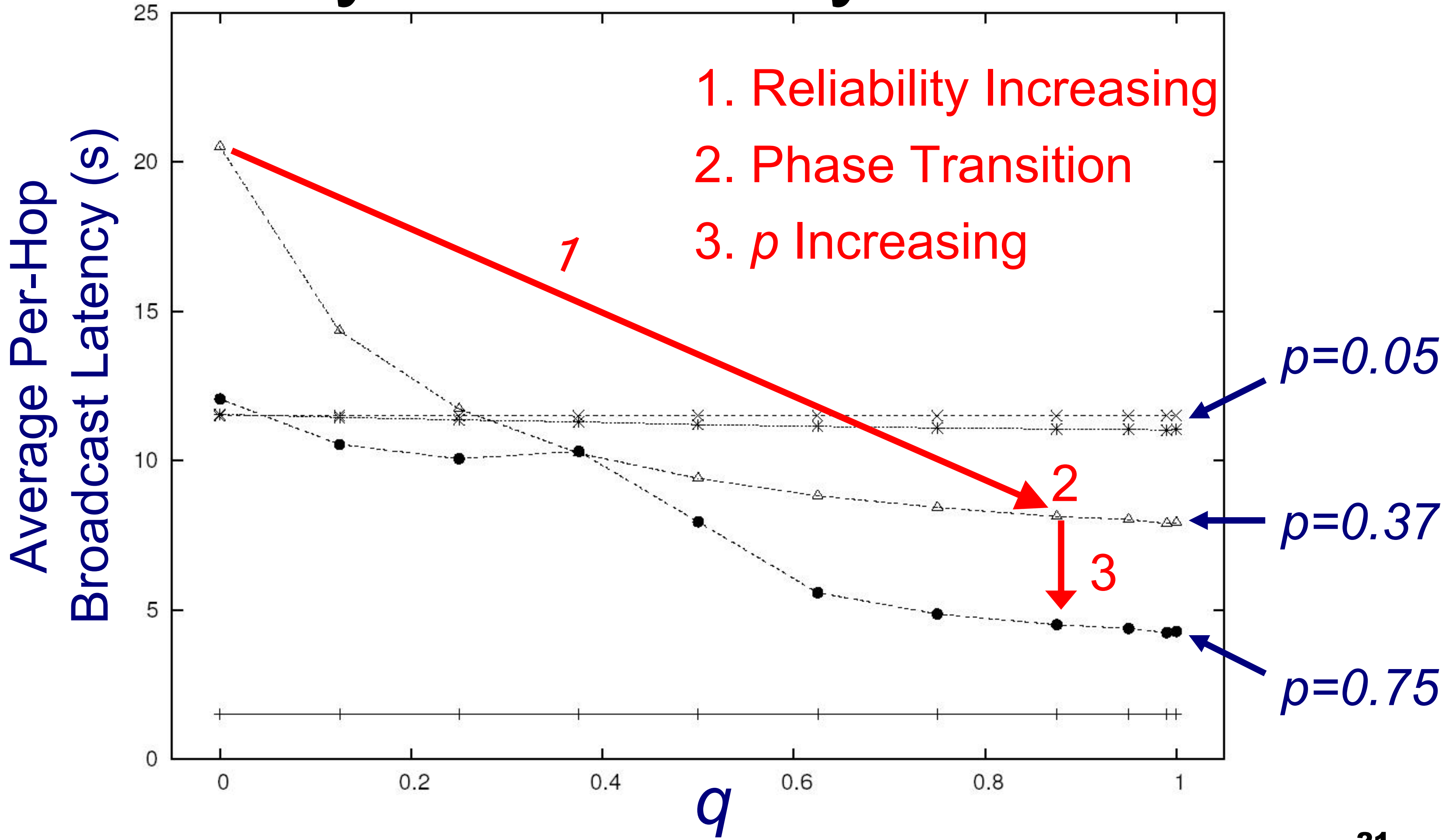
Analysis: Latency
Shortest Paths and Reliability



