AS-MAC: An Asynchronous Scheduled MAC Protocol for Wireless Sensor Networks

By Beakcheol Jang, Jun Bum Lim, Mihail Sichitiu, NC State University

Outline

- Related Work
- AS-MAC Design
- Theoretical Analysis
- Experiments
- Conclusions

Related Work

- Early duty cycled MACs: S-MAC, T-MAC
  - High duty cycle, poor performance with variable loads
- LPL Protocols: B-MAC, X-MAC
  - Long preambles
- SCP-MAC
  - Very low duty cycle but not perfect
- Major motivation – Beat SCP-MAC
  - Reduce contention and overhearing

Related Work (cont'd)
Problems with SCP-MAC

- Overhearing avoidance on CC2420
- High contention means high packet loss and low throughput
- High delay
  - SCP-MAC addresses this issue with adaptive channel polling, but this only works with high loads

Related Work (cont'd) Asynchronous Wake-up

- Introduced in 802.11 protocols
- Designed to increase network robustness
- Nodes store the wakeup schedules of their neighbors
- Not intended to decrease energy consumption

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AS-MAC Design

- Nodes wake up periodically to receive packets
- Senders wake up according to the recipient's schedule
- Two phases: initialization and periodic listening/sleep

AS-MAC Design (cont'd) Initialization Phase

- When a node is attempting to join the network
- AS-MAC uses two packet types: Hello and Data
- Listen to channel for hello interval time, build neighbor table
- Once NT is built, initializing node picks its wakeup time based on those of its neighbors
  - Strive for even distribution—new node's wakeup is half the point of the longest interval among neighbors

AS-MAC Design (cont'd)
Initialization Phase

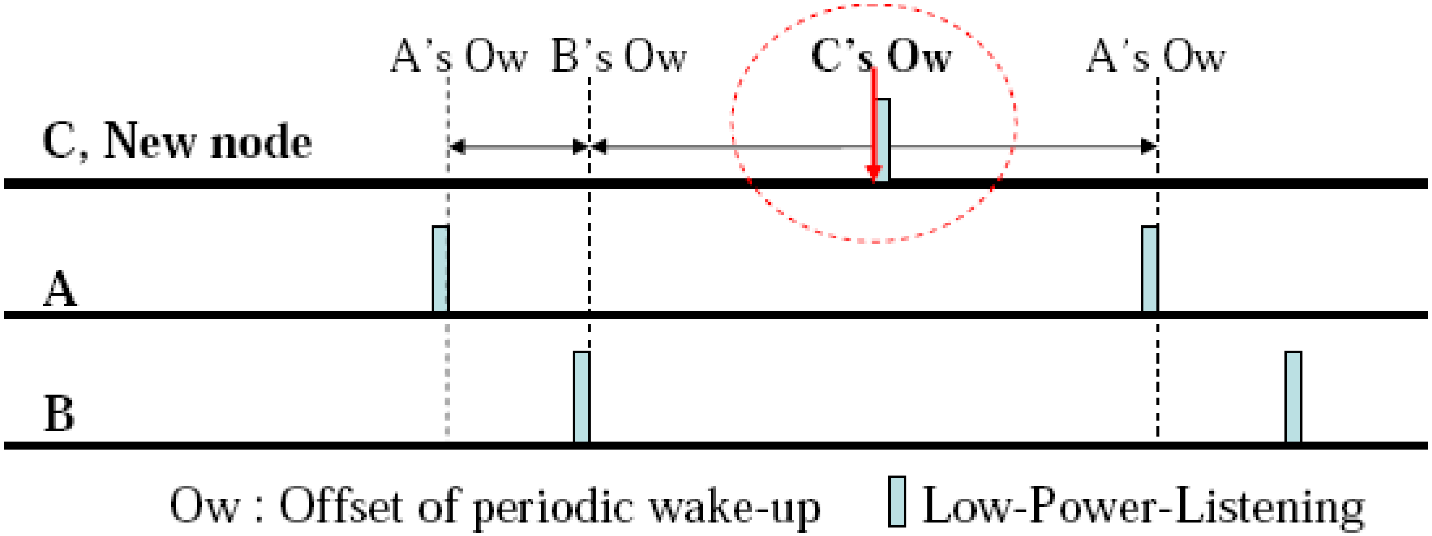


Figure 1. Initialization phase finding its offset

AS-MAC (cont'd)
Neighbor Table

Address	Wakeup Interval	Clock Difference	Hello Interval	Wakeup Estimate
2	1000	462	60	250
3	1000	728	60	500
4	1000	102	60	750

AS-MAC Design (cont'd)
Periodic Listening Phase: Receiving

- Periodically wake up and perform LPL
  - If channel is busy, receive. Otherwise, go back to sleep.
  - Occasionally send hello packets upon wakeup

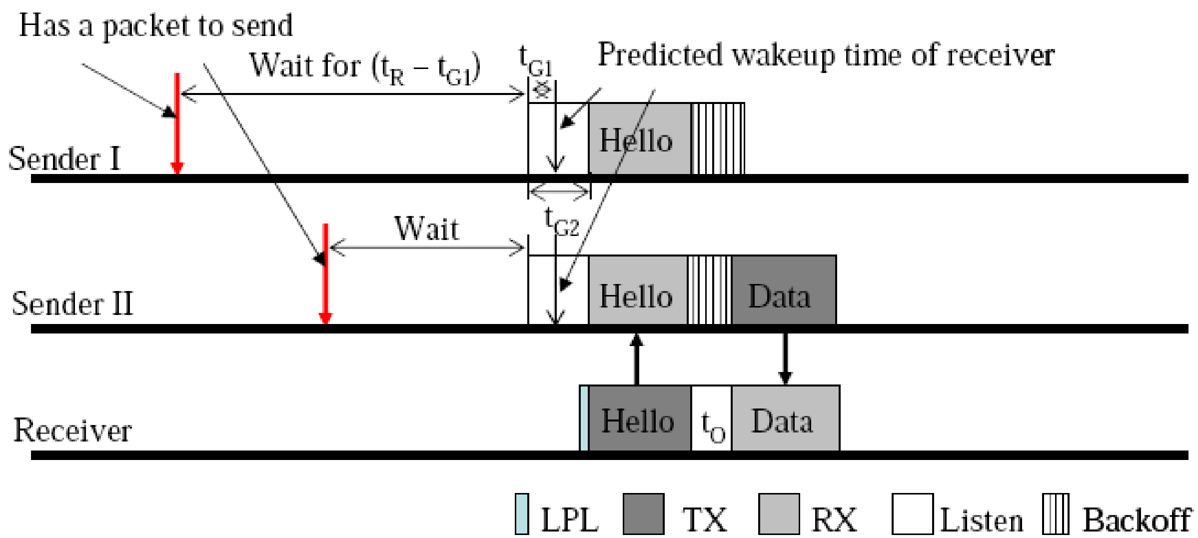


Figure 3. Communication at Hello time

AS-MAC Design (cont'd)
Periodic Listening Phase: Sending

- Sleep until the recipient's wakeup time
- Then transmit preamble followed by data

