Ultra-Low Duty Cycle MAC with Scheduled Channel Polling

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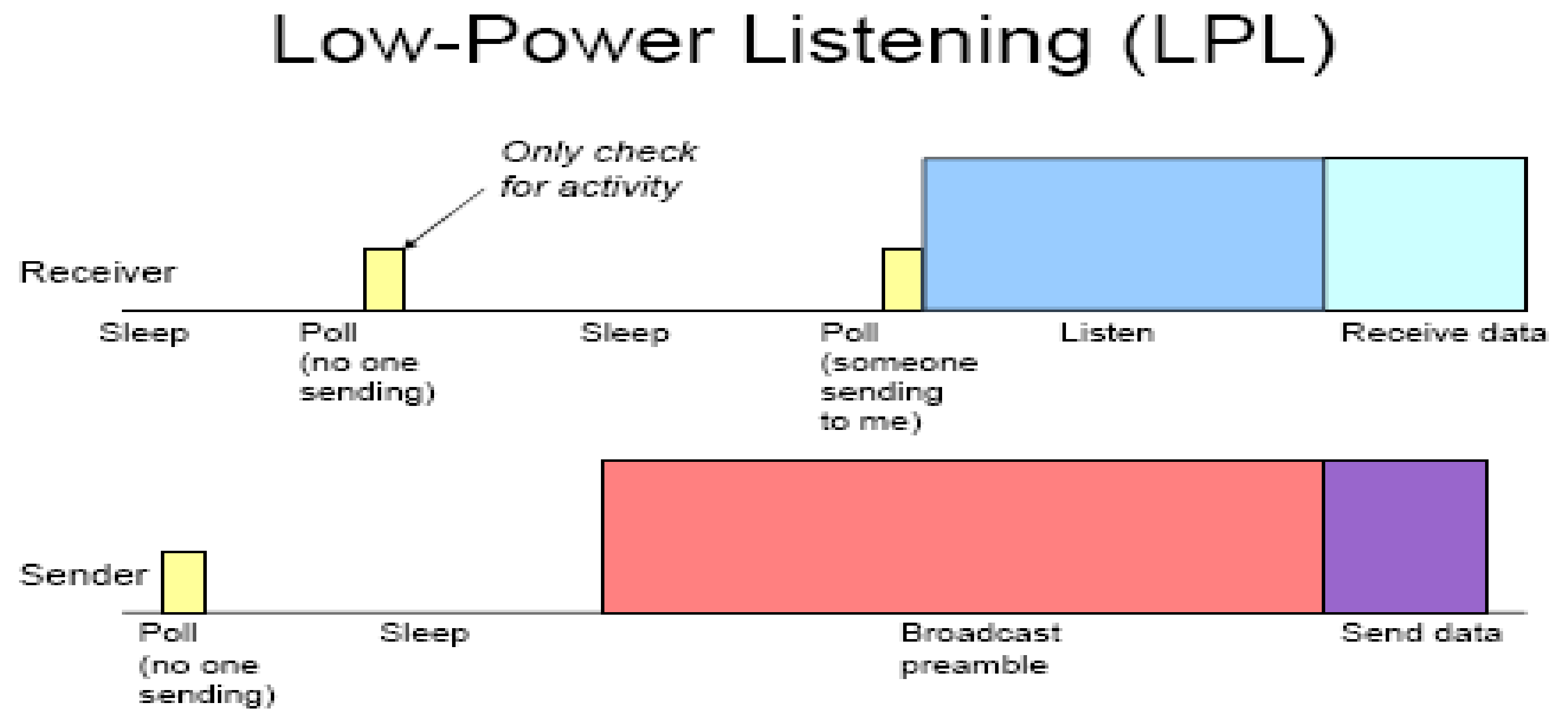
Outline

- **Introduction**
- SCP-MAC Design
- Analysis and Lower bounds for LPL and SCP
- Protocol Implementation
- Experimental evaluation
- Effects on new radios
- Conclusions

