Design and Evaluation of a Versatile and Efficient Receiver-Initiated Link Layer for Low-Power Wireless

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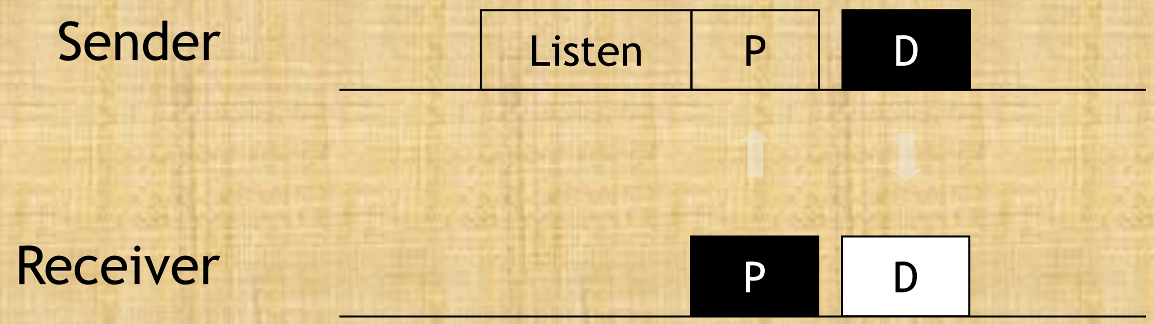
Outline

- Introduction
- A-MAC Design Overview
- Implementation Details
- Backcast Evaluation
- Macrobenchmark Evaluation
- Conclusions

Introduction

A receiver-initiated MAC



Benefits

- Handle hidden terminals better than sender-initiated ones
- Support asynchronous communication w/o long-preambles
- Support extremely low duty cycles or high data rates
- Support many low-power services
  - Wakeup
  - Discovery
  - Unicast
  - Broadcast
  - Pollcast
  - Anycast

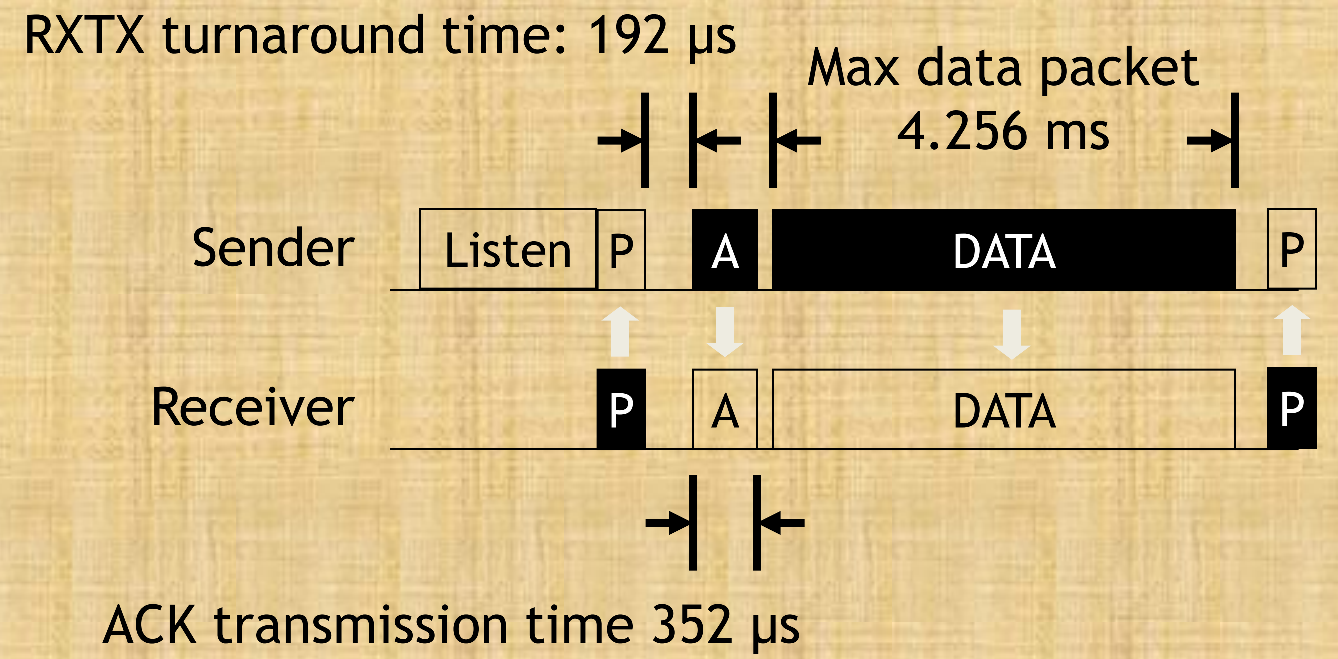
Drawbacks

- Probe (LPP) is more expensive than channel sample (LPL)
  - → Baseline power is higher
- Frequent probe transmissions
  - → Could congest channel & increase latency
  - → Could disrupt ongoing communications
  - → Channel usage scales with node density rather than traffic
- Services use incompatible probe semantics
  - → Makes concurrent use of services difficult
  - → Supporting multiple, incompatible probes increases power