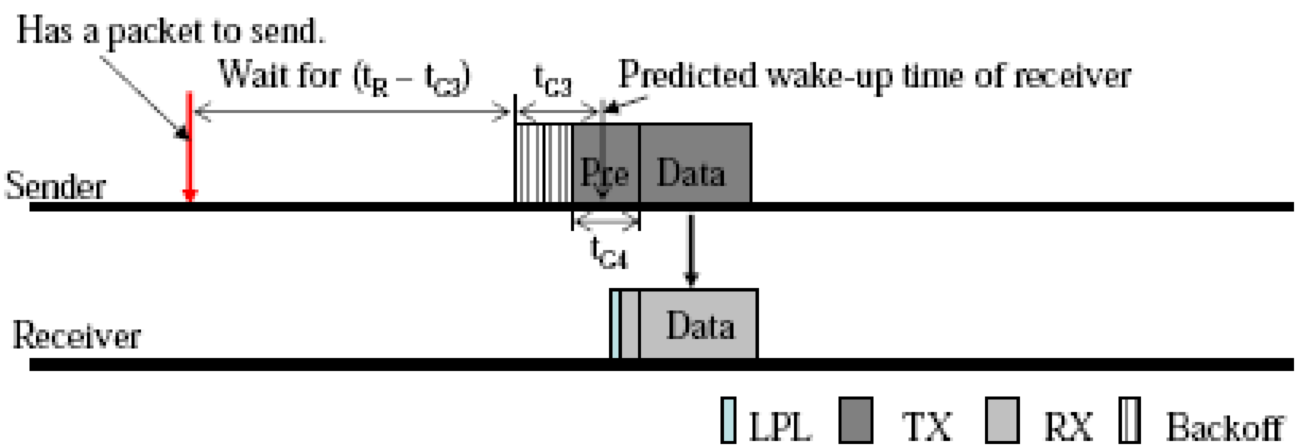
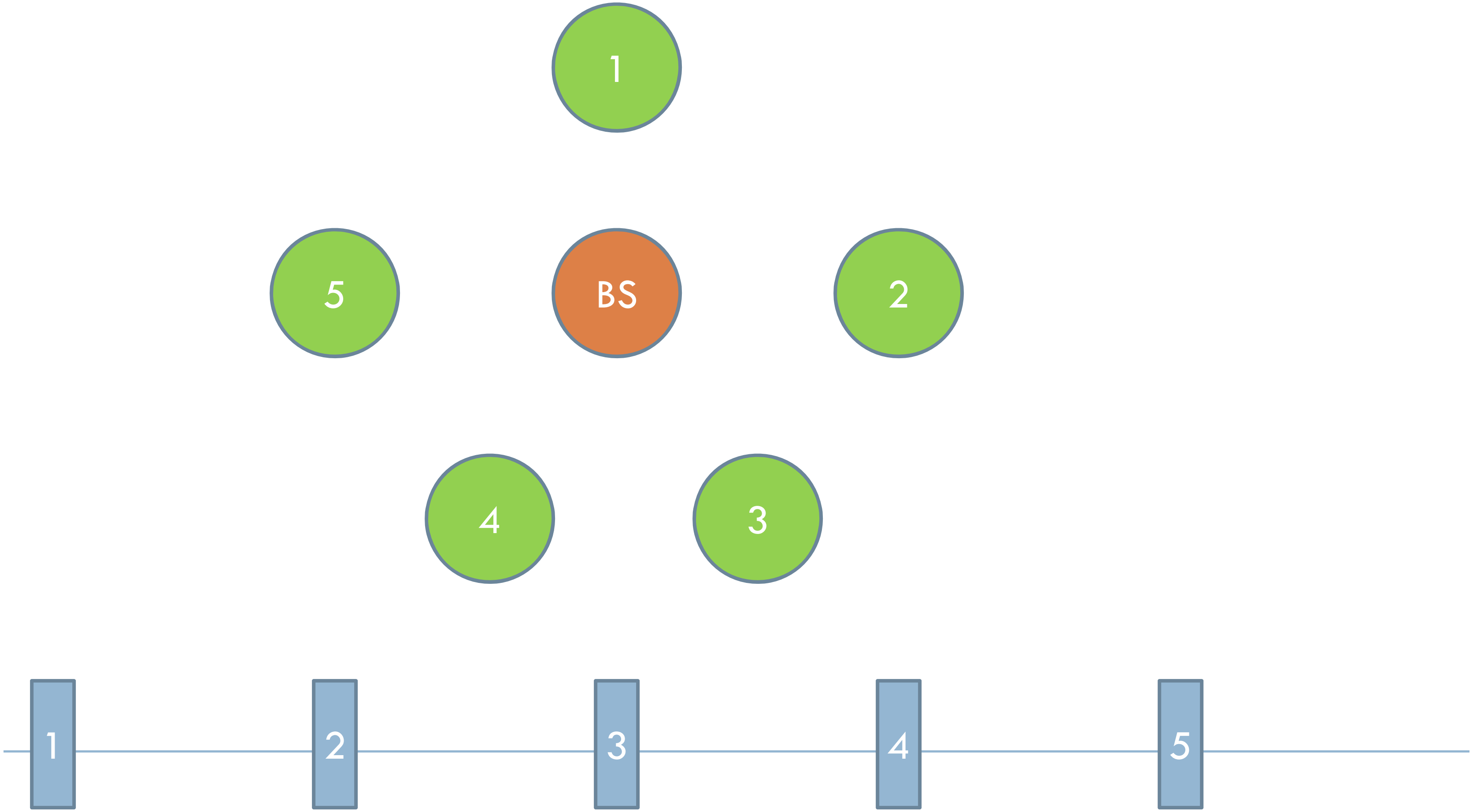


Figure 4. Communication at wake-up time

AS-MAC Design (cont'd)
Periodic Listening Phase: Contention

- What happens if multiple senders wish to simultaneously send to the same recipient?
- Slotted contention window
- Before sending, a random slot in the contention window is selected and someone wins
- But – what if the same slot is chosen by multiple senders?:
  - Not addressed. In reality, this is usually a packet loss.

