SPEEDMAC: Speedy and Energy Efficient Data Delivery MAC Protocol for Real-Time Sensor Network Applications

ICC 2010

1905
高麗大學校
Computer System Laboratory

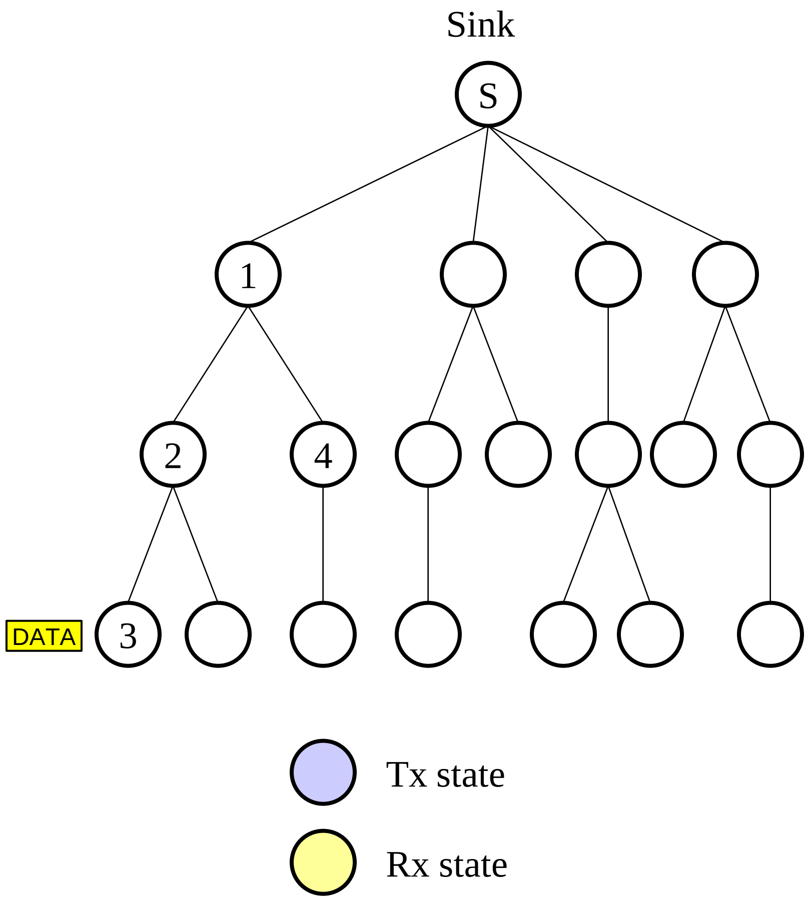
Motivation

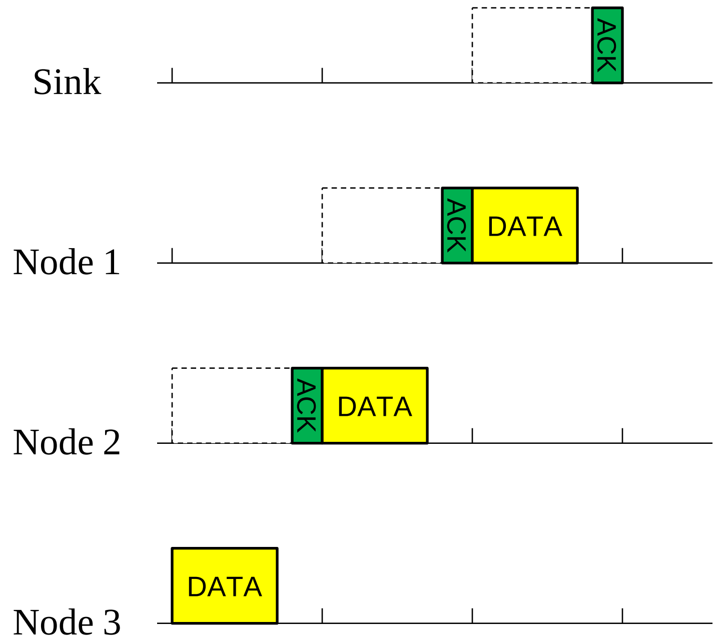
- **Sleep delay is the dominant factor of WSN packet latency**
  - A packet can traverse at most a single hop each cycle
    - Minimum packet latency = cycle time *hops
- **Most of WSN applications have real-time characteristics**
  - Disaster monitoring, real-time target tracking, intrusion detection, health, etc.
    - However, it is practically *impossible to obtain both low latency and low energy communication* at the same time
- **Sleep delay exists for both synchronous & asynchronous MAC**
  - Synchronous scheduling (S-MAC, A-MAC)
    - A packet can traverse at most a single hop (or 2 with 'adaptive listening') each cycle since nodes beyond one-hop from the receiver cannot overhear the data.
  - Asynchronous scheduling (B-MAC, Wise-MAC, XMAC)
    - A packet can traverse at most a single hop each cycle since a sender needs to send the preamble before starting the next-hop communication

