Z-MAC: a Hybrid MAC for Wireless Sensor Networks

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Outline

- Introduction
- Design of Z-MAC
- Performance Evaluation
- Conclusions and Discussions
- References

Introduction

- Comparison
- Goal
- Related Works

Comparison

- CSMA
  - Adv.
    - Simplicity, flexibility, and robustness
    - No clock synchronization and global topology
    - Adaptive to dynamic network topology
  - Dis.
    - Collision: hidden-terminal problems
    - RTS/CTS incurs high overhead of the channel capacity in sensor networks
- TDMA
  - Adv.
    - No extra overhead to solve the hidden terminal problem
  - Dis.
    - Needs a centralized node to find an efficient time schedule
    - Needs clock synchronization → high overhead
    - Handling dynamic topology change is expensive → high overhead
    - Interface irregularity

Goal

- Z-MAC is a hybrid MAC protocol
  - CSMA+TDMA
  - **Zebra MAC**
- To achieve
  - High channel utilization and low latency under <u>low</u> contention (like CSMA)
  - High channel utilization under <u>high</u> contention (like TDMA)
  - <u>Low power</u> operation
  - Simple implementation

Related Works

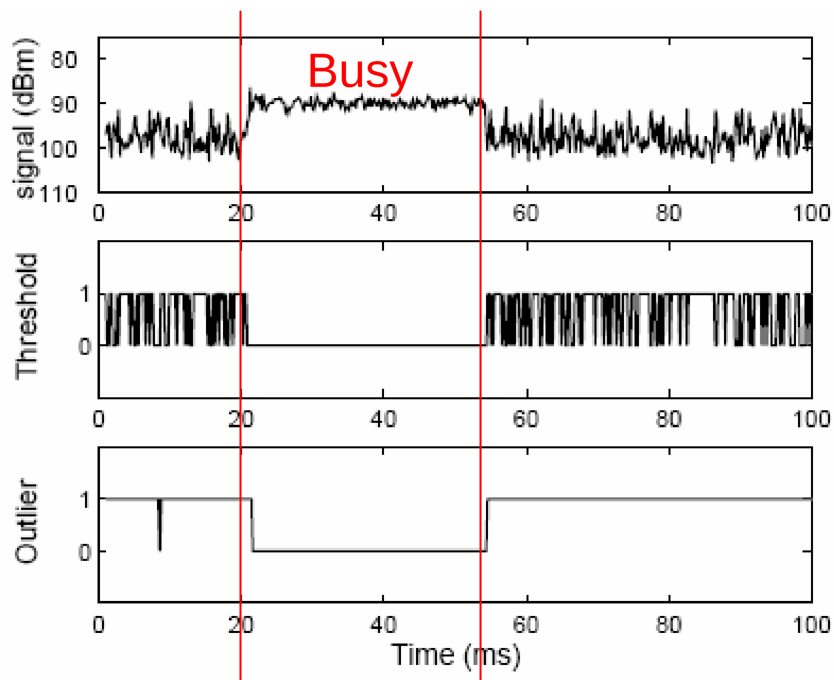
- S-MAC (Schedule MAC) [1]
  - Periodically sleeps, wakes up, listens to the channel, and then returns to sleep
- D-MAC (Duty cycle adaptation MAC) [2]
  - Improve the S-MAC uploading latency
- T-MAC (Time-out MAC) [3]
  - Dynamic active time to reduce the idle listening time

Related Works

- B-MAC (Berkeley MAC) [4]
  - B-MAC is only a link-layer protocol
    - No organization
    - No synchronization
  - B-MAC can be reconfigurable by network protocol
  - The main function of B-MAC
    - CCA: Clear Channel Assignment
    - LPL: Low Power Listening
  - The main technique
    - To estimate the channel signal strength and compare it with the noise signal strength

Related Works

- CCA: Clear Channel Assignment
  - Measure the channel signal strength and compare it with the noise floor
  - CC1000 low power FSK transceiver (chipcon.com)



>threshold=1: idle

<threshold=0: busy

Related Works

- LPL: Low Power Listening
  - Each time the node wakes up, it turns on the radio and checks for activity
  - Activity is detected (detect the preamble)
    - Node powers up and stays awake for receiving data
    - After reception, the node returns to sleep
    - If no data is received, a timeout forces the node back to sleep

Design of Z-MAC

- Neighbor Discovery and Slot Assignment
- Local Framing and Synchronization
- Transmission Control

Run only once during the setup phase

Overview of Z-MAC

- Z-MAC uses CSMA as the baseline MAC scheme, and uses a TDMA schedule to enhance channel utilization under high contention
- Unlike TDMA, a node may transmit during any time slot in Z-MAC

Neighbor Discovery and Slot Assignment

- Neighbor discovery
  - Periodically broadcasts a ping to its one-hop neighbors to gather one-hop neighbor list
- Slot assignment
  - DRAND [6]
    - is a distributed channel reuse scheduling algorithm
    - ensures a broadcast schedule where no two nodes within a two-hop communication neighborhood are assigned to the same slot