AS-MAC's Weakness: Broadcasting



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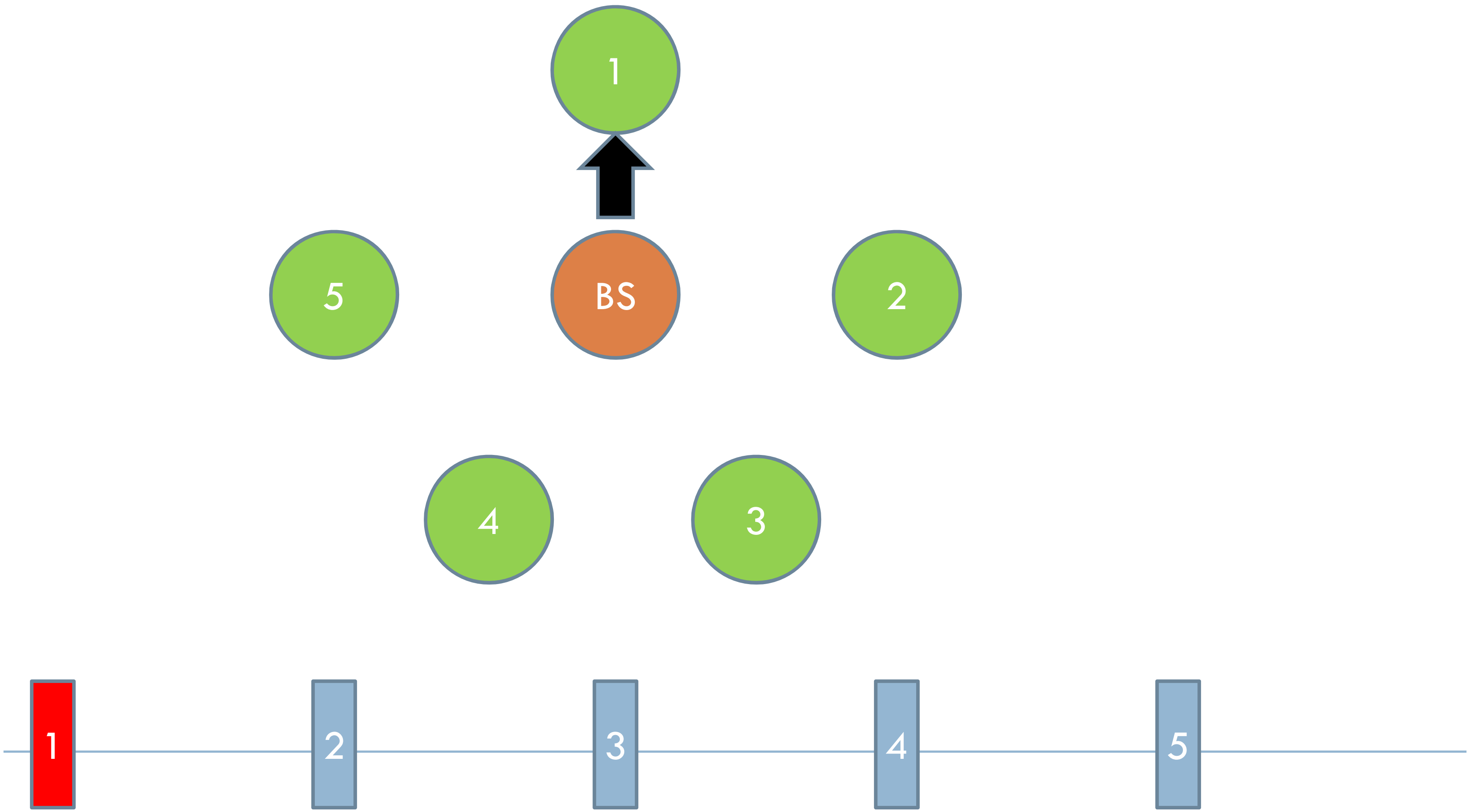

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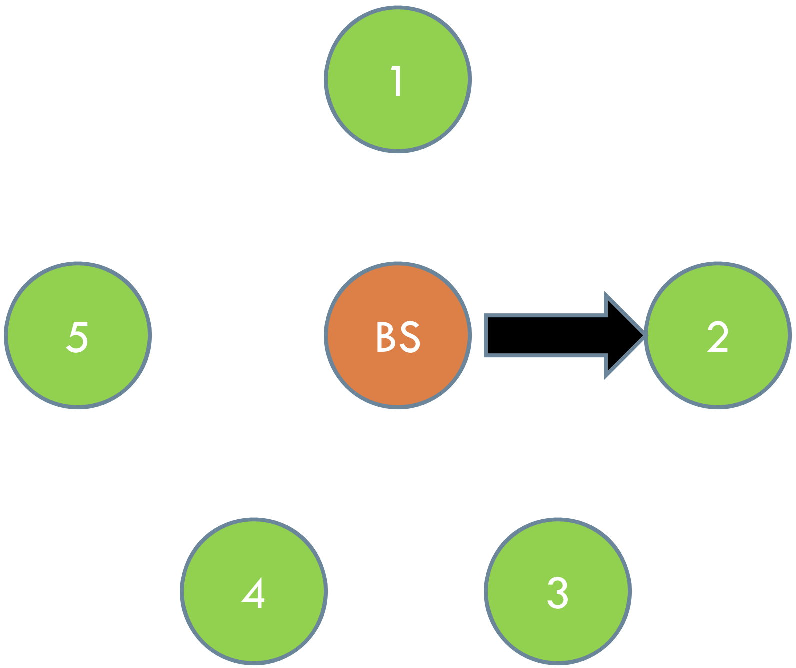

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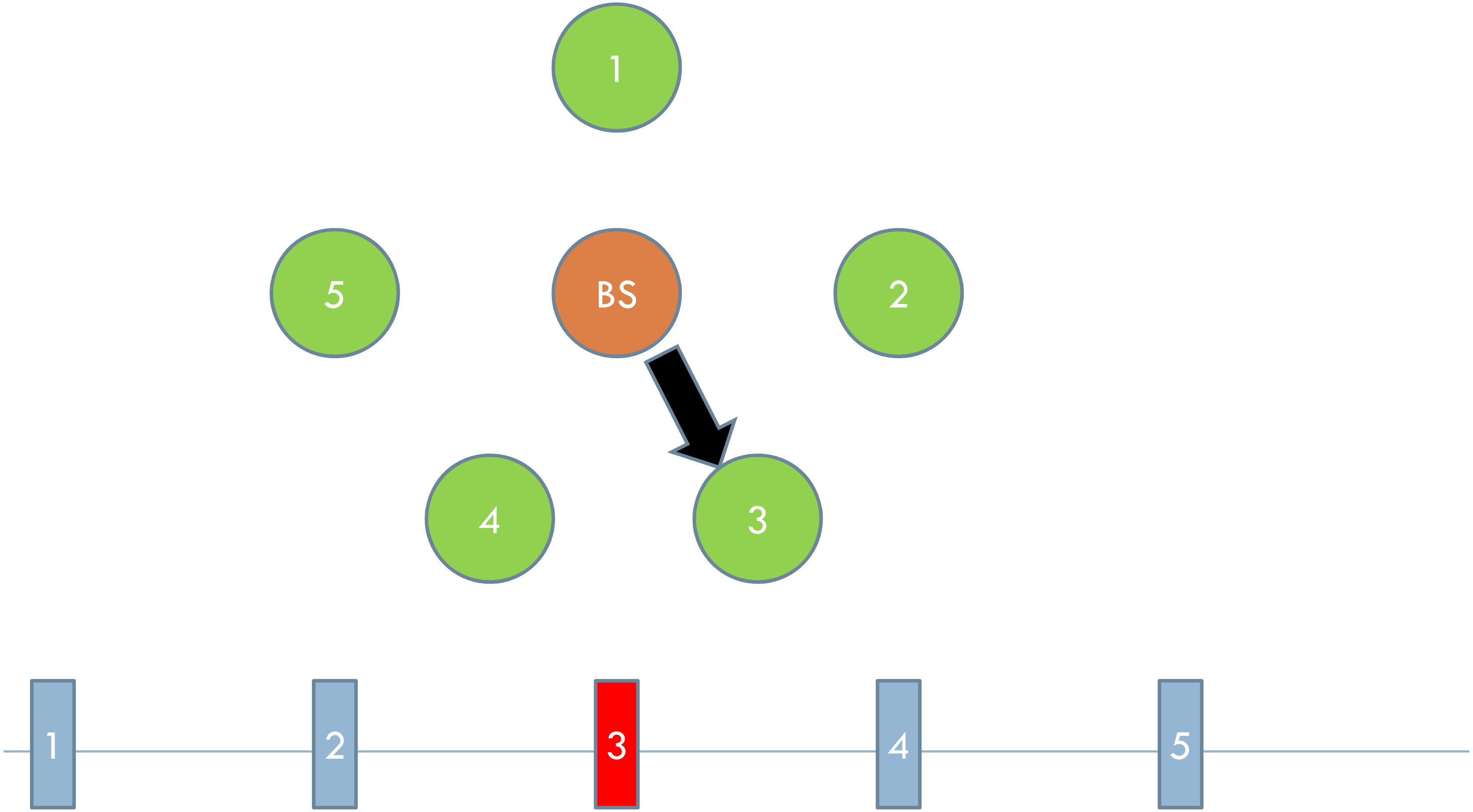