Motivation

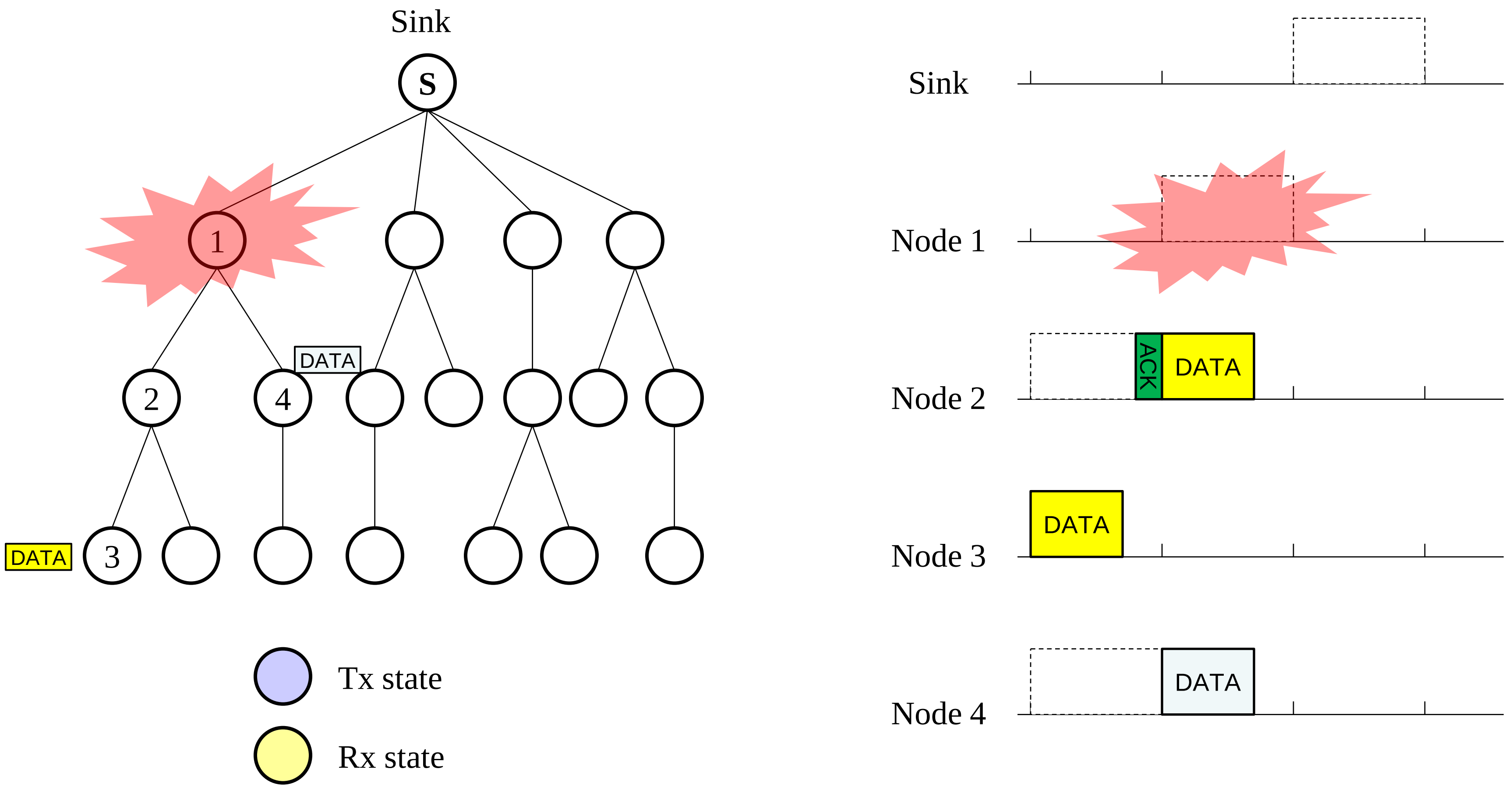
- **Synchronous skewed wakeup (DMAC) may be a solution!**
  - Schedule the wakeup time of each node in a pipelined fashion in the direction of packet movement so that
    - No sleep delay during the packet movement
- **Issues with synchronous skewed wakeup**
  - May fail to deliver the message when multiple sensors compete for the message delivery
    - A single event is likely to be detected by nearby multiple sensors
    - Multiple events may occur simultaneously, which leads to collisions and contentions
  - More idle listening
    - Since a node must wake up during the entire DATA transmission period instead of RTS period as in SMAC
  - May not be practically possible to use such wakeup scheduling techniques for real applications unless these issues are completely resolved.

