ADB: An Efficient Multihop Broadcast Protocol Based on Asynchronous Duty-Cycling in Wireless Sensor Networks

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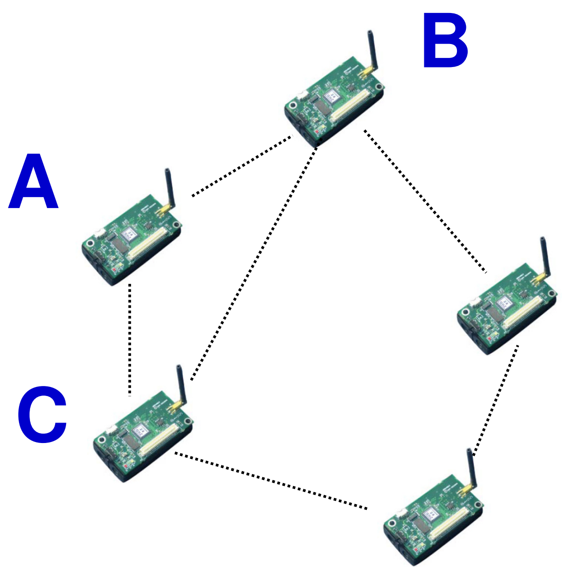
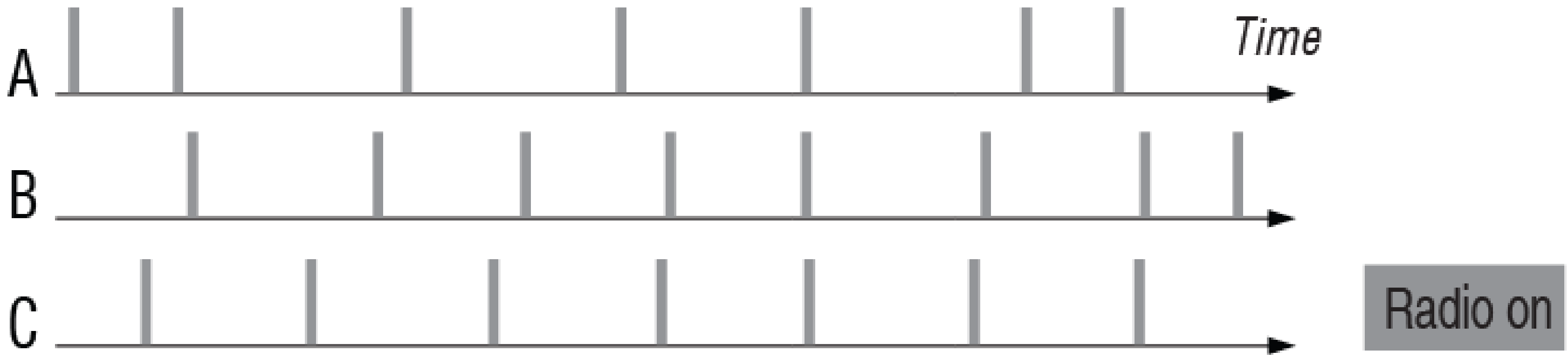
Asynchronous Duty Cycling

- Nodes are battery powered and wireless
- Each node decides its own wakeup schedule, wakes up asynchronously