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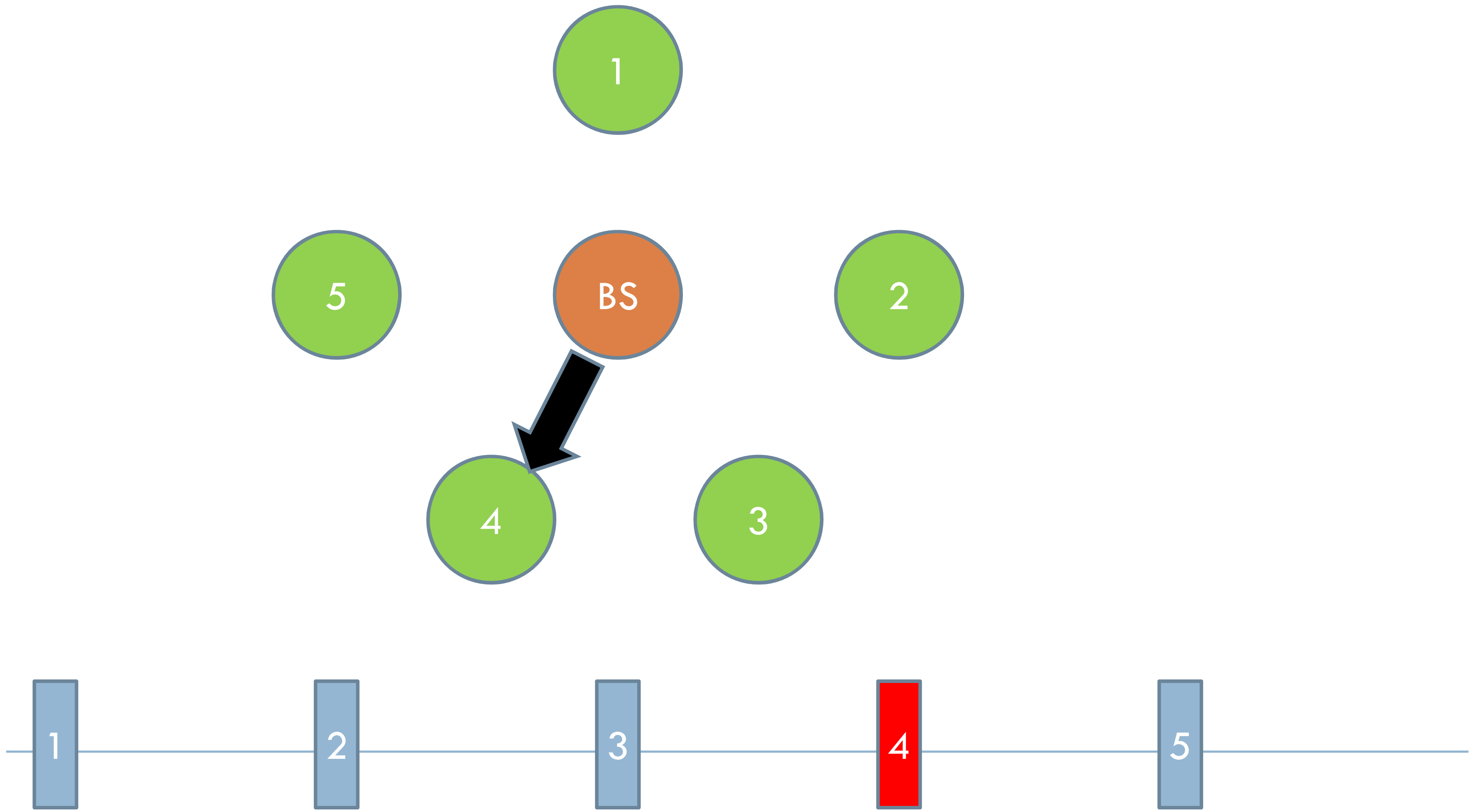
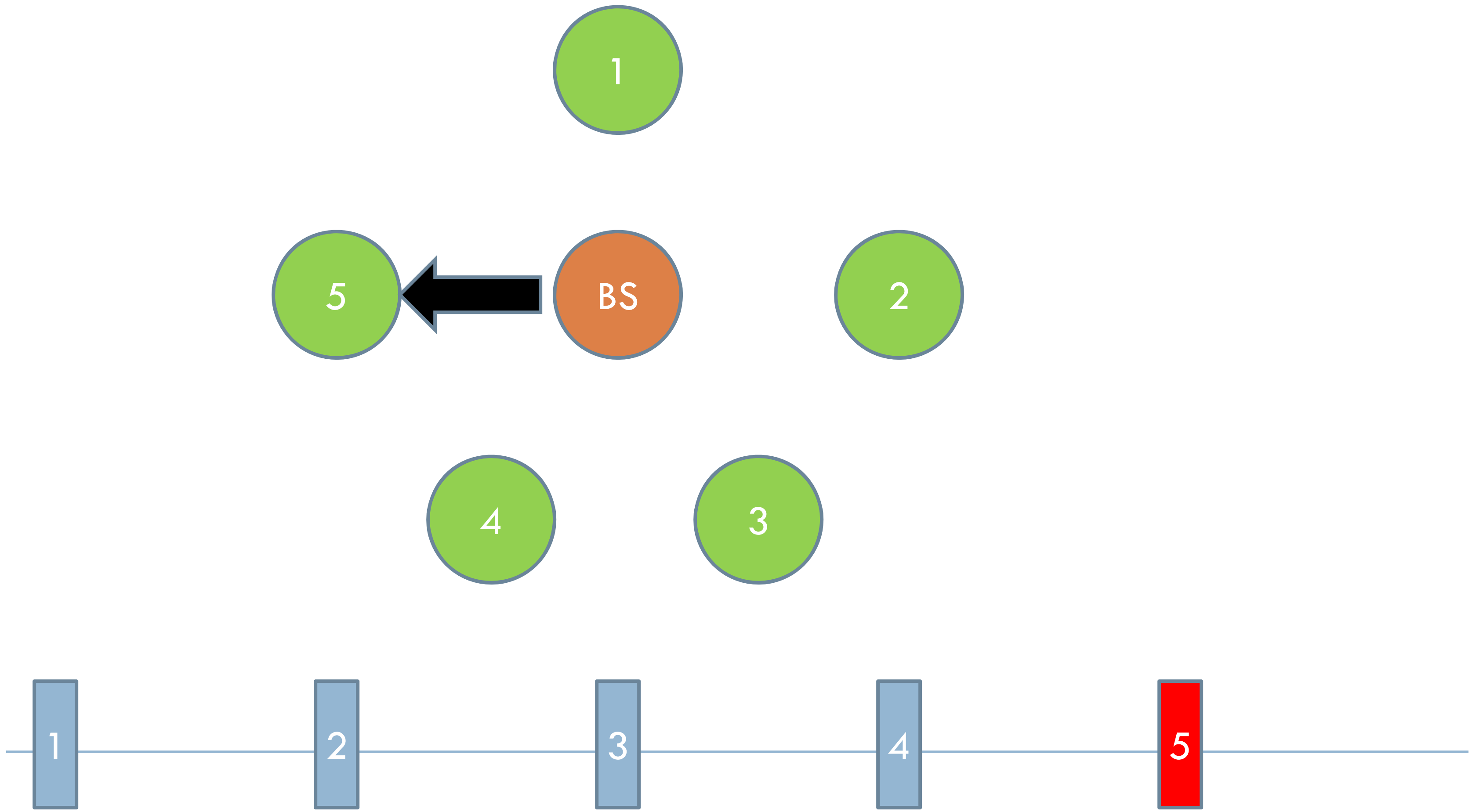
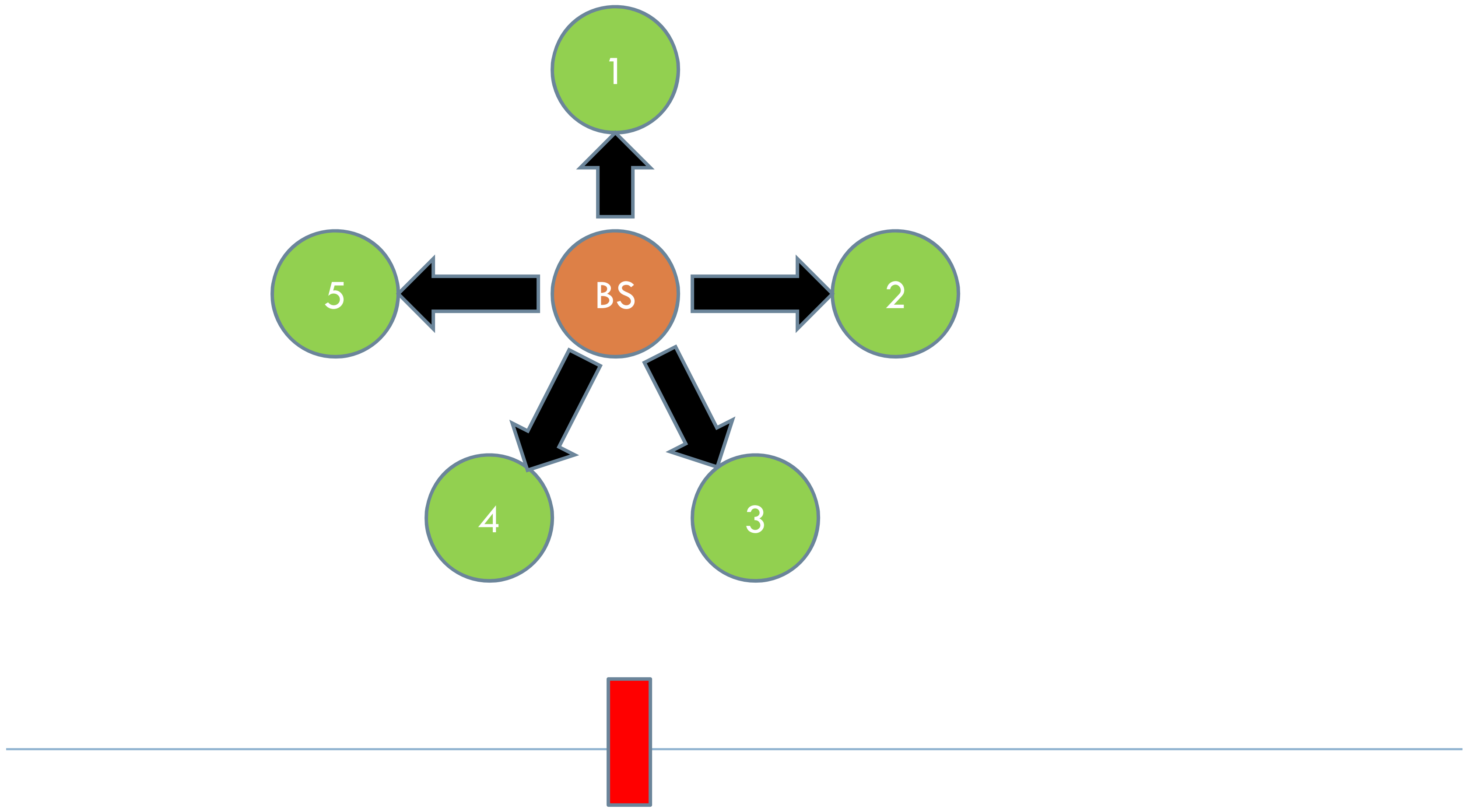