Local Framing and Synchronization

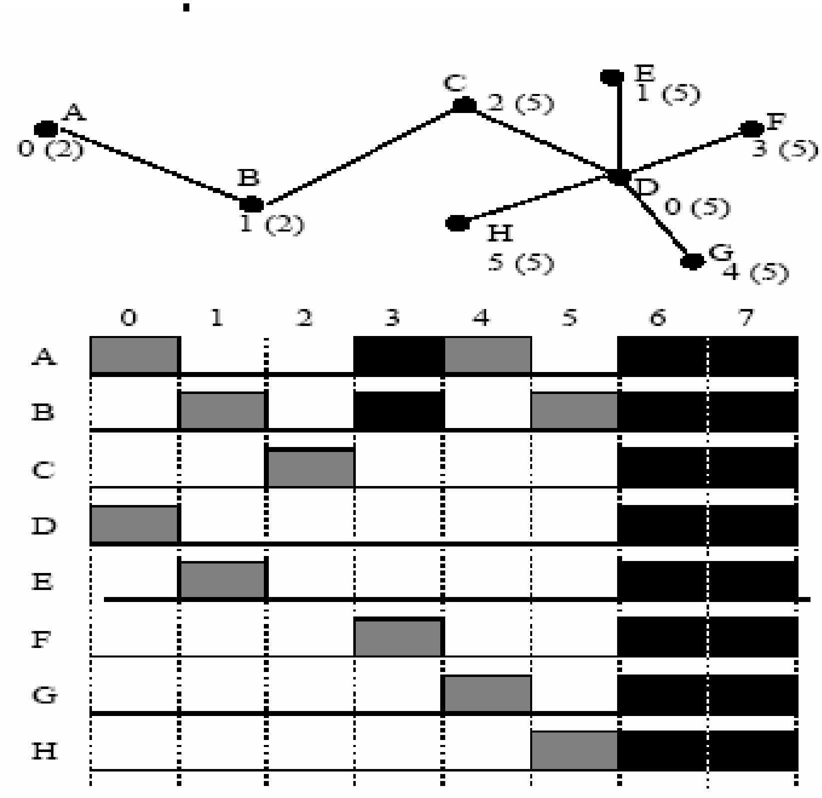
- Local Framing
  - Each node maintains its own local time frame that fits its local neighborhood size, but avoids any conflict with its contending neighbors.

Time frame rule (TF rule). Let a node i be assigned to a slot s_i according to DRAND and the MSN within its two-hop neighborhood be F_i. We set i's time frame to be 2^a where a positive integer a is chosen to satisfy condition $2^{a-1} \leq F_i < 2^a - 1$. That is, i uses the s_i-th slot in every 2^a time frame (is slots are $l \cdot 2^a + s_i$, for all $l = 1, 2, 3, \ldots$).

THEOREM 3.1. *If every node i uses only slots $l \cdot 2^a + s_i$, for all $l = 1, 2, 3, \ldots$, then no node j in the two-hop neighborhood of i uses any slot that i uses.*

Local Framing and Synchronization

- MSN: maximal slot



Dark slots are empty slots

Global time frame = **6** (MSN)

When the TF rule is used, the frame size is changing to **8**

$$2^{3-1} \le 6 < 2^{3} - 1$$

So, the frame size is $2^3 = 8$

Local Framing and Synchronization

- In order to use TF rule, the global clock synchronization is needed
- Synchronizing on slot **0**
- Z-MAC performs global clock synchronization such as TPSN [7], only once at the beginning
  - Please refers to the lab meeting report in 2004/02/13

Transmission Control

- A node can be in one of two nodes
  - **LCL: Low Contention Level**
    - Any node can compete to transmit in any slot
  - **HCL: High Contention Level**
    - Receives an explicit contention notification (ECN) message from two-hop neighbor within the last t_{ECN} period
    - Only the owners of the current slot and their one-hop neighbors are allowed to compete for the channel access

Transmission Control

- Transmission rule
  - If node i is the owner of the current slot
    - Takes a random backoff within a fixed time period T_0
    - Run CCA
      - If the channel is clear, it transmit the data
      - If the channel is not clear, wait and repeat the process

Transmission Control

- If node i is a non-owner of the current slot
  - In LCL and the slot is not owned by two-hop neighbors
    - Wait for T_0 and takes a random backoff within $[T_0, T_{no}]$
    - Run CCA
      - If the channel is clear, it transmit the data
      - If the channel is not clear, wait and repeat the process
  - In HCL
    - Postpones its transmission until it finds a time slot either that
      - is not owned by a two-hop neighbor
      - is its owner

Explicit contention notification (ECN)