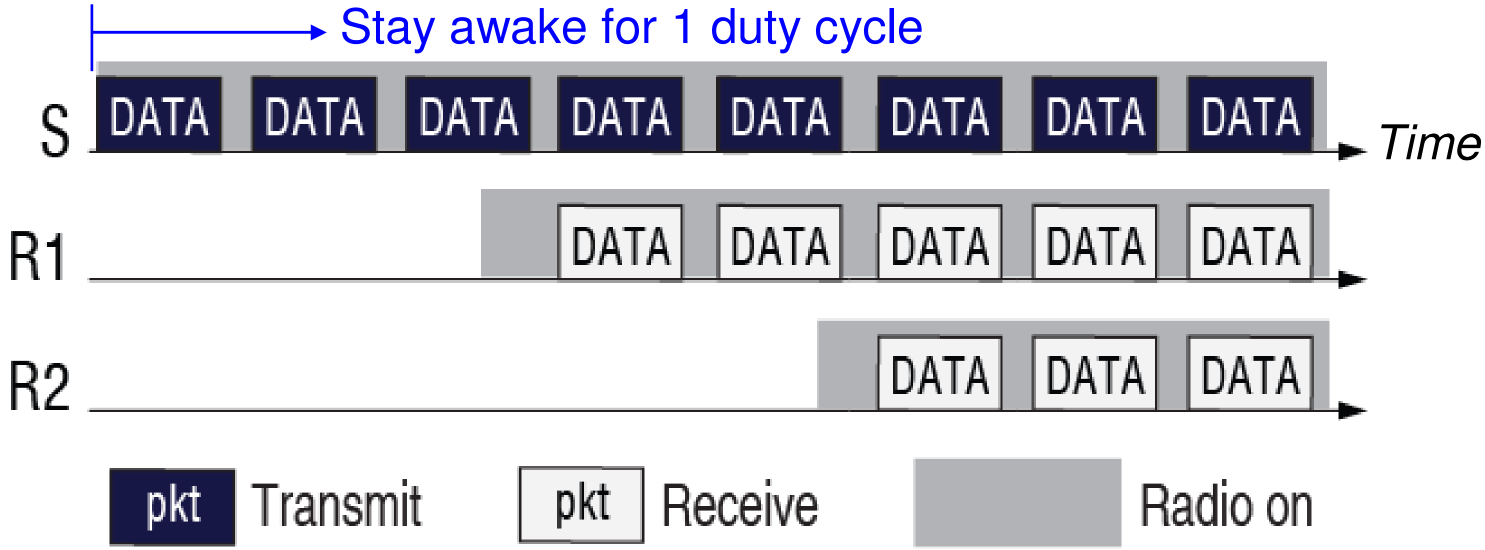


ADB: Asynchronous Duty-Cycle Broadcasting

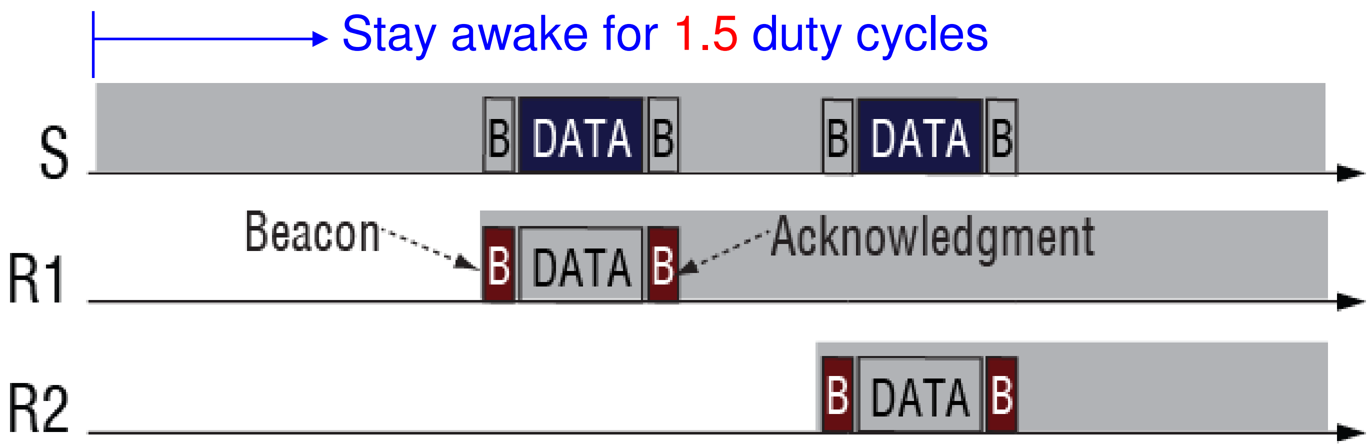
- Multihop broadcast over asynchronous duty cycling
  - High power efficiency
  - Low packet delivery latency
  - High packet delivery ratio

Existing Solutions

X-MAC
(UPMA of TinyOS, SenSys '06 and '07)

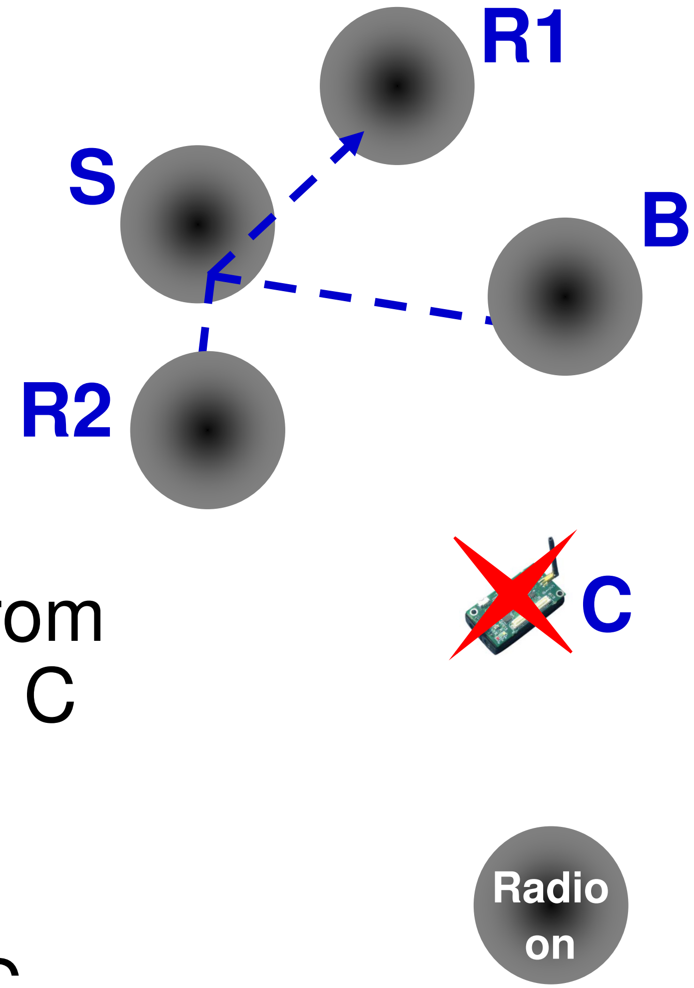


RI-MAC
(SenSys '08)



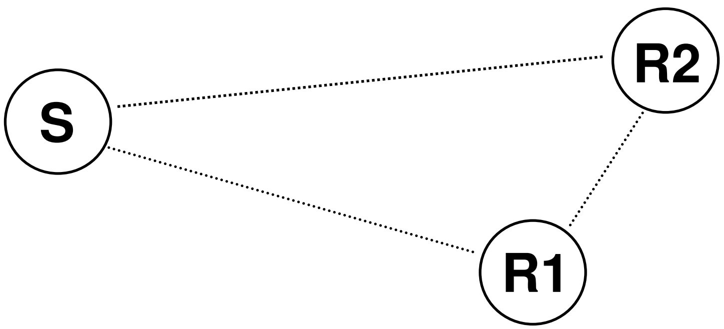
Challenges and Problems

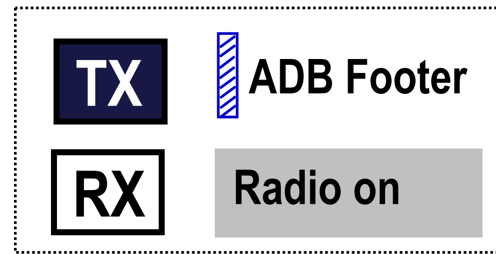
- Wastes energy
  - S still stays on after all neighbors are reached
  - R1 transmissions do not reach any new neighbors
- Increases latency
  - R1 transmissions block B from forwarding the broadcast to C
- Reduces delivery ratio
  - Transmissions from hidden nodes R2 and B collide at C

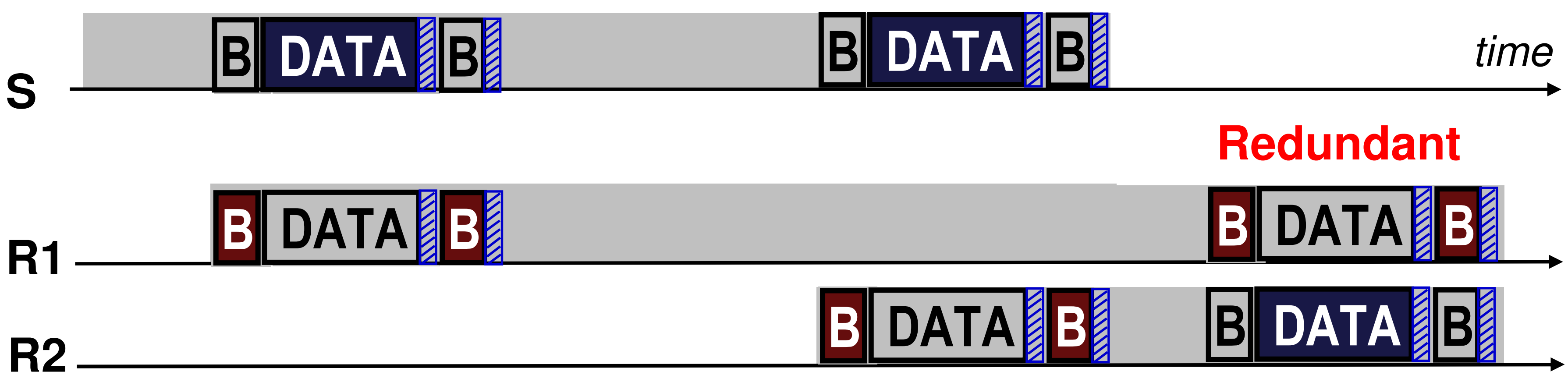


ADB: Use Unicast To Do Broadcast

- Unicast to each node when it wakes up
- Go to sleep if no more neighbors to reach