Synchronous Skewed Wakeup





Synchronous Skewed Wakeup

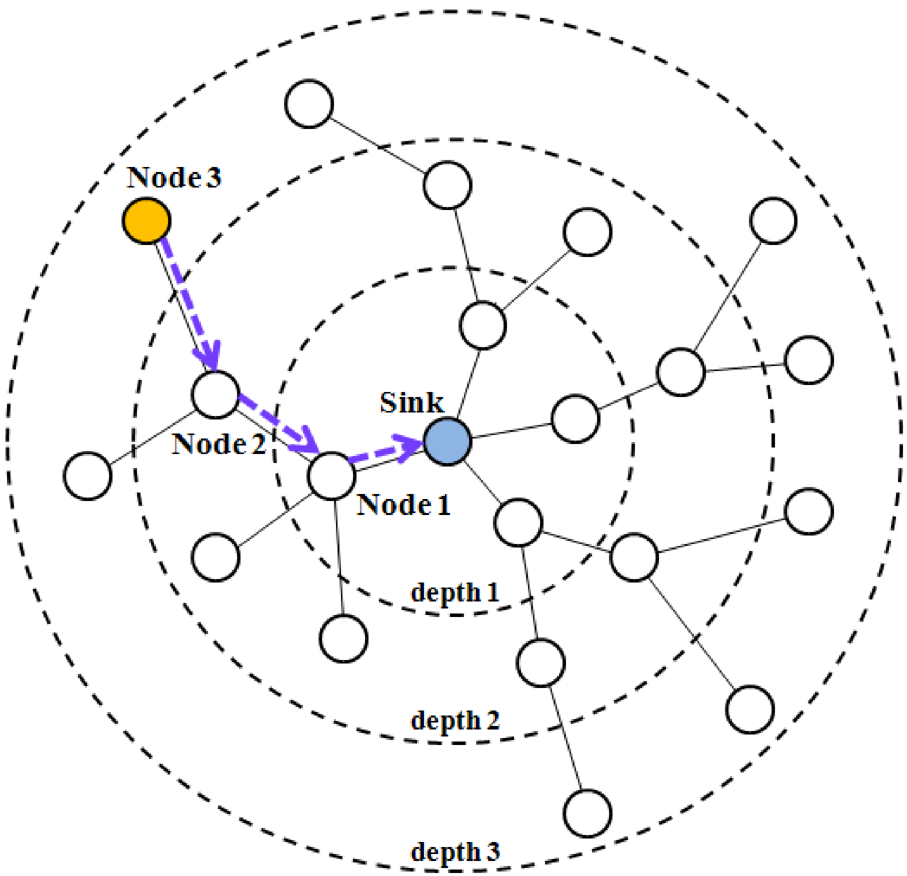


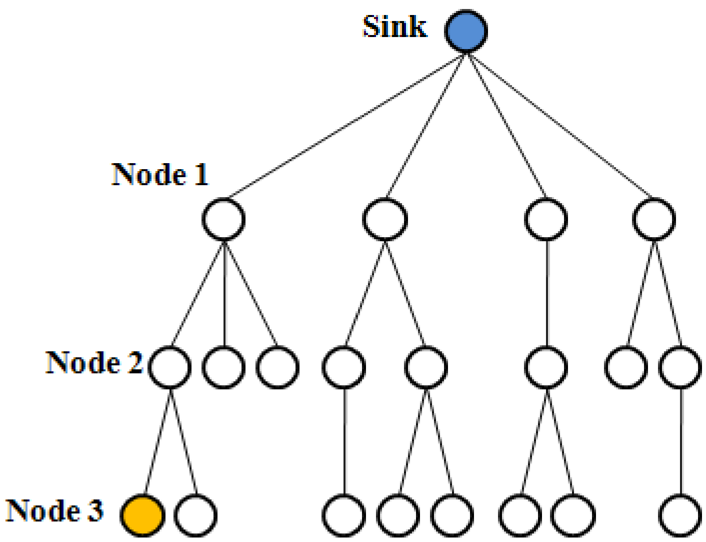
SPEED MAC Ideas

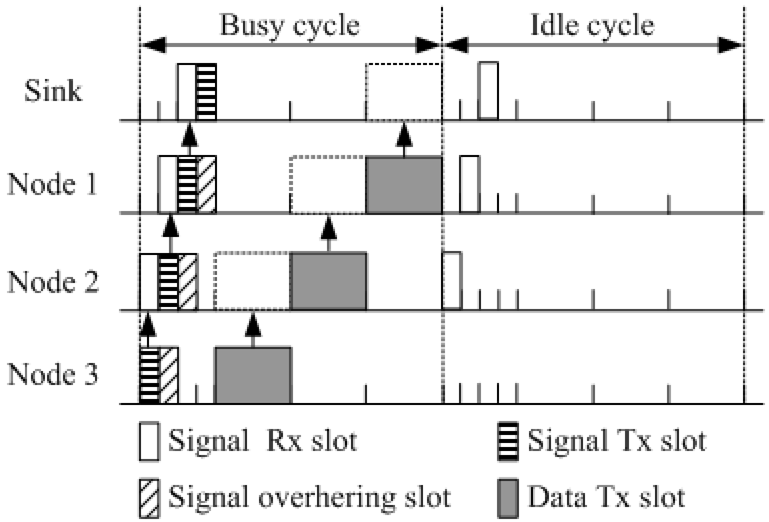
- **Goal: Can we achieve both low-energy and low-latency at the same time?**

- **1. A collision signal to detect multi-source events &for fast event delivery**
  - A special control packet called SIGNAL packet is used. It has different electrical characteristics from background noise
- **2. Separate event report period from data delivery period**
  - Faster event report using a short control signal
  - Lower energy consumption for idle period
    - To further reduce both the latency and the energy consumption
- **3. Adaptive wakeup for multi-source events**
  - Fast pipelined data delivery for a single-source event
  - Full wakeup and CSMA-based data delivery for a multi-source event
    - Full duty-cycle operation for high-bandwidth transmission
    - Use RTS/CTS for busy periods

Synchronous Skewed Wakeup







Issues with Synchronous Skewed Wakeup

- **Assumptions**
  - Stationary sensor nodes and stationary sinks
  - Many to one communication pattern from multiple sources to the sinks
- **Issues**
  - Contention
    - Only a single source can transmit the data and other sources may have to wait
  - Collision
    - When multiple nodes transmit at the same time, the packets will eventually collide in an upper layer and no packet can be transmitted
  - Transmission error
    - When a transmission error occurs, the sender needs to wait for the next cycle
- **For single-source event**
  - No contention, no collision, only need to consider error
- **For multiple-source events**
  - Need to consider contention, collision, and error

SPEED-MAC

Event announcement period: Fast Event Announcement

- In this period, nodes announce the presence of an event by sending a small control packet called a *SIGNAL packet*.
  - SIGNAL packet: consists of receiver address and collision bit
  - There is NO ACK packet for the signal packet.
- Collision detection for multi-source events
  - The *collision bit* tells that the event is a multi-source event.
  - Need to distinguish transmission errors from collision
- All the senders overhear the signal transmission from its parent
  - To distinguish a single source event from a multi-source event

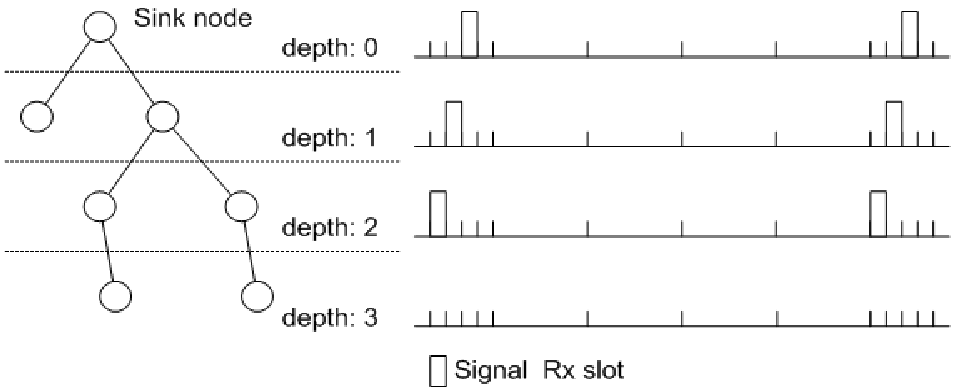
Data transmission period: Adaptive Wakeup

- In this period, nodes transfer messages by sending DATA packets
- For a single-source event, the period consists of DATA and ACK
  - Fixed scheduled data transmission for single-source events (not a CSMA)
- For a multi-source event, the period consists of RTS/CTS/DATA/ACK
  - Contention-based data transmission for multi-source events (CSMA/CA)