AS-MAC's Weakness: Broadcasting



For Comparison: SCP-MAC Broadcast



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Theoretical Analysis

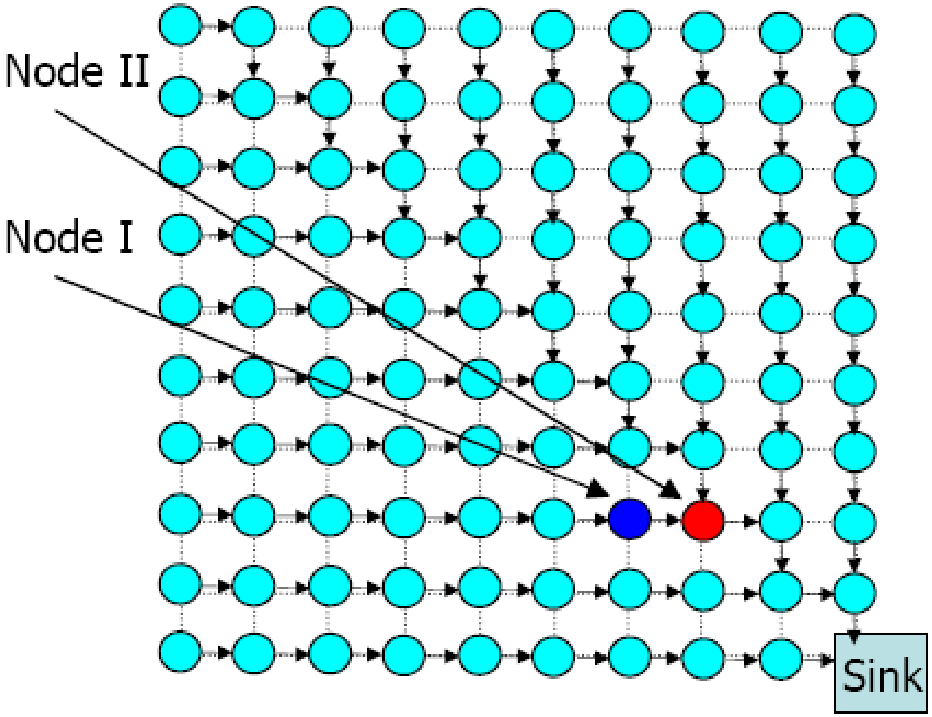
- Model: multi-hop CC2420 network rooted at sink
- SCP-MAC considered without collision avoidance, two-phase contention or adaptive channel polling
- Simple energy model:

$$E = T_{tx}P_{tx} + T_{rx}P_{rx} + T_{lx}P_{lx} + T_{lpl}P_{lpl} + T_sP_s, \quad (5)$$

