Ming Hsieh Department of Electrical Engineering

Achieving Energy-Efficiency in Large and Sparse Wireless Sensor Networks

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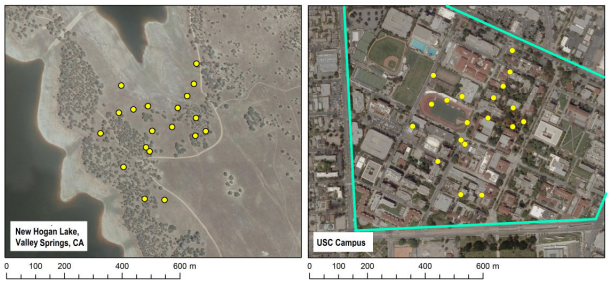
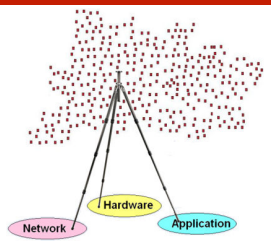
Introduction & Motivation

- **Fact 1:** Lack of real-world, long-term, large, and sparse Wireless Sensor Networks (WSNs) [1]
- **Fact 2:** Large WSNs in outdoors have a significant high total cost of ownership (TCO)
- **Traditional approaches in WSNs:**
  - Heavily rely on energy harvesting techniques [1]
  - Solve the high physical coverage area challenge by means of:
    - high #nodes (intensive collaboration)
    - high #infrastructure nodes (~1 per 8 sensor nodes) [1]
- **Our goals** (assumption: low duty-cycle environmental monitoring application):
  - 1 node per ~5,000 m^2 (54,000 ft^2) with low-power transceiver
  - Use 1 infrastructure node per ~30 sensor nodes
  - Achieve overall network overhead < 1%
  - Extend the lifetime of non-rechargeable batteries by multiple folds



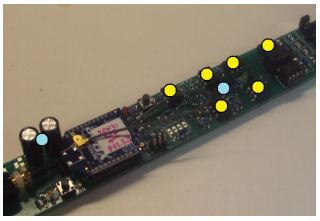
Initial Vision

- Energy efficiency can be significantly enhanced :
  - **Application:** low duty-cycle
  - **Hardware:** adopt hibernation and design for non-rechargeable batteries
  - **Network:** overhead < 1%
- **Our strategy**:
  - Design an **overlay solution** (runs on top of existing hardware/software)
  - **Trade network perfomance** for energy-efficiency
  - **Homogeneous energy consumption** among nodes



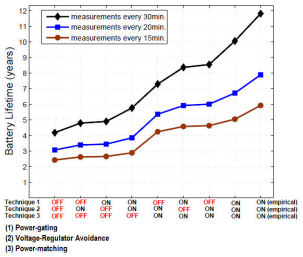
Ultra-Low Power Management Techniques [2]

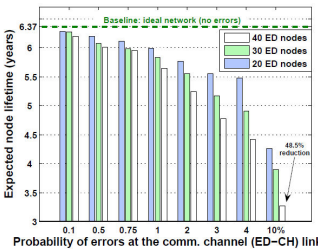
- **Hibernation technique:** use of electronic switches to power on/off the devices (non-trivial technique)
- **Power-Matching (PM) technique:** only very small currents are supplied by the battery (use of supercapacitors)
  - Without this technique, the lifetime of non-rechargeable batteries in a WSN node is only ~10 to 30% of the expected

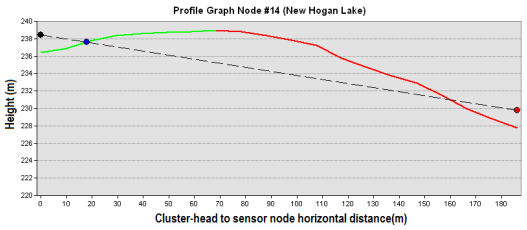


BETS: a novel cross-layer protocol for low duty-cycle WSNs [3]

- **2-Tier network:** asynchronous and segmented solution
  - ☺ Higher scalability ☹ Higher latency ☹ Mobile nodes not supported
- **Hybrid and open:** any wireless point-to-point technology
- **New cross-layer protocol (BETS) :** application-level overlay
  - ☺ Network overhead smaller than 0.5% no matter the network size
  - ☺ Impressive energy performance due to hibernation and PM techniques







Conclusions & Future Work

- So far, 98 sensor nodes (from a total of +170) have been deployed at the Sacramento (CA) area and Canton (OK): among the largest WSNs so far deployed (in terms or coverage area). The first experiments started on Nov 2011.
- The majority of the nodes already achieved the double lifetime compared with current state-of-the-art WSN solutions.
- The solution imposes a significant time gap between the messages of the nodes (~4s). Nonetheless, the overall message loss is smaller than 5% under very critical deployment scenarios (distances and topography).
- We plan to adapt the solution to Wireless Underground Communication networks [4].

References

[1] Mahta Moghaddam et. al. "A wireless soil moisture smart sensor web using physics-based optimal control: concept and initial demonstration," *IEEE-JSTARS*, vol. 3, no. 4, pp. 522-535, December 2010.
[2] Agnelo Silva, Mingyan Liu, and M. Moghaddam . "Power Management Techniques for Wireless Sensor Networks and Similar Low-Power Devices Based on Non-Rechargeable Batteries," *EURASIP Journal on Wireless Communications and Networking*, vol. 2012, Article 757291, August 2012.
[3] Agnelo Silva, Mingyan Liu, and M. Moghaddam . "BETS: Best-Effort Time-Slot Allocation Networking Protocol for 2-Tier Wireless Sensor Networks," *Proc. ACM MiSeNet' 12*, August 2012.
[4] Agnelo Silva and Mehmet Vuran, "Development of a Testbed for Wireless Underground Sensor Networks," *EURASIP Journal Wireless Communications and Networking*, vol. 2010, Article 620307, 2010.

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