Low Power Wireless System

18-452/750 Wireless Networks and Applications

Survey presentation

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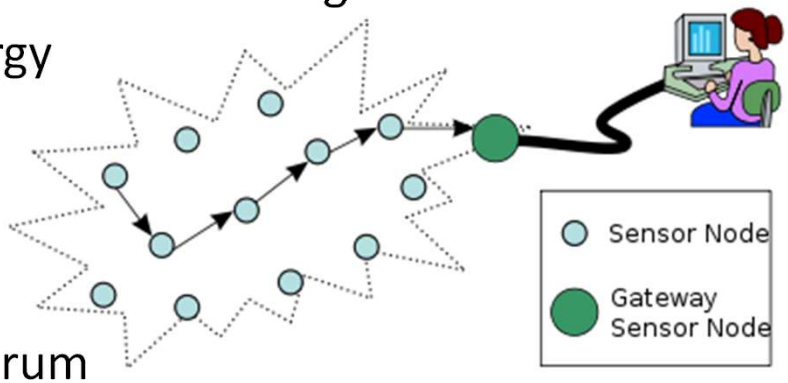
Outline

- Background
  - ✓ Importance, challenges, LPP and LCP
- B-MAC
  - ✓ J. Polastre et al, Versatile Low Power Media Access for Wireless Sensor Networks (2004)
- Koala
  - ✓ R. Musaloiu-E et al, Koala: Ultra-Low Power Data Retrieval in Wireless Sensor Networks (2008)
- A-MAC
  - ✓ P. Dutta et al, Design and Evaluation of a Versatile and Efficient Receiver-Initiated Link Layer for Low-Power Wireless (2010)
- Opinion on these papers

Background (recap from lectures)

- Low power wireless communication draws attention in IoT era
  -> Trend: more general purpose, large scale
  - ✓ A lot of wireless sensors -> ex) environment monitoring
  - ✓ Reliable communication while low energy
  - ✓ Easy to deploy and maintain



- Challenges / Design Issue
  - ✓ Low cost – Hardware, Unlicensed Spectrum
  - ✓ Power Management – Energy Efficiency, Routing Protocol
  - ✓ MAC Protocol
  - ✓ Data collection – Aggregate packets, Delay Torelant
  - ✓ Reliability
  - ✓ Scalability

Picture from:
https://ja.wikipedia.org/wiki/%E3%82%BB%E3%83%B3%E3%82%B5%E3%83%8D%E3%83%83%E3%83%88%E3%83%AF%E3%83%BC%E3%82%AF#/media/%E3%83%95%E3%82%A1%E3%82%A4%E3%83%AB:WSN.svg

Quick Overview of Protocols

Protocol	Priority	MAC Type	Initiative
B-MAC (2004)	Energy	CSMA	Sender
Koala (2008)	Energy	CSMA	Receiver
A-MAC (2010)	Energy	CSMA	Receiver
S-MAC (2002)	Energy	CSMA	Sender
DSMAC (2004)	Latency	CSMA	-------
TRAMA (2003)	Energy	TDMA	-------
TRACE (2003)	Energy	TDMA	-------

TDMA	CSMA
Strict Sync	Flexible Sync
Controlled Access	Random Access
High Channel Utilization under high contentions	High Channel Utilization under low contentions
Need Central Control	Decentralized

- Priority: Generally Energy
- More CSMA
- Receiver initiative protocol draws attention these days because it treats hidden terminal problem well

M. Dener et al, Medium Access Control Protocols For Wireless Sensor Networks: literature Survey (2012)

B-MAC

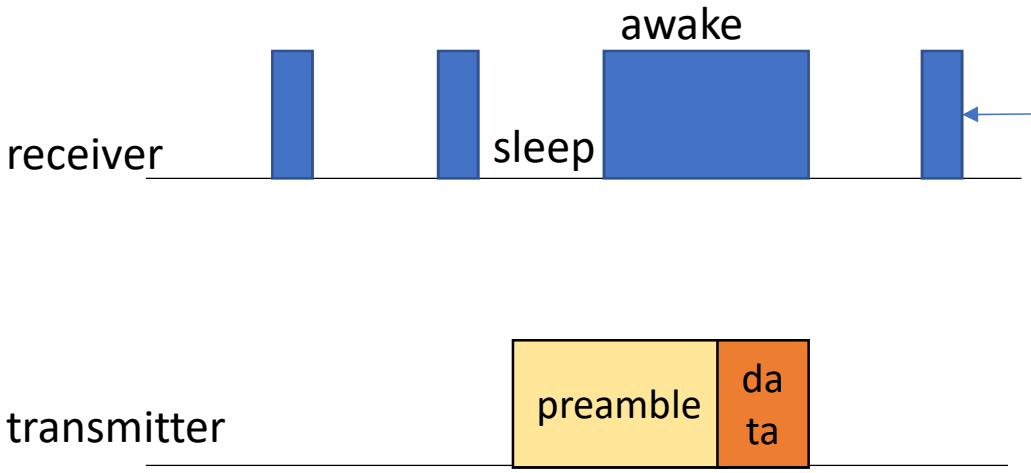
- Big issue for low power: idle listening
- Listening without data is the same as receiving data