SPEED-MAC: Single Source Event

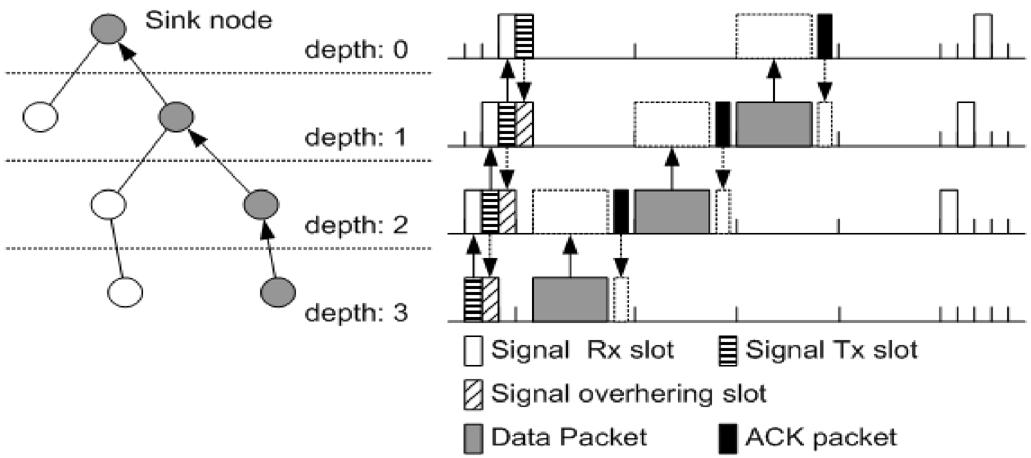
No traffic

- Nodes wakeup only during a signal rx slot.



Single source traffic: single-packet data

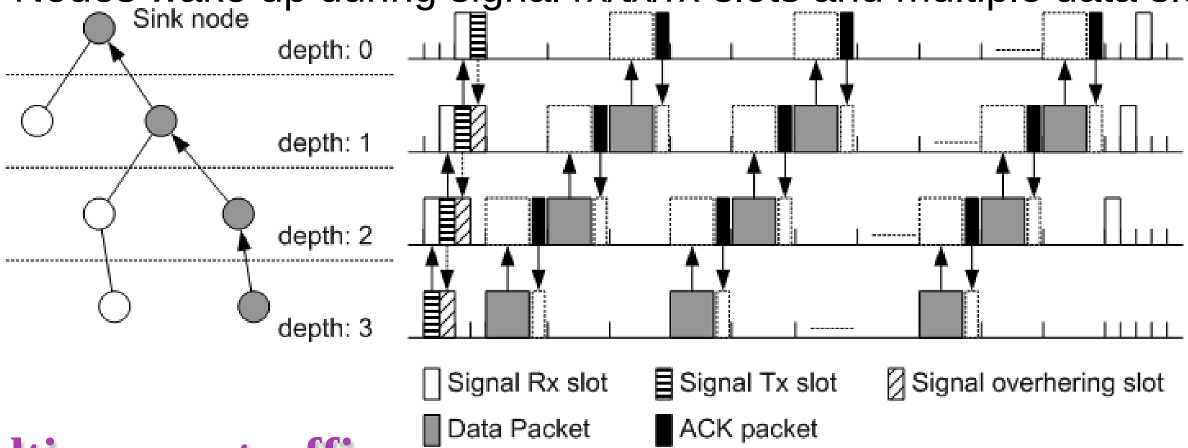
- Nodes wake up during signal rx/tx/rx slots and data slot



SPEED-MAC: Multi-Packet & Multi-Source Event

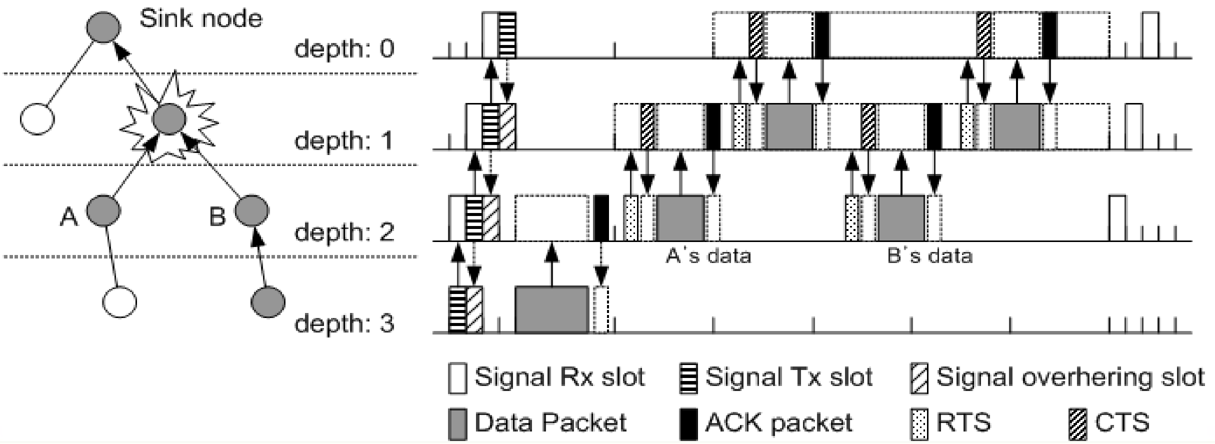
Single source traffic: multi-packet data