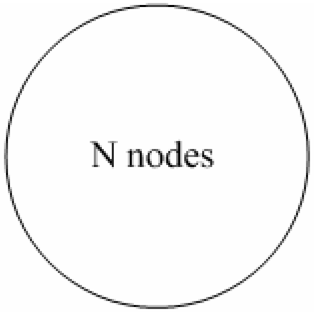
- ECN message notify two-hop neighbors not to act as hidden terminals to the owner of each slot when contention is high
- Two way to estimate two-hop contention
  - To receive ACK form the one-hop receiver and measure the packet loss rate
    - Sending feedback incurs extra overhead
  - To measure the noise level of the channel
    - Use CCA to measure

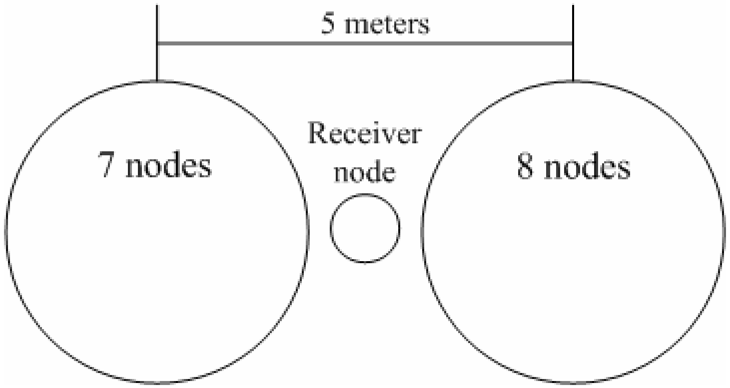
Performance Evaluation

- Experimental Method
- Throughput
- Energy Efficiency

Experimental Method

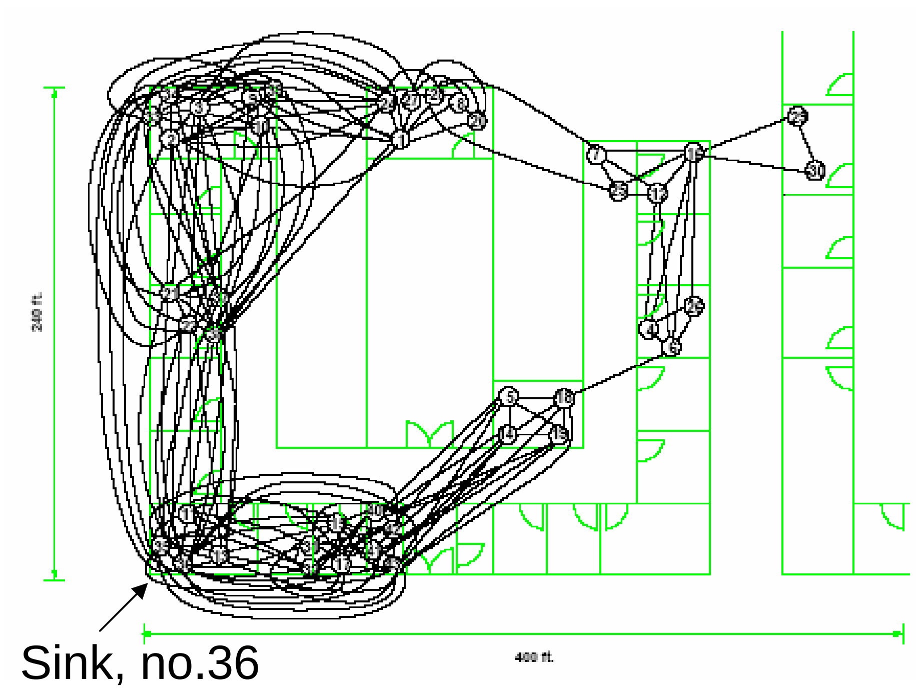
- Implementation in NS-2 and Mica2/TinyOS
- One-hop benchmark
  - N nodes are placed in a circle
  - No hidden terminals
- Two-hop benchmark
  - 2 clusters
  - Hidden terminals are present