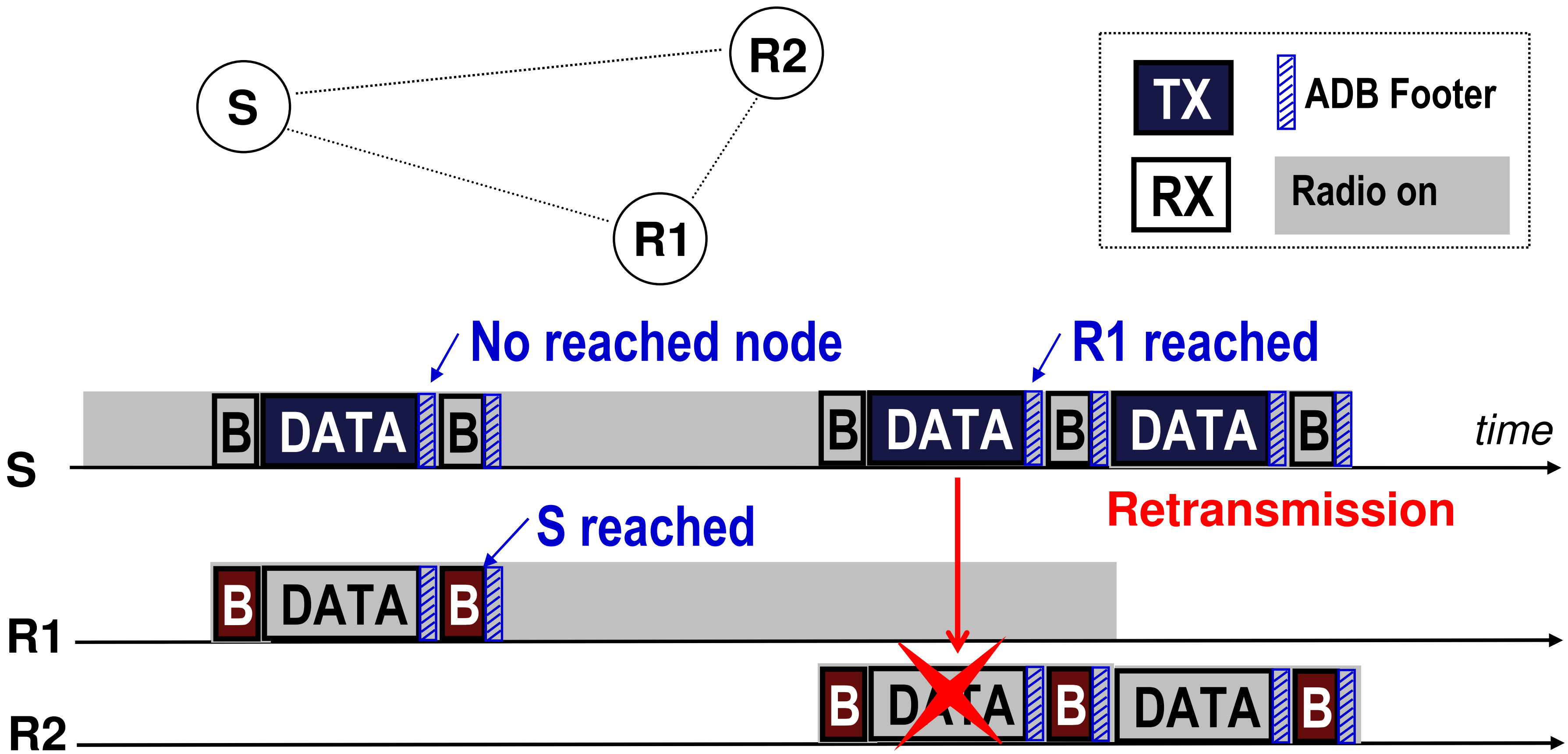




* Overheard packets now shown

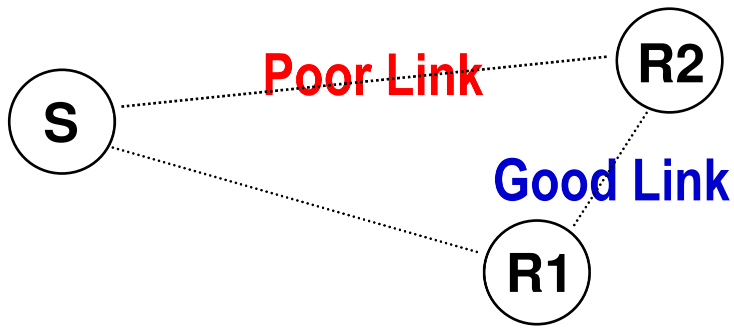
ADB: Disseminate Progress Information

- Append progress information as footer to each packet
- Indicate which nodes have been reached