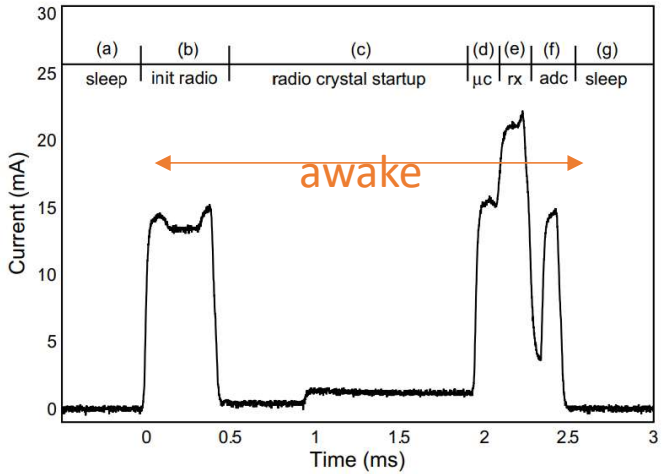
- Solution? Turn the node on and off

B-MAC

- On/Off cycle with Low Power Listening
  - ✓If a signal comes in during the awake cycle, keep being awake
  - ✓ Preamble must be longer than sleep cycle duration
  - ✓ No RTS/CTS
  - ✓ Single application on a node
  - ✓ Apply noise floor estimation

(Same picture from the lecture)