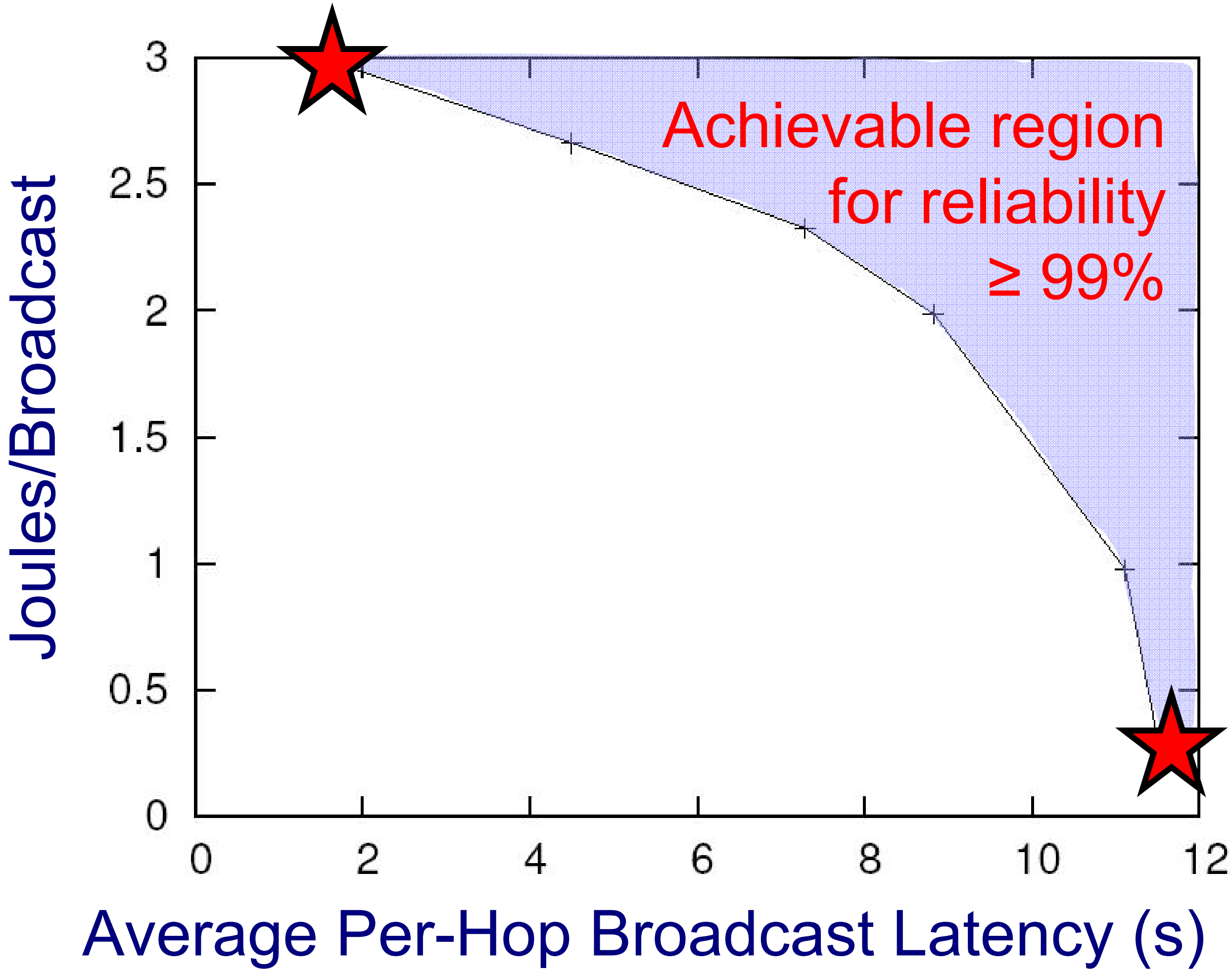
Analysis: Latency



Analysis: Latency



Analysis: Energy-Latency Tradeoff

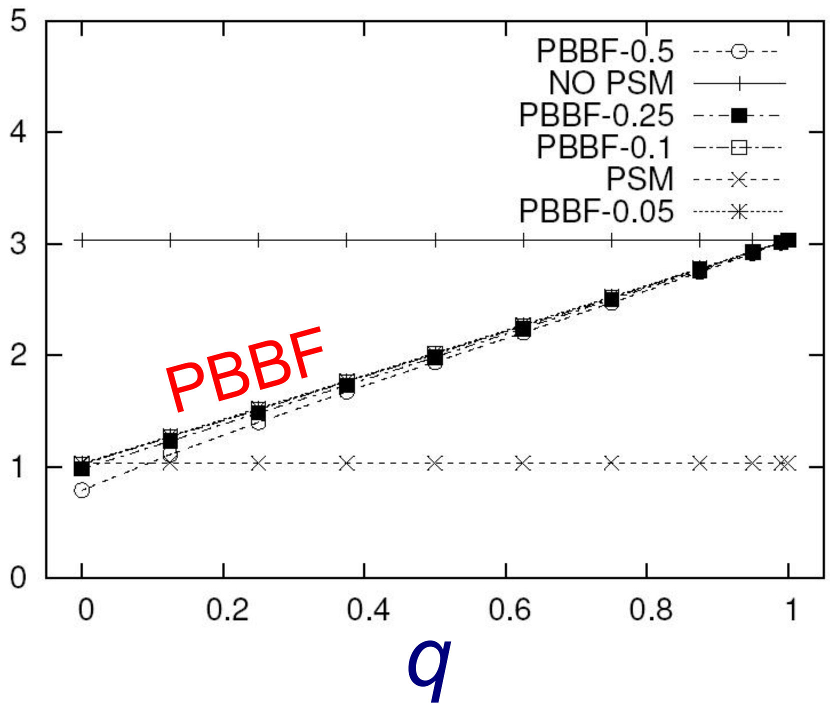


Application Results

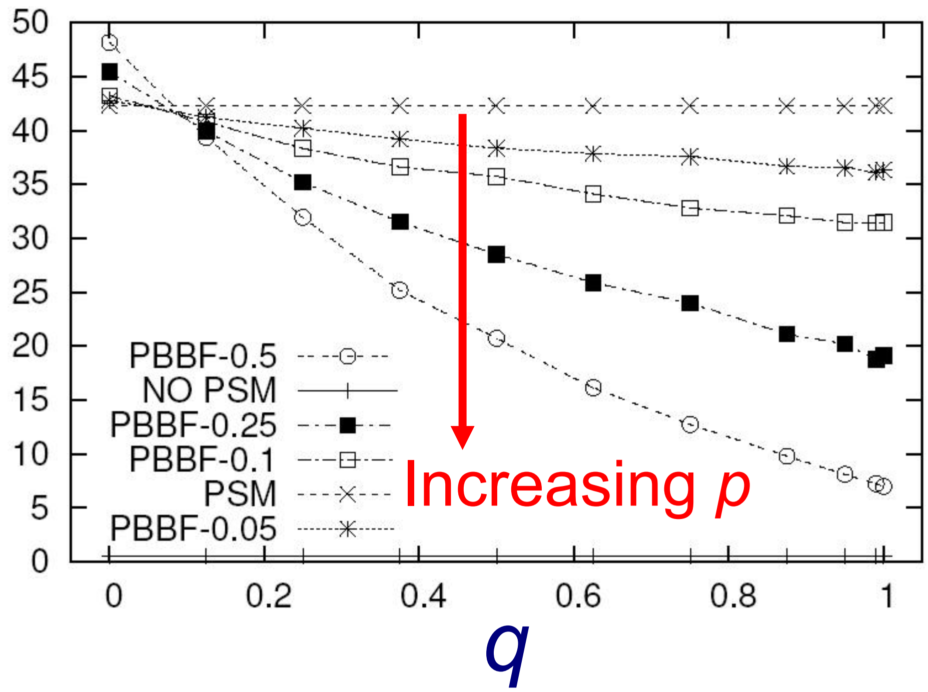
- Simulated code distribution application in *ns*-2, where a base station periodically sends patches for sensors to apply
  - 50 nodes
  - Average One-Hop Neighborhood Size = 10
  - Uniformly random node placement in square area
  - Topology connected
  - Full MAC layer