P_{tx}	Power in transmission mode	52.2 mW
P_{rx}	Power in reception mode	56.4 mW
P_{listen}	Power in listen mode	56.4 mW
P_s	Power in sleep mode	0.003 mW
P_{lpl}	Power in LPL mode	12.3 mW

Theoretical Analysis (cont'd)
Simulation Setup

- 100 nodes in a 10x10 grid
  - All nodes have the same wake-up interval
  - Only communicate with immediate neighbors



Theoretical Analysis (cont'd)
Simulation Results

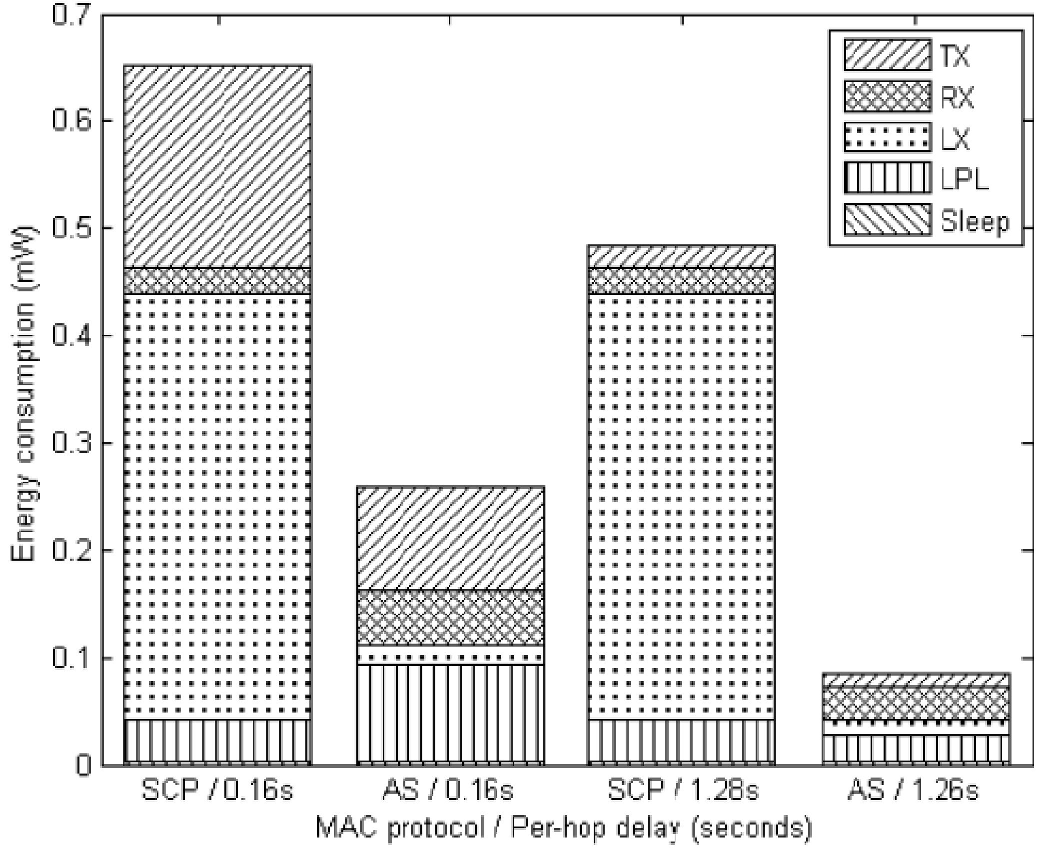


Figure 7. Sources of Energy of Node I

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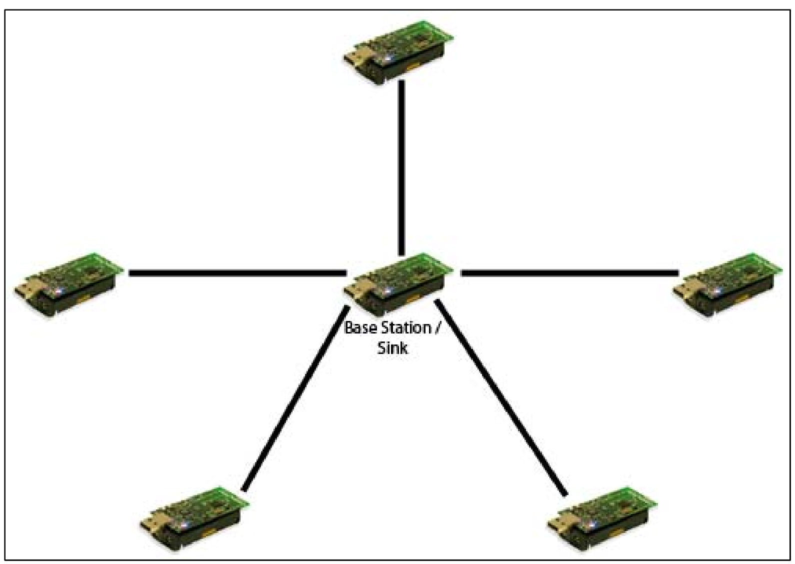
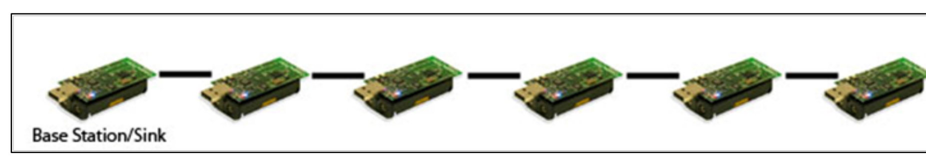
Experiments

- TinyOS implementation on MicaZ (CC2420) motes
- Measured energy, latency and packet loss
- Single-hop star and multi-hop line topologies





Experiments (cont'd)
Measurement Methodology

- Monitored changes in the state of the radio
  - Done by modifying TinyOS' CC2420 radio drivers
- Used timers to measure time in each state
- Computed energy by multiplying time in each state by energy consumed in that state

Experiments (cont'd)
Energy Experiment Methodology

- Used a static initialization table (skip init phase)
- Senders transmit to BS every 10 seconds for 200s
- Wakeup interval 1 second
- 60 second HELLO (AS) and SYNC (SCP) intervals
- Contention window of size 16
- SCP-MAC's optimizations disabled
  - Two-phase contention, adaptive channel polling