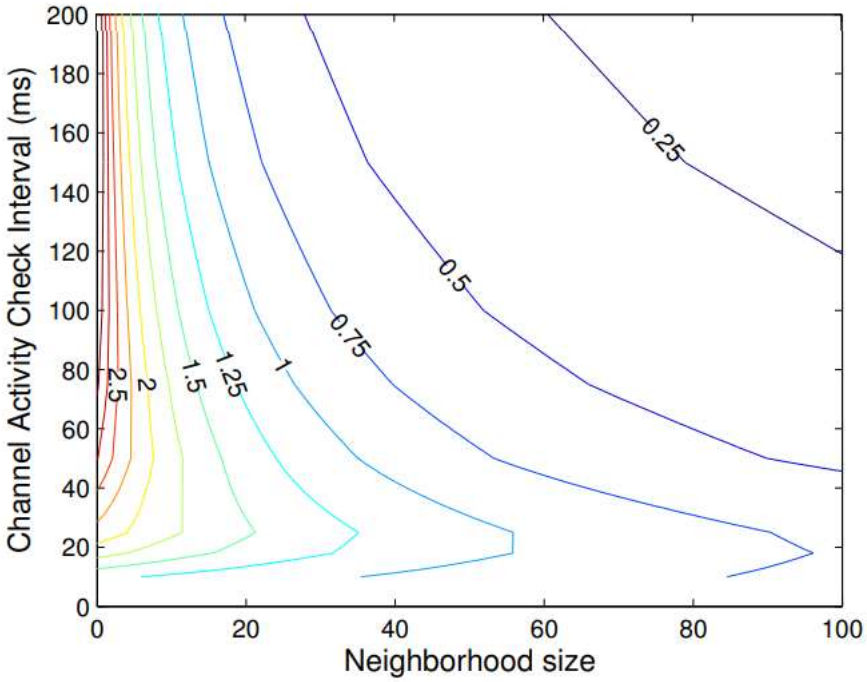




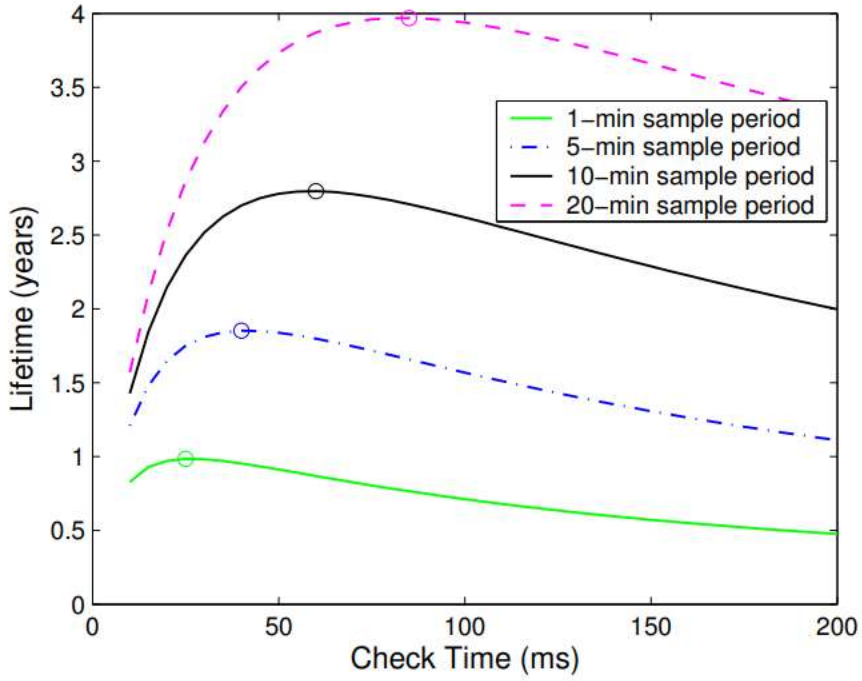
Operation	Time (s)		I (mA)	
Initialize radio (b)	350E-6	$t_{r_{init}}$	6	$c_{r_{init}}$
Turn on radio (c)	1.5E-3	$t_{r_{on}}$	1	$c_{r_{on}}$
Switch to RX/TX (d)	250E-6	$t_{rx/tx}$	15	$c_{rx/tx}$
Time to sample radio (e)	350E-6	t_{sr}	15	c_{sr}
Evaluate radio sample (f)	100E-6	t_{ev}	6	c_{ev}
Receive 1 byte	416E-6	t_{rxb}	15	c_{rxb}
Transmit 1 byte	416E-6	t_{txb}	20	c_{txb}
Sample sensors	1.1	t_{data}	20	c_{data}

B-MAC

- Lifetime depends on Neighborhood size, Check interval, Traffic
  - ✓ Calculated Lifetime is as follows:



Contour of node lifetime based on LPL check time and network density



Lifetime of each node based on sample period and check time

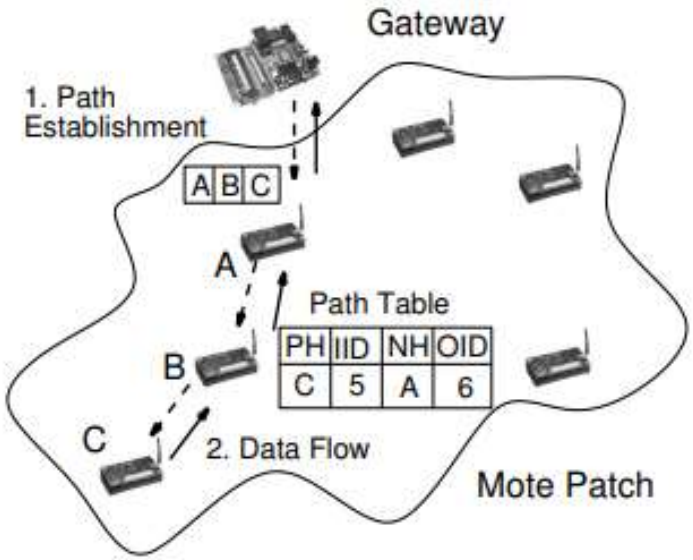
B-MAC

- Microbenchmark analysis
  - ✓ How correct is the previous life expectancy ?
  - ✓ Experiment: average neighbors=5
  - ✓ Depends on configuration, but generally between 0.7 ~1.5 years

- Comments on B-MAC
  - ✓ For small network, B-MAC works very well both in throughput and energy consumption
  - ✓ However, for larger network, the advantage disappears
  - ✓ Overall, MAC protocol is crucial factor for low energy network

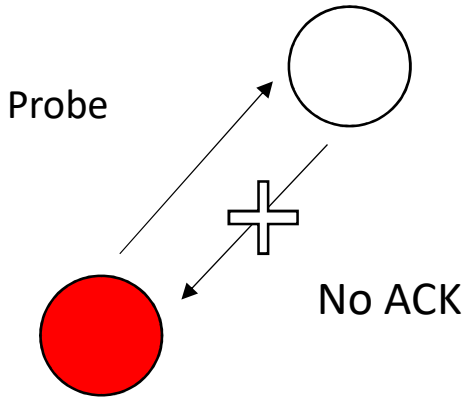
Koala

- System designed for Long Term Environmental Monitoring
  - ✓ Primary requirement: energy efficiency, large scale
- Flexible Control Protocol (FCP)
  - ✓ Protocol to install routing paths
  - ✓ Assume multi-hop transmission
  - ✓ Calculate path at Gateway, and give paths to each node

