EN.600.450.01.FA11
Network Embedded Systems/Sensor Networks
Week 4: Medium Access Control

Marcus Chang, Andreas Terzis @ CS JHU

Outline

- Background in MAC protocols
  - Role and features of MAC protocols
  - Scheduled access vs. Randomized access
  - Additional WSN requirements
- Examples
  - S-MAC
  - T-MAC
  - B-MAC
  - X-MAC (Thursday’s paper)
  - SCP-MAC
  - RI-MAC (Project)

MAC and its Classification

- Medium Access Control (MAC)
  - When and how nodes access the shared channel

- Classification of multiple access MAC protocols
  - Scheduled protocols
    - Schedule nodes onto different sub-divisions
    - Examples: Time (TDMA), Frequency (FDMA), Code (CDMA)
  - Contention-based protocols
    - Nodes compete in probabilistic coordination
    - Examples: ALOHA (pure & slotted), Carrier Sense (CSMA)

MAC Attributes

- Collision avoidance
  - Basic task of a MAC protocol
- Energy efficiency
- Scalability and adaptivity
  - Network size, node density and topology change
- Channel utilization
- Latency
- Throughput
- Fairness

Primary

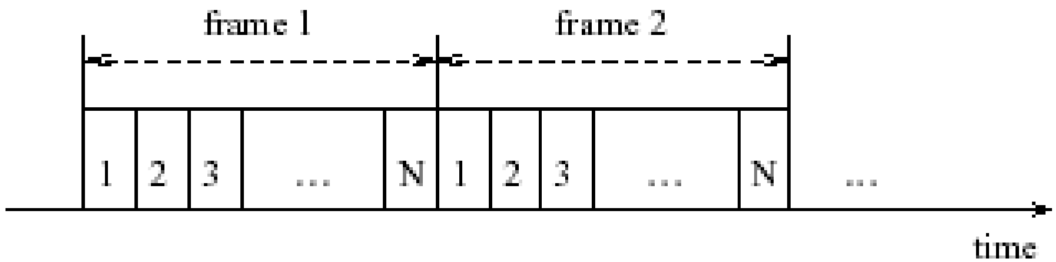
Secondary

Energy Efficiency in MAC Design

- What causes energy waste?
  - Packet collisions
  - Control packet overhead
  - Overhearing unnecessary traffic
  - Long idle time
    - Bursty traffic in sensornet applications
    - Idle listening consumes 50—100% of the power for receiving
  - Wakeup period (time between wakeups)
  - Duty Cycle = listen period/Wakeup period

Scheduled Protocols

- TDMA



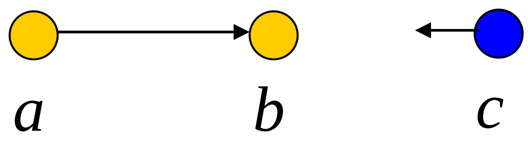
  - Advantages
    - No collisions
    - Energy efficient — easily support low duty cycles
  - Disadvantages
    - Bad scalability and adaptivity
      - Difficult to accommodate node changes
      - Difficult to handle inter-cluster communication
    - Requires time synchronization

Scheduled Protocols

- Polling
  - A special TDMA without pre-assigned slots
  - A master plus one or more slaves (star topology)
    - The master node decides which slave can send by polling the corresponding slave
    - Only direct communication between the master and a slave
  - Examples
    - IEEE 802.11 infrastructure mode (CFP)
    - Bluetooth *piconets*

Contention-Based Protocols

- CSMA — Carrier Sense Multiple Access
  - Listening before transmitting
  - Collisions can still occur



Hidden terminal: *a* is hidden from *c*'s carrier sense

  - Examples
    - IEEE 802.11 – CSMA/CA
      - Collision Avoidance – random back-off time
    - IEEE 802.11 RTS/CTS
      - RTS/CTS/DATA/ACK

Case Study: S-MAC

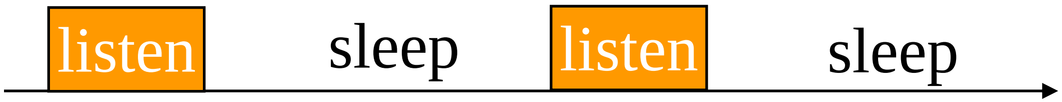
- S-MAC — by Ye, Heidemann and Estrin
- Tradeoffs
  - Increase latency and decrease fairness to improve energy efficiency
- Major components in S-MAC
  - Periodic listen and sleep
  - Collision avoidance
  - Overhearing avoidance
  - Message passing

From “Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks” by Ye et al.

