Funneling-MAC: A Localized, Sink-oriented MAC for Boosting Fidelity in Sensor Networks

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Outline

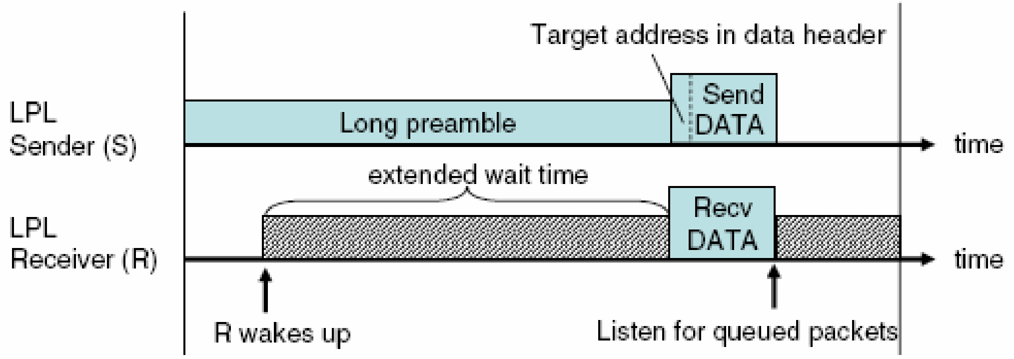
- Introduction
- Funneling MAC
- Performance Evaluation
- Conclusions
- Discussions

Introduction

- Three categories
  - Synchronized approaches
    - Pre-scheduled wake-up pattern
    - Ex: S-MAC (2002), T-MAC (2003)
  - Asynchronous approaches
    - Independent wake-up pattern
    - Ex: B-MAC (2004), Wise-MAC (2005), X-MAC (2006)
  - Hybrid approach
    - CSMA + TDMA
    - Z-MAC (2005)

Asynchronous Protocol

- No idle listening
- Low power listening (LPL)
  - Preamble sampling
- A sender transmits a ***preamble*** before sending data.
- When the receiver will wake up and detect the preamble, it **stays awake** to receive this data.



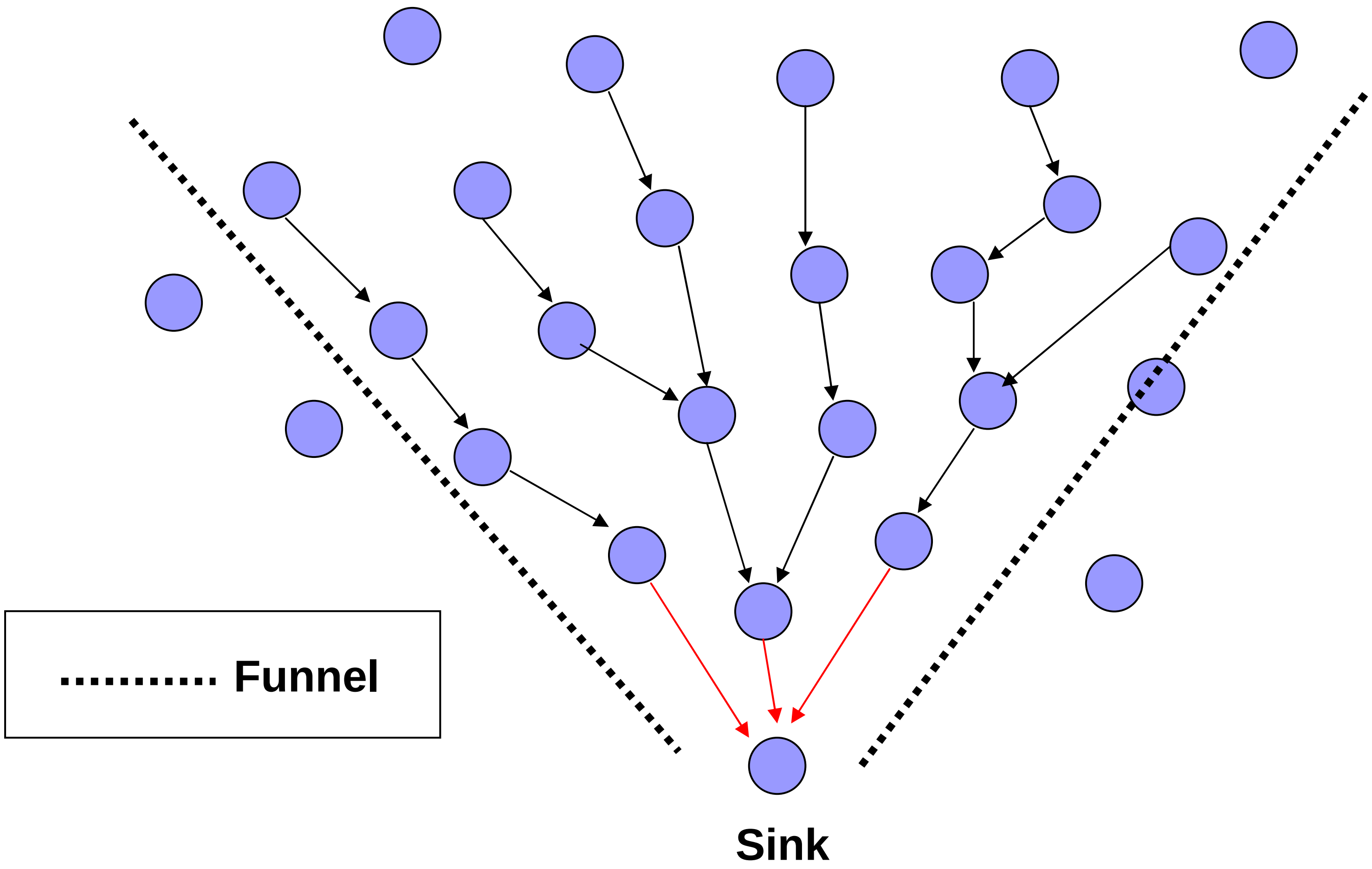
Asynchronous Protocol

- Advantages
  - The duty cycles of sender and receiver are completely decoupled
  - No synchronized overhead
  - Low power listening saves energy
- Disadvantages
  - Long waiting time
  - Overhearing problem
  - Per-hop latency