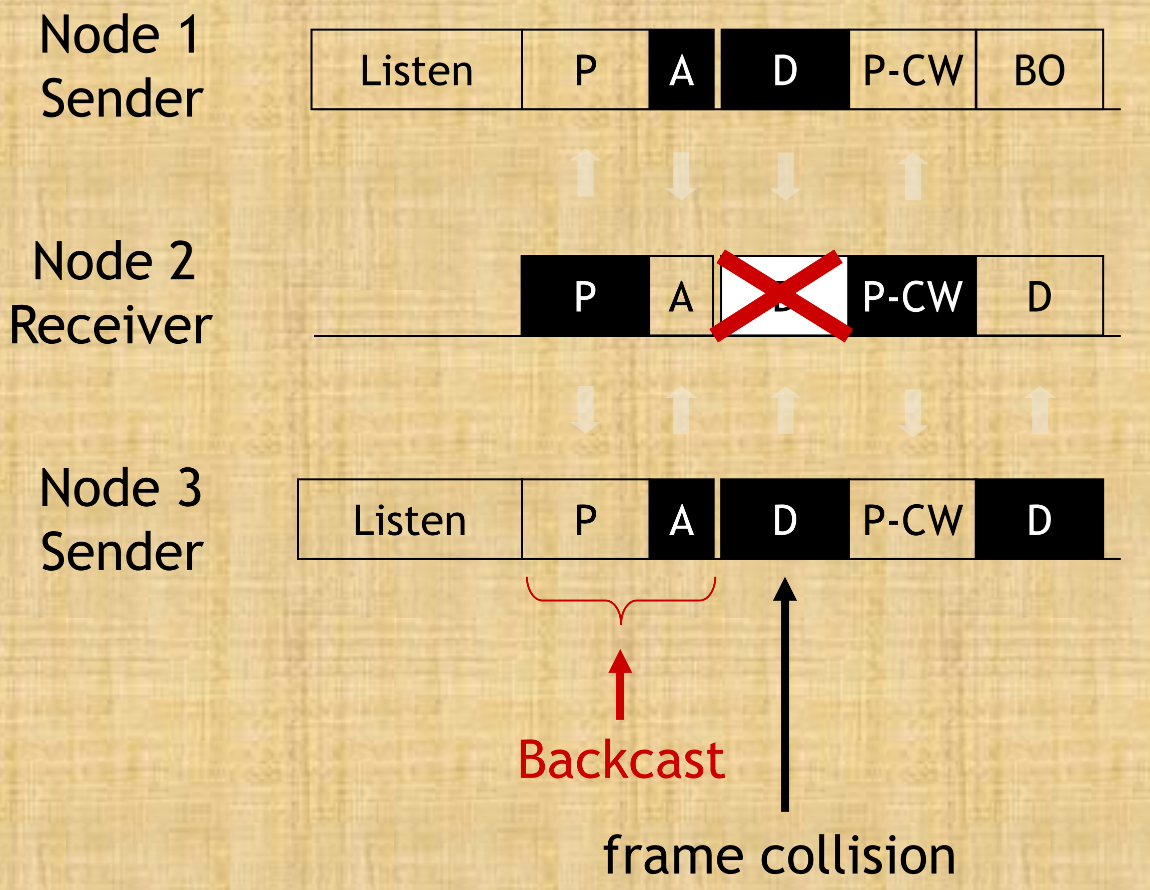
Is it possible to design a general-purpose, yet efficient, receiver-initiated link layer?

A-MAC Design Overview

A-MAC communication over 802.15.4



A-MAC's contention mechanism



A-MAC Communications

Benefits:

- Save energy:

(1)only has to wait marginally longer than the radio's RX/TX turnaround time;
(2)IEEE 802.15.4 standard, a turnaround occurs in 192 *µs, nearly 20 times faster than the 3.75 ms beacon-data* turnaround time that **RI-MAC** requires with its software based protocol processing

- Distinguish between collisions and interference

Therefore, A-MAC is far less susceptible to interference based false alarms than either LPL or RI-MAC.

Implementation Details

Problems

- Overreacting:

  -a sender will auto-ack *every probe it receives,* including probes from neighbors for which the sender has no pending traffic.