Coordinated Sleeping

- Problem:
  - Idle listening consumes significant energy

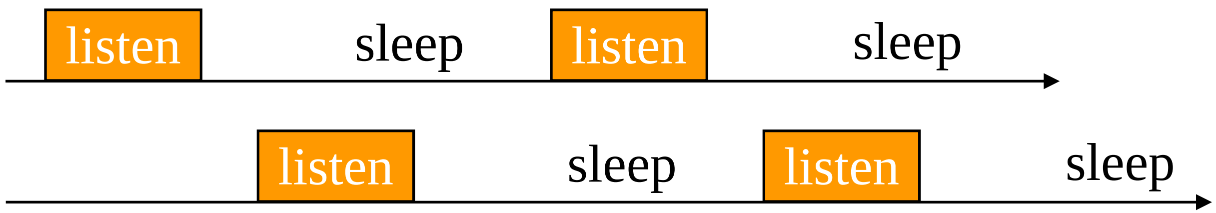
- Solution:
  - Periodic listen and sleep



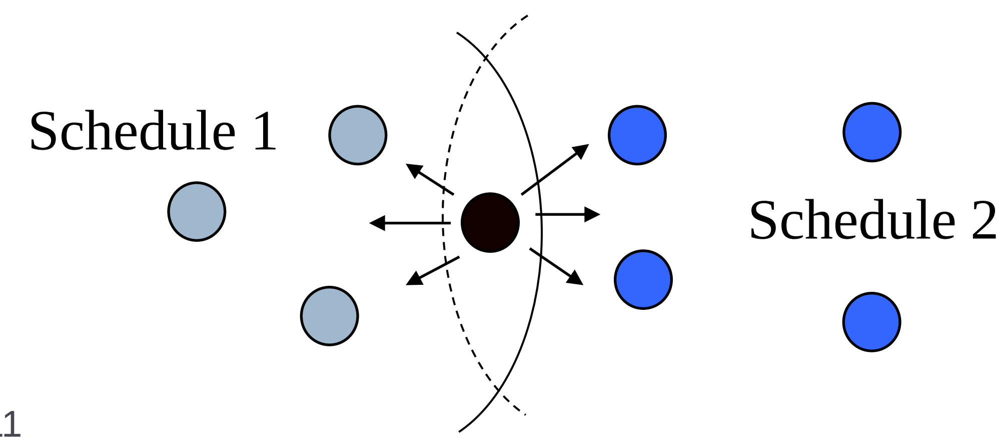
- Turn off radio when sleeping
- Reduce duty cycle to ~ 10% (120ms on/1.2s off)

Coordinated Sleeping

- Schedules can differ



- Prefer neighboring nodes have same schedule
— easy broadcast & low control overhead