Saving Energy

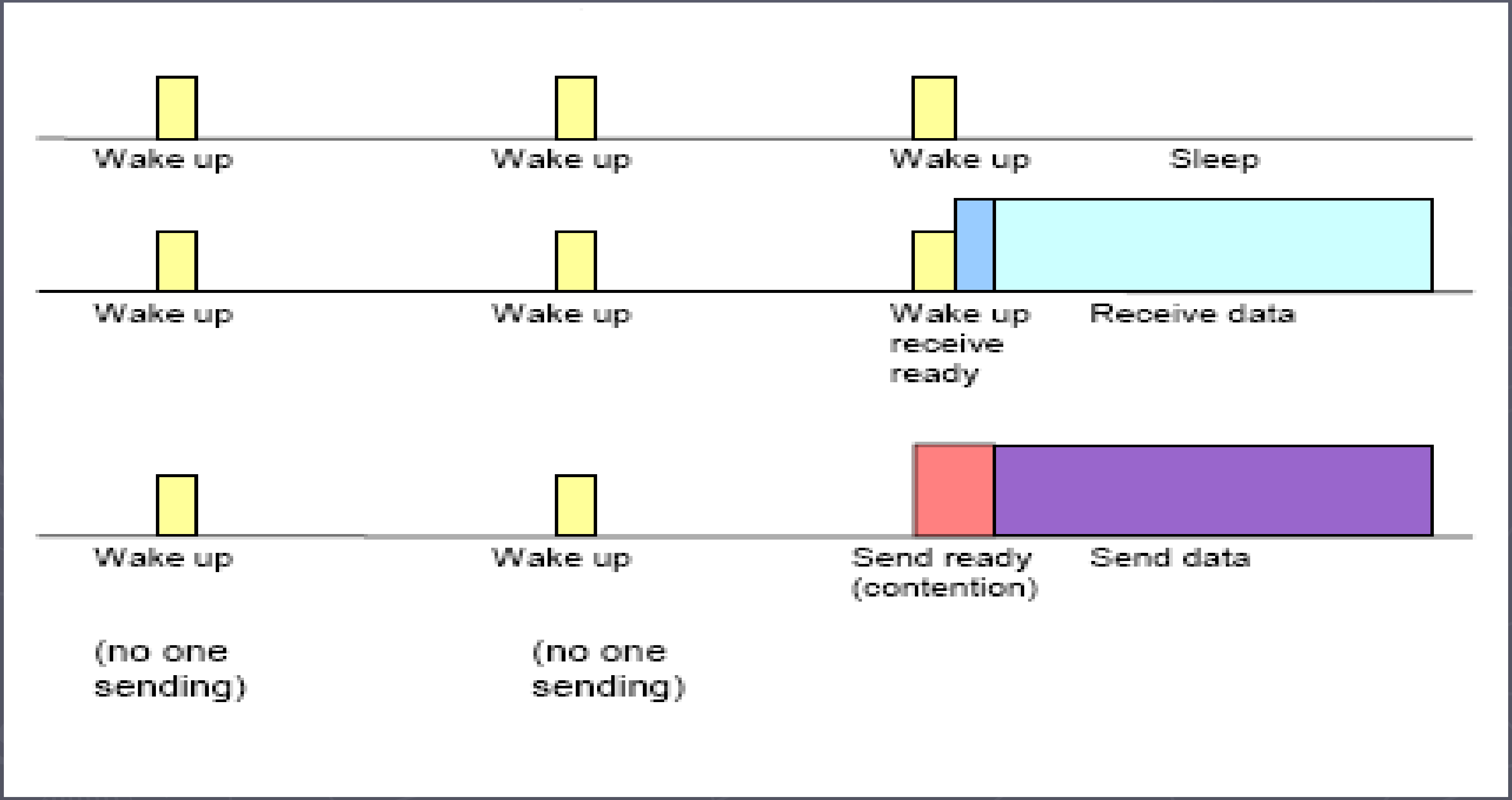
- Various protocols have been implemented to solve the problem of energy in Sensor networks
- CSMA- Periodic Listen and Sleep; Contention during listening
- Low-Power Listening (LPL)- Asynchronous Listening
- Scheduled Listening (S-MAC)- Maintaining Synchronization

Low-Power Listening (LPL)



Reference:http://www.cse.wustl.edu/~lu/cs537s/Slides/scp.pdf

Scheduled Listening



Reference:http://www.cse.wustl.edu/~lu/cs537s/Slides/scp.pdf

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

The need for a new Protocol

- Idle Listening is a major issue when light traffic
- Duty cycle should be low
- Sensor networks have varying traffic loads
- So there is a need to adapt to the traffic with consistent performance

Highlights of the paper

- Finding lower bounds of energy consumption for LPL and Scheduled Channel Polling (SCP)
- Design SCP-MAC to achieve ultra-low duty cycle; very less than 1
- Also adjusting duty cycles to variable traffic
- Evaluating design options on different radios