Application: Energy and Latency

Energy
Joules/Broadcast

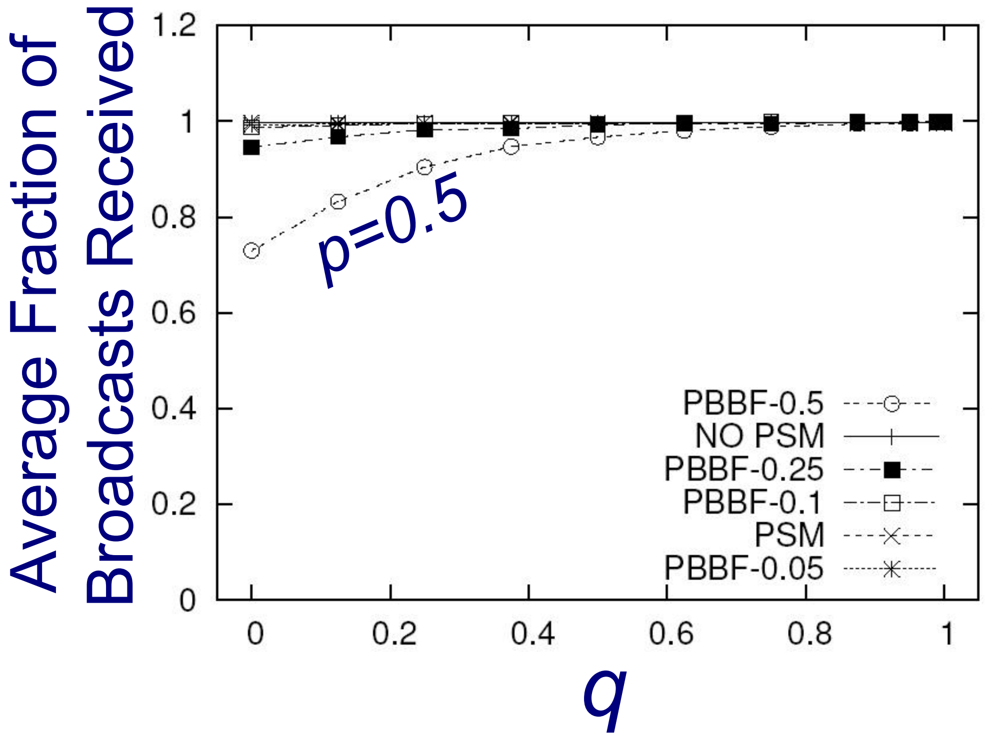


Latency
Average 5-Hop Latency



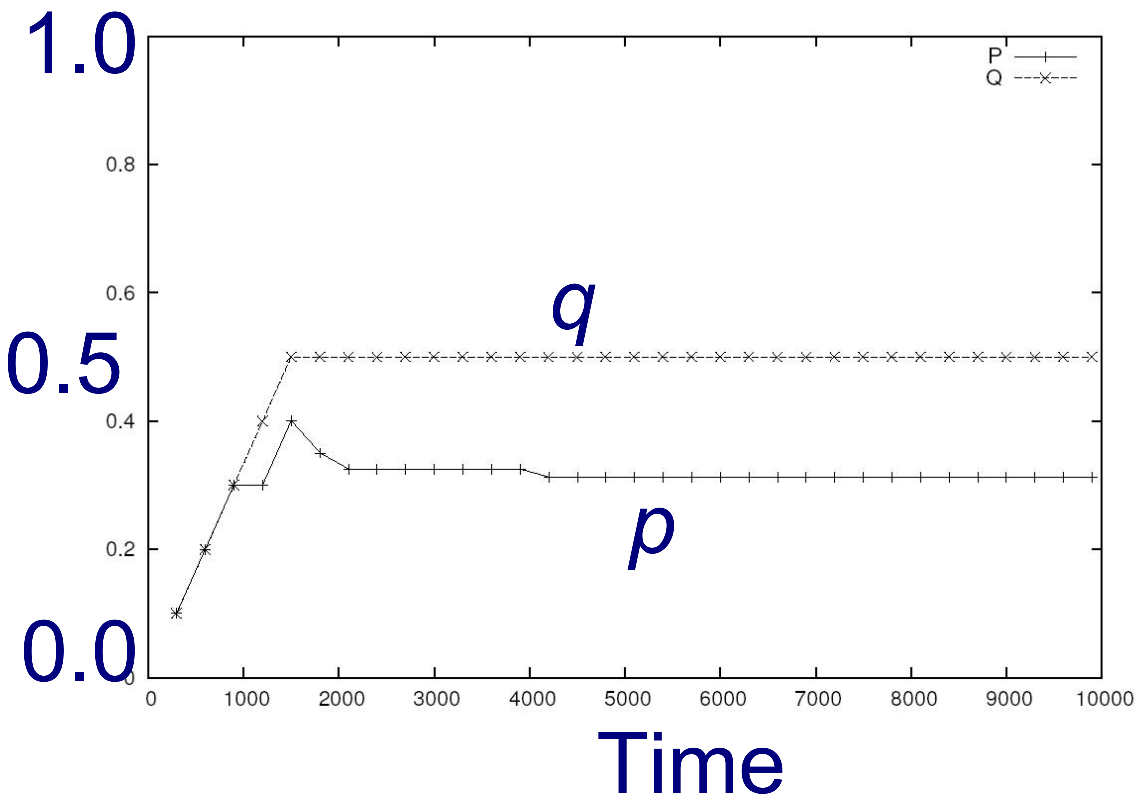
Application: Reliability

- Different reliability metric
- Average fraction of broadcasts received per node
- Better fit for application