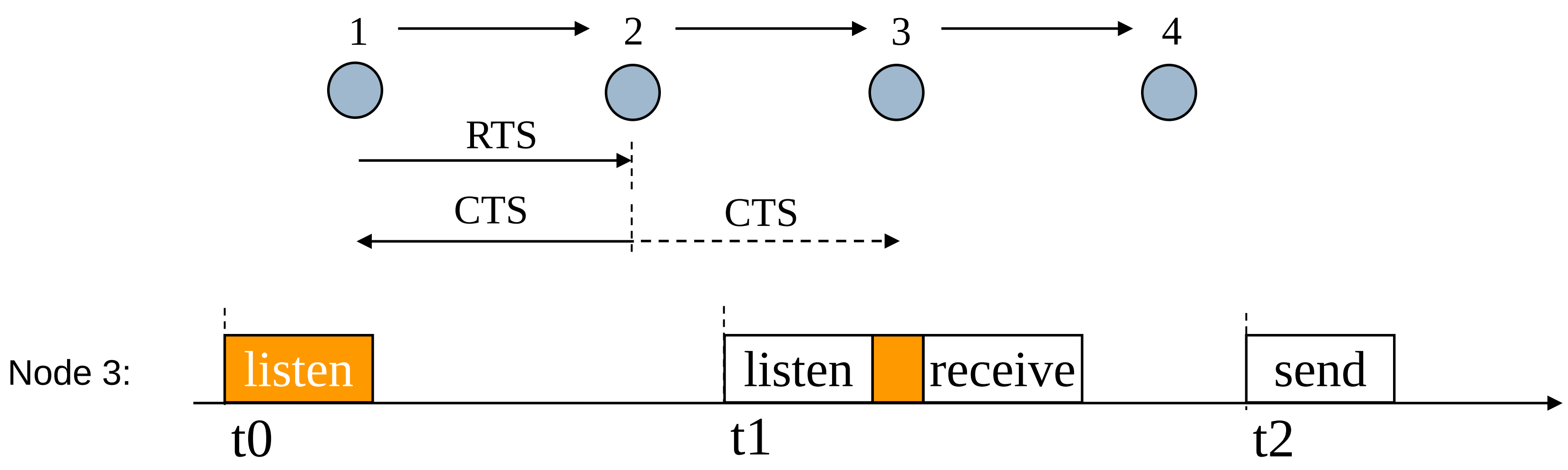
Border nodes: two schedules

Coordinated Sleeping

- Schedule Synchronization
  - New node tries to follow an existing schedule
  - Remember neighbors' schedules
    - — to know when to send to them
  - Each node broadcasts its schedule every few periods of sleeping and listening
  - Re-sync when receiving a schedule update
- Periodic neighbor discovery
  - Keep awake in a full sync interval over long periods

Adaptive Listening

- Reduce multi-hop latency due to periodic sleep
- Wake up for a short period of time at end of each transmission



- Reduces latency by at least half

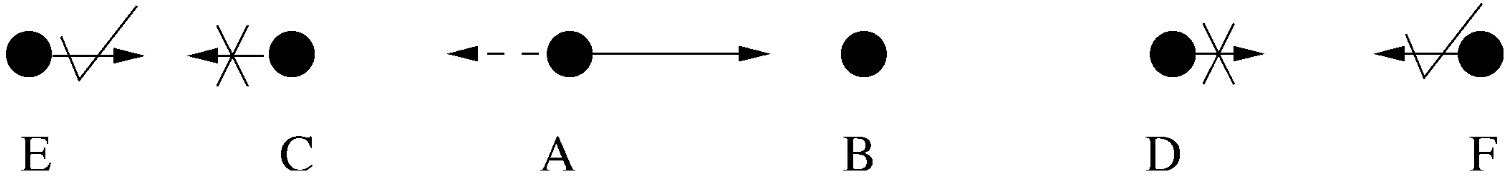
Collision Avoidance

- S-MAC is based on contention

- Similar to IEEE 802.11 ad hoc mode (DCF)
  - Physical and virtual carrier sense
  - Randomized backoff time
  - RTS/CTS for hidden terminal problem
  - RTS/CTS/DATA/ACK sequence

Overhearing Avoidance

- Problem: Receive packets destined to others
- Solution: Sleep when neighbors talk
  - Basic idea from PAMAS (Singh, Raghavendra 1998)
  - But only use in-channel signaling (RTS/CTS)
- Who should sleep?
  - All immediate neighbors of sender and receiver



- How long to sleep?
  - The duration field in each packet informs other nodes the sleep interval