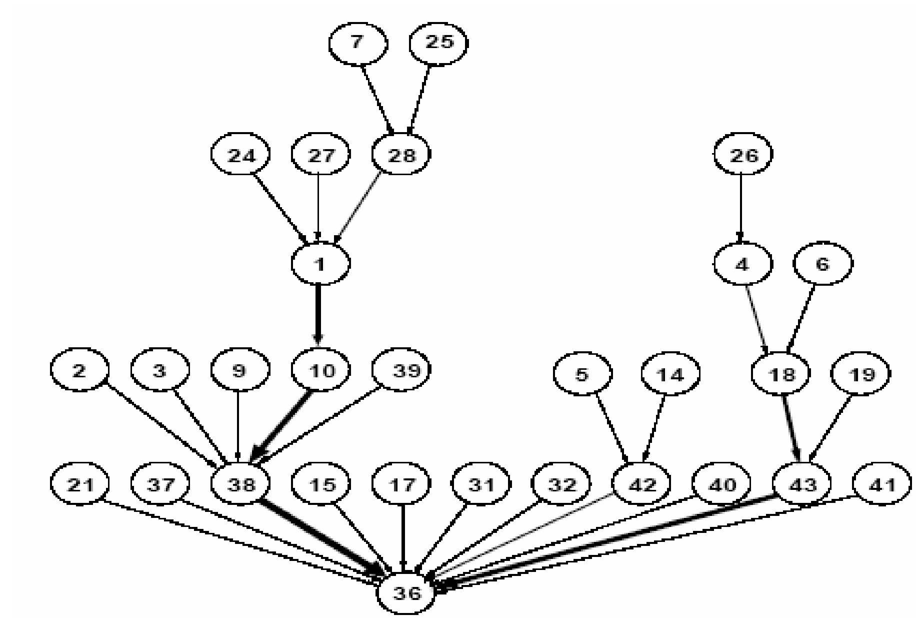




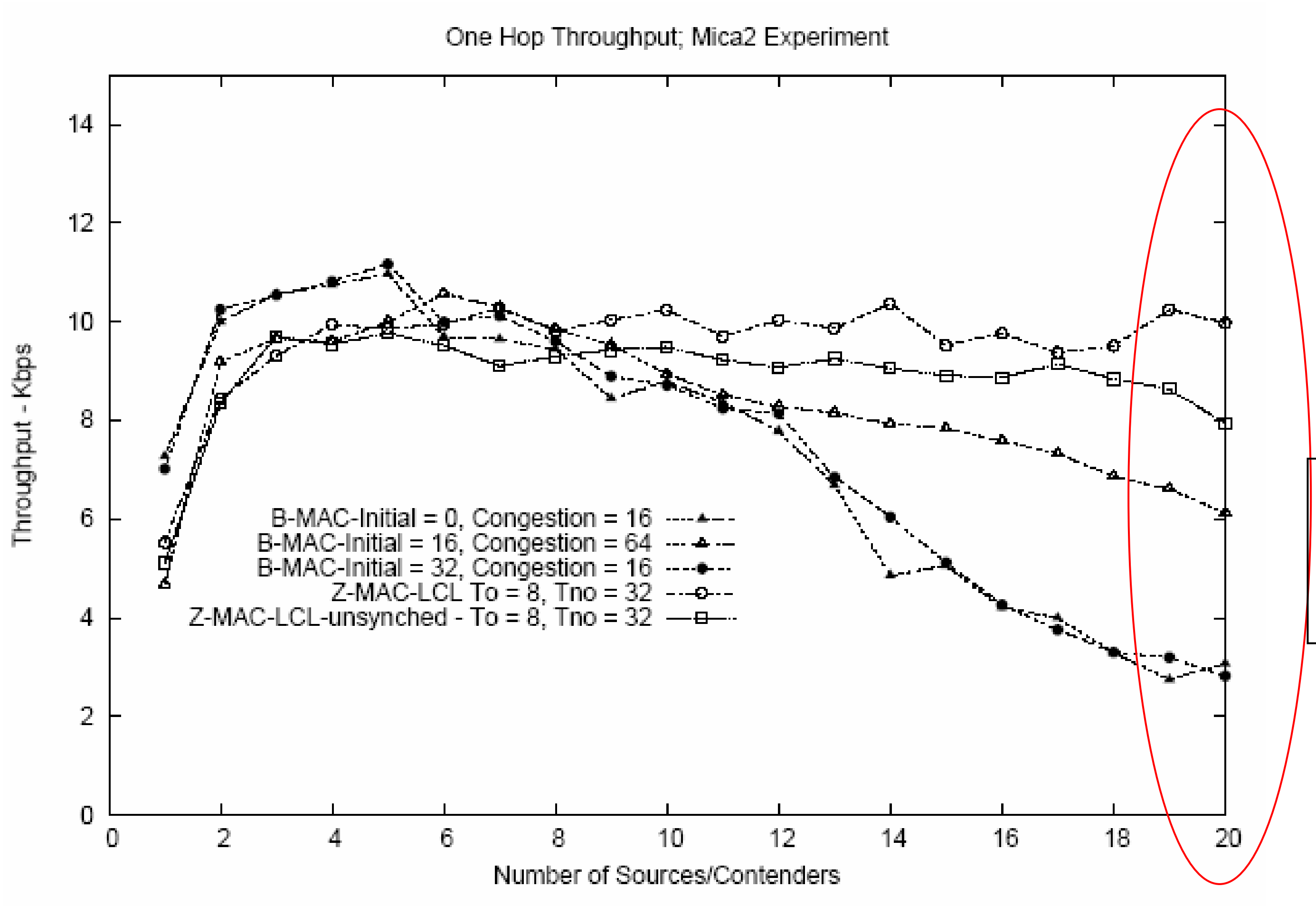
Experimental Method

- Multi-hop benchmark
  - 42 nodes



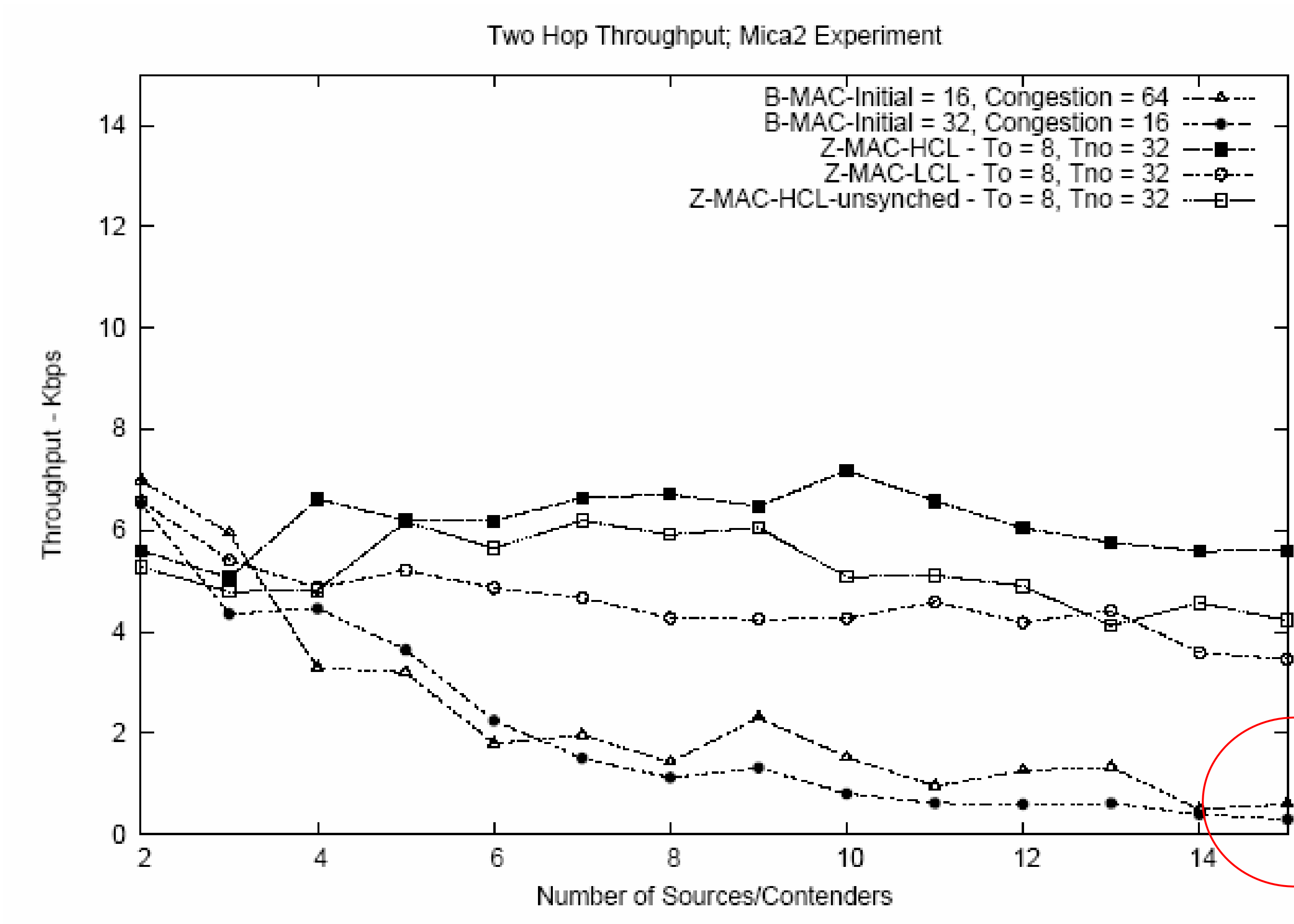