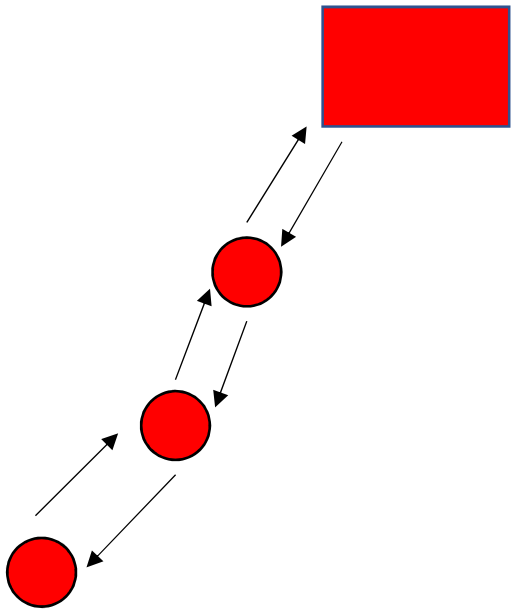


Koala

- Low Power Probing (LPP)



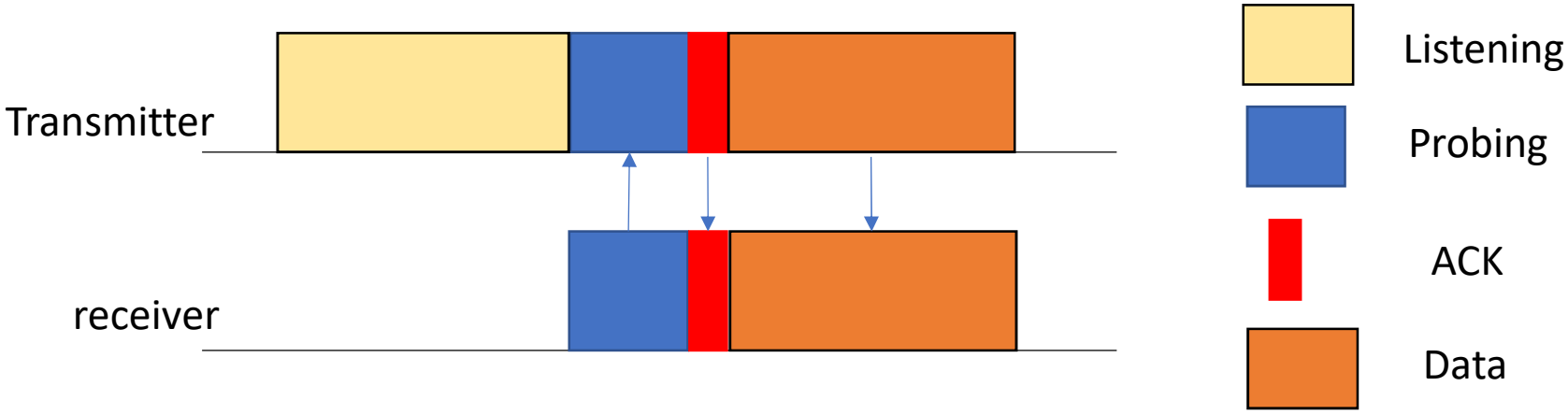
Node goes back to sleep



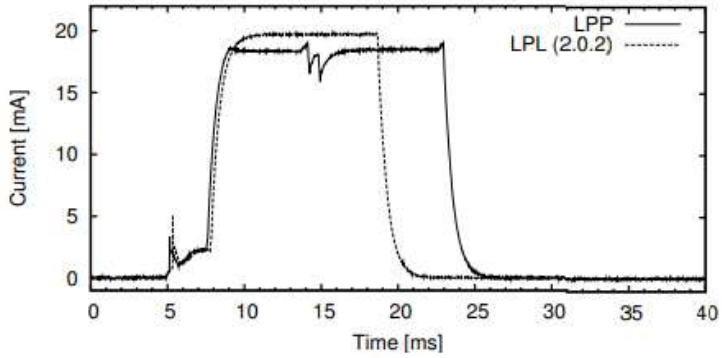
Node joins the active chain

Koala

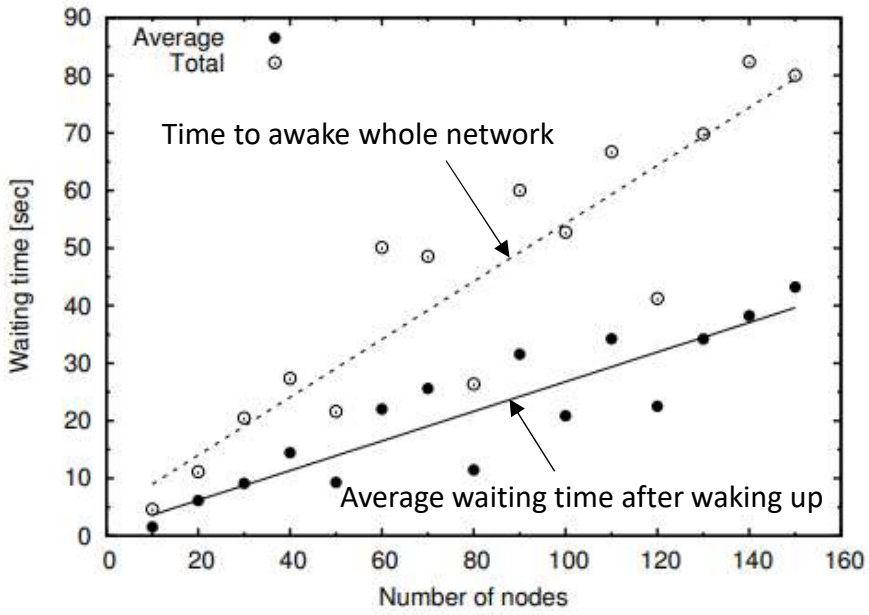
- Low Power Probing (LPP)
  - ✓ Design choice between LPP and Low Power Listening (LPL, B-MAC)
    - — LPL is designed for waking up individual node