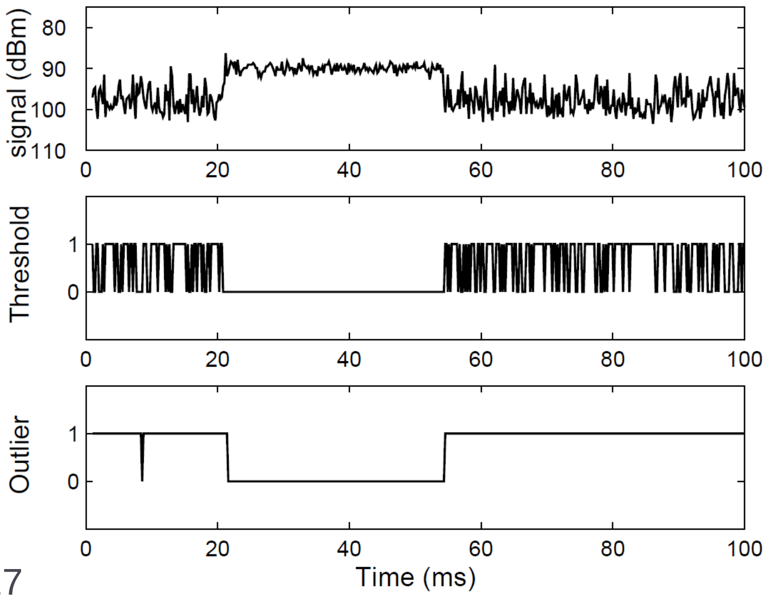
Adaptive Listen Slots

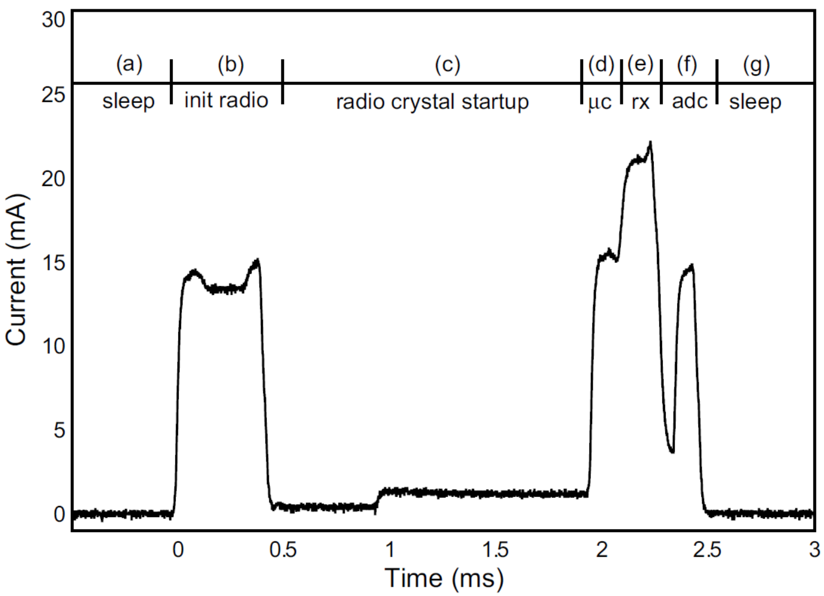
- In S-MAC all nodes have listen slots of the same duration
  - Different nodes might have different Tx/Rx patterns
  - Idle listening wastes power
  - Idea: adaptively change the idle listen slot

"An Adaptive Energy-Efficient MAC Protocol for Wireless Sensor Networks" (aka T-MAC) by T. van Dam, K. Langendoen

Low Power Listening (contention based)

- Principle
  - Node periodically wakes up, turns radio on and checks channel
    - Wakeup time fixed, "Check time" variable
    - If energy is detected, node powers up in order to receive the packet
    - Noise floor estimation used to detect channel activity during LPL