Throughput
One-hop benchmark



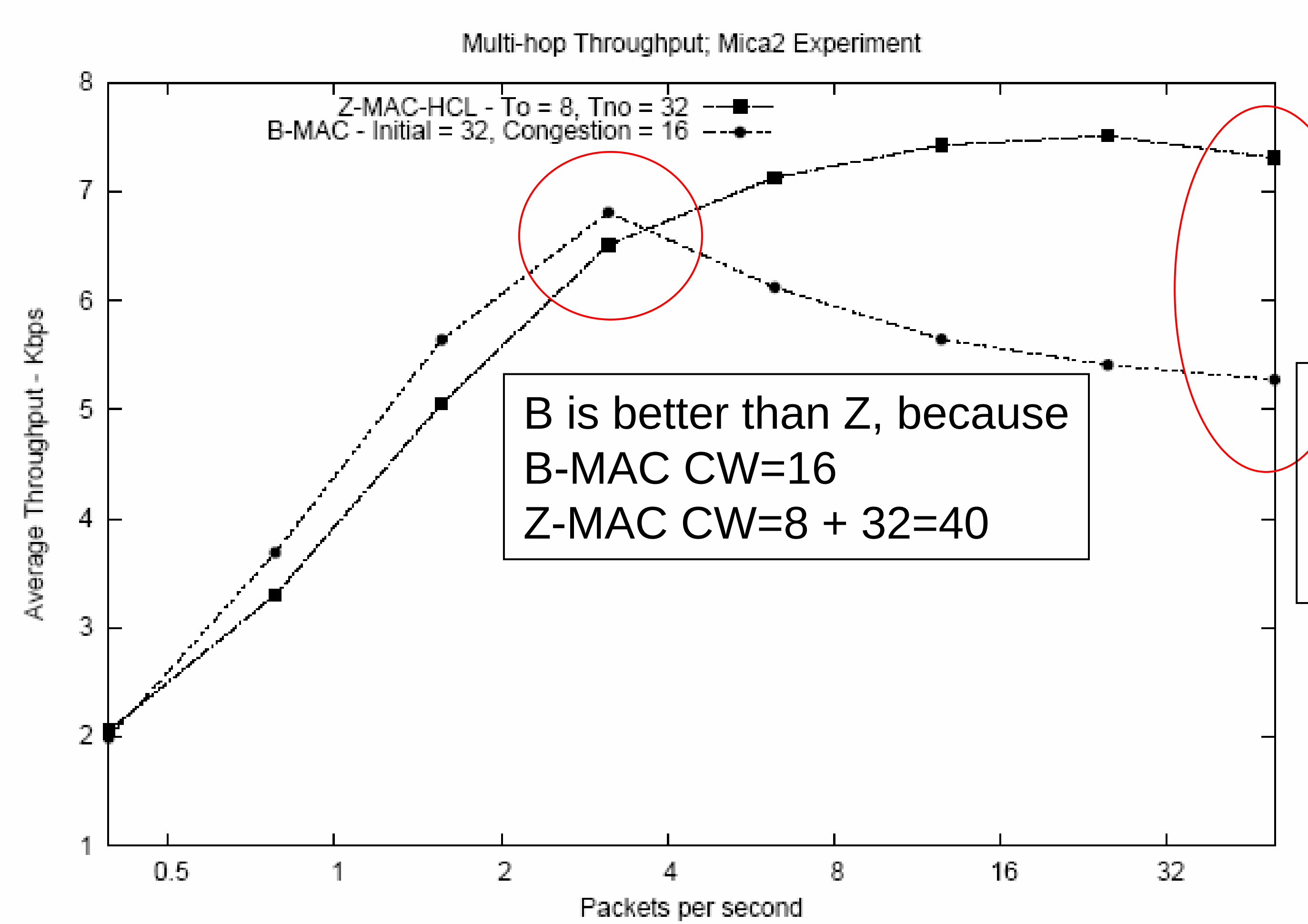
Larger CW size reduce the contention among senders

Throughput
Two-hop benchmark