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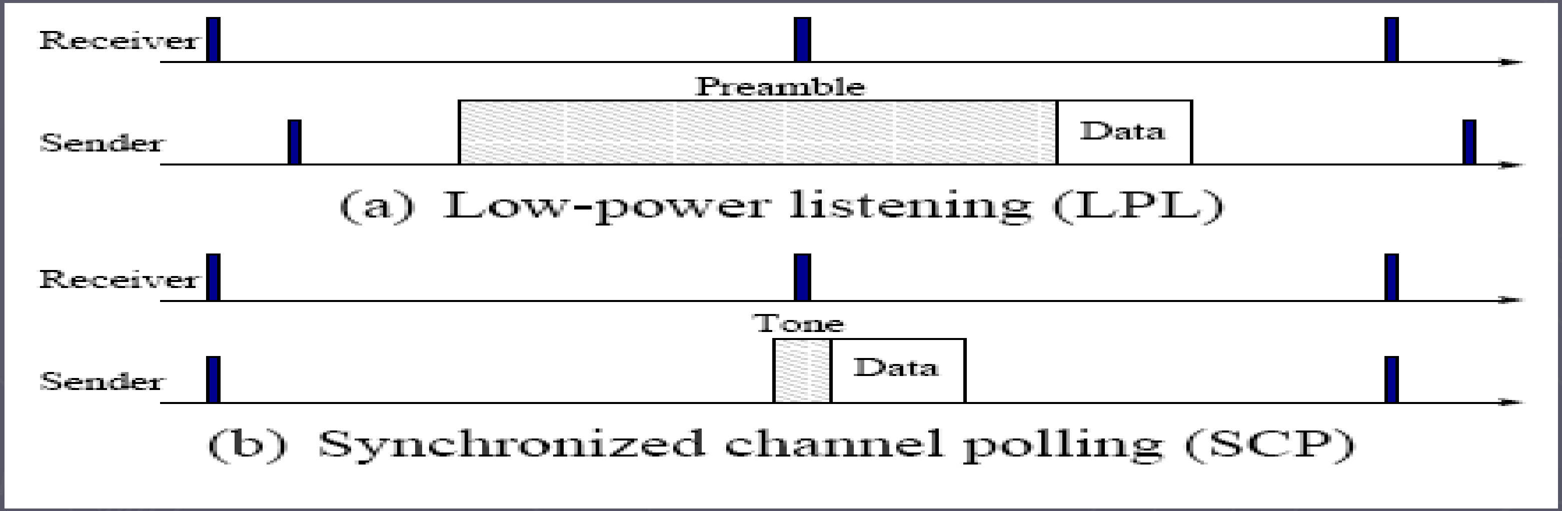
Design Overview

- Goals
  - Ultra Low Duty cycle-1/10th of current MAC
  - Adapt to variable traffic
- Approach
  - Combining strengths of scheduling and LPL
    - Finding optimal parameters under periodic traffic
  - Adaptive channel polling and multi-hop streaming
  - Other optimizations

