Low Power Wireless System

18-452/750 Wireless Networks and Applications
Survey presentation
Jorge Huete Solis & Jun Taguchi
Outline

• Background
  ✓ Importance, challenges, LPP and LCP

• B-MAC

• Koala

• A-MAC

• 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 Tolerant
  ✓ Reliability
  ✓ Scalability

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

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Priority</th>
<th>MAC Type</th>
<th>Initiative</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSMAC (2004)</td>
<td>Latency</td>
<td>CSMA</td>
<td>------</td>
</tr>
<tr>
<td>TRAMA (2003)</td>
<td>Energy</td>
<td>TDMA</td>
<td>------</td>
</tr>
<tr>
<td>TRACE (2003)</td>
<td>Energy</td>
<td>TDMA</td>
<td>------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TDMA</th>
<th>CSMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strict Sync</td>
<td>Flexible Sync</td>
</tr>
<tr>
<td>Controlled Access</td>
<td>Random Access</td>
</tr>
<tr>
<td>High Channel Utilization under high contentions</td>
<td>High Channel Utilization under low contentions</td>
</tr>
<tr>
<td>Need Central Control</td>
<td>Decentralized</td>
</tr>
</tbody>
</table>

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

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)
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

![Diagram showing the protocol design](image)

- Transmitter A
  - 192us
  - ~4.256ms
- Receiver
  - 352us
- Transmitter B
  - Collision case
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
A-MAC - Immunity

- 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

<table>
<thead>
<tr>
<th>Primitive Operation</th>
<th>w/o 802.11 interference</th>
<th>w/ 802.11 interference</th>
<th>Increase in Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>TinyOS LPL</td>
<td>175 µA</td>
<td>3,030 µA</td>
<td>17.3×</td>
</tr>
<tr>
<td>RI-MAC LPP</td>
<td>383 µA</td>
<td>12,576 µA</td>
<td>54.7×</td>
</tr>
<tr>
<td>A-MAC LPP</td>
<td>206 µA</td>
<td>230 µA</td>
<td>1.12×</td>
</tr>
<tr>
<td>Hui LPL</td>
<td>36 µA†</td>
<td>72 µA‡</td>
<td>2.0×‡</td>
</tr>
</tbody>
</table>

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

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

• 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