~ 2kbps
RTS/CTC is a
big overhead

Throughput
Multi-hop benchmark



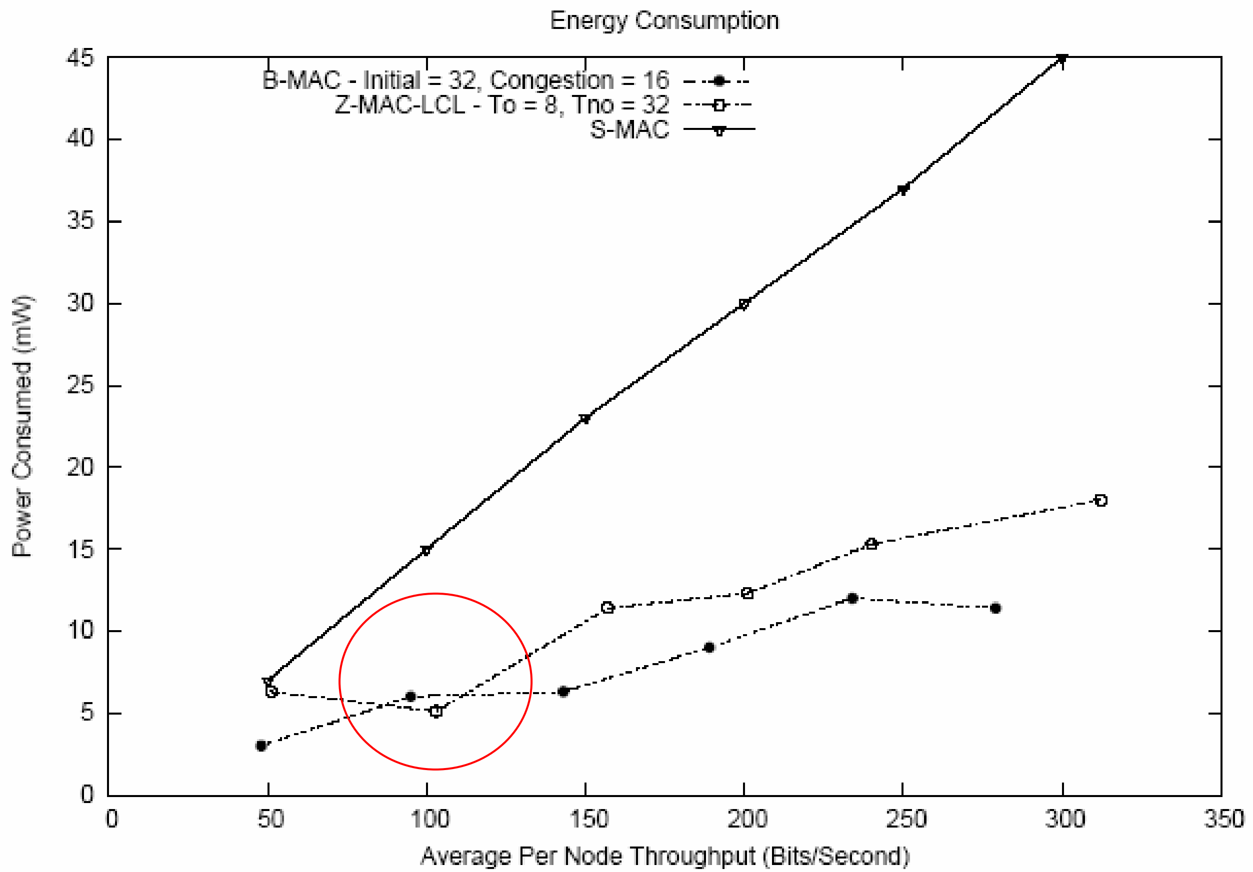
B is better than Z, because
B-MAC CW=16
Z-MAC CW=8 + 32=40