Experiments (cont'd) Energy vs Senders

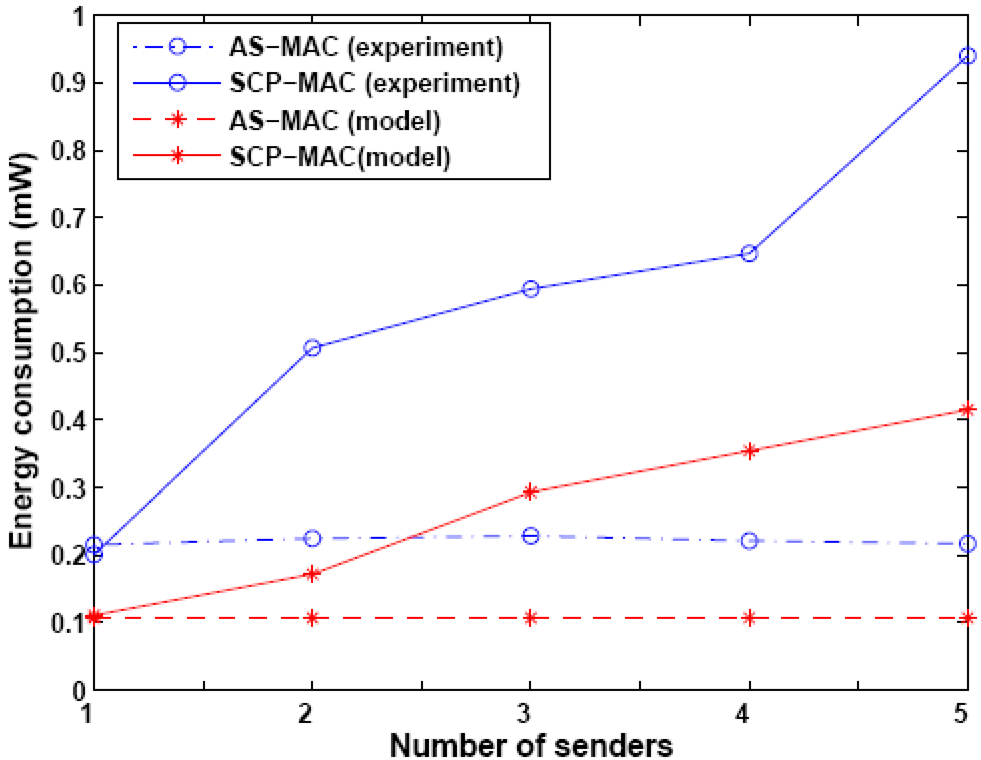


Figure 10. Energy consumption as a function of the number of senders.

Experiments (cont'd)
Energy Experiment Results

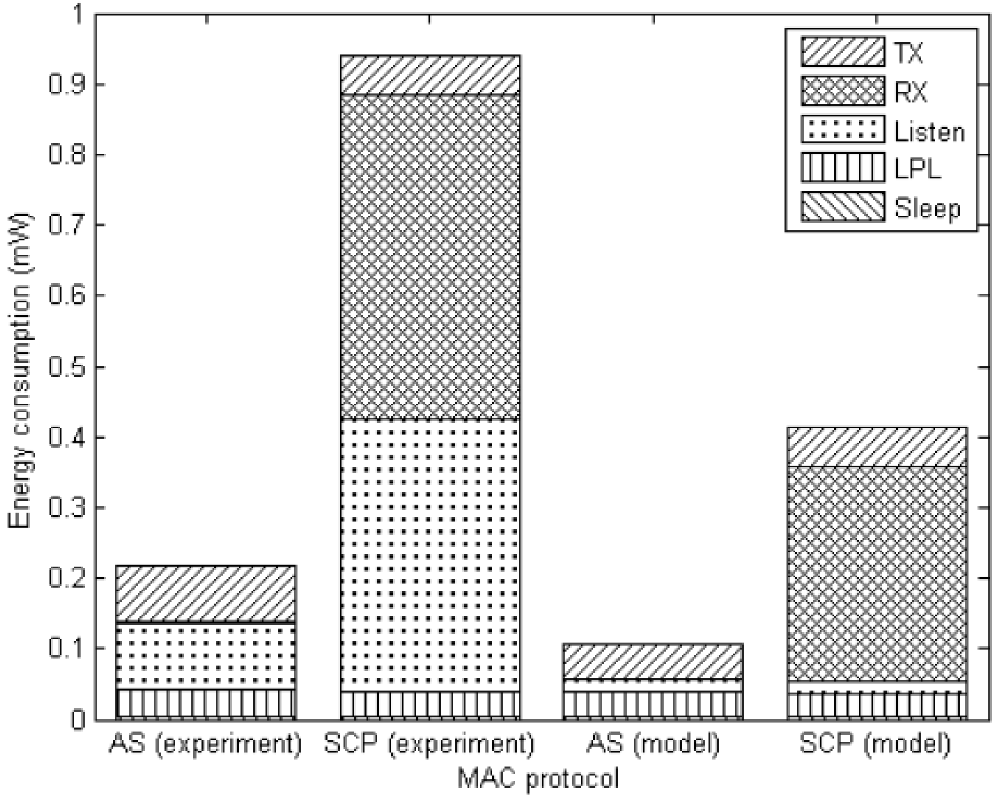


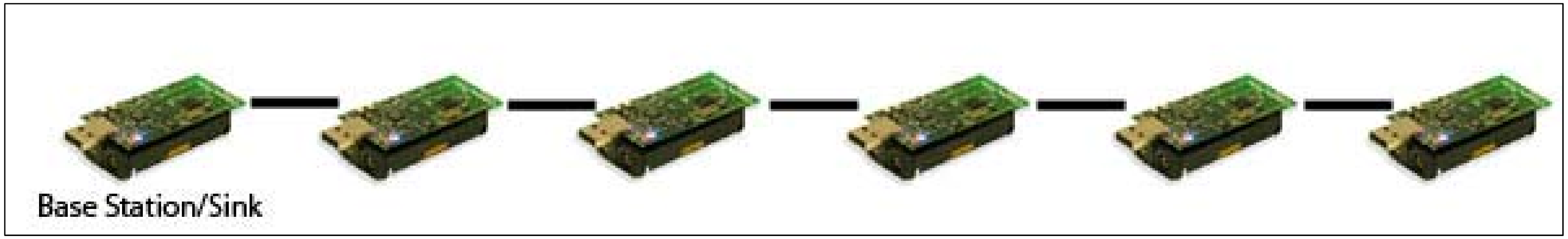
Figure 12. Sources of energy of senders in the star topology with five senders.

Experiments (cont'd) Energy Consumption Analysis

- SCP suffers badly from overhearing
  - CC2420 packet-based radio amplifies this
- Theoretical model underestimated energy costs
  - Due to unrealistic estimates of hardware timing

Experiments (cont'd)
Packet Loss Experiment Methodology

- Line topology with five nodes
  - Packets routed to sink at one end
- Experiment lasted until all nodes had successfully sent ten packets to the Base Station
- Size of contention window reduced to 4
  - To emphasize AS-MAC's reduced contention vs SCP
  - SCP's Two-phase contention disabled