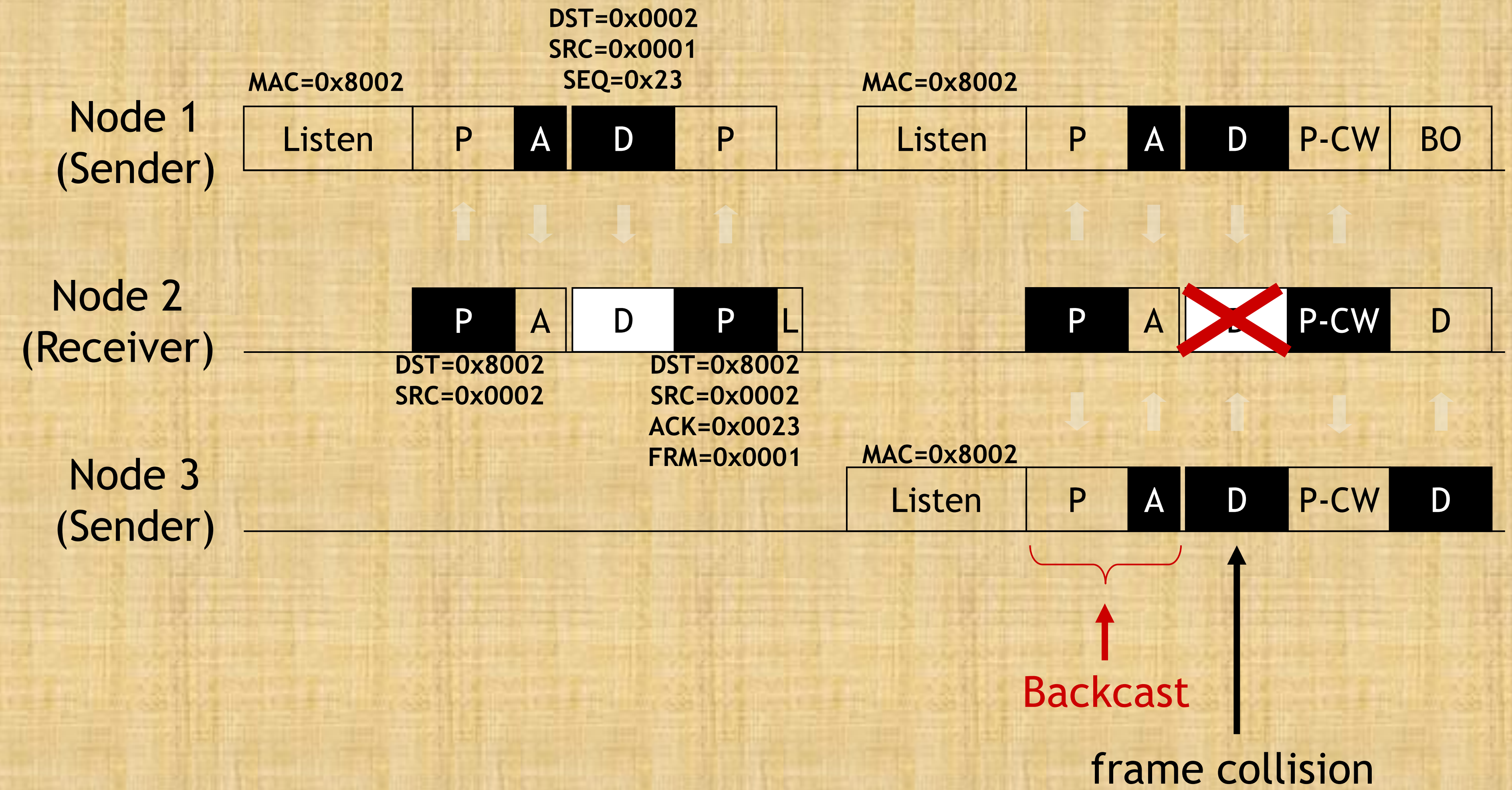
- Against Standards

  -the IEEE 802.15.4-2006 standard specifically prohibits this behavior, any frame that is broadcast shall be sent with its Acknowledgment Request subfield set to zero.

- Mixed radio support

  - because this behavior is prohibited, it enjoys somewhat mixed radio support: while the CC2420 [34] radio and AT86RF230 [3] radio Rev A silicon both support broadcast auto-acks, the Rev B silicon "fixes" this standards non-compliance and does not auto-ack broadcast frames.

Unicast Communications



Broadcast Communications

- Broadcast Communications
  - A-MAC broadcast design is identical to Unicast, with an important diference: sender disables hardware address recognition but keeps hardware auto-acks enabled
  - In this way, sender will auto-ack every probe it receives and it will send the data packet like in the unicast case

Backcast Evaluation

Methodology

Two important metrics:

•***Received signal strength indicator (RSSI)***

Signal strength, measured by the radio over the first eight symbols of an acknowledgment (ACK) frame

•***Signal quality (LQI)***

measured by the radio over the first eight symbols and is reported as a 7-bit unsigned integer that can be viewed as the average correlation value or chip error rate (***values near 100 indicate an excellent link***).