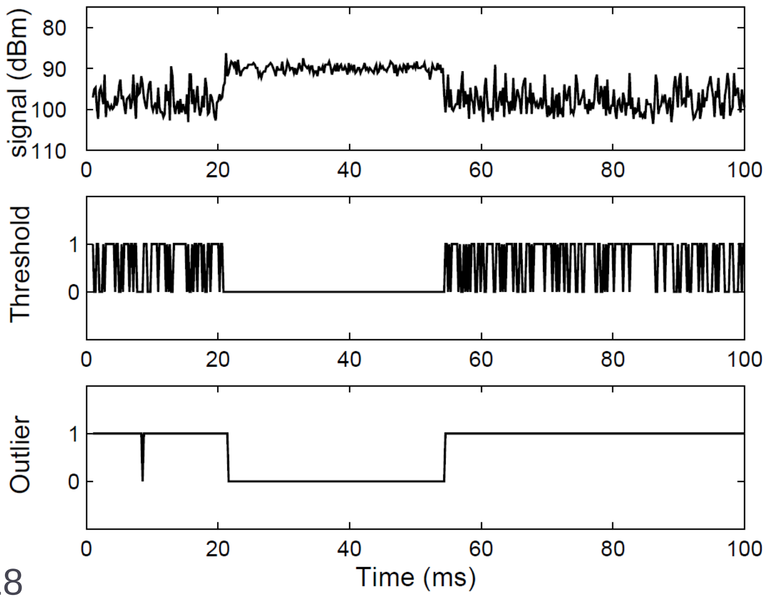


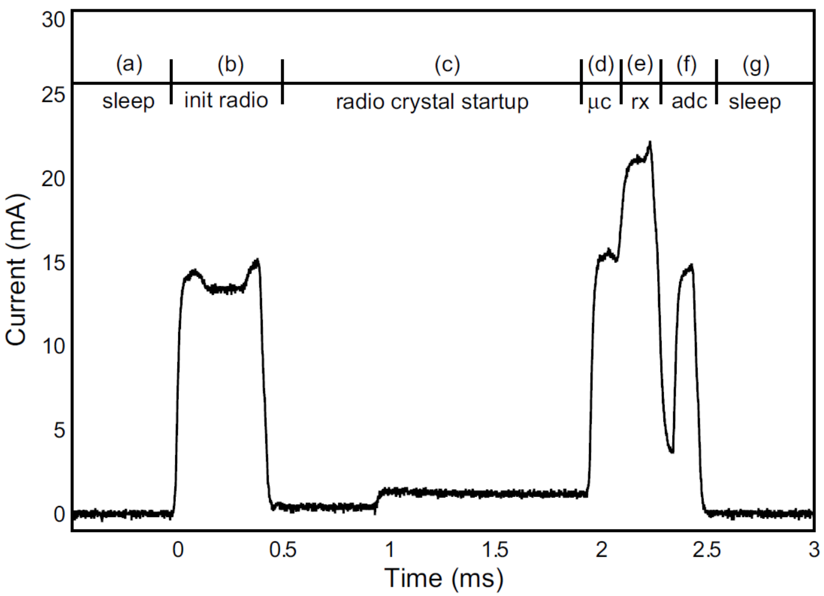


From "Versatile Low Power Media Access for Wireless Sensor Networks" by Polastre et al.

Low Power Listening

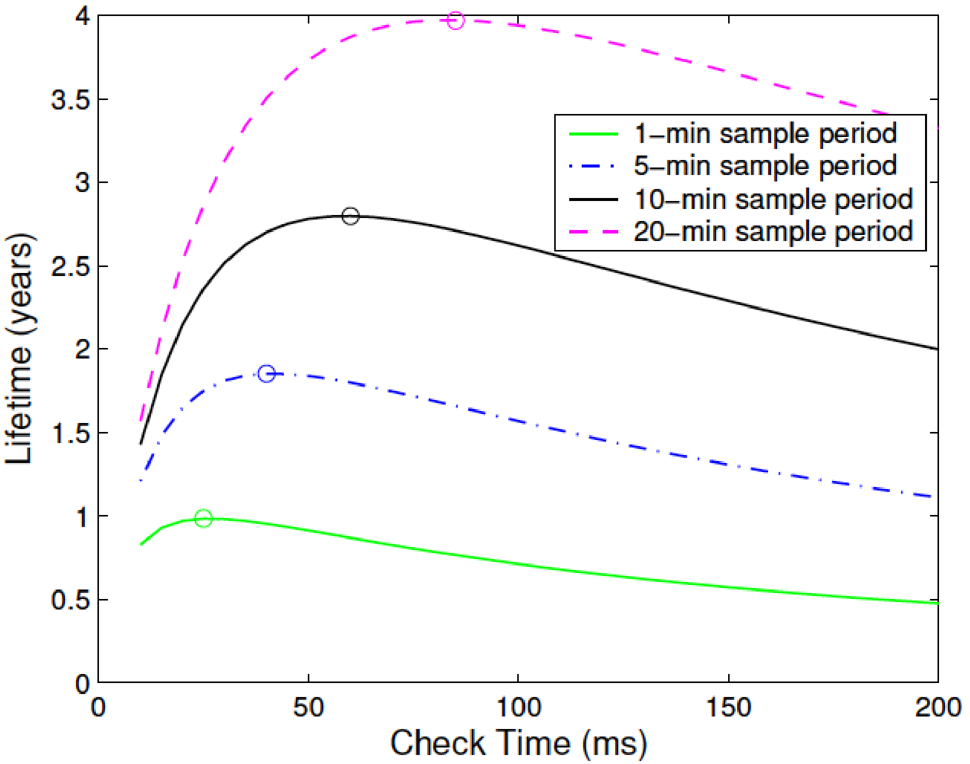
- Node goes back to sleep
  - If a packet is received
  - After a timeout
- Preamble length matches channel checking period
  - No explicit synchronization required
- Goal: minimize listen cost





LPL check interval (B-MAC)

- Single-hop application doing periodic data sampling
- Sampling rate (traffic pattern) defines optimal check interval
- Check interval
  - Too small: energy wasted on idle listening
  - Too large: energy wasted on transmissions (long preambles)
- In general, it's better to have larger preambles than to check more often!