The network is densely populated, nodes can sense each other very well

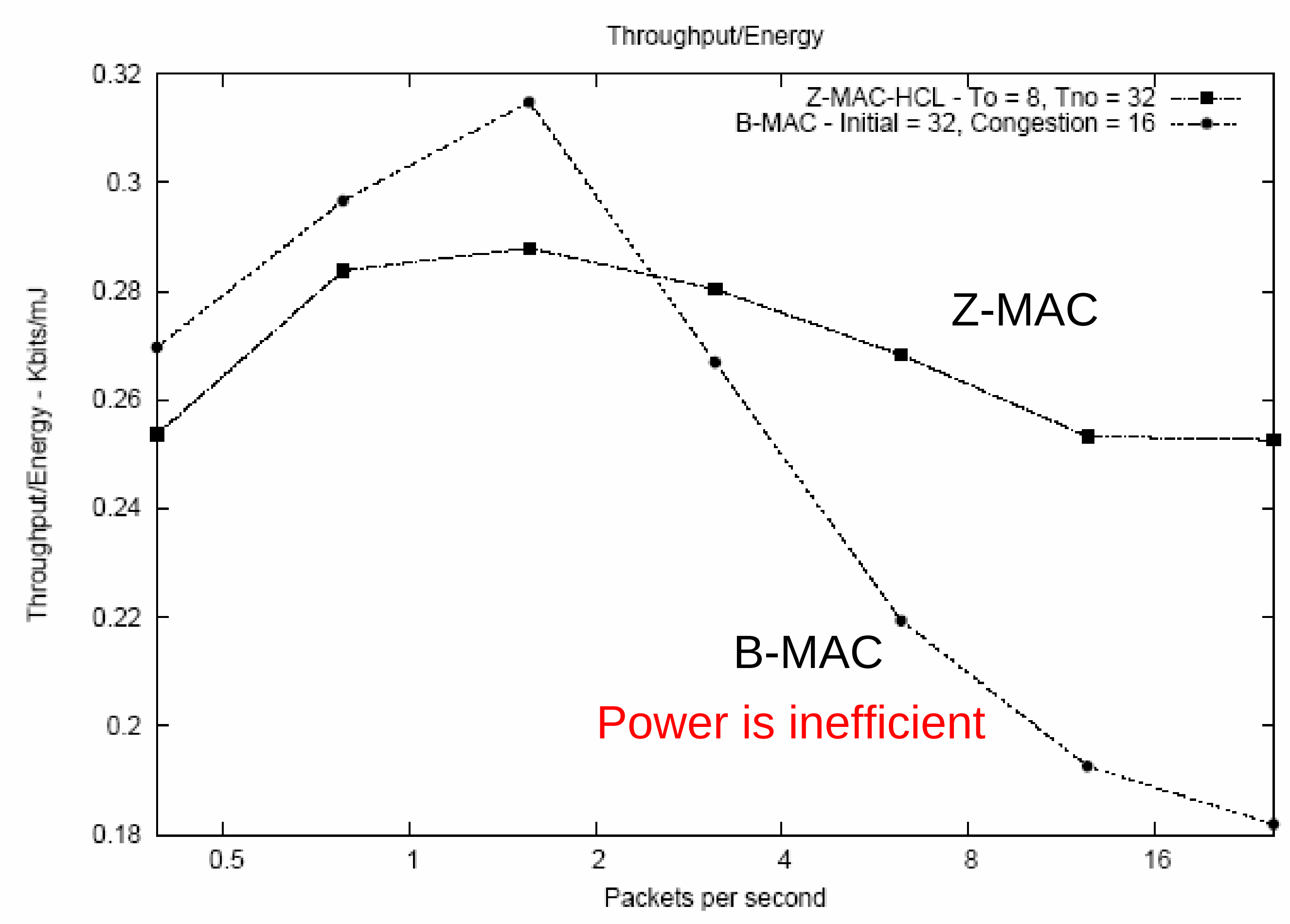
One-hop contention dominates two-hop Contention,
like one-hop benchmark