Large scale performance

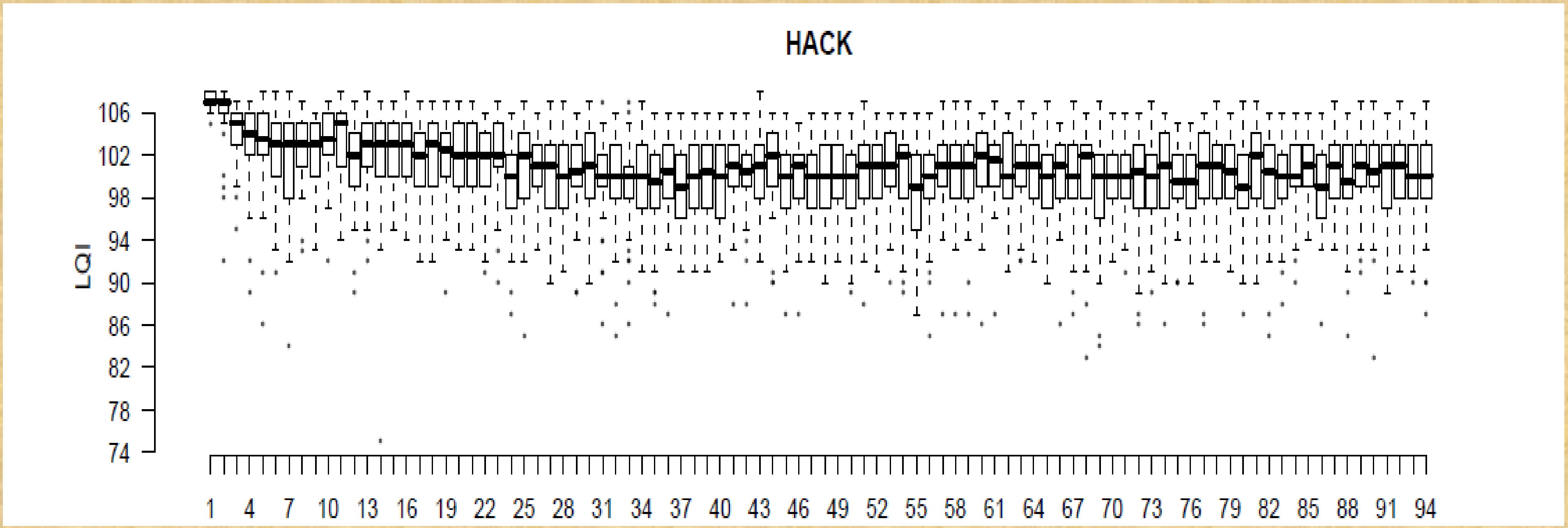


Figure 7. The effect on LQI as the number of concurrent ACKs increases from 0 to 94 in a typical indoor deployment setting. The median value of LQI falls quickly for the first six nodes and then falls slowly. Beyond approximately 30 nodes, the LQI values stabilize at approximately 100. The data suggest that even in the presence of a large number of ACK collisions, the receiver can successfully decode the ACK frame. Note the y-axis ranges from 74 to 106.

Conclusion: The statistical superposition of an increasing number of signals does not lead to destructive interference, making backcast a robust synchronization primitive.

Robustness to External Interference

Primitive Operation	w/o 802.11 interference	w/ 802.11 interference	Increase in Current
TinyOS LPL	175 μA	3,030 μA	17.3×
RI-MAC LPP	383 μA	12,576 μA	54.7×
A-MAC LPP	206 μA	230 μA	1.12×

Table 1. The effect of interference on idle listening current in an office environment using three different synchronization schemes