Hybrid Protocol: Z-MAC

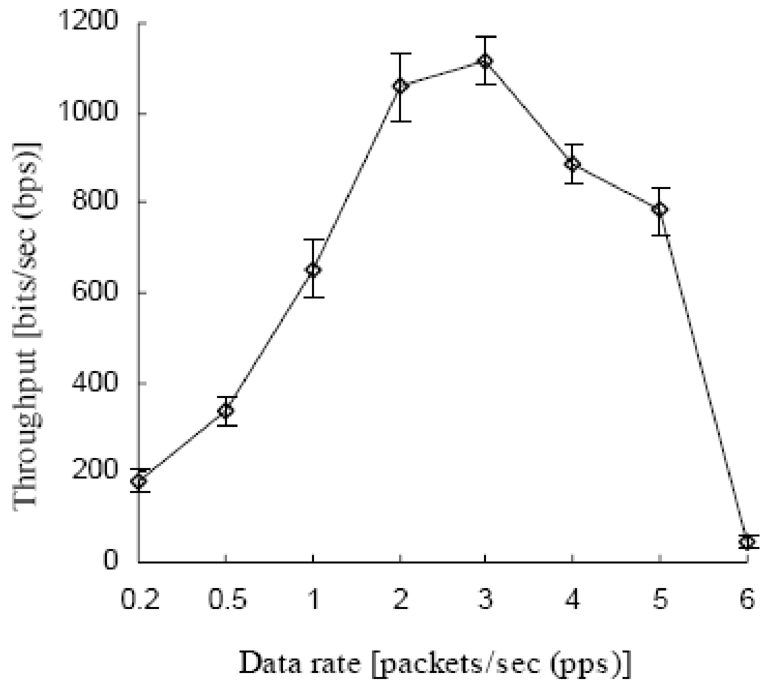
- Z-MAC uses CSMA as the baseline MAC scheme, and uses a TDMA schedule to enhance channel utilization under high contention
- Unlike TDMA, a node may transmit during any time slot in Z-MAC

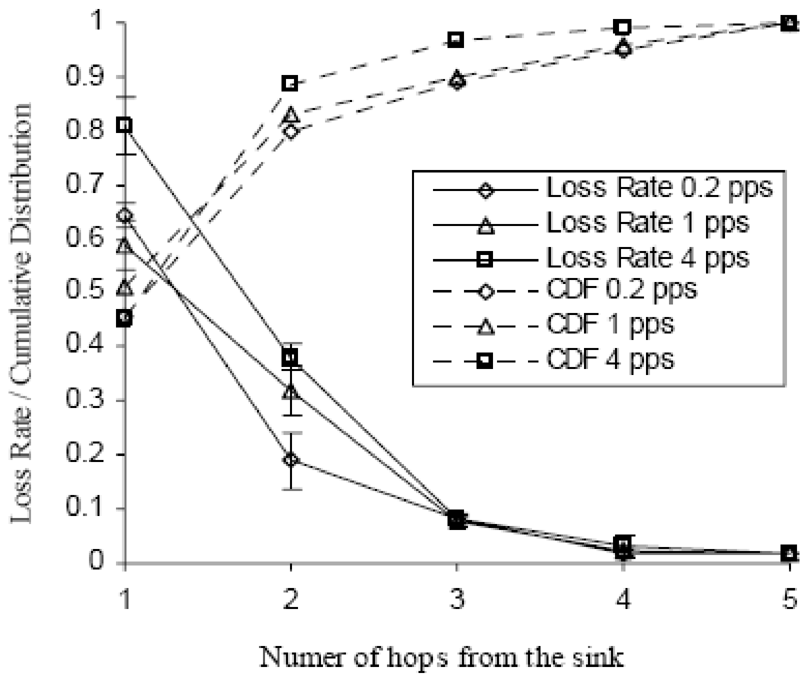
Funneling Effect



Funneling Effect

- The majority of packet loss in a sensor network within the first few or more hops from the sink, even under light traffic conditions.





Funneling-MAC

- A hybrid protocol
  - CSMA/CA + localized TDMA
- Sink-oriented
  - The TDMA scheduling is managed by the **sink**
- Localized TDMA
  - TDMA only operates in the funneling region close to the sink, called **intensity region**.