- Nodes wake up during signal rx/tx/rx slots and multiple data slots



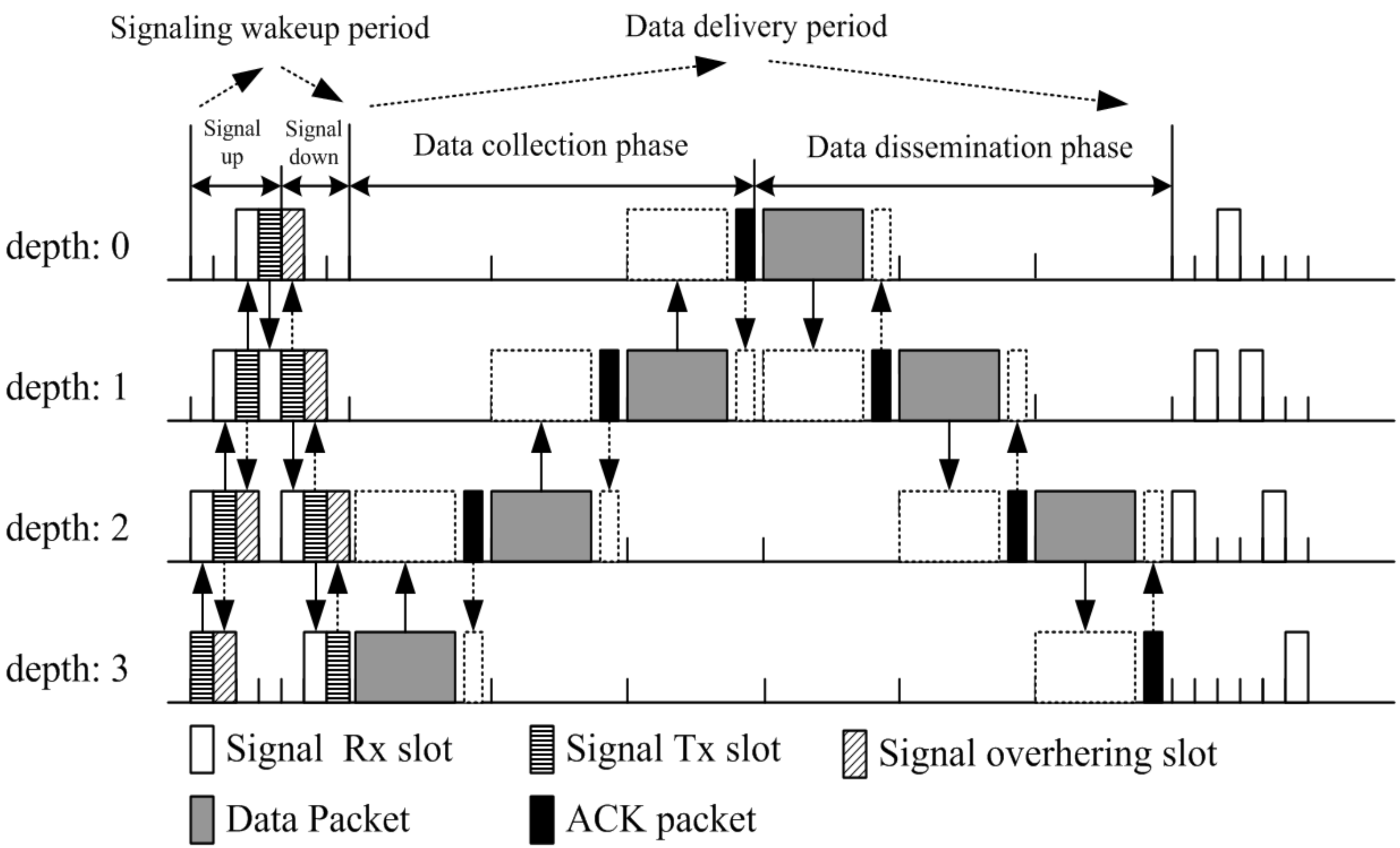
Multi-source traffic

- Nodes wake up during signal rx/tx/rx slots and several RTS/CTS/DATA/ACK slots



SPEED-MAC with Multiple Sinks

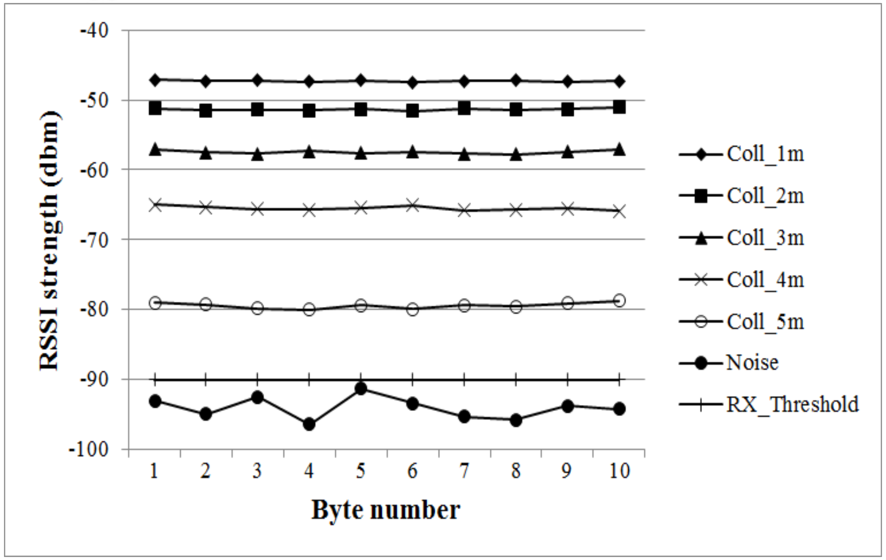
- We can handle sink-to-sensor, sensor-to-sensor, and many sensors-to-many sinks scenarios