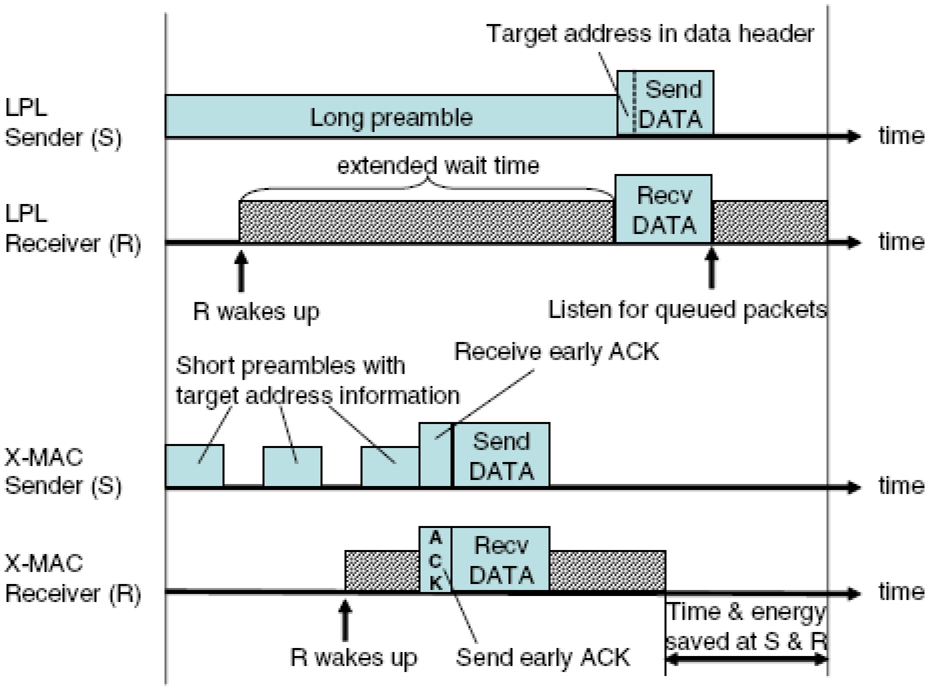
From "Versatile Low Power Media Access for Wireless Sensor Networks" by Polastre et al.

LPL Limitations

- Overhearing: Non-targeted receivers who sample the channel during preamble transmission have to wait until the end of the preamble to go back to sleep
  - Energy expenditure is a function of density as well as traffic load
- Entire preamble needs to be sent before data transmission
  - Even though on average receiver wakes up half way through the preamble
- Multiple senders need to send entire preamble to the same receiver

X-MAC

- Preamble contains destination ID
  - Other receivers can return to sleep
- Strobed preamble
  - Receiver sends ACK after receiving short preamble
- Receiver stays awake after packet reception
  - Transmissions from pending senders can proceed without additional preambles