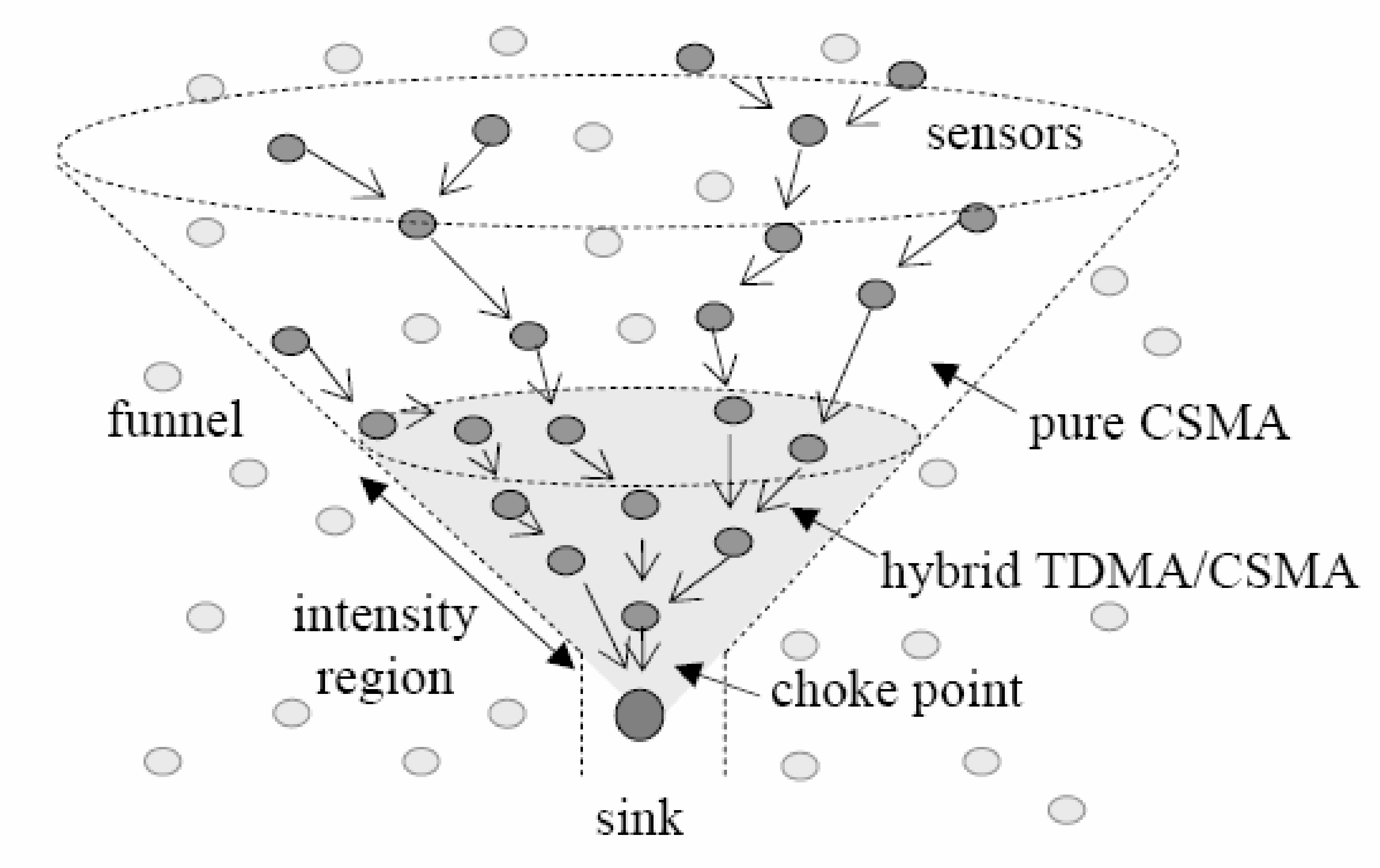
Funneling-MAC

- On-demand beaconing
- Sink-oriented scheduling
- Timing and framing
- Dynamic depth-turning
- Meta-scheduling Advertisement

On-demand beaconing

- Two operation modes
  - CSMA: by default
  - TDMA: the nodes that receive a beacon from a sink
- Intensity region
  - Covered by the beacon message
  - ***f*-node**
  - TDMA operation

On-demand beaconing

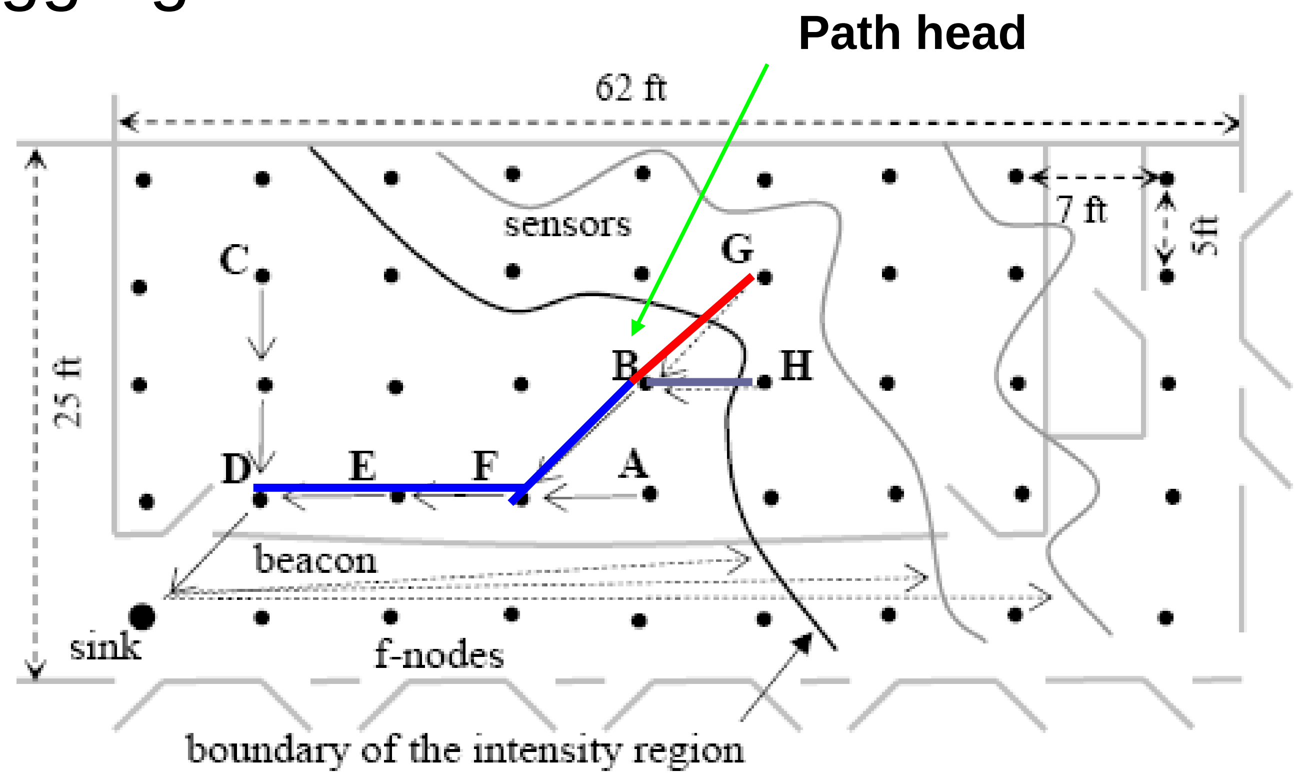


On-demand beaconing

- The sink node controls the **transmission power** of the beacon to regulate the boundary of the intensity region.
- Beacon packet
  - <beacon interval, superframe duration, TDMA duration>
- The beacon is sent periodically every beacon interval