Experiments (cont'd)
Packet Loss Experiment Results

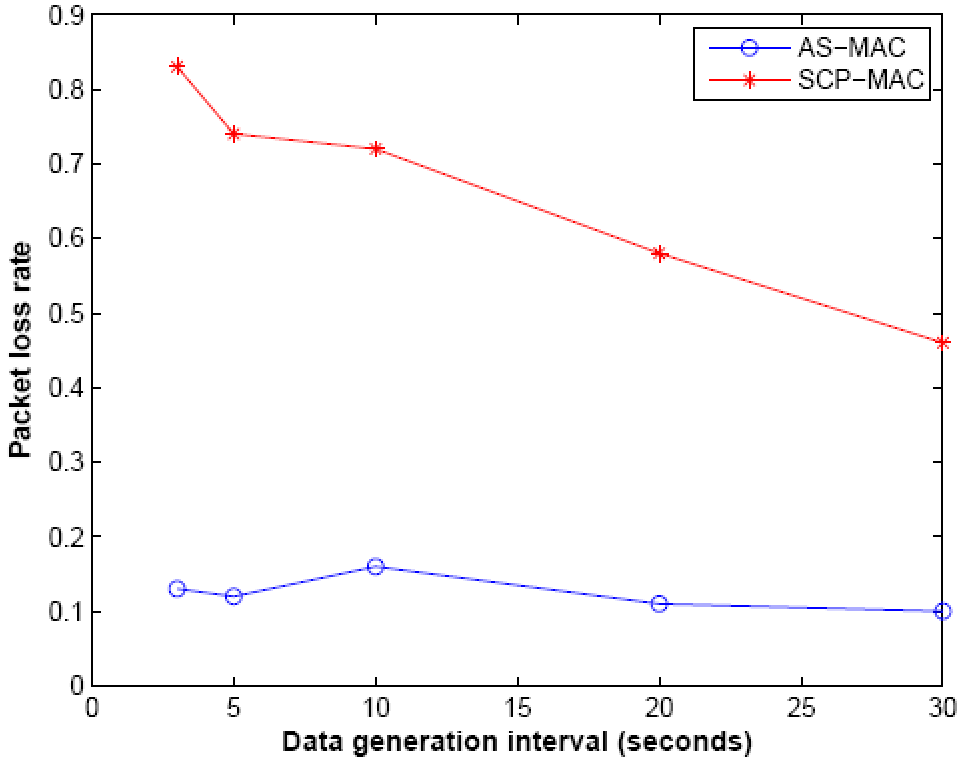


Figure 13. Packet loss at the sink for the multihop chain topology.

Experiments (cont'd)
Packet Loss Analysis

- SCP-MAC experiences greater contention than AS-MAC
- This experiment was clearly designed to crush SCP
- Disabling of two-phase contention unfair

Experiments (cont'd)
Delay Experiment Results

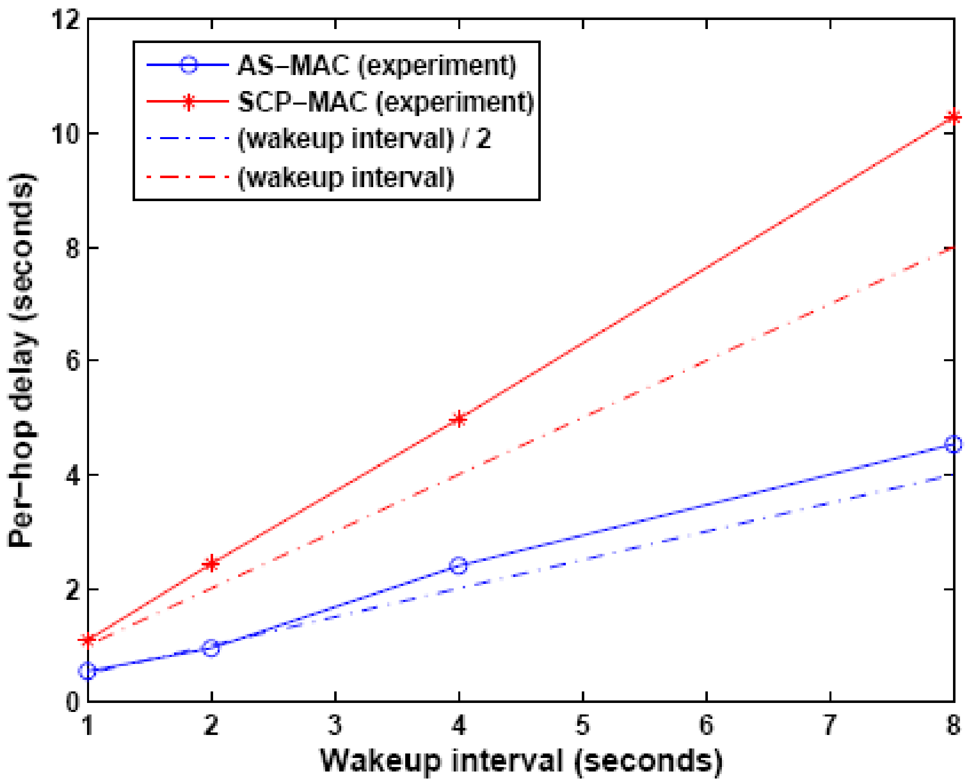


Figure 14. Per-hop delay as a function of the wake-up interval.

Memory Footprint

- MicaZ: 4000 bytes RAM
- SCP-MAC: 898 bytes
- AS-MAC: 944 bytes
- Neighbor table overhead

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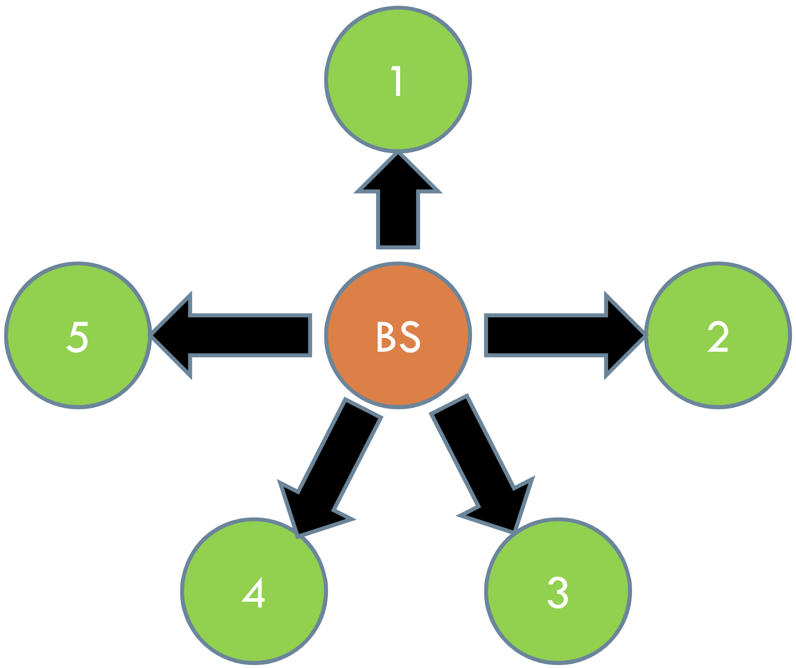
Conclusions

- Asynchronous coordination of receiving slots among neighbors can significantly reduce overhearing, contention and delay in some situations
- Broadcasting inefficient, and scales poorly
- A step forward, but there is still no “best” MAC protocol for all scenarios – tradeoffs exist

Recent WSN MAC Research: BAS-MAC

- Broadcasting Asynchronous Scheduled MAC
  - MQP - Brian Bates and Andrew Keating
- Added broadcast slot to wakeup periods
  - Frequency is adjustable
- More versatile than AS-MAC

BAS-MAC Broadcasting



Questions?

- Thank you!