Robustness to External Interference

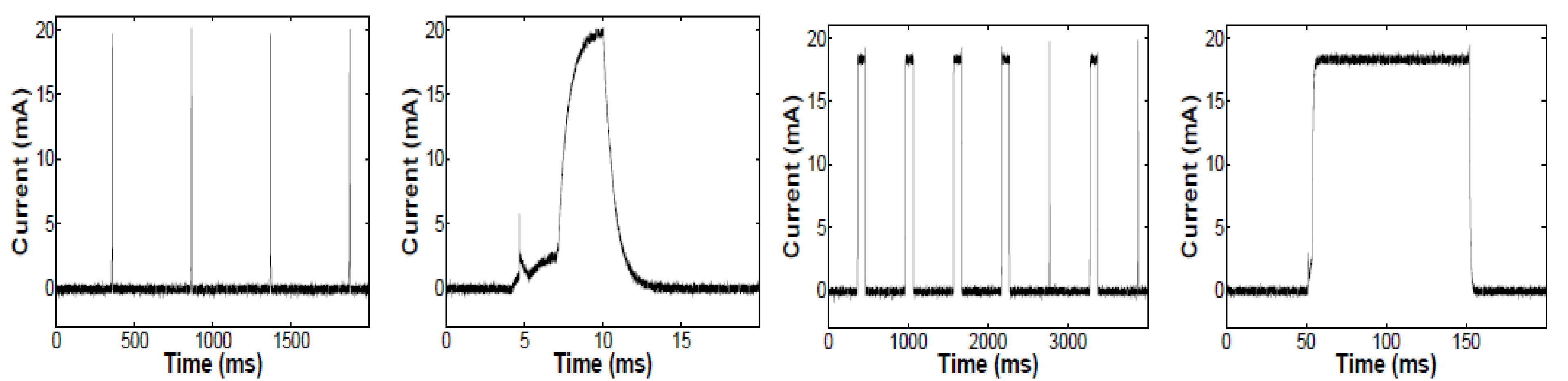


Figure 10. LPL preamble sampling techniques leave receivers susceptible to noisy wireless environments, such as those caused by 802.11 interference.
Figures (a) and (b) show the macroscopic and microscopic behavior of the TinyOS 2.1sampling algorithm when the channel is clear: the receiver immediately returns to sleep. Figures (c) and (d) show the macroscopic and microscopic behavior while a file transfer is in progress using a nearby 802.11 access point. Of the seven channel samples visible in this trace, five are unnecessarily lengthened due to channel noise.

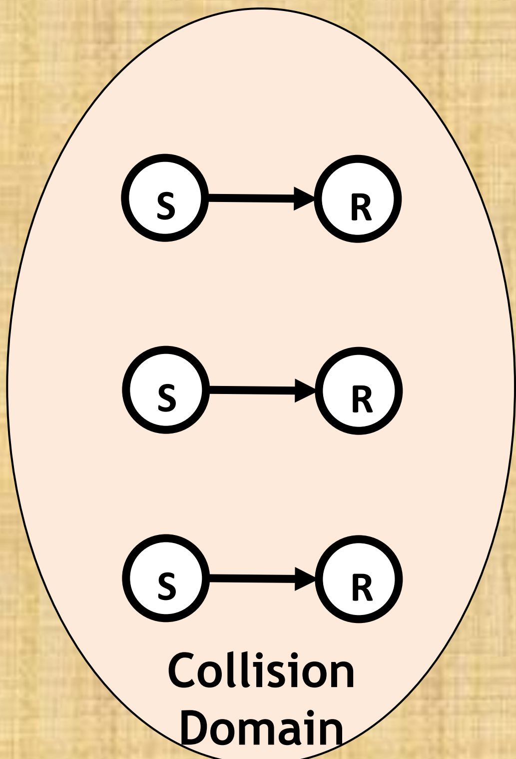
Macrobenchmark Evaluation

Multiple Contending Unicast Flows

MAC	No. of Senders	Packet Delivery Ratio		
		Avg	Min	Max
RI-MAC	1	99.9%	—	—
	2	97.5%	97.3%	97.7%
	3	95.6%	95.0%	96.8%
	4	90.7%	90.3%	90.9%
A-MAC	1	99.9%	—	—
	2	99.3%	98.2%	100%
	3	99.3%	98.3%	99.5%
	4	98.5%	96.7%	99.5%

Table 2 shows between one and four senders contending to transmit to *a single receiver* for both RI-MAC and A-MAC.

Multiple Parallel Unicast Flows



WL	Tx:Rx	Probe	Pkt/s	# Pkts	Time	PDR
3	1:1	512	48.4	8010	164 s	100%
3	1:1	128	71.9	8056	112 s	100%
3	2:2	128	78.7	5982	76 s	99.2%
			78.9	5365	68 s	99.4%
1	2:2	128	27.8	1895	68 s	98.9%
			58.9	3535	60 s	99.9%
6	2:2	128	74.7	5975	80 s	99.2%
			77.0	6007	78 s	99.3%
6	3:3	128	88.9	4912	60 s	99.3%
			80.7	4834	60 s	99.3%
			85.0	5098	60 s	99.4%
1	3:3	128	22.1	1324	60 s	97.0%
			30.8	1845	60 s	98.3%
			36.5	2219	59 s	99.3%

Table 3 shows **A-MAC throughput and packet delivery ratio** as a function of the **number of different whitelisted channels** that are available for use, the **number of sender:receiver pairs** transferring data concurrently, and the receivers' **probe interval**.