Sink-oriented scheduling

- The sink node manages the TDMA scheduling of sensor events in the intensity region.
- Path aggregation



Sink-oriented scheduling

- The sink needs to gather path information from incoming packets.
- Path information field (in packet header)
  - <path head id, # of hops>
  - EX: path A-F-E-D-sink
    - path information: <A, 4>

Sink-oriented scheduling

- Slot allocation rule:

  Example:
  traffic rate of a path = k packets/superframe
  number of hops = h

  $\lfloor k \rfloor \times h$ is allocated to the path

- Schedule packet

Header	A ; 3	B ; 4	C ; 3

Sink-oriented scheduling

- Each f-node maintains a table to compute which slots are allocated to itself.

  <path-head id, # of hops>

- Ex: <A, 2> and <B, 2> in node E's table

Timing and Framing

- Super frame = CSMA + TDMA
- The schedule packet typically follows a beacon

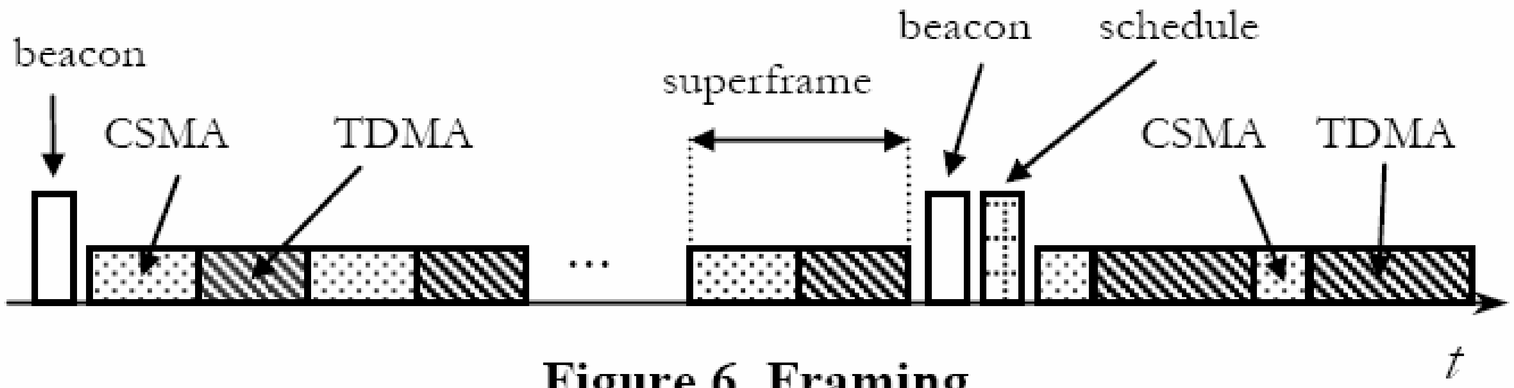


Figure 6. Framing

- TDMA duration is dynamic (Max. = 80%)

Dynamic Depth Tuning

- Parameters

A: total # of slots scheduled

A_{max}: Max. available slots in one superframe

d: the depth of the intensity region

d_{max}: the upper bound of the depth d

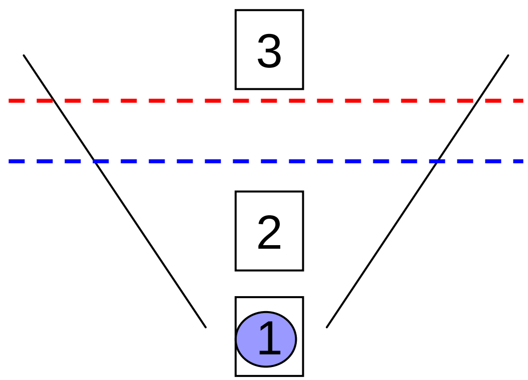
- The depth is controlled by the transmission power

Dynamic Depth Tuning

- Depth-tuning algorithm
  - Star up: common power
  - $A < A_{max}$: increase the transmission power for the next beacon until $A > A_{max}$ or $d > d_{max}$
  - $A > A_{max}$: decrease the transmission power for the next beacon
  - $A = A_{max}$: the depth is at the optimal point

Meta-Scheduling Advertisement

- Interference issues
  1. Hybrid MAC and broadcasting of sink signal
  2. In the intensity region, some nodes do not receive beacons
  3. Nodes outside the boundary of the intensity region do not know the TDMA schedule



