Ming Hsieh Department of Electrical Engineering

A novel hybrid, asynchronous, and open architecture for highly-scalable and low duty-cycle Wireless Sensor Networks

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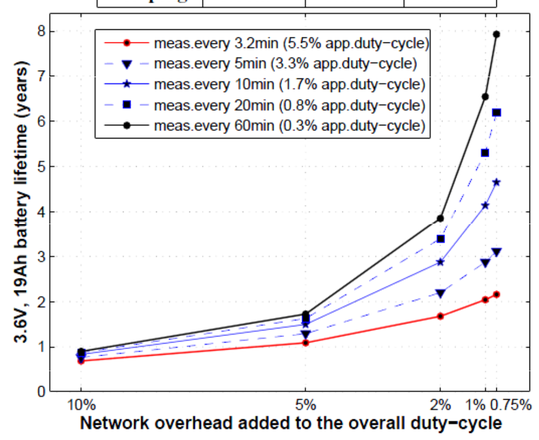
Introduction & Motivation

Wireless Sensor Networks (WSNs) enable people and machines to interact with the environment (air, soil, water bodies, buildings, roads, cars, human body, etc.).

- **Fact 1: WSN nodes typically are battery-powered.**
- **Fact 2: current WSN protocols have a high overhead. For larger networks, such overhead is typically higher than 10%, aggravating the issues related to energy.**
- **Fact 3: for very low duty-cycles regimes (i.e. < 1%), the battery lifetime is drastically reduced if the network overhead is higher than 0.75% (vide figure). [1]**
- **Traditional approach: energy harvesting techniques, in particular for outdoors. [2]**
- **Our goal: design a WSN architecture *tailored* for low duty-cycles applications which is low-cost, highly-scalable, reliable, and has impressive energy performance.**

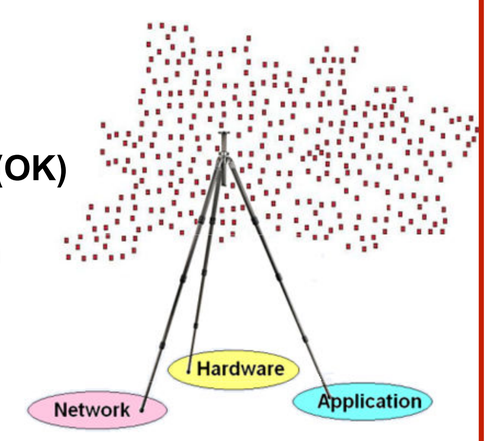
	MCU	Sensors	Radio
Active	5mW	30mW	70mW
Sleeping	0.01mW	0.1mW	0.1mW



Initial Vision

Energy efficiency can be significantly enhanced by simultaneous actions in:

- **Application: low duty-cycle (OK)**
- **Hardware: reducing the sleeping power consumption**
- **Network: reducing network overhead to less than 0.75%**



<u>Bottom line</u>: a *cross-layer* approach involving the above 3 areas

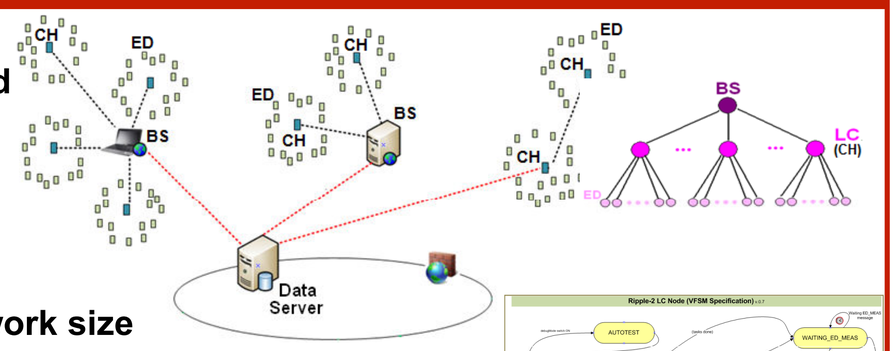
Action 1: Ultra-Low Power Management [3]