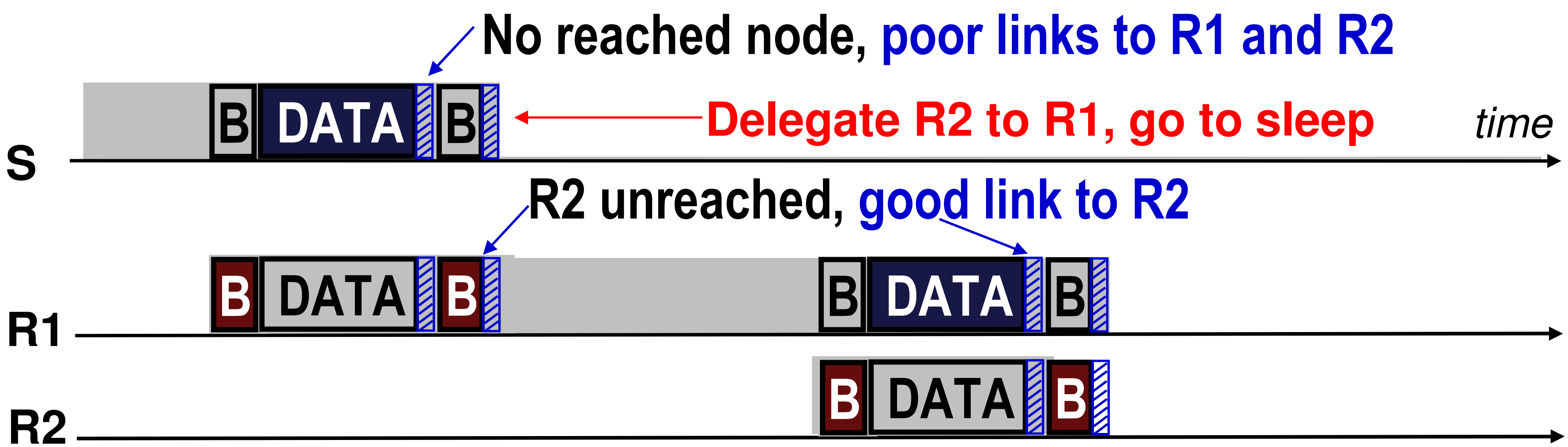
ADB: Link Quality Aware Delegation

- Add link quality into footers *
- Avoid transmission over poor links when possible



Assumptions of ADB

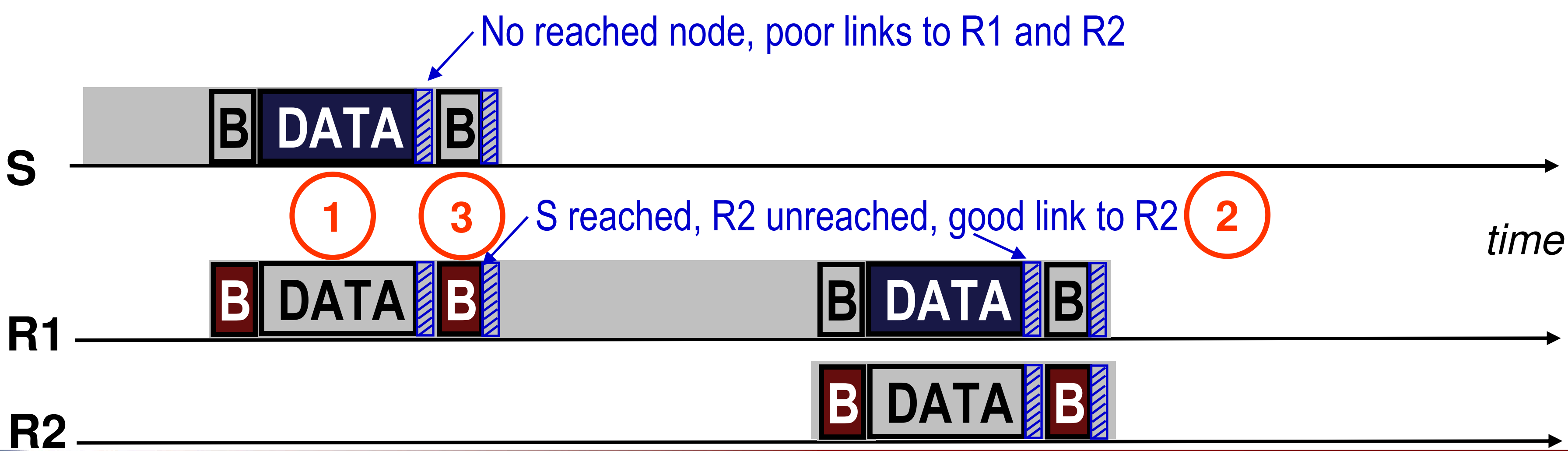
1. Direct neighbors
2. Link qualities



* E.g., four bit link estimation, STLE

Summary of ADB Features

1. Unicast with ARQ → higher reliability; learn progress
2. Dissemination of progress information → early sleep and less redundancy
3. Link quality aware delegation → less redundancy
4. No long occupation of the medium → shorter delivery latency
   Optimal latency in a collision- and error- free network, proved in the paper
5. No dependency on forwarding tree → broadcasts from any node



Encoding of ADB Control Information

- Use two-hop neighbor list build an ADB footer
- Length of a ADB footer is 3 bits × (# of direct neighbors of a sending node)
- Memory complexity $O(D^2)$, D is max node degree