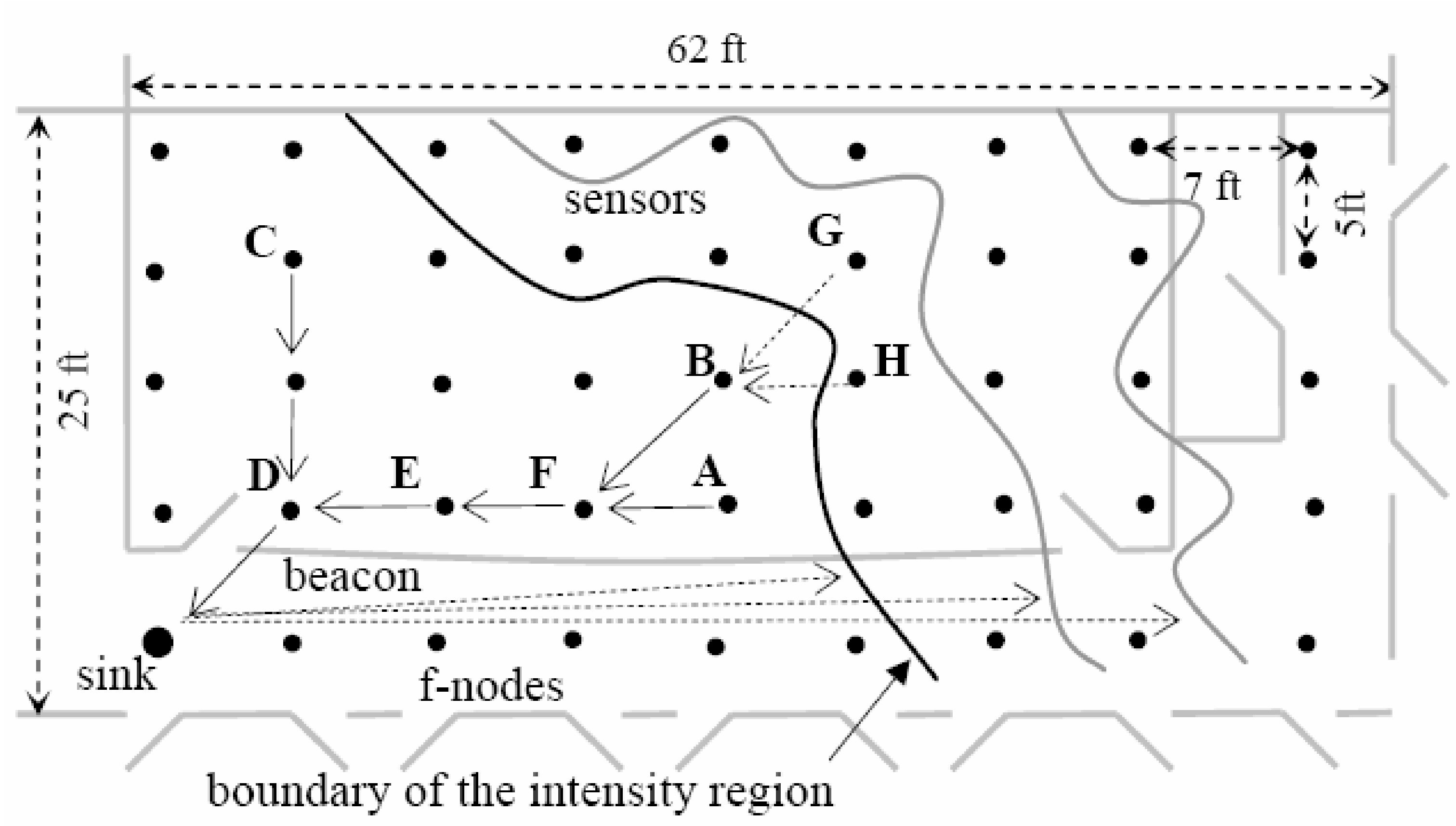
Meta-Scheduling Advertisement

- All f-nodes that received beacon and schedule embed the meta-schedule in the **first** event data packet transmitted toward the sink **every** beacon interval.
- A meta-schedule contains:
  - Superframe duration
  - TDMA duration
  - Time left of the current TDMA frame
  - # of superframe repetitions

Performance Evaluation

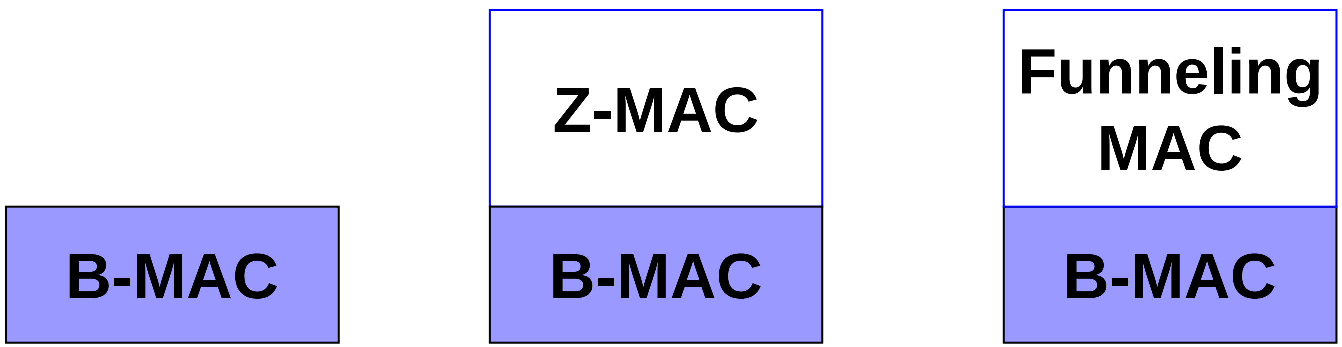
- 45 mica2 motes
- Bit rate = 19.2 kbps
- Packet size = 36 bytes
- Transmission power = -10 ~ 5 dBm
  - Default transmission power = -10 dBm
- Beacon interval = 20 sec
- Super frame size = 1 sec
- Slot size = 30 msec