Energy Efficiency
low-data rate with low duty cycle

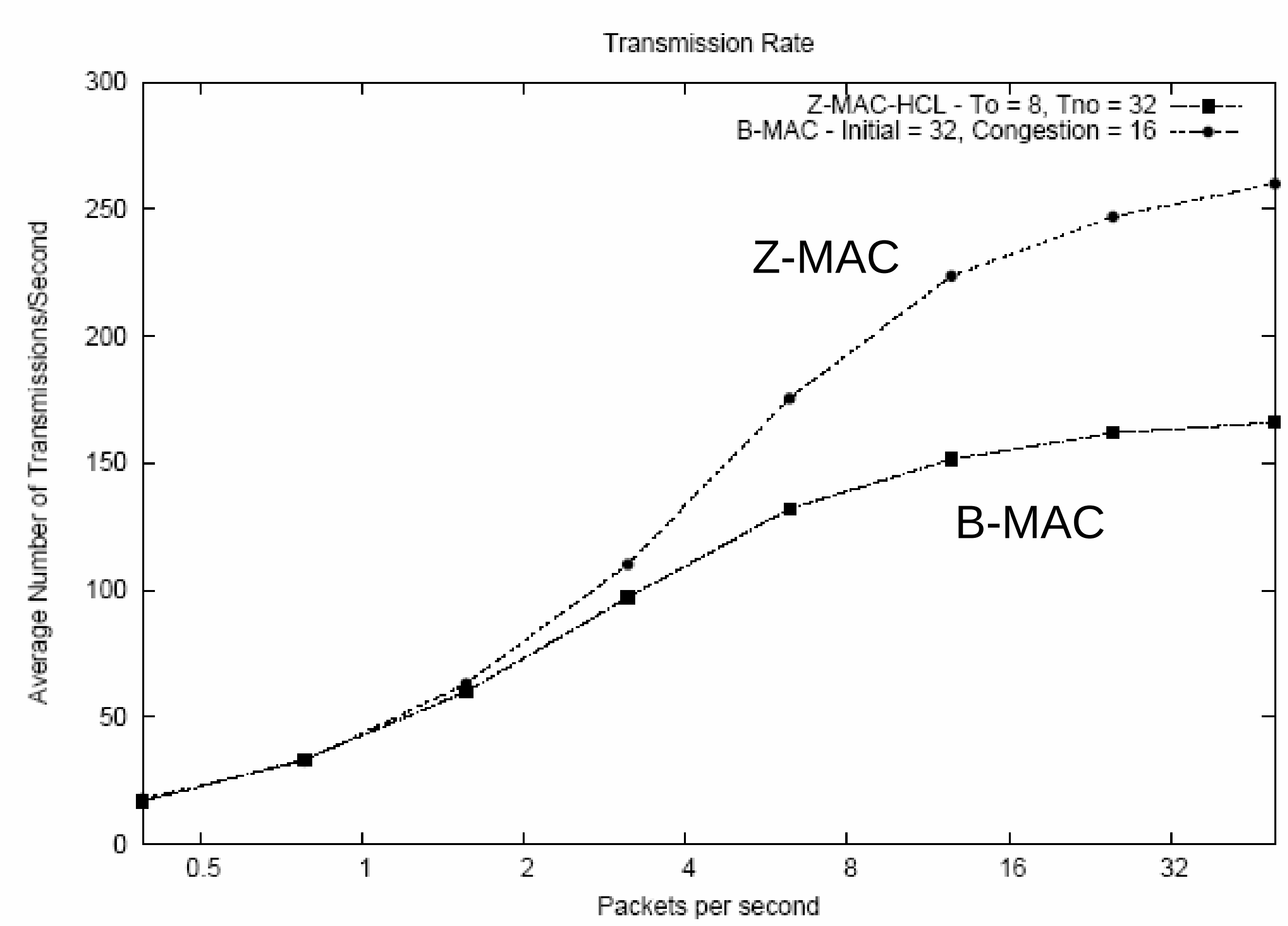
- Backoff window sizes are larger
- Clock synchronization message are periodically sent



Energy Efficiency
Multi-hop benchmark



Energy Efficiency Multi-hop benchmark



Conclusions

- Z-MAC uses CSMA as the baseline MAC scheme, and uses a TDMA schedule to enhance channel utilization under high contention
  - Under light load, it acts as CSMA protocol
  - Under heavy load, it acts as TDMA protocol
- Z-MAC acts as an upper layer over B-MAC
- Z-MAC is implemented in Mica2/TinyOS
  - http://www.csc.ncsu.edu/faculty/rhee/export/zmac