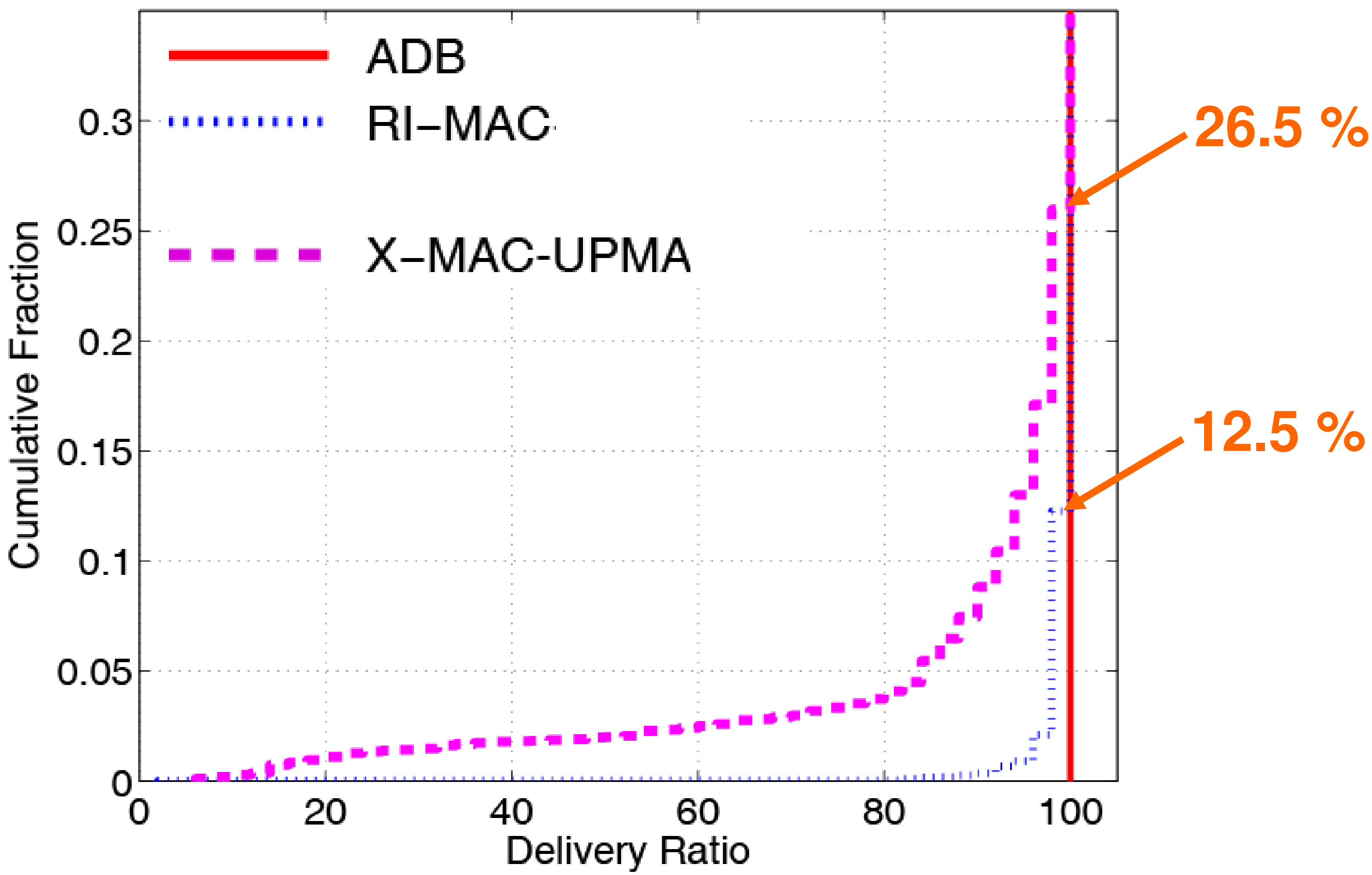
ADB Evaluation

- *ns-2* simulation-based evaluation
  - 100 random networks (50 nodes in 1km x 1km area)
    - Default ns-2 channel model
    - A new channel model with increased packet losses *(in the paper)*
- TinyOS-based implementation and evaluation on MICAz motes
  - A clique network *(in the paper)*
  - A 10-node “random” network

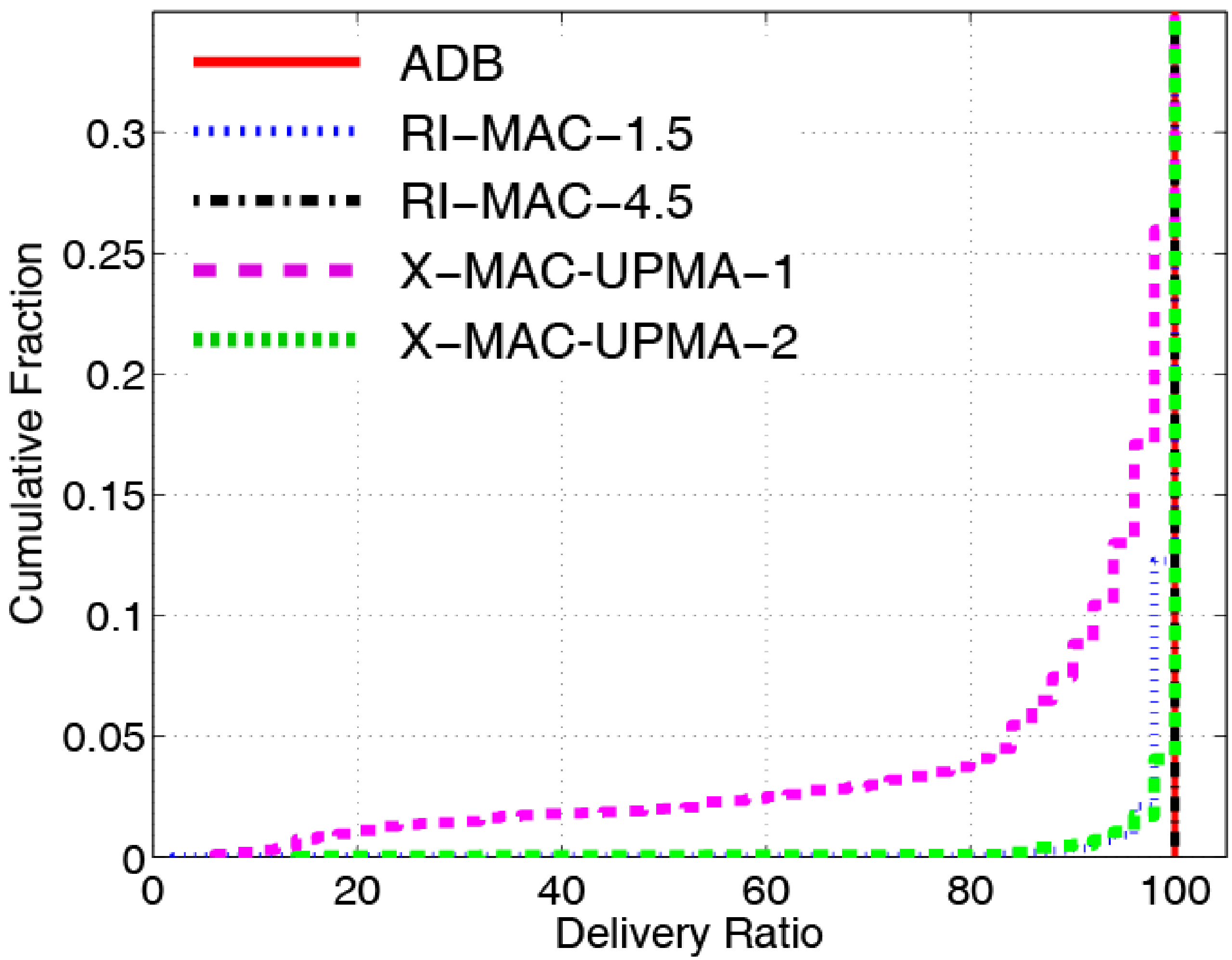
Evaluation Parameters

- 1-second average wakeup interval
- 28-byte DATA frames
- 3 bits for status of each node in a ADB footer
- A lightweight link quality estimation mechanism that takes advantage of the beacons used by RI-MAC
- Radio and MAC parameters from the UPMA paper and the RI-MAC paper
- Simulation-specific: 250 m transmission range and 550 m carrier sensing range (default ns-2 parameters)