Testbed Environment

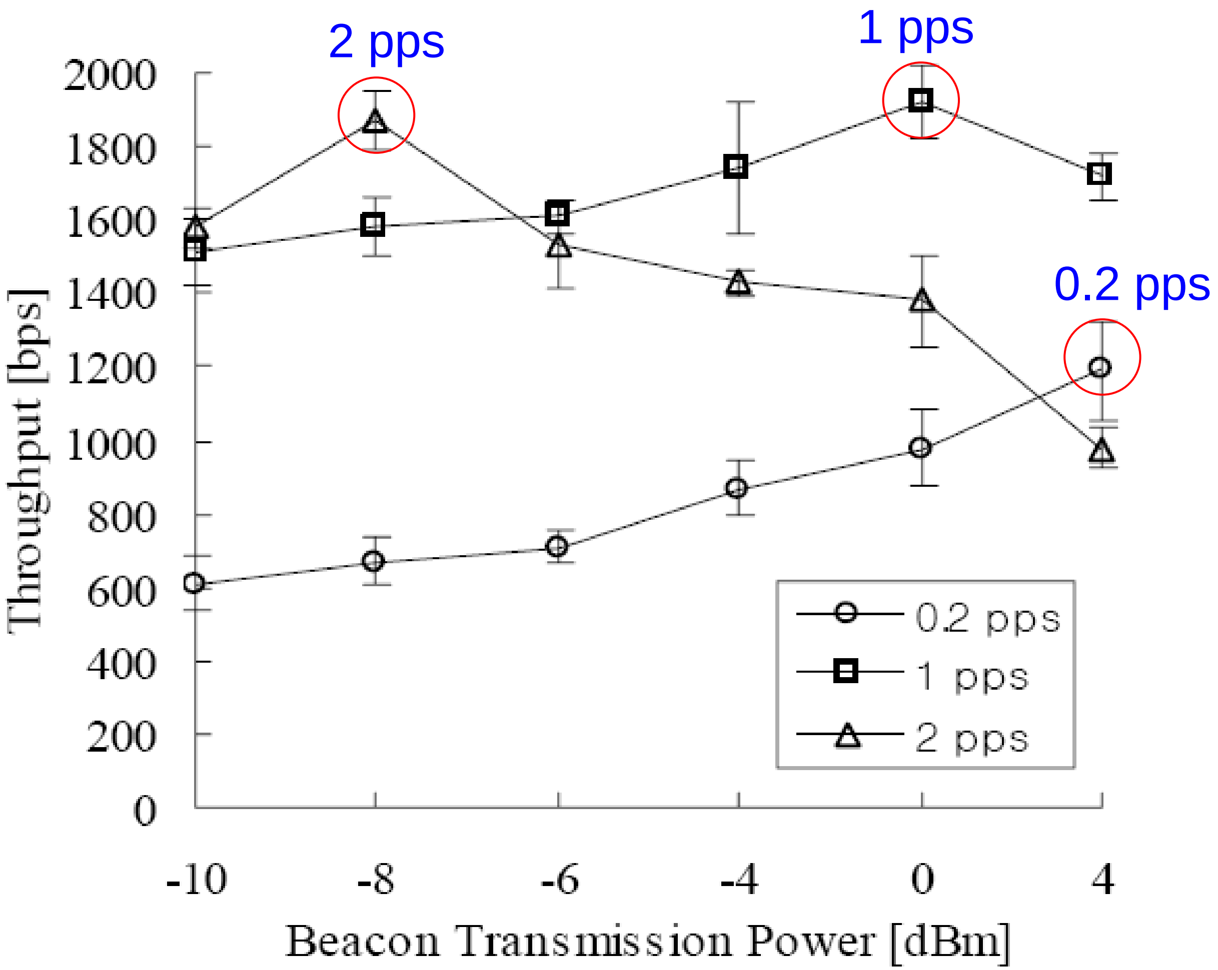


Comparison Protocols

- Turn off low power listening
- Use the same preamble size



Impact of Depth-Tuning

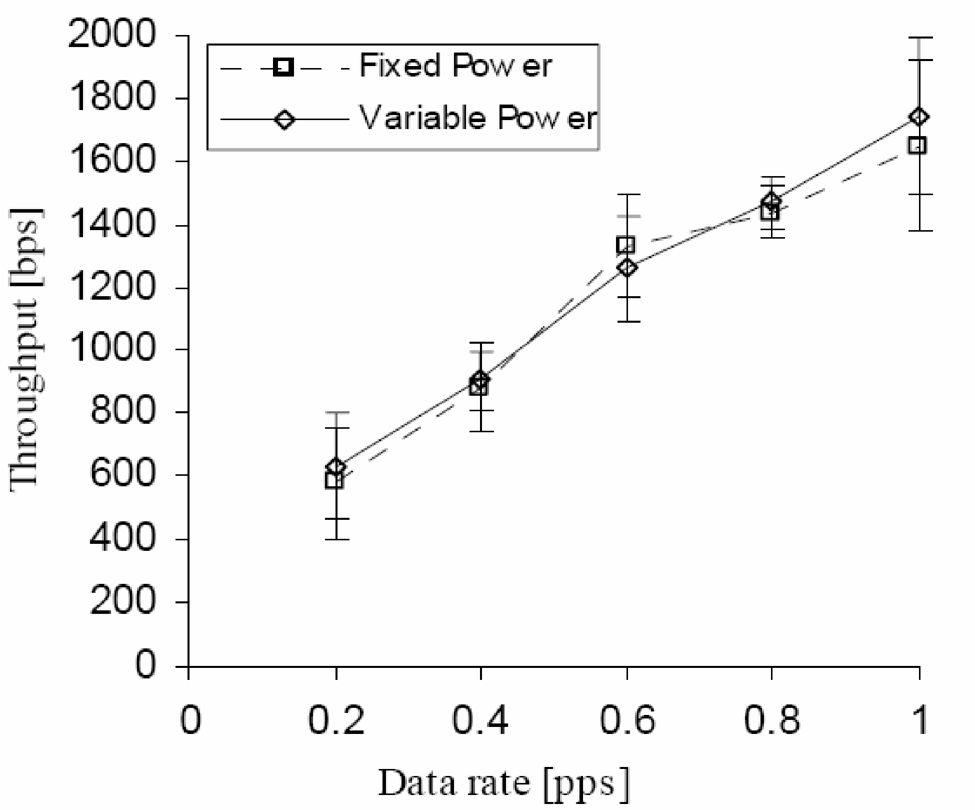


Optimal point:

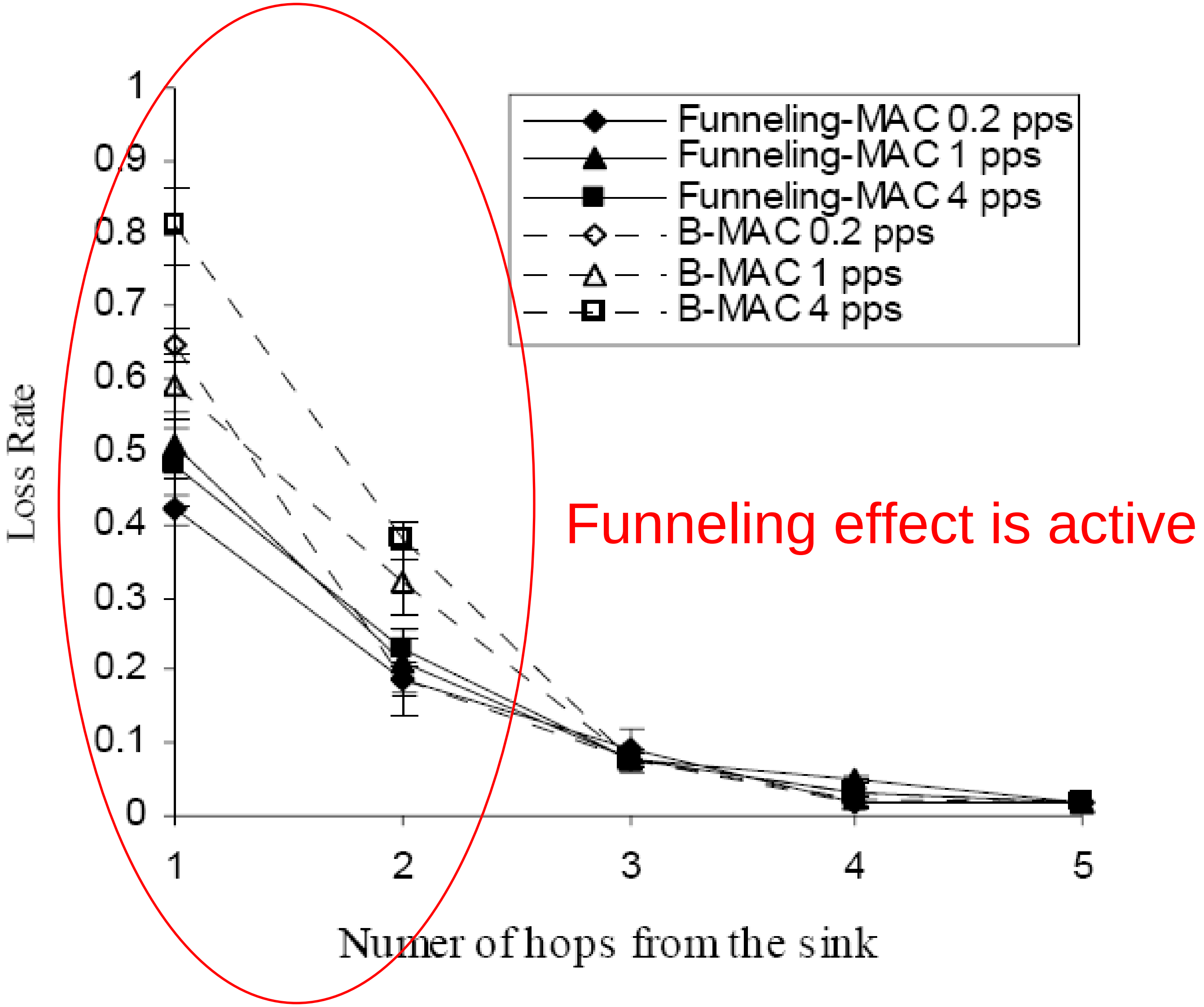
0.2 pps : 4 dBm
1 pps : 0 dBm
2 pps : -8 dBm

Impact of Boundary Node Interference

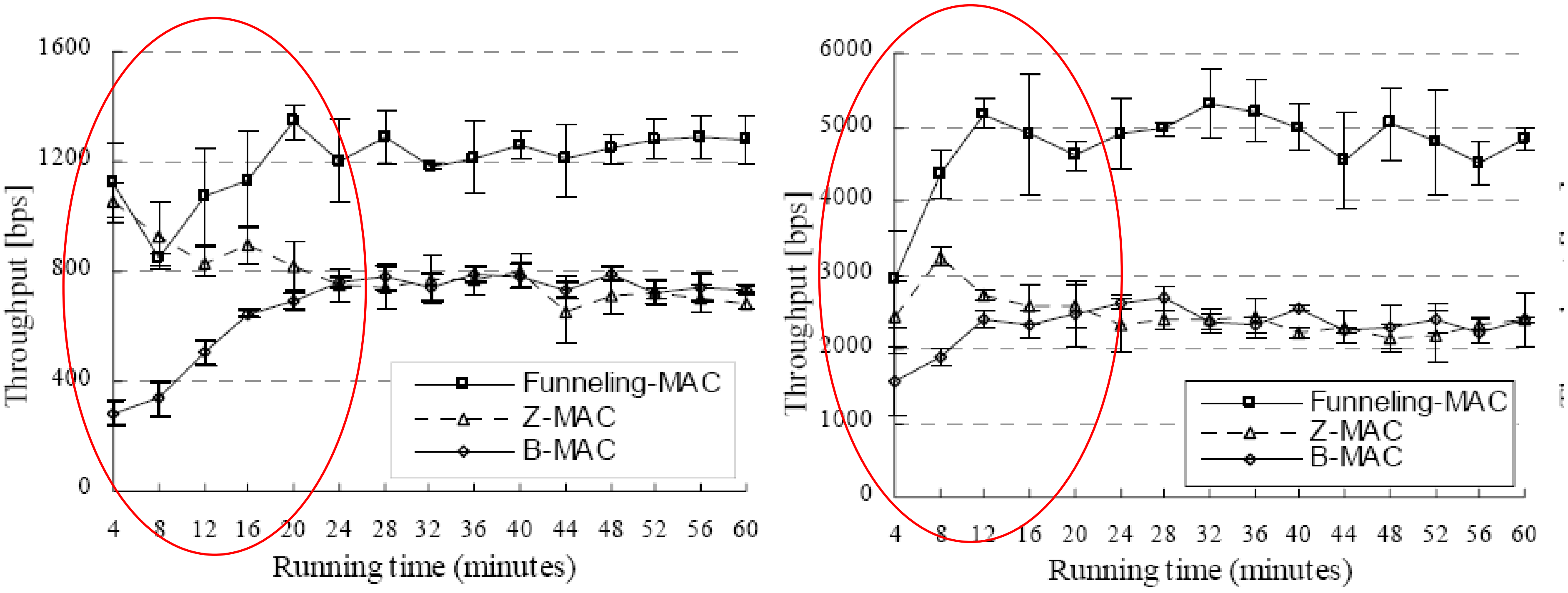
- Transmission power range: -6 ~ -8 dBm
- Fixed power level = -7 dBm