Scheduled 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

Adaptive Channel Polling

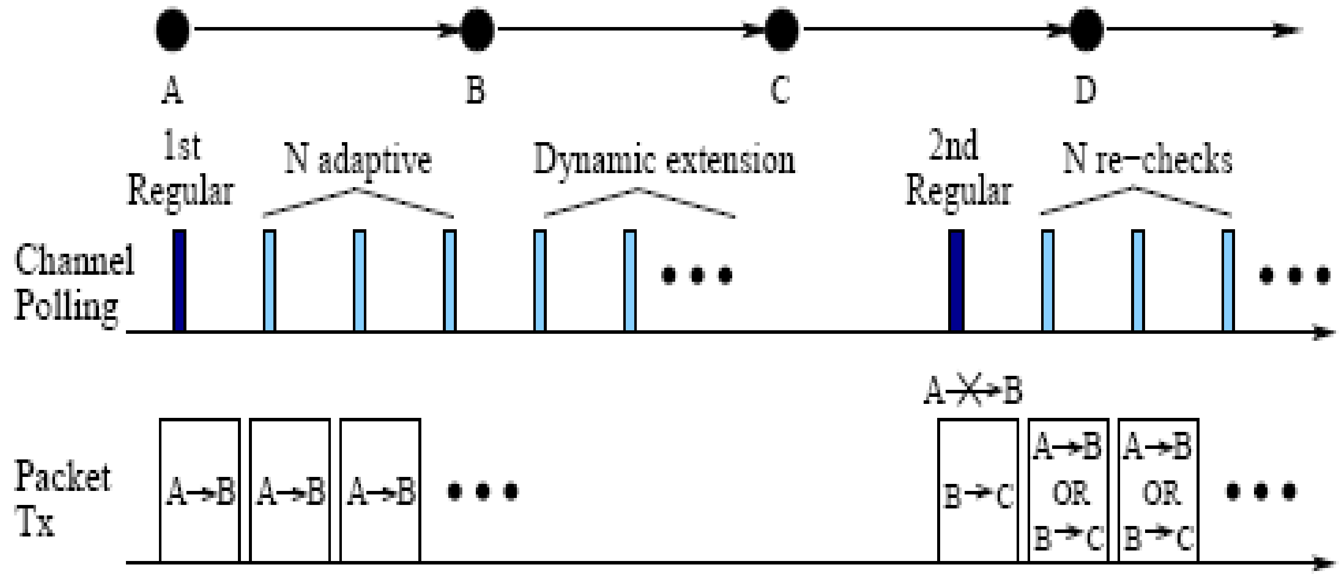


Figure 2. Adaptive channel polling and multi-hop streaming.

Adaptive Channel Polling

- Increased duty cycle at heavy traffic
- No explicit signaling is required
- Multi-hop wake up and streaming can be achieved

Other Optimizations

- Two-Phase Contention

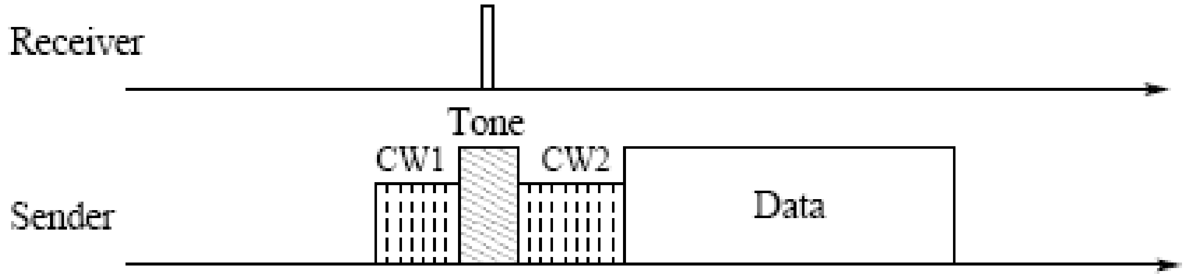


Figure 3. Two-phase contention in SCP-MAC.

- Lower collision probability compared to a single contention window with the same length
- Alternatively use shorter window to save energy

Other Optimizations (contd..)

- Overhearing Avoidance
  - SCP-MAC performs overhearing avoidance from MAC headers
  - Receiver examines destination address of a packet immediately after receiving its MAC header
  - If destined to another node, it immediately stops reception and radio goes to sleep

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Models and Metrics

- Network: single hop with n+1 nodes
- Traffics is periodic from each node at a known rate
- Energy model
  - Four stable states: P_{rx} , P_{rx}, P_{listen}, P_{sleep}
  - Radio during transition state during polling: P_{poll} (average)
  - Expected energy: sum of energy in each state $E=P_{listen}t_{cs} + P_{tx}t_{tx} + P_{rx}t_{rx} + P_{poll}t_{poll} + P_{sleep}t_{sleep}$
- Goal: To find best possible performance of LPL and SCP

Synchronization Overheads in SCP

- Piggyback sync info on data packets if possible
- Send *sync* packets periodically if there there is no data
- Optimal *Sync* period depends on:
  - Clock Drift rate, node density and data rate
  - Wakeup tone length includes guard time to tolerate clock drift between two *sync* messages
  - Increasing Sync period reduces cost on sending Sync, but increases wakeup tone length

Optimal Sync Period

- Synchronization cost is not as high as it is thought to be
- Rather synchronization is required every tens on minutes