    - — Large Scale Network requires the whole system to wake
  - ✓ Protocol
    - — Transmitter starts listening to the channel
    - — Receiver sends Probing signal, and Transmitter detects
    - — Transmit ACK and then send data

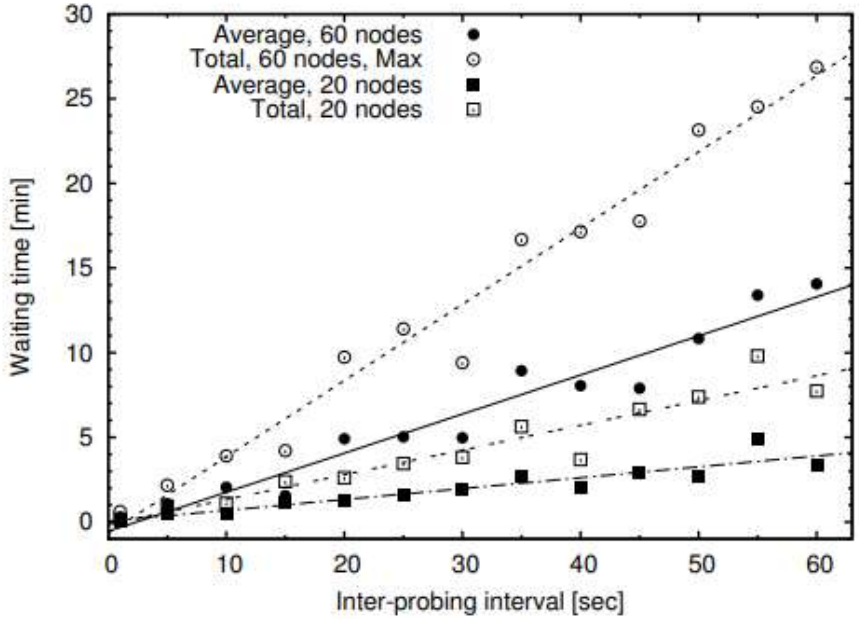


Koala



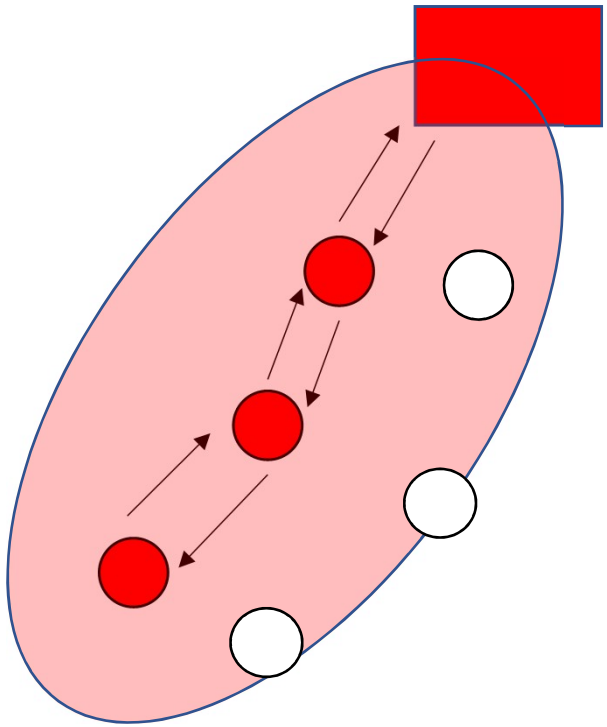
- Evaluation
  - ✓LPP analysis
    - —Energy Consumption: 32% more expensive than LPT
  - ✓Wake up performance