Loss Rate Distribution

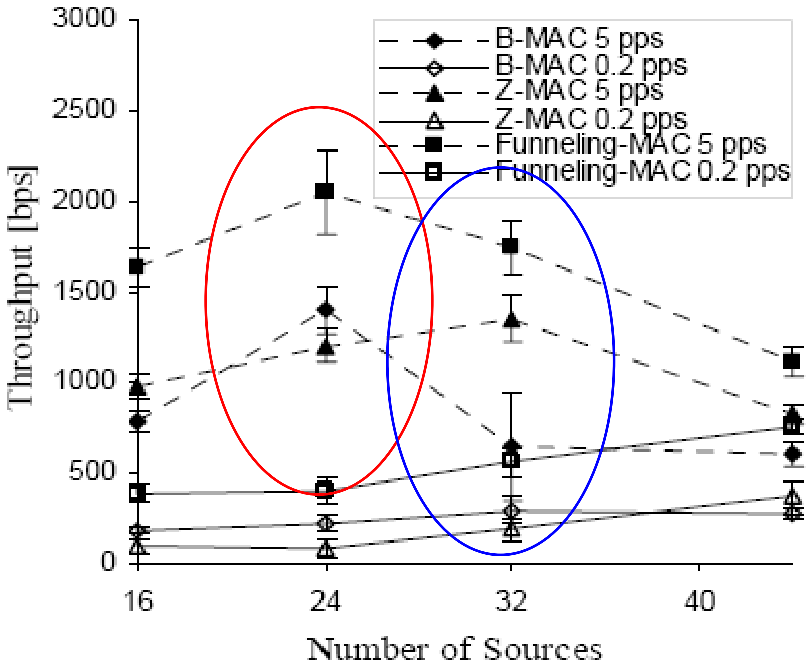


Multi-hop Throughput

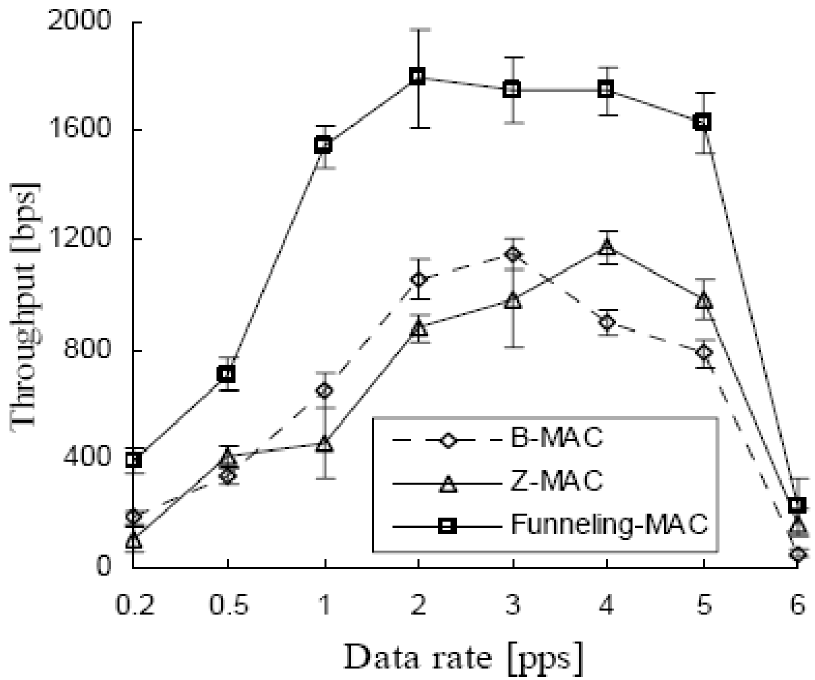


Schedule drift will degrade the network throughput
--especially for Z-MAC

Multi-hop Throughput



(a) Varying number of sources



(b) 16 sources with varying data rate

- For light load, Z-MAC and B-MAC perform the same
- For heavy load, Z-MAC outperforms B-MAC

Throughput

	0.2 pps	1 pps	2 pps
B-MAC	272	1099	1631
Baseline (d = 1)	645 (124 %)	1511 (37 %)	1583 (0 %)
Funneling (d dynamic)	1191 (338 %)	1925 (75 %)	1872 (15 %)

Conclusions

- This paper proposes a hybrid TDMA/CSMA MAC protocol
  - Using TDMA in the intensity region
  - The intensity region is controlled by the transmission power of the beacon
- The funneling MAC outperforms B-MAC and Z-MAC under a wide variety of network and traffic conditions