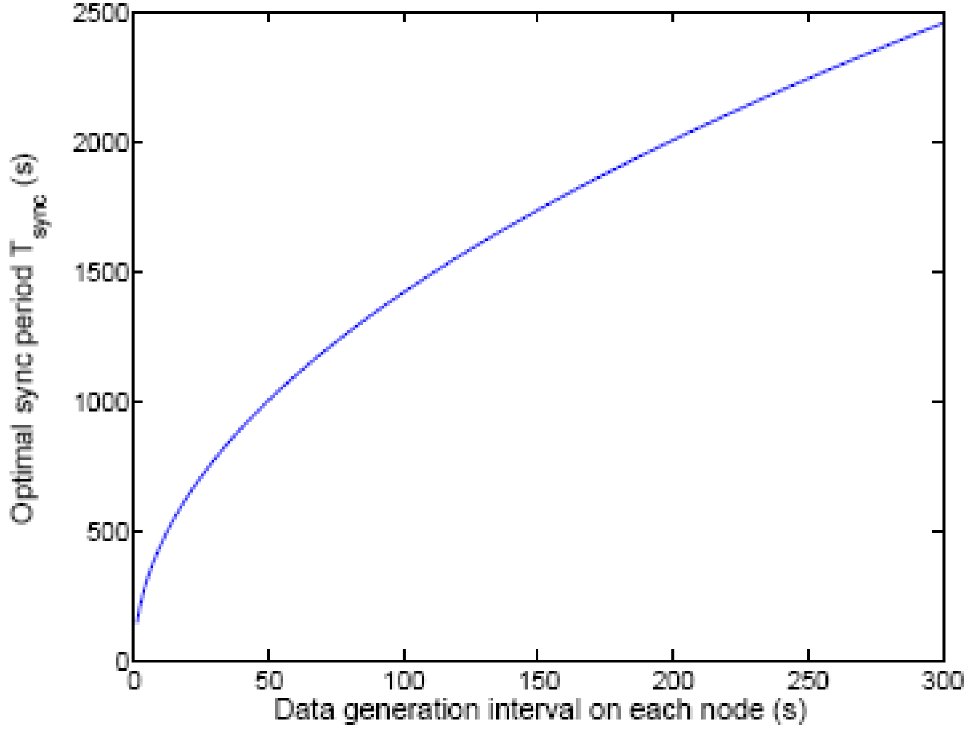
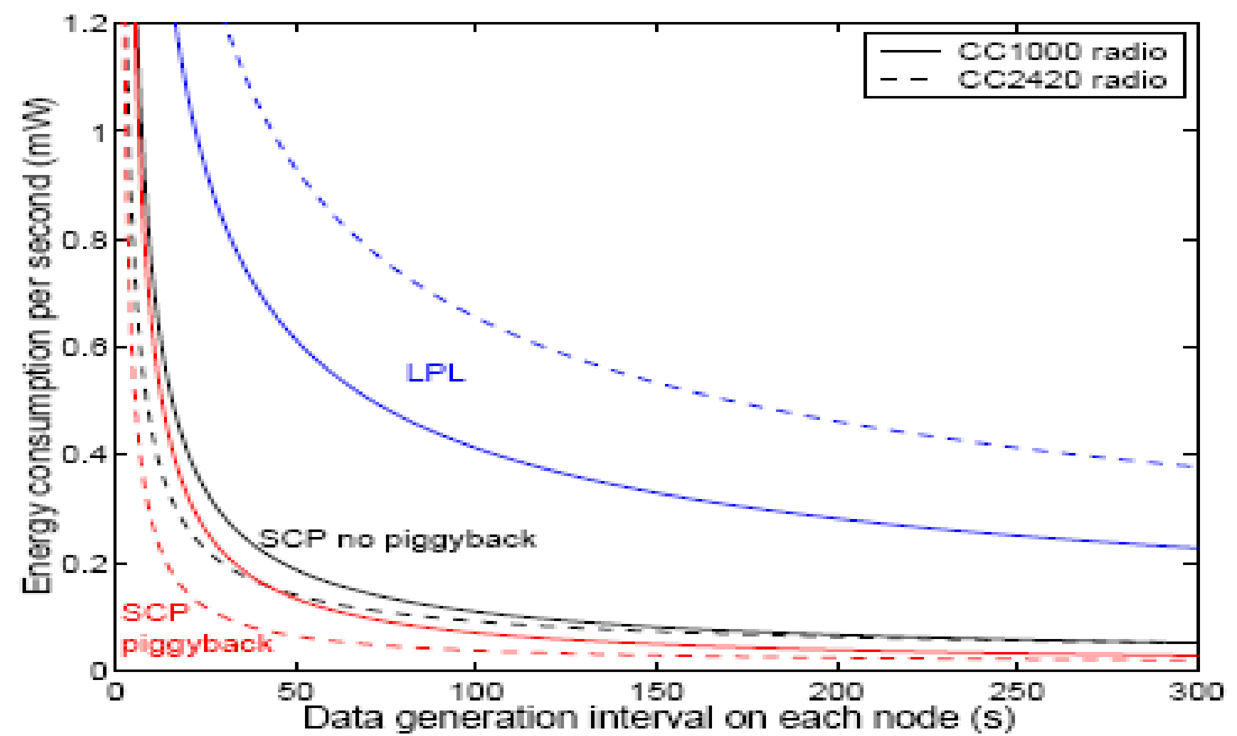


Figure 5. Optimal SYNC period for SCP-MAC.