Asynchronous Network Wakeup

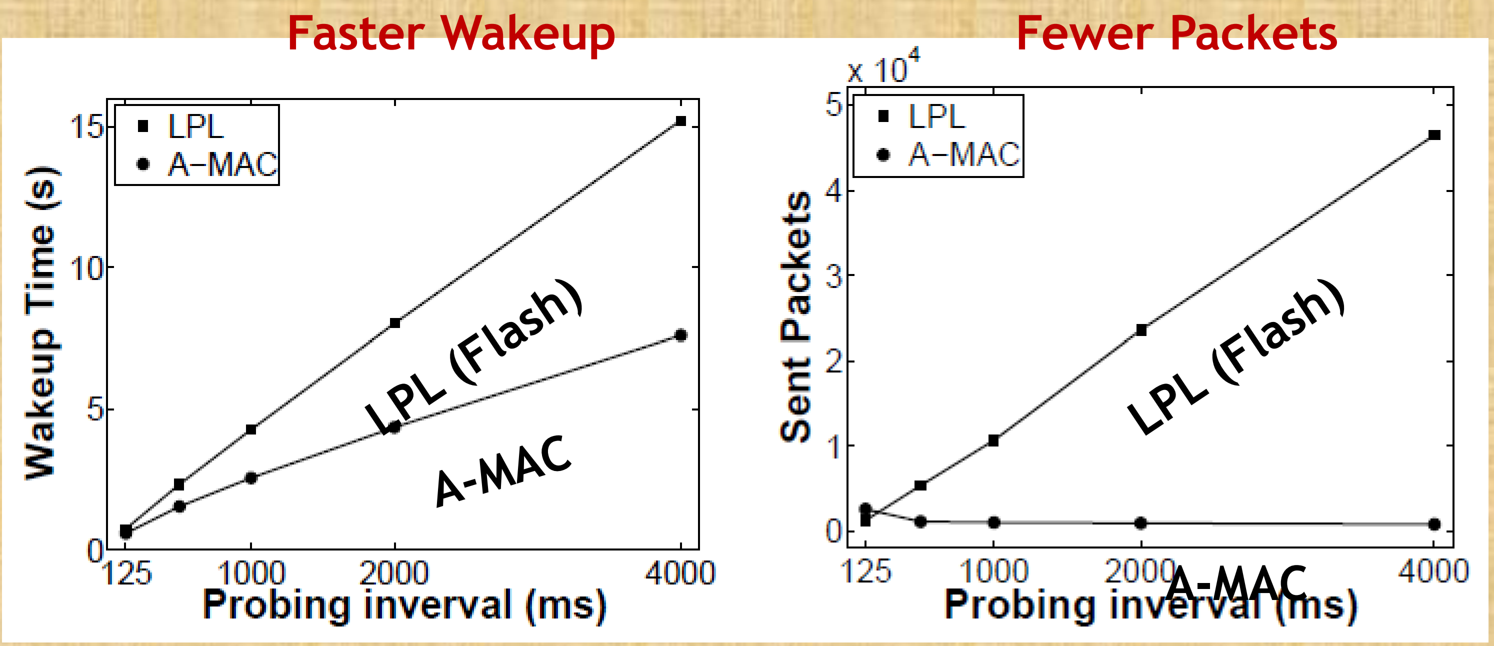


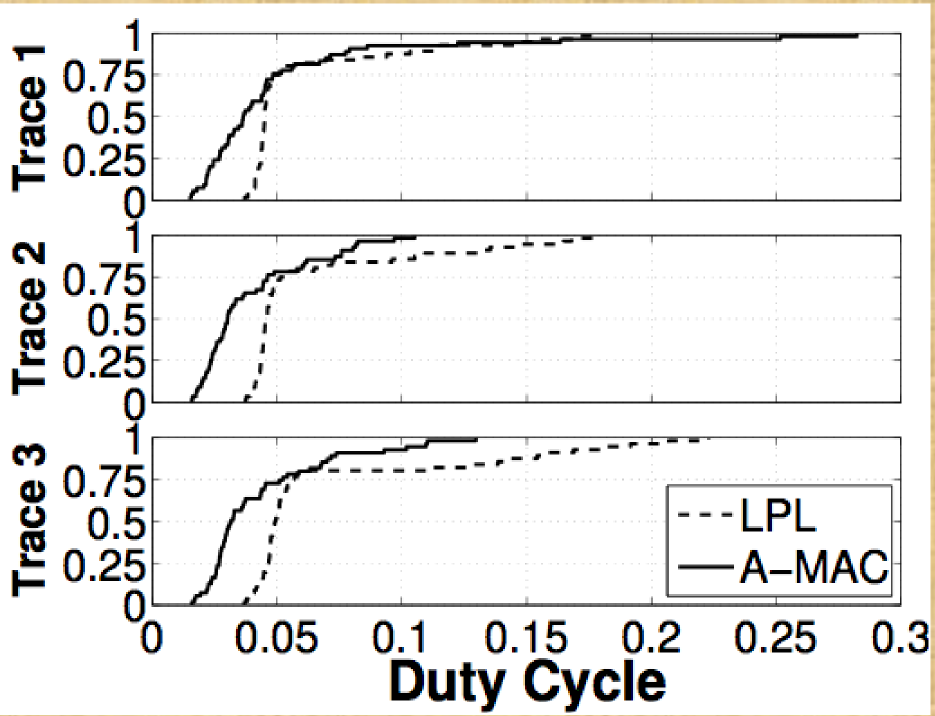
Figure 11 shows the wakeup times of 59 nodes in a multihop testbed across a range of sampling/probing intervals.