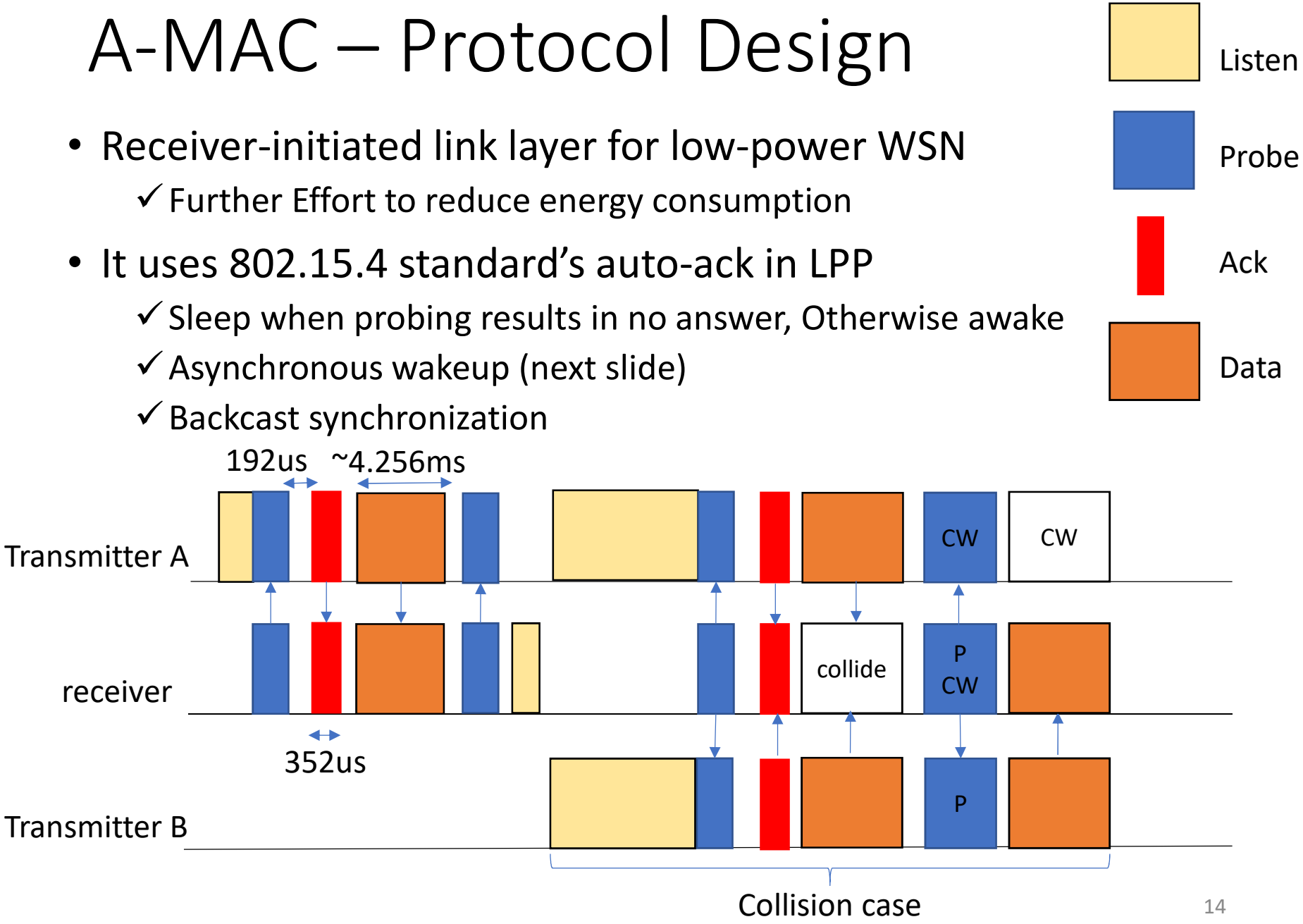
Koala

- Channel Switching
  - When large data transfer are taking place, active routes keep neighbors awake.
  - The easiest solution is changing channels