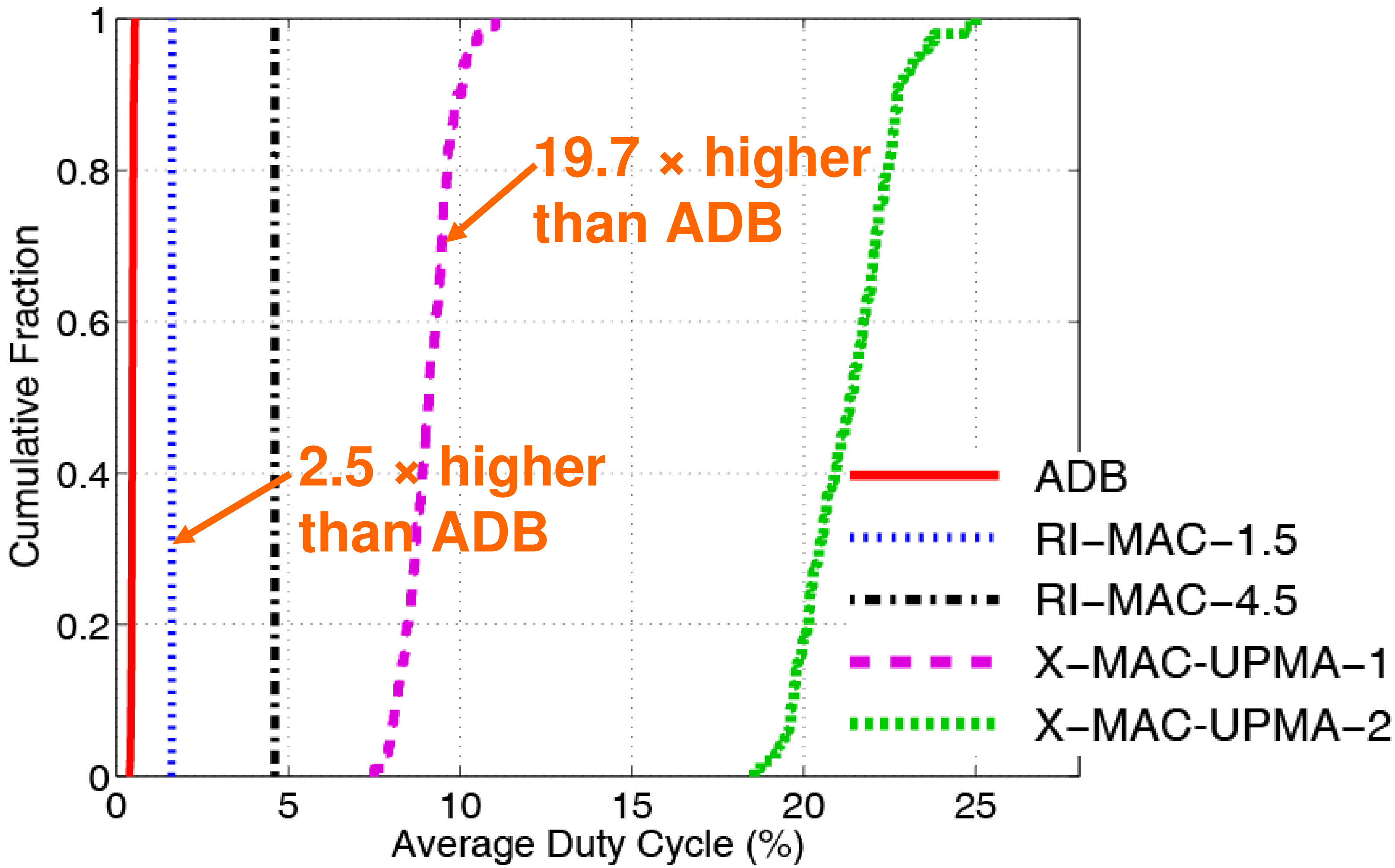
Delivery Ratios



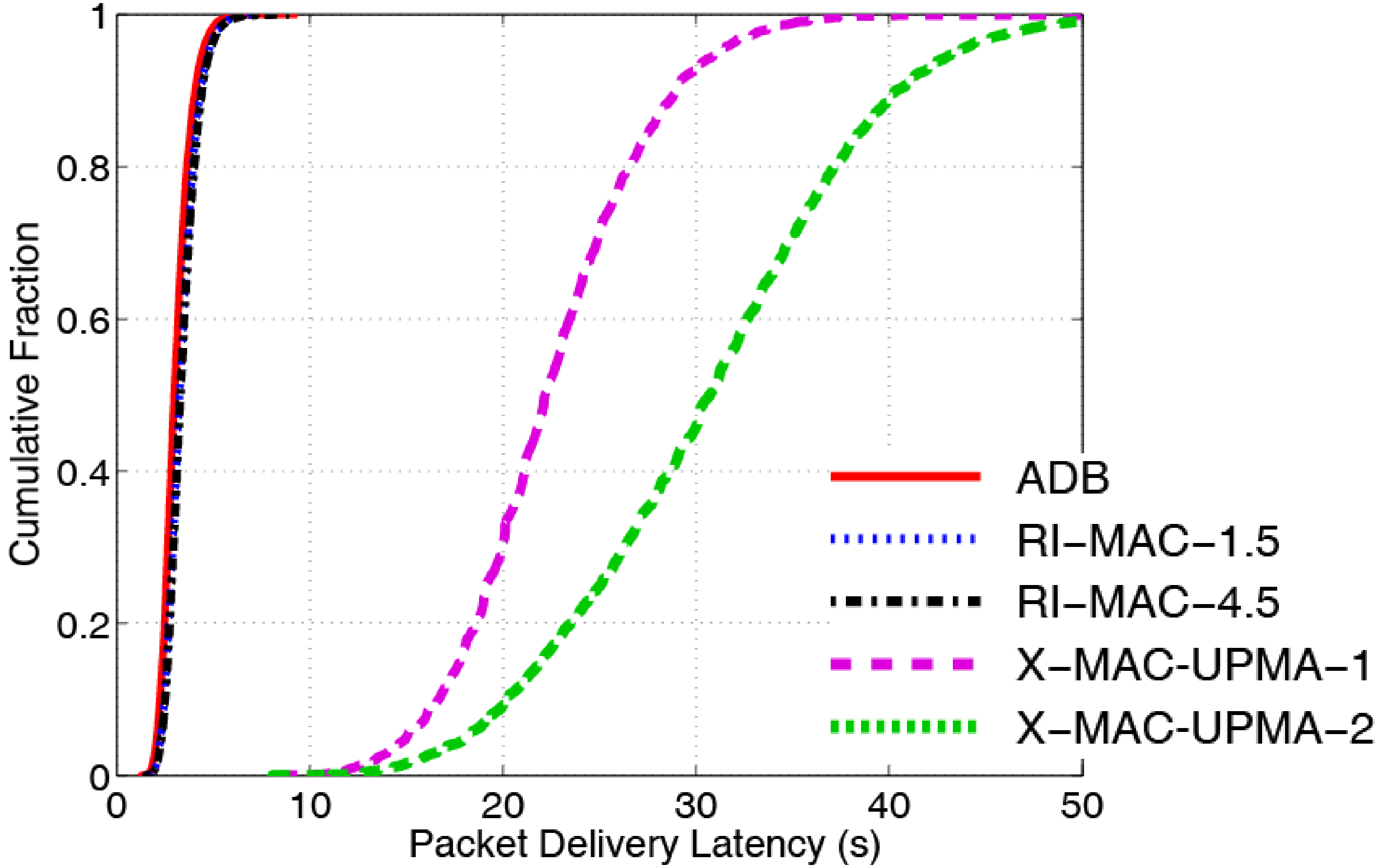
Delivery Ratios



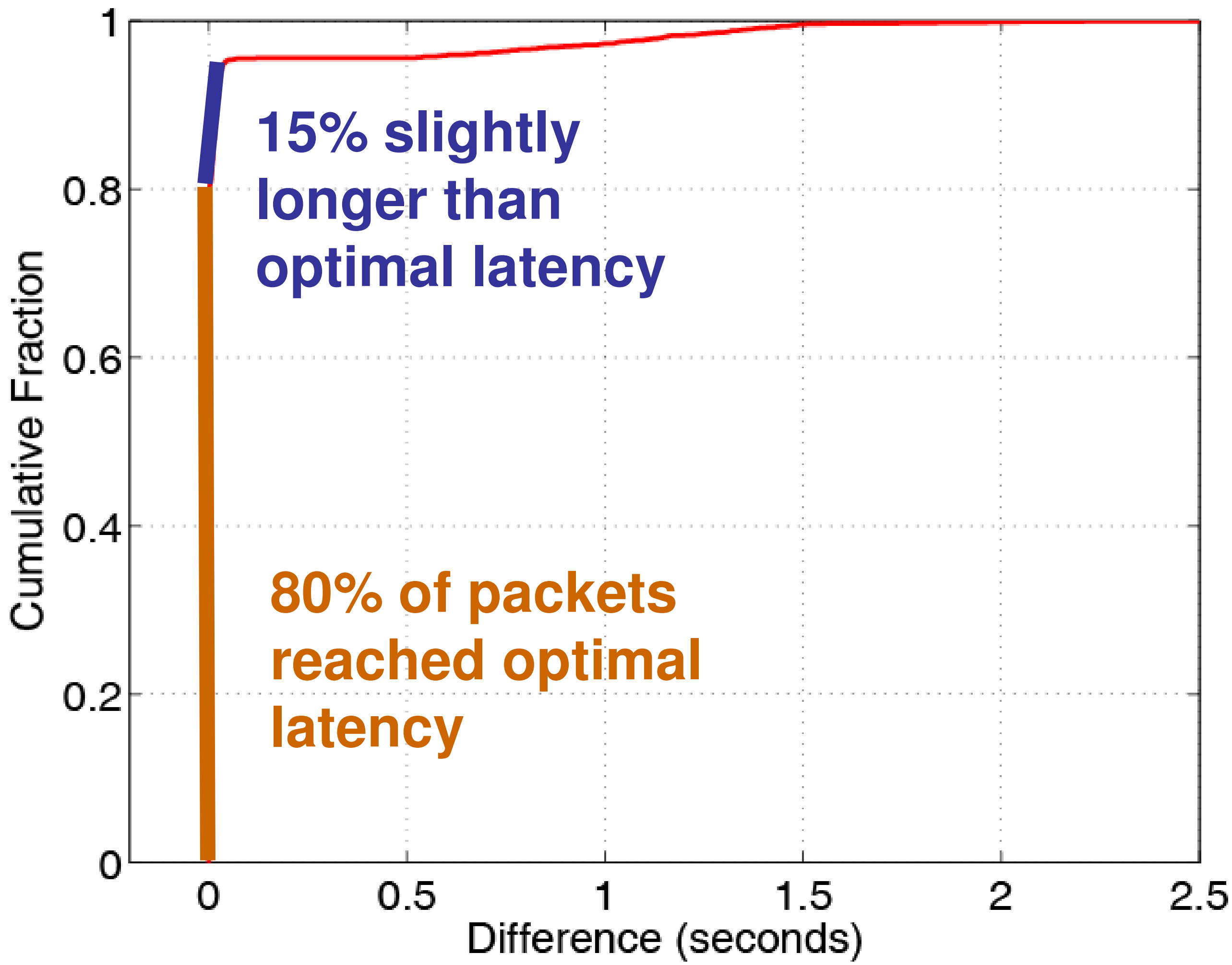
CDF of Average Duty Cycles



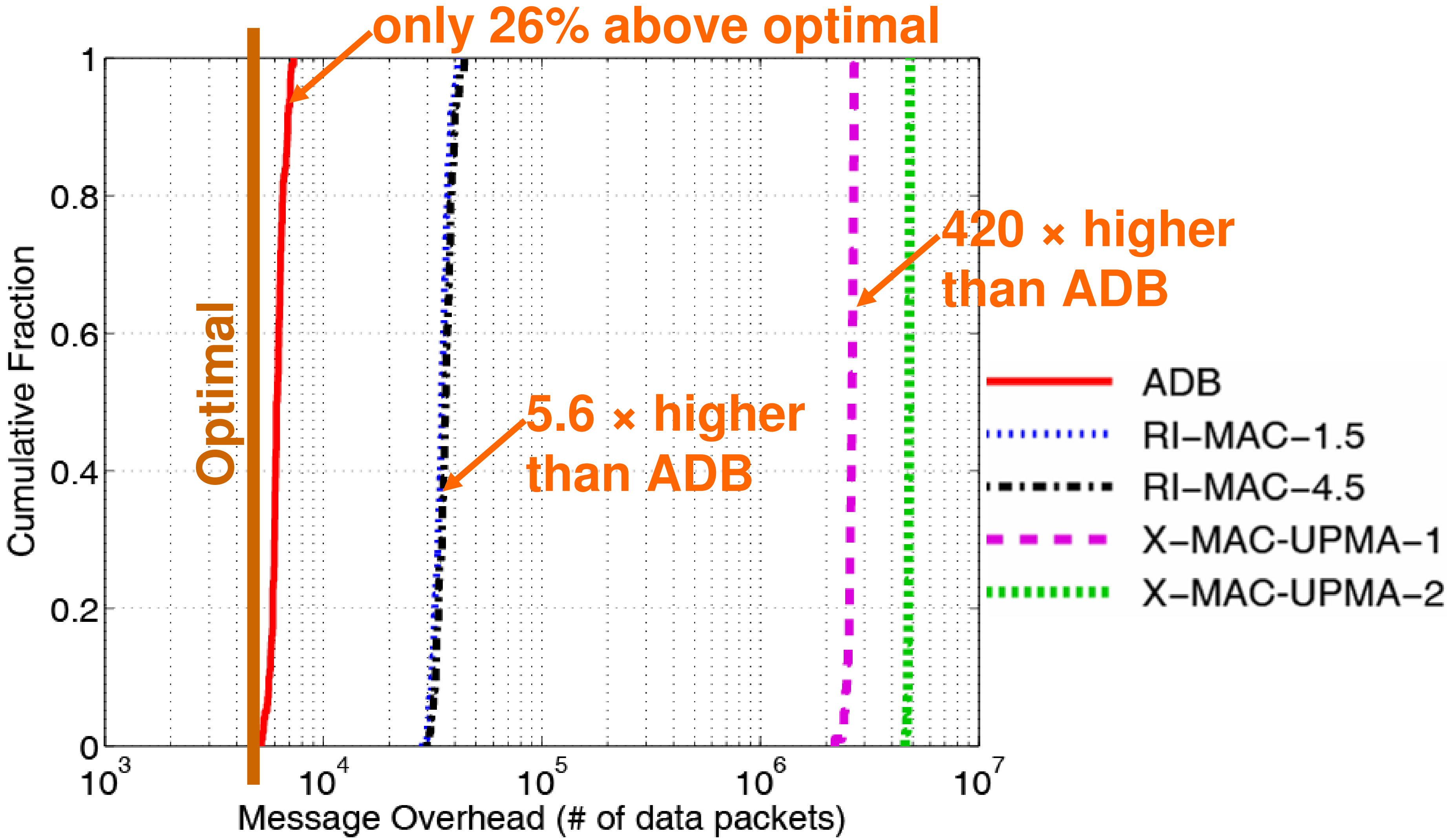
CDF of Packet Delivery Latency



How Close to Optimal Latency?

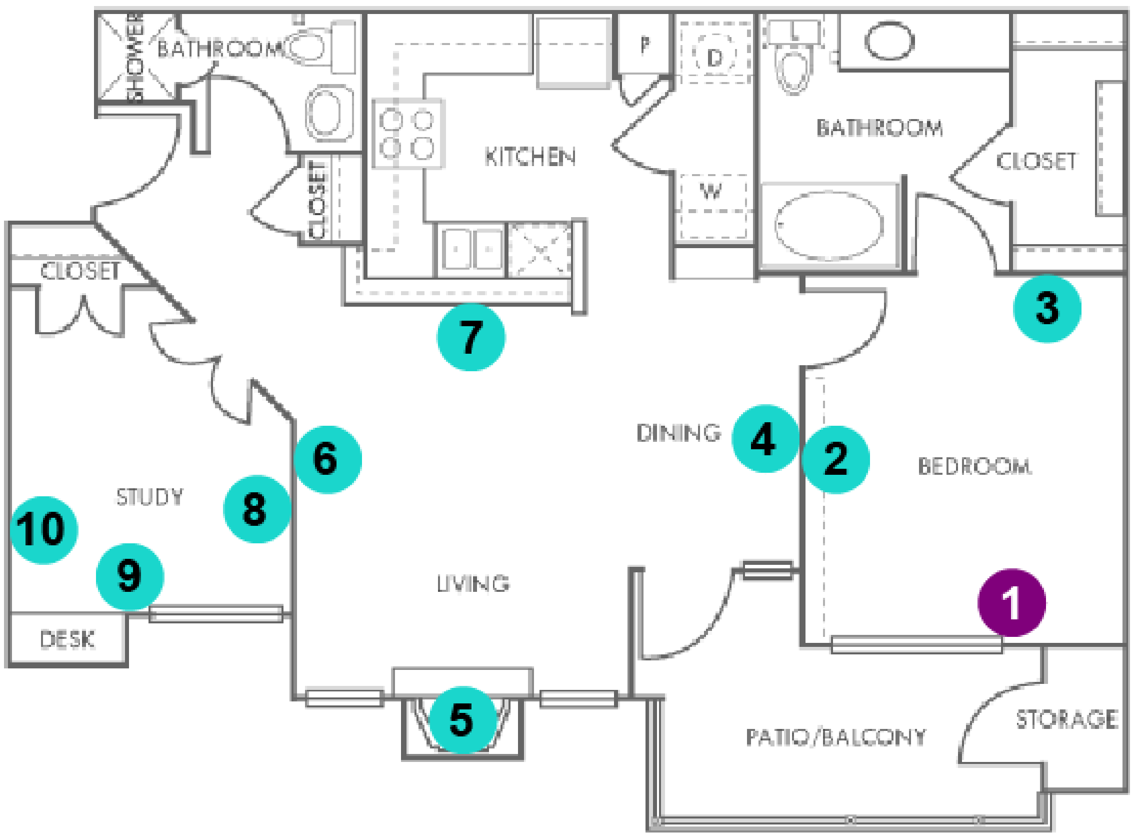


Message Overhead (# of Data Transmissions)



A "Random" Network: Nodes below Wall Power Outlets with Node 1 as Traffic Generator

- ADB implementation in TinyOS on MICAz motes
- 75 broadcasts generated with 20-second interval



Experimental Results

- Overall performance comparison

	X-MAC-UPMA	ADB
Average duty cycle (%)	27.00	2.77