Collection Tree Protocol Performance

N = 59 T_{data} = 60 s T_{probe} = 500 ms

	LPL	A-MAC
Average Duty Cycle	6.36%	4.44%
Average Packet Delivery Ratio	95.1%	99.7%
Average Hop Count	7.34	4.85
Maximum Hop Count	14	13

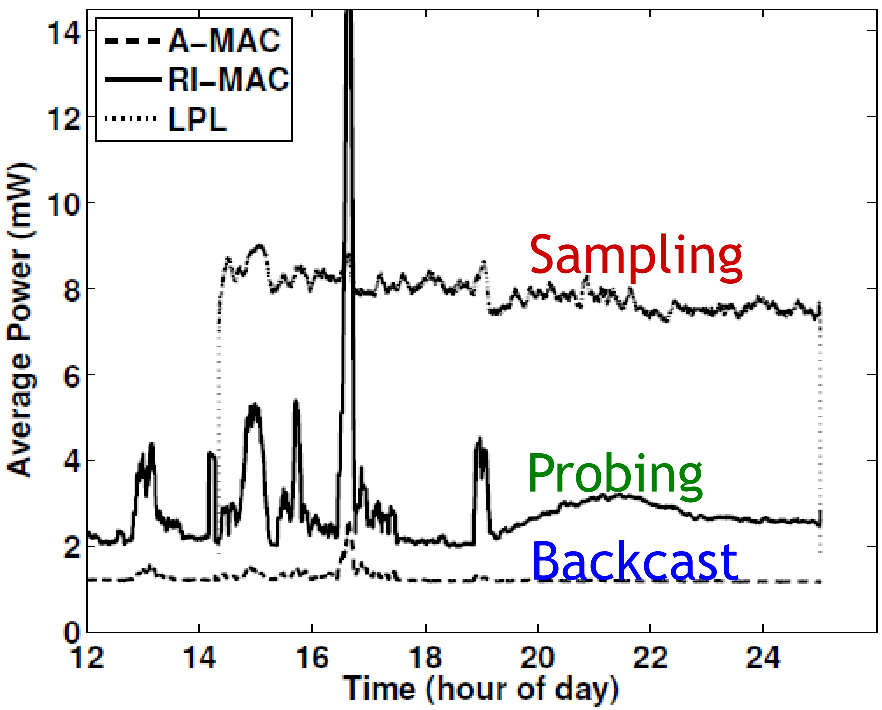
Table 4. CTP performance over LPL and A-MAC.