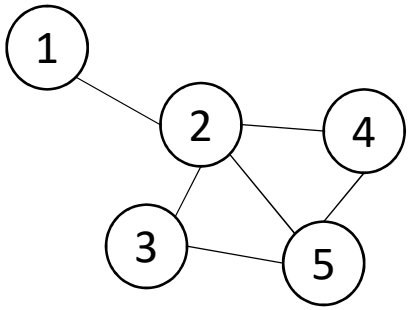


A-MAC – Protocol Design

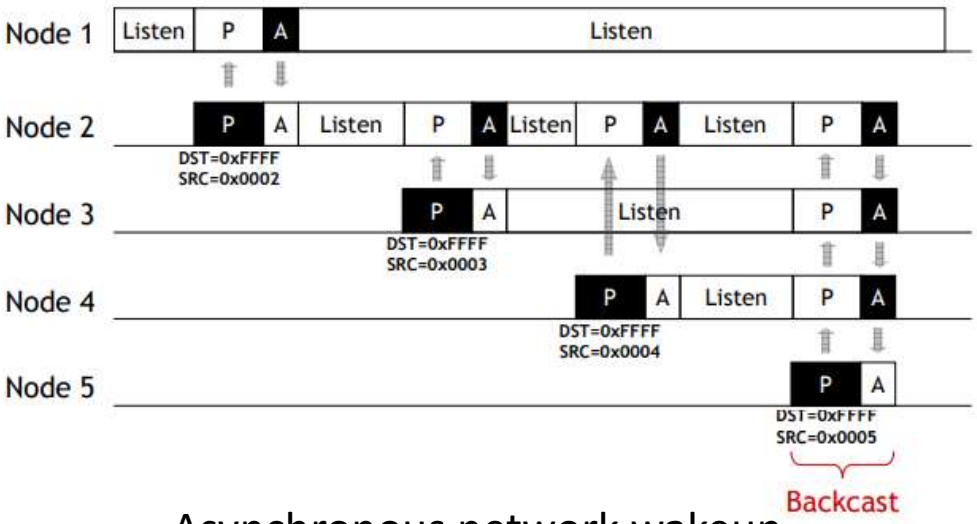
- Receiver-initiated link layer for low-power WSN
  - ✓ Further Effort to reduce energy consumption
- It uses 802.15.4 standard's auto-ack in LPP
  - ✓ Sleep when probing results in no answer, Otherwise awake
  - ✓ Asynchronous wakeup (next slide)
  - ✓ Backcast synchronization



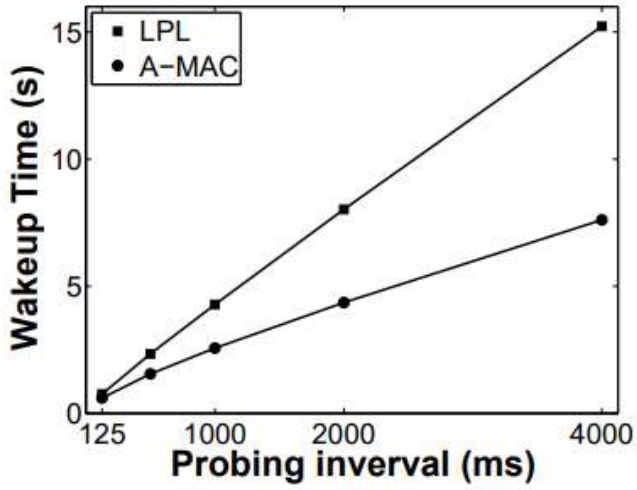
A-MAC – Wakeup



- Asynchronous network wakeup
  - ✓ Node1 initiates waking up, and other nodes follow
  - ✓ Link Quality to stable as concurrent acks increase
  - ✓ Each node decodes ACK even though large number of collisions occur
    - ✓ This attributes to the timing in the protocol, which minimizes ISI
  - ✓ Wakeup is 38% faster than typical LPL (Low Power Listening)
  - ✓ Back cast allows a node to know all neighboring nodes