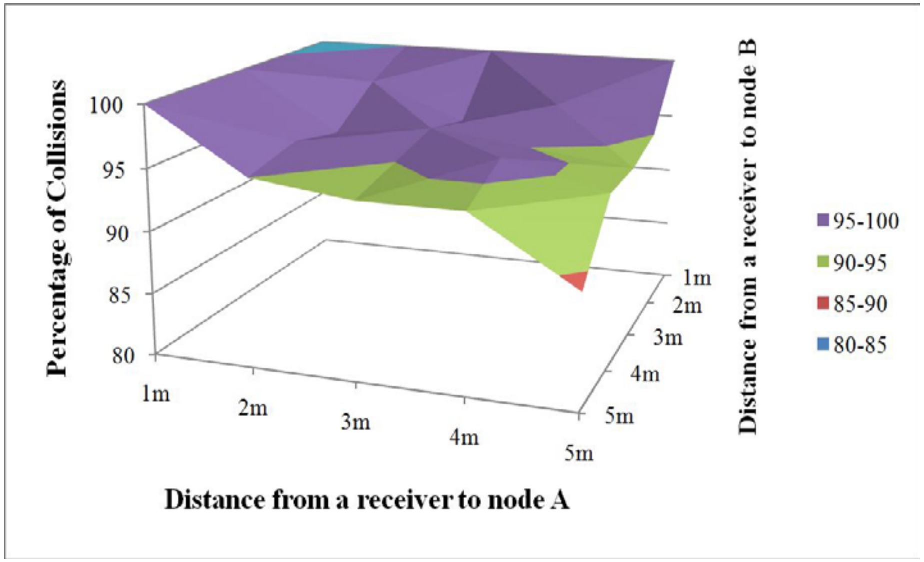


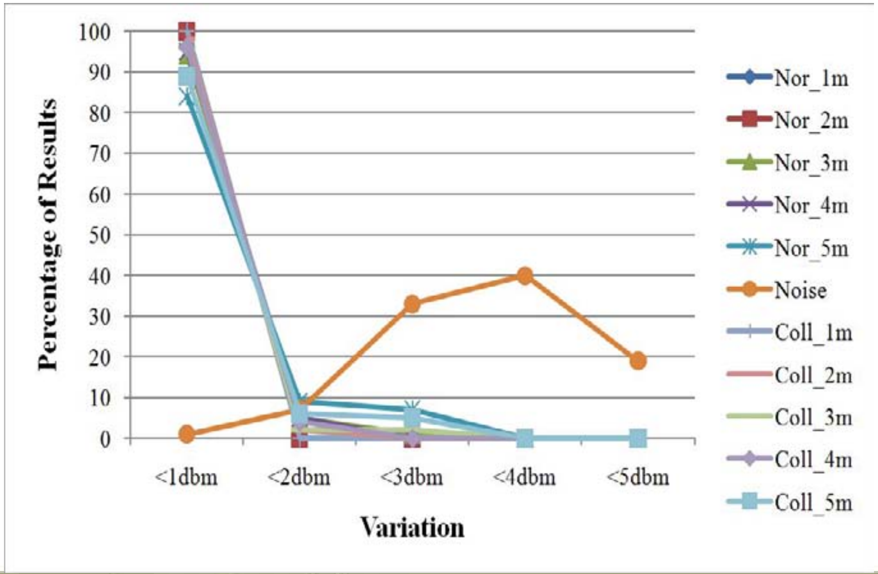
Collision/Error Differentiation

- **Transmission error can occur due to two reasons**
  - Noise (Error)
    - Unwanted electrical signals interfering with the desired signal
    - The strength of the signal is irregular and variable
  - Collision
    - Multiple simultaneous transmission collide at the receiver
    - The strength of the signal is regular and stronger
    - Can be differentiated at the physical layer by tracking RSSI
- **In case of collision, the SIGNAL control packet is already destroyed.**
  - COLLISION SIGNAL does not contain the receiver address anymore.
  - COLLISION SIGNAL packet is broadcast to the nodes in the upper layers
    - *False-positive delivery*: Nodes in the upper layers after the collision may unnecessarily wakeup

Collision/Error Differentiation







NS-2 Simulation Parameters

- **# of nodes: 400 grid nodes + 1 sink node**
- **Power**
  - Tx : 30mW, Rx : 15mW, Idle : 15mW
- **Bandwidth: 20Kbps**
- **Packet size**
  - Data packet: 100B
  - Signal packet: 6B
  - Control packet: 10B
- **Tx & Rx slot length**
  - Data: 103ms, Signal: 22ms
- **Simulation time: 10 min**
- **Total number of event: 20 events**
- **# of source nodes: 1, 2, 4, 8, 16 nodes**
- **Basic cycle time**
  - SMAC: 1.44s
  - SPEED-MAC, D-MAC: 2.88s

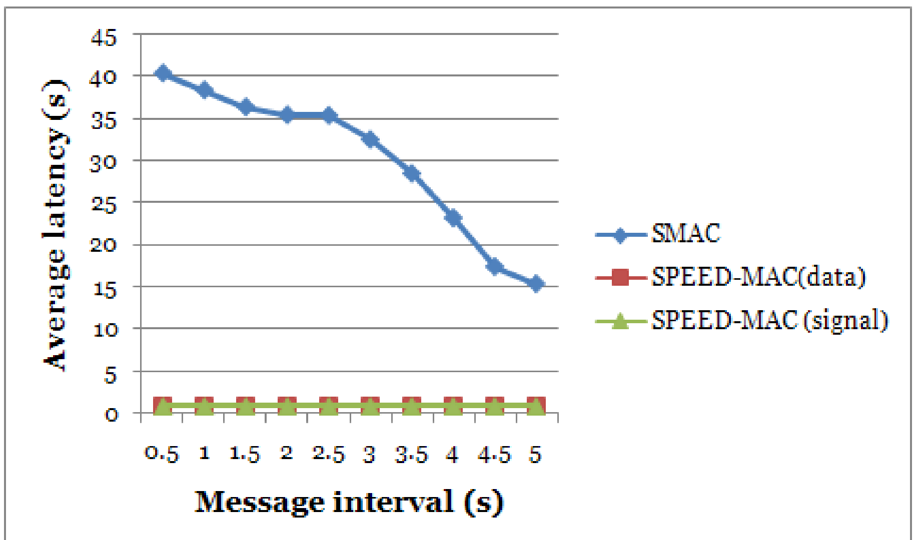
Single Source – Latency

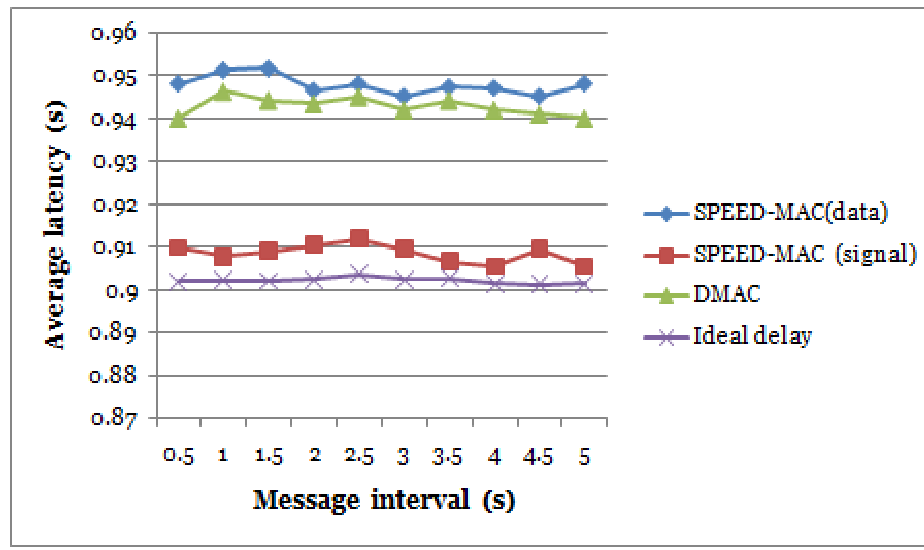
SMAC

- SMAC suffers from the sleep delay and the additional buffering delay when the message generation interval is small.