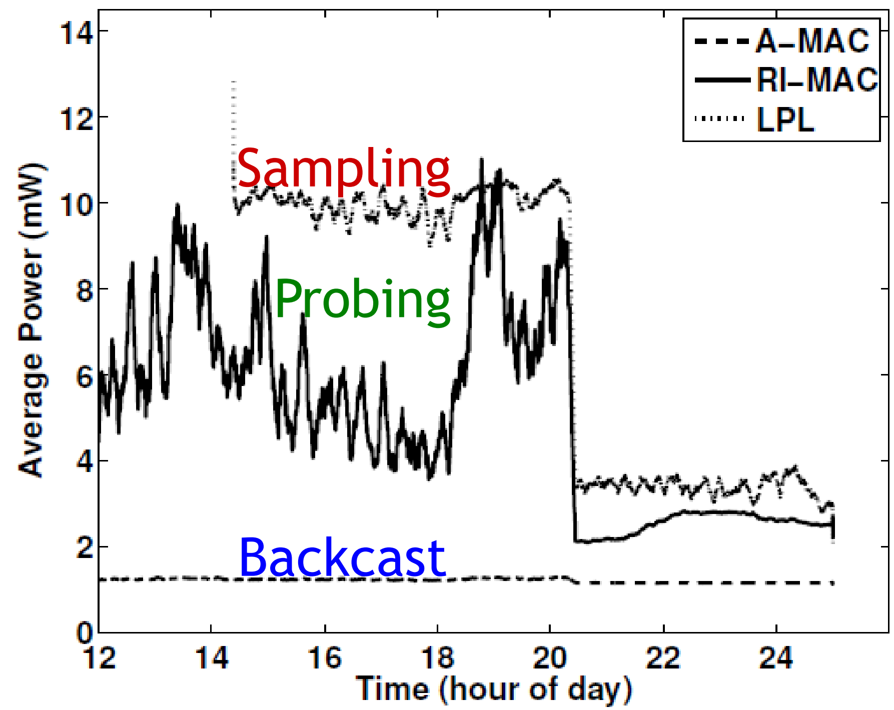
(a) CDF of CTP Duty Cycles

Inference Vulnerability

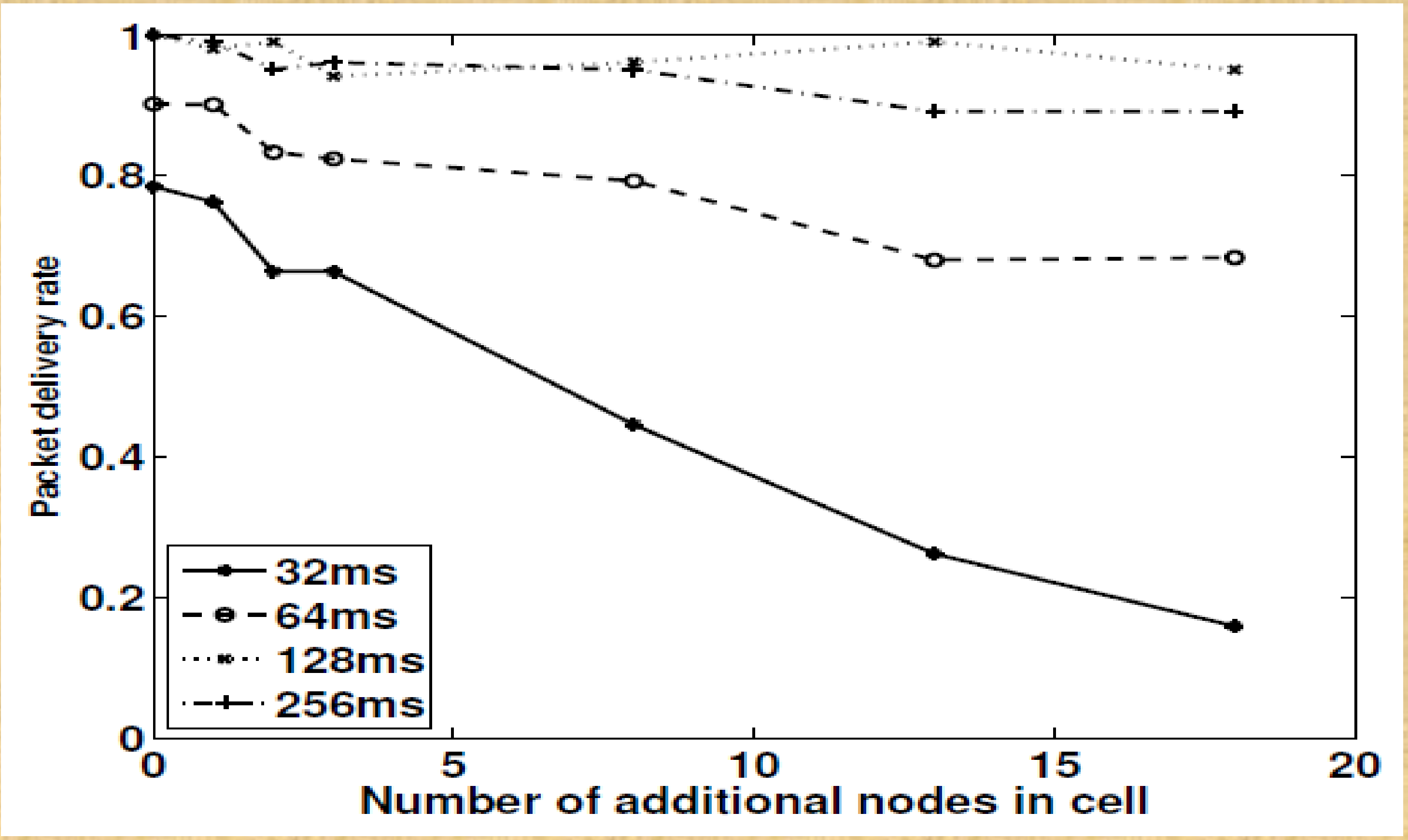
Channel 18



Channel 26



Effect of Density on Packet Delivery



Same collision domain (between 0, 1, 2, 3, 8, 13, and 18) who simply transmit probes with varying probe periods (32 ms, 64 ms, 128 ms, and 256 ms)

Conclusion

- Backcast provides a new synchronization primitive
  - Common abstraction underlying many protocols
  - Can be implemented using a DATA/ACK frame exchange
  - Works even with a 8, 12, 94 colliding ACK frames
  - Faster, more efficient, and more robust than LPL, LPP
- A-MAC augments Backcast to implement
  - Unicast
  - Broadcast
  - Network wakeup
  - Robust pollcast
- Results show
  - Higher packet delivery ratios
  - Lower duty cycles
  - Better throughput (and min/max fairness)
  - Faster network wakeup
  - Higher channel efficiency

Thank you
Questions？