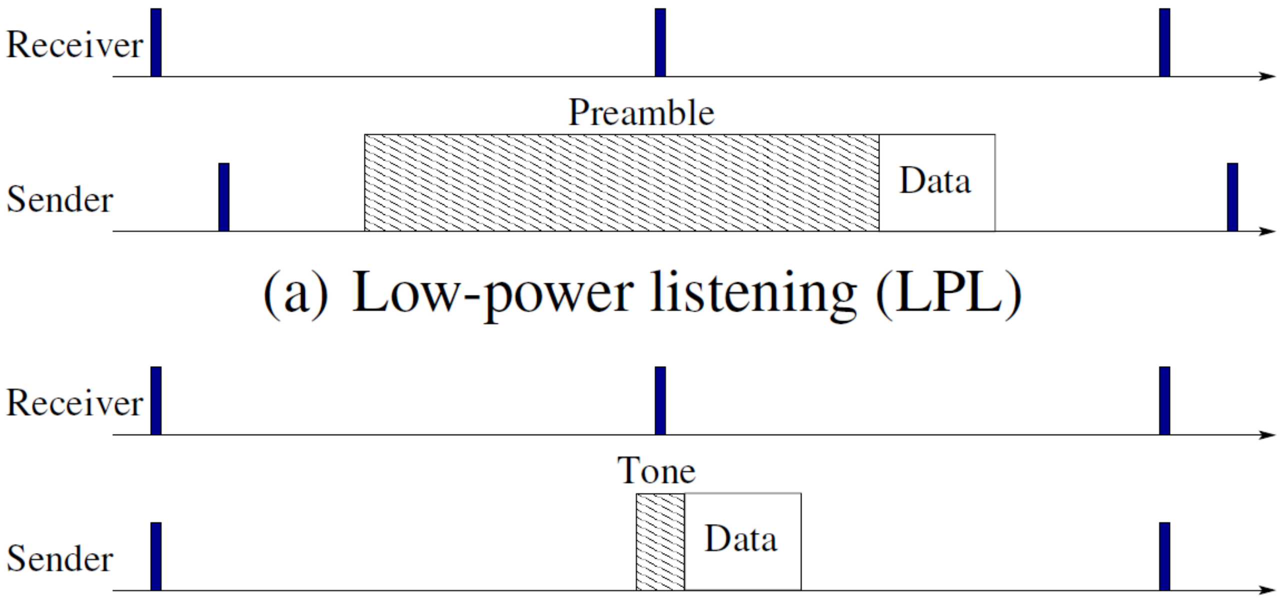


From "X-MAC: A Short Preamble MAC Protocol for Duty-Cycled Wireless Sensor Networks" by Buettner et al.

Scheduled Listening and LPL

- Scheduled listening
  - Advantage – efficient transmission
  - Disadvantages-
    - Synchronization overhead
    - Listen interval is too long in existing protocols
- Low-Power Listening
  - Advantage – minimizes listen cost when no traffic
  - Disadvantage – high costs on transmission

Scheduled Channel Polling (SCP-MAC)



(a) Low-power listening (LPL)

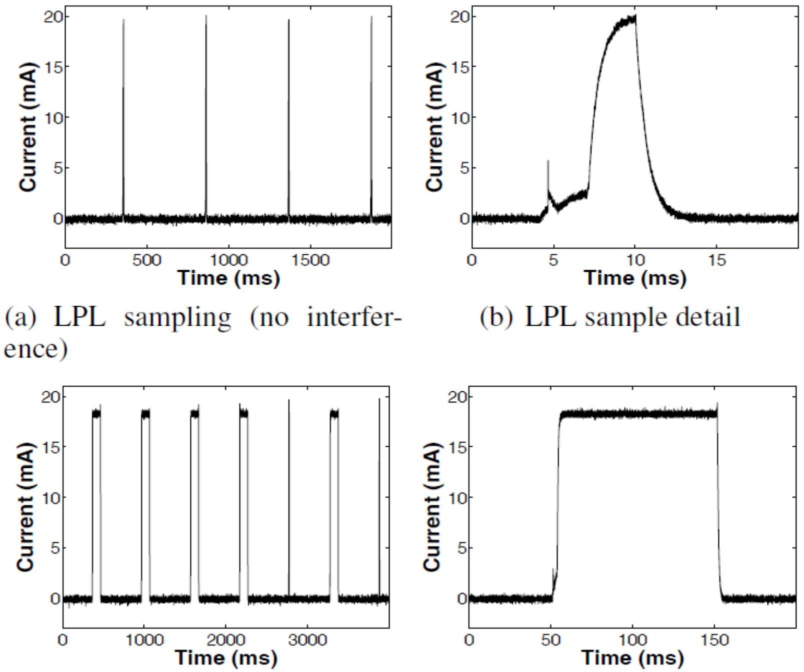
(b) Synchronized channel polling (SCP)

- SCP synchronizes neighbor's channel polling time
  - A short wake up tone wakes up receiver
  - It is efficient for both unicast and broadcast packets

From "Ultra-Low Duty Cycle MAC with Scheduled Channel Polling" by Ye et al.

"You talkin' to me?"

- Inherent problem with LPL
  - Overhearing increases idle listening
  - WiFi can trigger overhearing



(a) LPL sampling (no interference)