Energy Performance of LPL and SPC with optimal settings



- LPL consumes about 3-6 times more energy than SCP on CC1000- it is due to long preambles in LPL
- Also due to piggybacking energy consumed is reduced to almost half when data is sent rarely

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Protocol Implementation

- Software architeture – MAC functionality divided into four layers:
  - Physical layer – bottom on stack
  - CSMA layer – responsible for performing carrier sensing
  - LPL – implemented on top of CSMA
    - Major purpose is to poll the channel & make radio sleep when there’s no activity
  - Scheduling – this is implemented over LPL in SCP model

Implementation (contd..)

- TinyOS is used for CPU power management
- SCP-MAC adapted to run on IEEE 802.15.4 radios found on:
  - MicaZ hardware, originally on Mica2 platform with CC1000 radios
- MicaZ implementation is still very preliminary as significant work remains to tune implementation and improve robustness

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Experimental Evaluation

- Verified the analysis and did a few more experiments
- Used Mica2 Motes for experiments
- Having TinyOS

Optimal Setup with Periodic Traffic

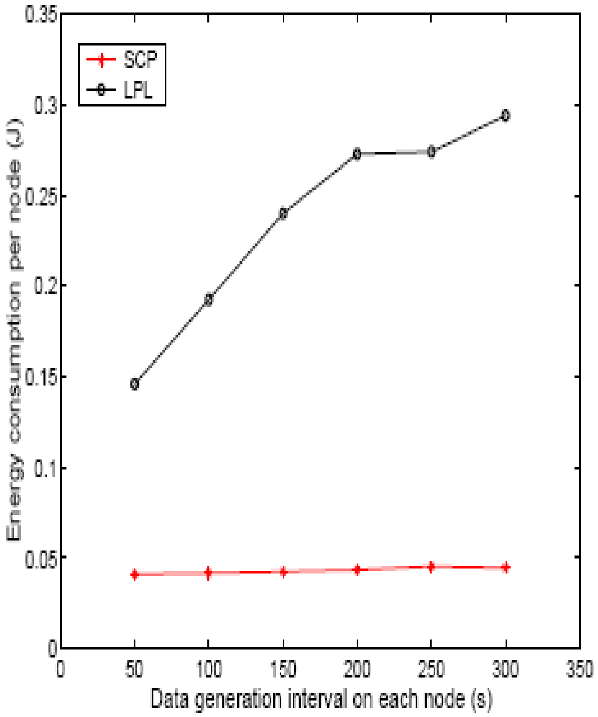

Figure 8. Mean energy consumption (J) for each node as traffic rate varies (assuming optimal configuration and periodic traffic).

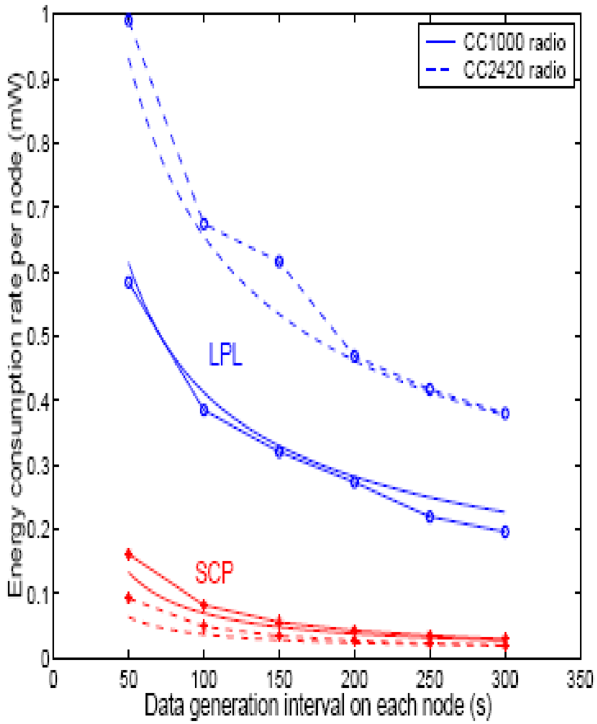

Figure 9. Mean energy consumption rate (J/s or W) for each node as traffic rate varies (assuming optimal configuration and periodic traffic). The radios are the CC1000 (solid lines) and CC2420 (dashed).