SPEED-MAC vs. DMAC

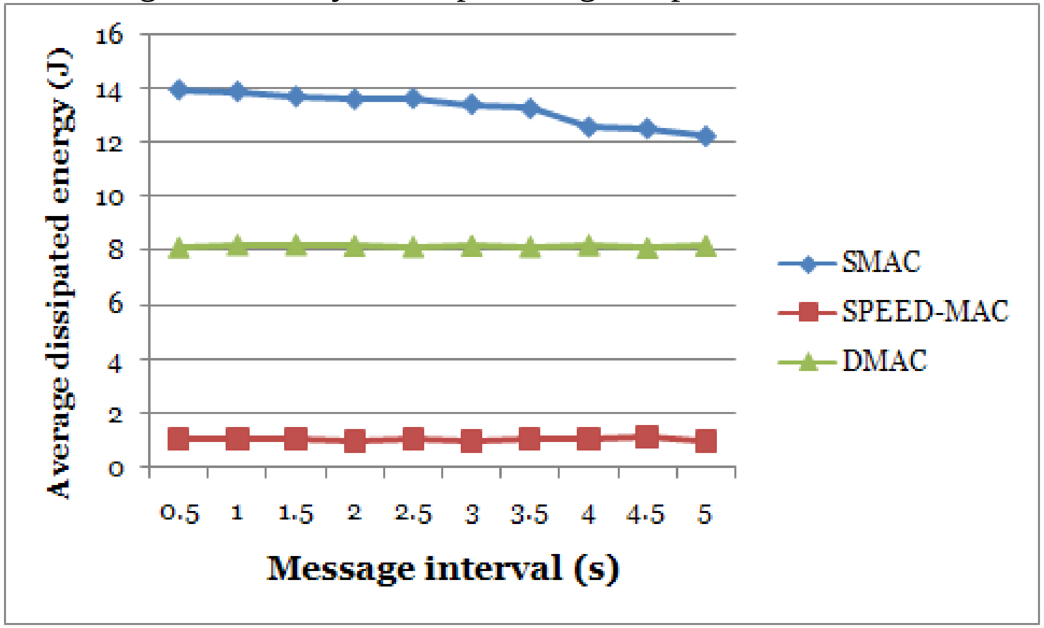
- Due to the signaling wakeup period, SPEED-MAC's data latency is slightly higher than that of DMAC.
- Signal delivery latency of SPEED-MAC is almost close to the minimum delay achievable and is much smaller than DMAC's data delivery latency





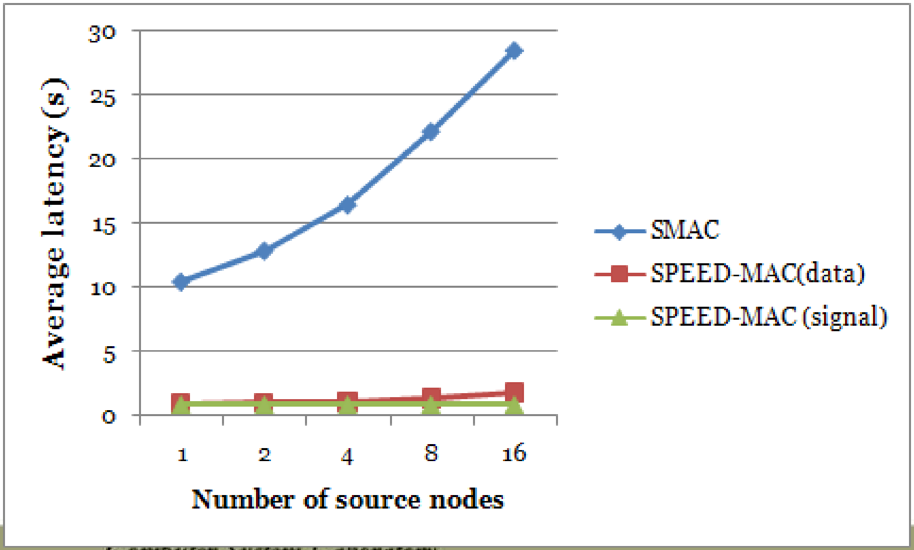
Single Source - Energy

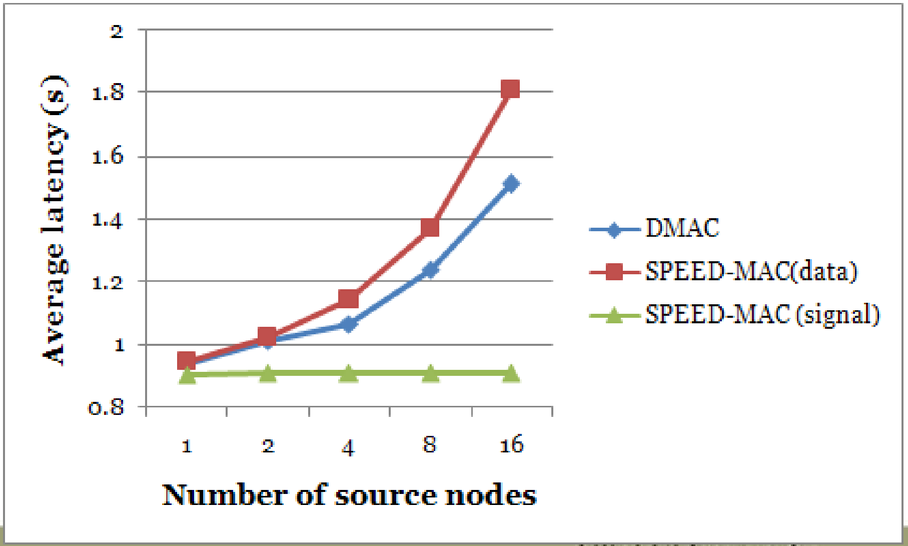
- **SMAC**
  - As the packet generation interval decreases SMAC spends more energy in repeated wakeups and buffering.
- **SPEED-MAC vs. DMAC**
  - SPEED-MAC can achieve *an order of magnitude reduction* in the energy consumption compared to DMAC
    - By reducing the idle listening overhead and
    - By removing unnecessary wakeups during idle periods