Asynchronous network wakeup

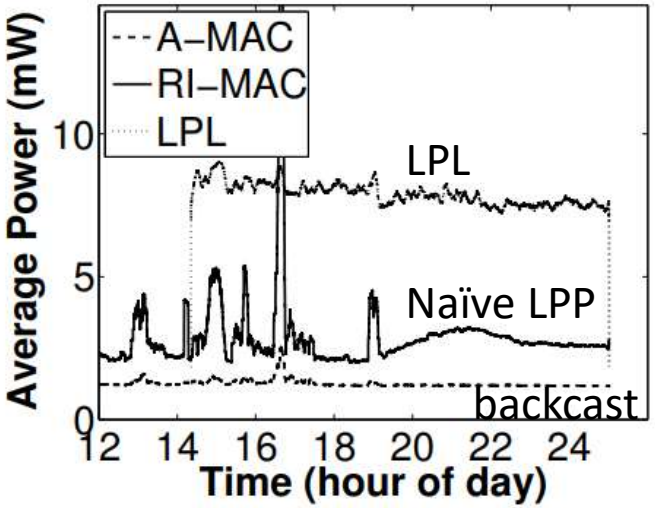


(a) Wakeup Latency

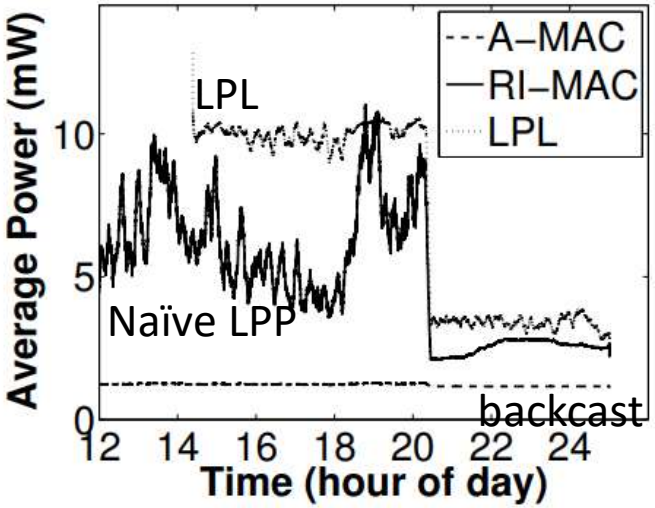
A-MAC - Immunity

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×
Hui LPL	36 μA†	72 μA‡	2.0×‡

- Interference problem with WSN
  - ✓ Basically, LPL is vulnerable to interference since other signals can prevent nodes from sleeping
  - ✓ A-MAC protocol is less vulnerable to external signal thanks to explicit probe, backcast
  - ✓ Throughout the day, average external environmental interference is smaller than other protocols



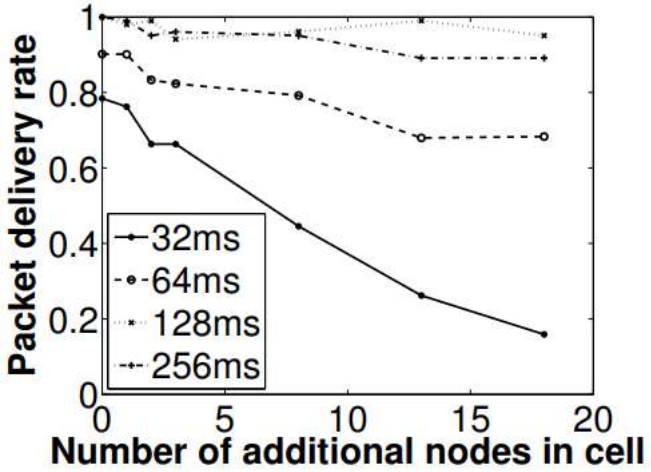
Interference Effect (Ch.18)



Interference Effect (Ch.26)

A-MAC - Density

- Problem with Density in the cell
  - ✓ Probe period is crucial
  - ✓ Experiment: 100 packets, 500 ms interval
  - ✓ We need to probe less frequently as nodes increase to achieve high delivery rate



(d) Effect of Density

- Packet Delivery Rate
  - ✓ Better than RI-MAC (LPL)
  - ✓ Again, density is the problem

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%

- Comments on A-MAC
  - ✓ Probing is fundamentally expensive, but somewhat mitigated
  - ✓ It is not suitable for the network with high density
  - ✓ Propagation delay can be critical: problem in
  - ✓ Fast wake up is good
  - ✓ Immune to external interference, which is good

Opinion / Conclusion

- Best protocol depends on the situation
  - ✓ Scale? Real time data? Favorable duty cycle?
  - ✓ Similar to HW1: Aloha or CSMA
- B-MAC
  - ✓ Pros: Simple, flexible
  - ✓ Cons: Scalability
- Koala
  - ✓ Pros: Simple, flexible
  - ✓ Cons: Higher energy consumption than LPL, Multiple channels
- A-MAC
  - ✓ Pros: Immune to external 802.11 network
  - ✓ Cons: Probing is fundamentally expensive, Density problem
- Future work needed