Performance with Unanticipated Traffic

- Comparing MAC's Performance when traffic load changes
- Settings:
  - Configured as low duty cycle (0.3%)
  - Heavy traffic occurs suddenly on a few nodes

Performance with Unanticipated Traffic

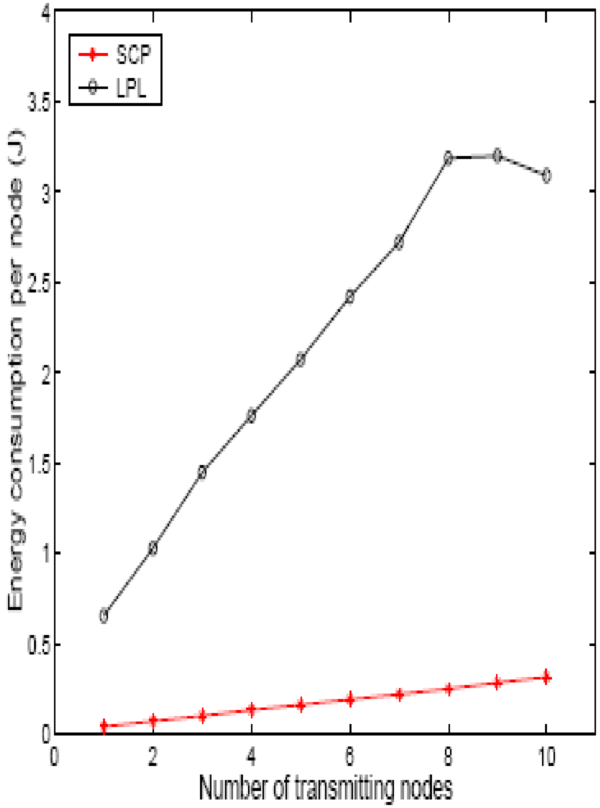

Figure 10. Energy consumptions on heavy traffic load with very low duty cycle configurations.

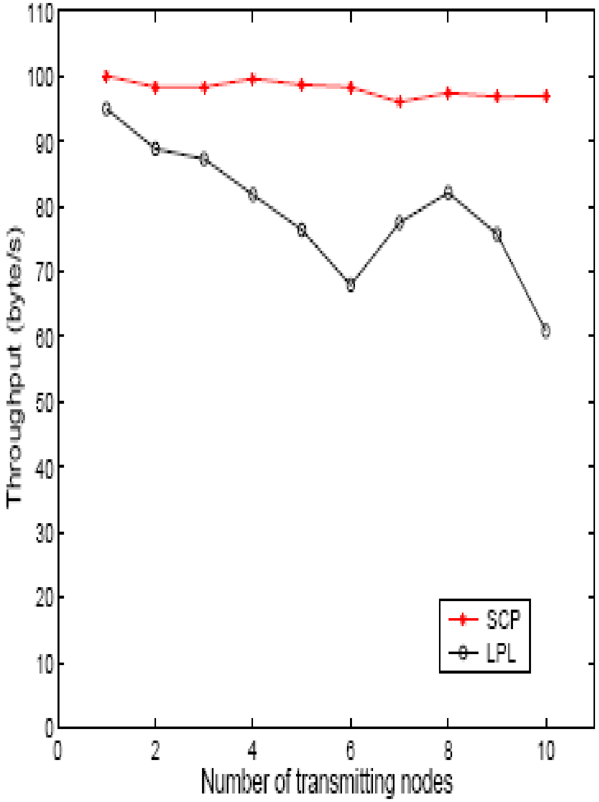

Figure 11. Throughput on heavy traffic load with very low duty cycle configurations.

- LPL consumes 8 time more energy than SCP –
  - Short wakeup tone is Robust to variable traffic

Energy consumption in Multi-hop Network

- Multi-hope network settings:
  - Unicast over a 9-hop linear network
  - No clear optimal configuration
  - Configure according to delay requirement (1s polling period , 0.3% duty cycle)