Multiple Sources - Latency

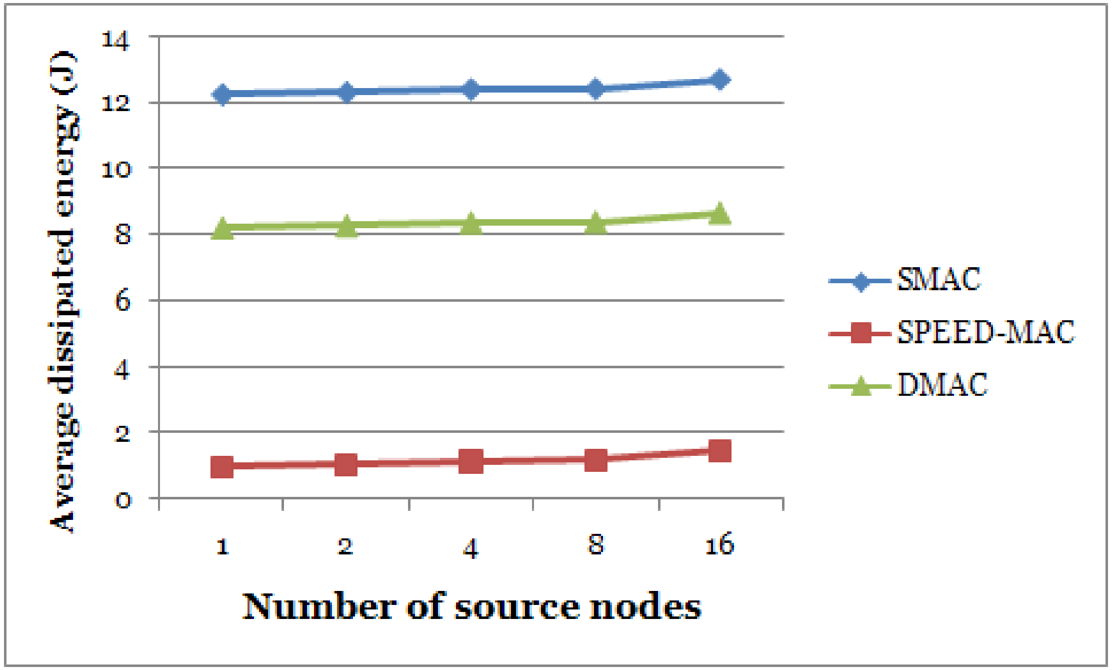
- **SMAC**
  - Latency increases substantially as the number of source nodes increases.
    - This is due to the increased contention and buffering for multiple transactions.
- **SPEED-MAC vs. DMAC**
  - Constant and faster signal delivery latency even in multi-source events
  - Noticeably higher data packet delay due to its adaptive wakeups and increased control packet (RTS and CTS) overhead for multi-source events.
    - *For DMAC we use their assumption that an interference range of a node is twice larger than its transmission range to avoid collision for multi-source events.*





Multiple Sources - Energy

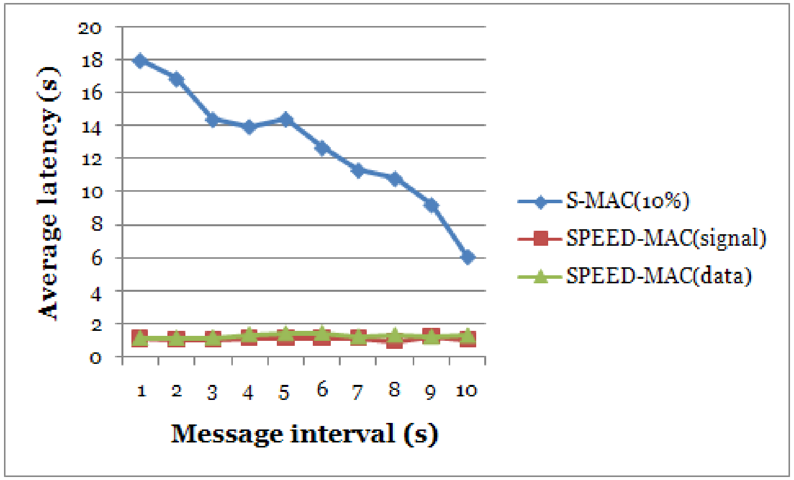
- SMAC
  - SMAC spends more energy due to its higher duty cycle operations
- SPEED-MAC vs. DMAC
  - Like the single-source case, SPEED-MAC can substantially reduce the energy consumption by reducing the idle listening and removing unnecessary wakeups.

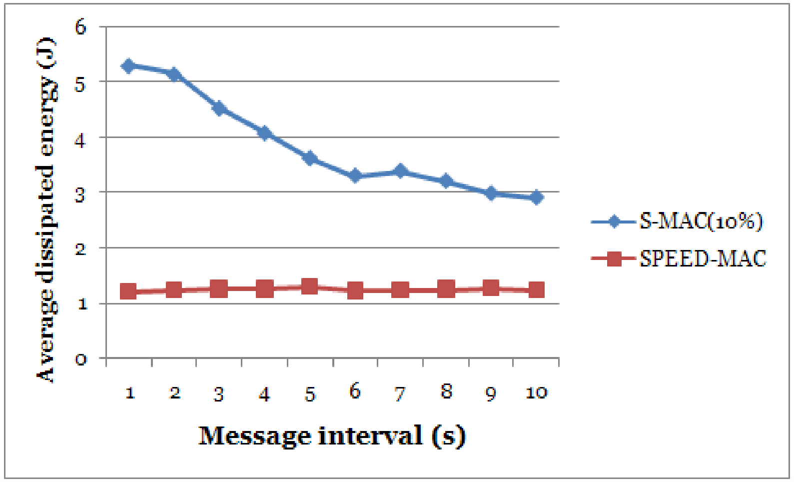


MICA-2 Mote Implementation

- **Packet size: control packet: 10B, data packet: 100B**
- **Contention window: SYNC packet: 15 slots, Data packet: 31 slot**

SINGLE SOURCE RESULTS





MULTIPLE SOURCE RESULTS