Delivery ratio	99.47	99.47
Average latency (s)	0.71	0.64

- Duty cycles at each node

Node ID	1	2	3	4	5	6	7	8	9	10
X-MAC-UPMA	22.8	25.8	25.5	28.2	24.9	26.9	28.2	29.3	29.6	28.8
ADB	7.2	4.8	2.5	1.9	3.6	1.5	1.7	1.1	2.0	1.4

Other Related Work

- Existing Schemes are not Optimized for Asynchronous Duty Cycling
  - In wireless ad hoc and mesh networks: simple flooding, counter-based schemes, CDS based schemes, …
  - In wireless sensor networks: Trickle, Dip, RBP, …
- Work Focusing on Asynchronous Duty Cycling
  - F. Wang and J. Liu at ICC '08 and INFOCOM '09
    - Assuming future wake-up schedules of 2-hop neighbors
    - Only focused on scheduling, not clear on how to support unicast
  - S. Guo and et al. at MobiCom '09 (6 weeks ago)
    - Assuming future wake-up schedules of 1-hop neighbors
    - Assuming an energy-optimal tree

Conclusion

- ADB is a multihop broadcast protocol for asynchronous duty-cycling
  - Dissemination of progress information of the broadcast
  - Unicast-based broadcast with link quality-aware delegation
  - Supports broadcast from any node without knowing wakeup schedules of nodes
- Evaluated in *ns-2* and TinyOS/MICAz
  - Achieves close to optimal delivery latency
  - Shows lower duty cycle than flooding with X-MAC and with RI-MAC
  - Achieves greater than 99% delivery ratios