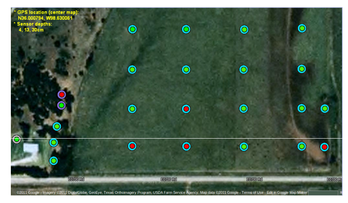
- **Power-Gating technique: use of an electronic switch to power on/off the devices (non-trivial technique):**
  - ☺ **Energy savings higher than <u>1 order of magnitude</u>**
  - ☹ **Higher complexity and costs**
  - ☹ **Higher latency: lower network performance**
- **Power-Matching technique: only small currents from the battery, no matter the load [3]:**
  - ☺ **The expected reduction lifetime of a non-rechargeable cell: from more than 50% to <u>less than 15%</u>**
  - ☹ **Higher complexity and costs (supercapacitors)**

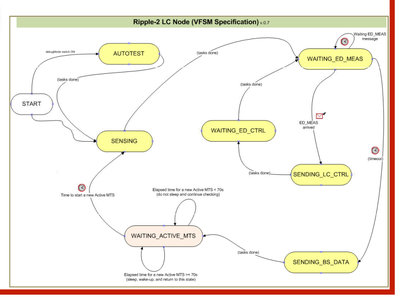
Action 2: New network architecture and cross-layer protocol [1]

- **2-Tier network: asynchronous and segmented solution**
  - ☺ **Higher scalability** ☹ **Higher latency** ☹ **Mobile nodes not supported**
- **Hybrid and open: any wireless point-to-point technology**
  - ☺ **Lower obsolescence risk, easy adoption**
  - ☹ **Lower network performance**
- **New cross-layer protocol (BETS) : application-level overlay**
  - ☺ **Impressive <u>network overhead smaller than 0.5%</u> no matter the network size**
  - ☺ **Impressive overall energy performance: lifetime of the network can be realistically extended <u>multiple times</u> in comparison with state-of-art WSNs**
  - ☹ **Lower network performance**

<u>Bottom line</u>: network performance is traded for energy efficiency + scalability

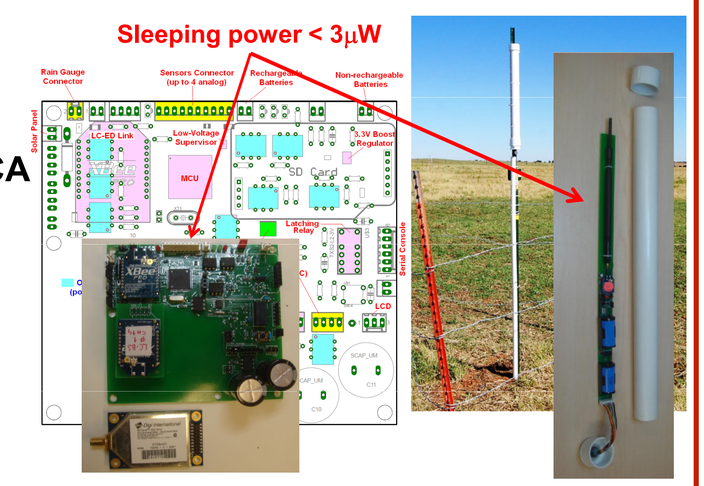






Industry Impact & Future Work

- **Outdoors deployments since Aug11: the above results have been confirmed.**
- **So far, more than 14,000 lines of code: a new software engineering methodology for embedded systems was developed based on virtual finite state machines.**
- **A deployment of a150-node network (450 soil moisture sensors) at Sacramento-CA (Summer 12) will be the largest WSN so far deployed in terms of coverage area.**
- **The energy efficiency is high enough to allow a full-deployment based on <u>non-rechargeable batteries</u> (lifetime ~2yr for 20-min measurement cycles).**
- **This solution can be potentially applied to any sense-and-send periodic application with low-duty cycle which does not involve mobile nodes. In particular, infrastructure and <u>environmental monitoring</u> systems and wireless <u>underground sensor networks</u> [4] are potential target applications.**



References

[1] M. 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] A. Silva and M. Moghaddam . “BETS: Best-Effort Time-Slot Allocation Networking Protocol for 2-Tier Wireless Sensor Networks,” *submitted for publication*, March 2012.
[3] A. Silva and M. Moghaddam . “Power Management Techniques for Wireless Sensor Networks and Similar Low-Power Devices Based on Non-Rechargeable Batteries,” *submitted for publ.*, March 2012.
[4] A. Silva and M. C. Vuran, “Development of a Testbed for Wireless Underground Sensor Networks,” *EURASIP Journal on Wireless Communications and Networking*, vol. 2010, Article ID 620307, 2010.

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