(b) LPL sample detail

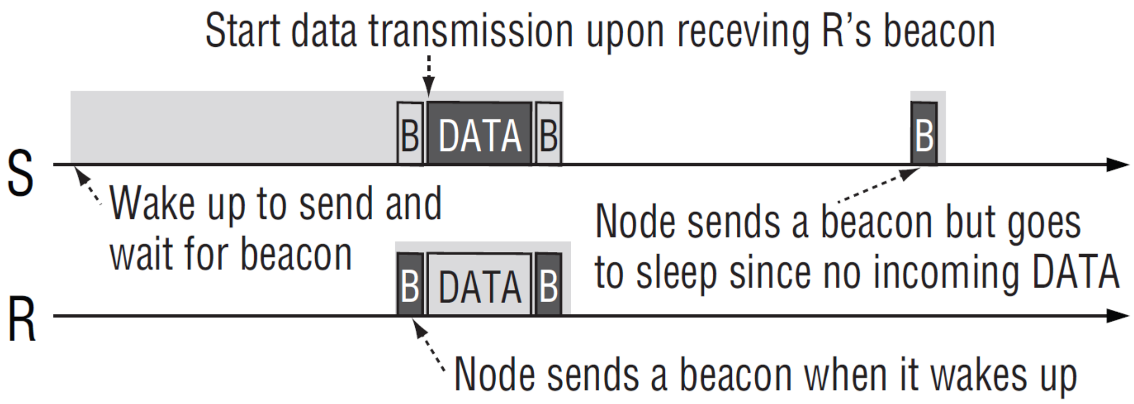
(c) LPL sampling (w/ interference)

(d) LPL overhearing detail

From "Design and Evaluation of a Versatile and Efficient Receiver-Initiated Link Layer for Low-Power Wireless" by Dutta et al.

Receiver Initiated MAC

- Goal:
  - Reduce idle overhearing in dense networks
- RI-MAC
  - Sender does the idle listening
  - Receiver transmits beacons



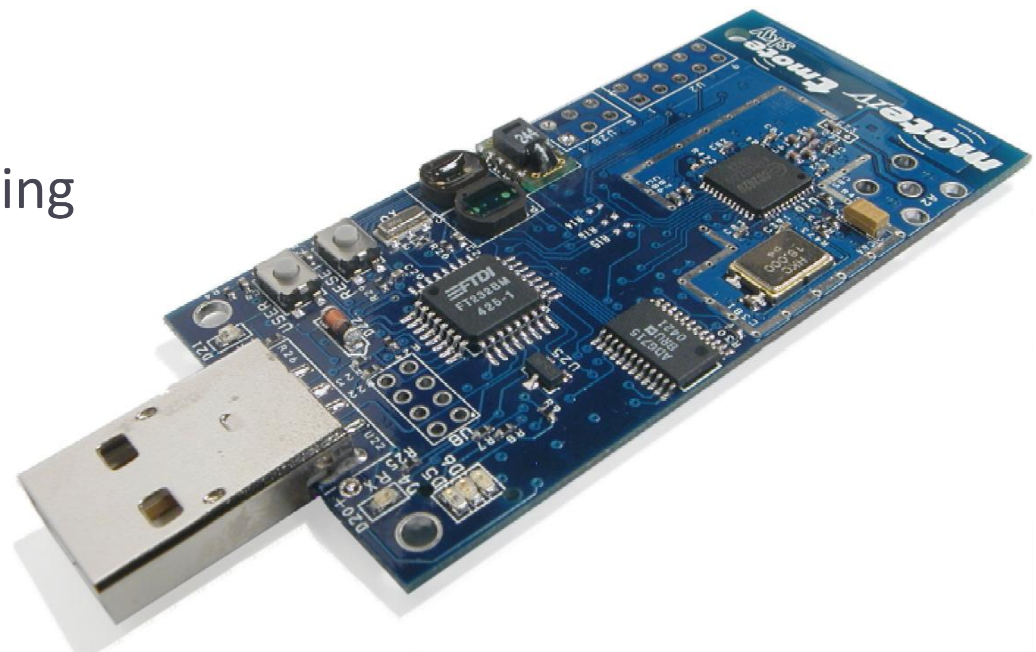
- Implementation part of the final project!

From "RI-MAC: A Receiver-Initiated Asynchronous Duty Cycle MAC Protocol for Dynamic Traffic Loads in Wireless Sensor Networks" by Sun et al.

Summary

- Medium Access Control
- Scheduled
- Contention
- [A-Z]-MAC

- Next week:
  - Link Estimation and Routing



Schedule

- Week 1: Introduction and Applications
- Week 2: Mote Hardware
- Week 3: Embedded Programming
- Week 4: Medium Access Control
- **Week 5: Link Estimation and Tree Routing**
- Week 6: IP Networking
- Week 7: Energy Management
- Week 8: Time Synchronization
- Week 9: Review and Midterm
- Week 10: Operating Systems and Programming Languages
- Week 11: Advanced Networking Topics
- Week 12: Localization
- Week 13: Energy Harvesting
- Week 14: TBD