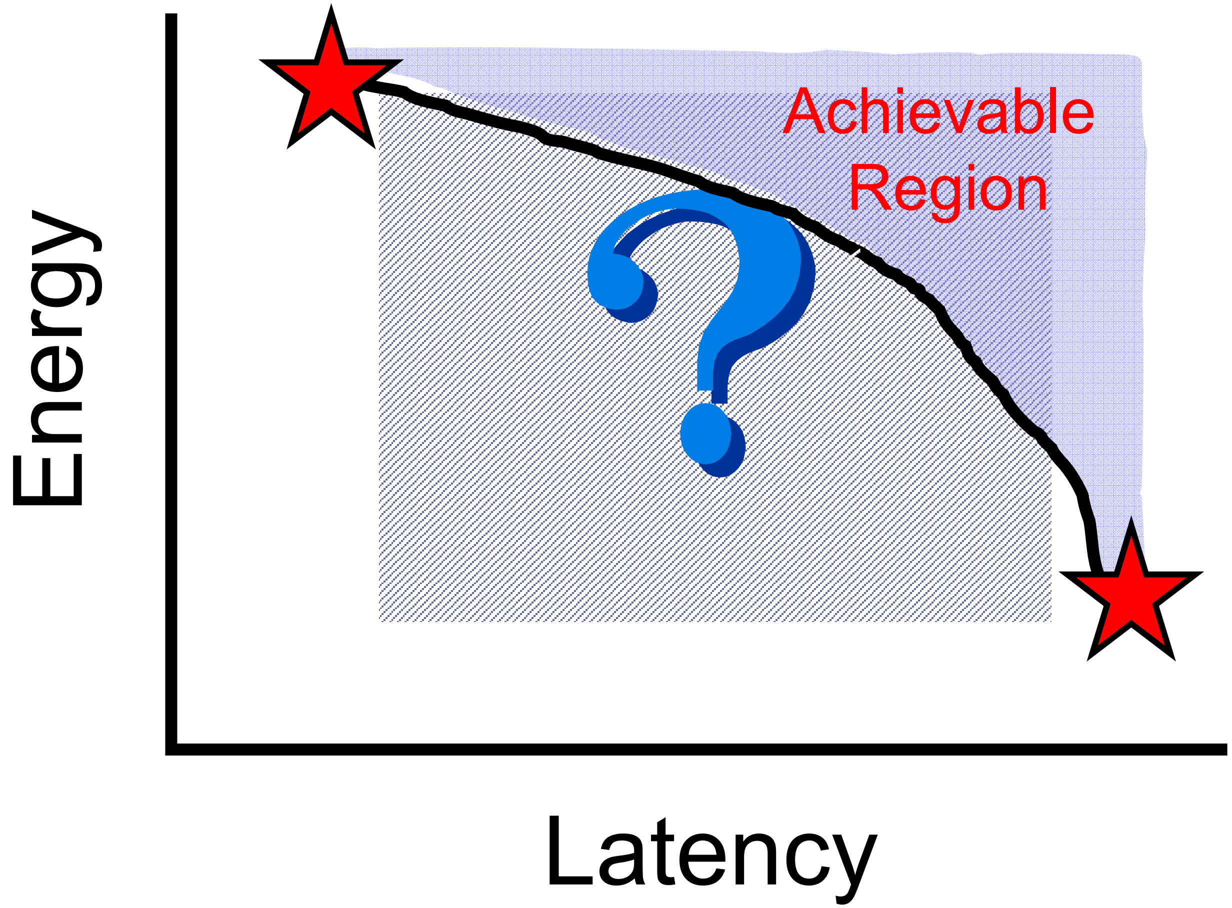


Work In Progress

- Dynamically adjusting *p* and *q* to converge to user-specified QoS metrics
- E.g., Energy and latency are specified
- Subject to those constraints, *p* and *q* are adjusted to achieve the highest reliability possible



Conclusion



Questions???

Matthew J. Miller

https://netfiles.uiuc.edu/mjmille2/www

Cigdem Sengul

https://netfiles.uiuc.edu/sengul/www

Indranil Gupta

http://www-faculty.cs.uiuc.edu/~indy