Energy consumption in Multi-hop Network

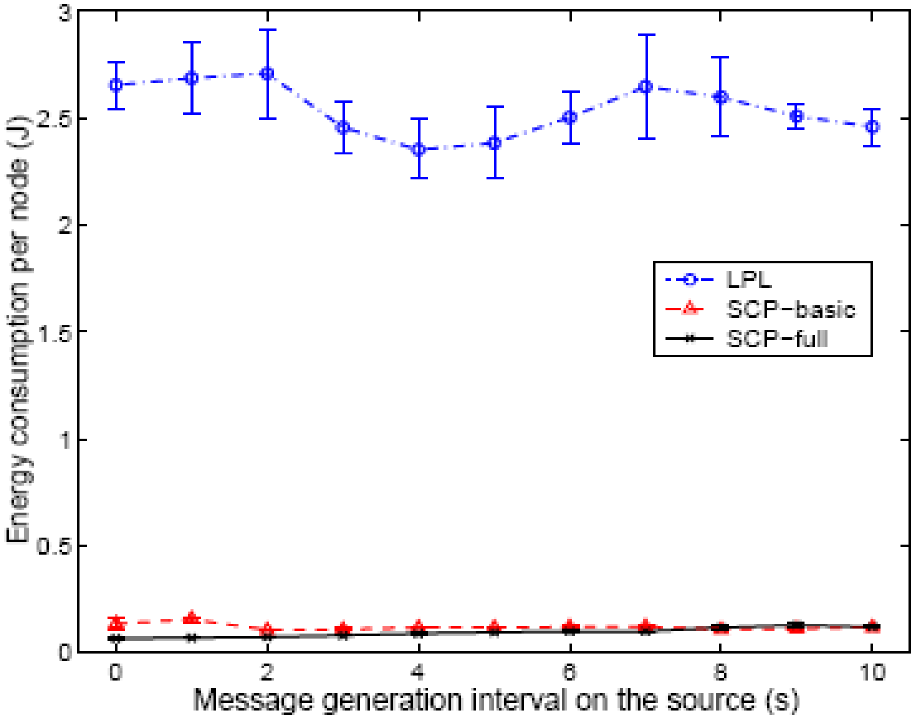

Figure 12. Mean energy consumption per node for multi-hop experiments (20 packets over 9 hops).

- LPL uses 20-40 times more energy than SCP
  - LPL costs due to overhearing and false wakeups

Latency in Multi-hop Network

- This shows how adaptive polling helps with heavy traffic
  - 9- hop network
  - Source generates 20 msgs at faster rate
  - Measure time for passing all msgs, normalized to the number of msgs

Latency in Multi-hop Network

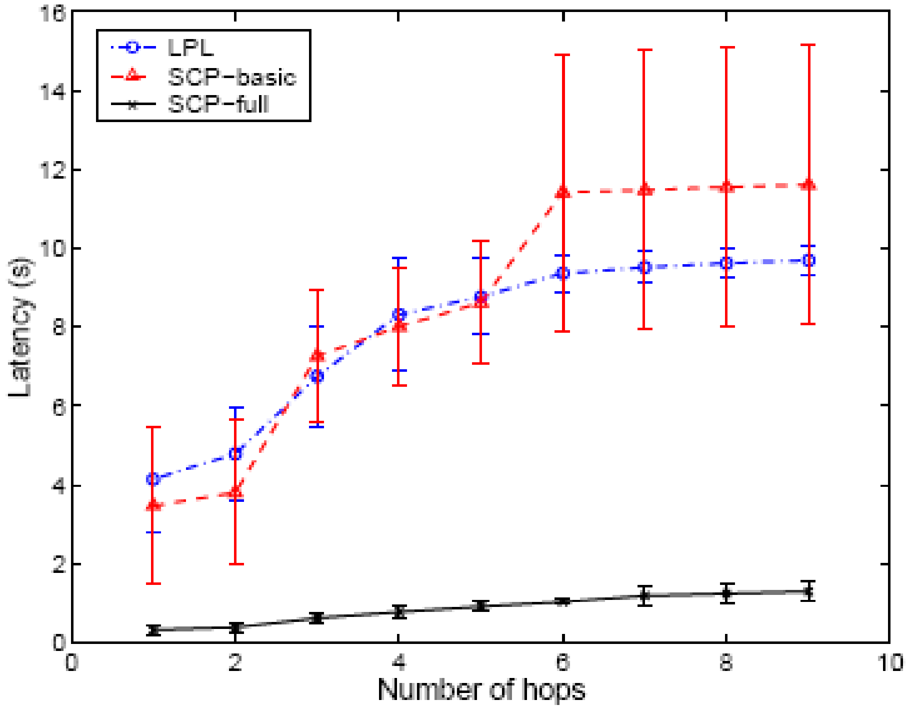

Figure 13. Mean packet latency over 9 hops at the heaviest load.

- Adaptive channel polling is 7 times faster than LPL and basic SC

Conclusions

- Better understanding of MAC performance limits
  - Find optimal performance under periodic traffic
  - Demonstrate low cost of synchronization
- SCP achieves duty cycles of < 0.1%
- SCP adapts well to variable traffic
- Long preamble cost more on faster radios

Comments

- Hidden terminals problem not discussed
- How does SCP compare to S-MAC?

References

- http://www.isi.edu/~weiye/pub/Ye06_SenSys.pdf
- http://www.cse.wustl.edu/~lu/cs537s/Slides/scp.pdf
- http://www.isi.edu/~weiye/talk/SenSys06_SCP.pdf

Thank You

Questions?