Building Adaptable Sensor Networks with Sensor Cubes:

A Modular, Ultra-Compact, Power-Aware Platform

H. Diall, K. Raja, I. Daskalopoulos, S. Hailes, T. Torfs, C. Van Hoof and G. Roussos

Contact: Tom.Torfs@imec.be or dima@dcs.bbk.ac.uk

Porting TinyOS to the sensor cube platform

Porting challenges

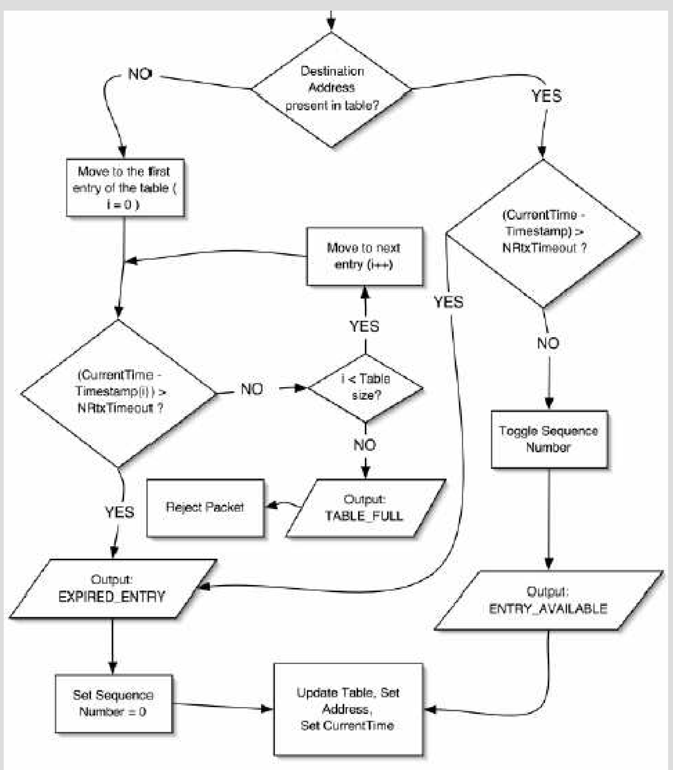
- **Minor changes**: support for the MSP430-based platform and sensor modules
- **Major challenge**: adding support for the Nordic wireless transceiver
- Evident from early on that a **different MAC layer** (i.e. no carrier sense or long preambles as in B-MAC) would be required to exploit the radio's characteristics:
  - by design, the hardware platform lacks a high speed clock source to avoid substantially higher power consumption, thus precluding the use of the transceiver's so-called Direct Mode that enables a fine-grained control of the radio (at the cost of greater software complexity);
  - the alternative ShockBurst mode provides a simple packet send/receive interface, limited to 32 bytes of length (including header and payload), with addressing and CRC processing being handled by the radio chip.

Design decisions

- **Aloha-based MAC protocol** using ShockBurst mode (short packets and high bit rate reduce collision probability);
- **Radio duty cycle** to reduce active time, thus achieving low energy consumption;
- Link layer **acknowledgements and retransmissions** to increase reliability;
- **20 bytes of payload** for standard TinyOS Active Messages.

Deployment decisions

- Duty cycle (sleep and awake time) selection for target application scenario;
- Radio chip bit rate: 250Kbps or 1Mbps;
- Optionally, other protocol parameters:
  - disabling acks & retransmissions;
  - ack/retx timing thresholds.

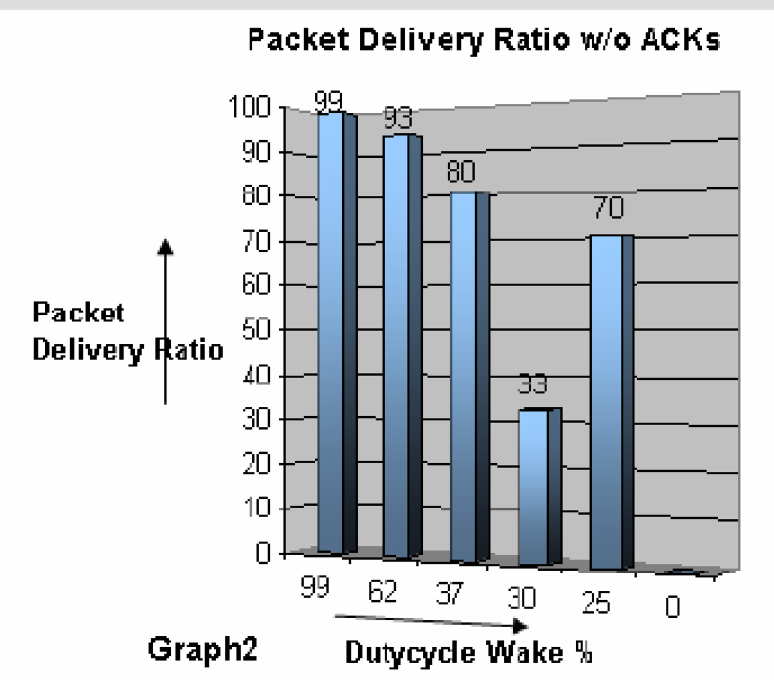


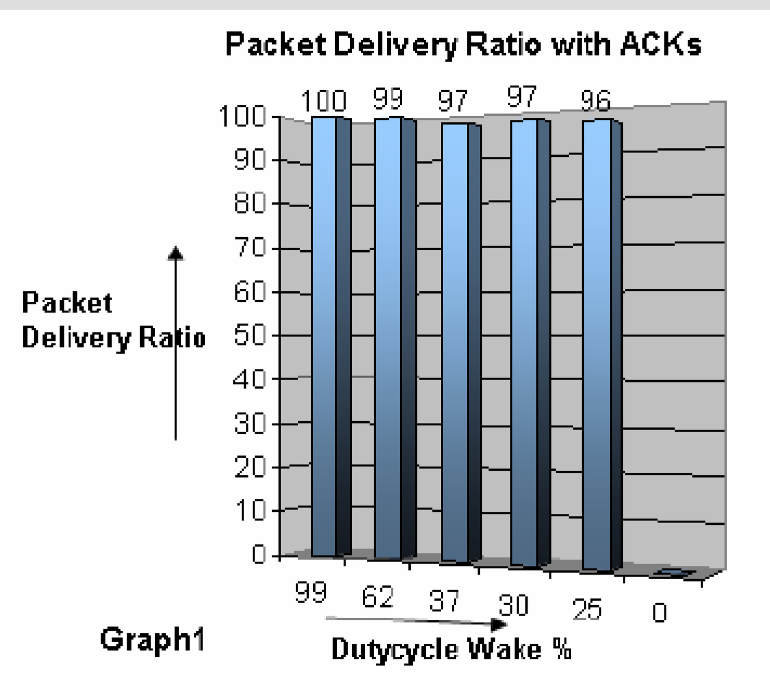
Transmitter's MAC table logic:

Performance:

Two sets of experiments were conducted:

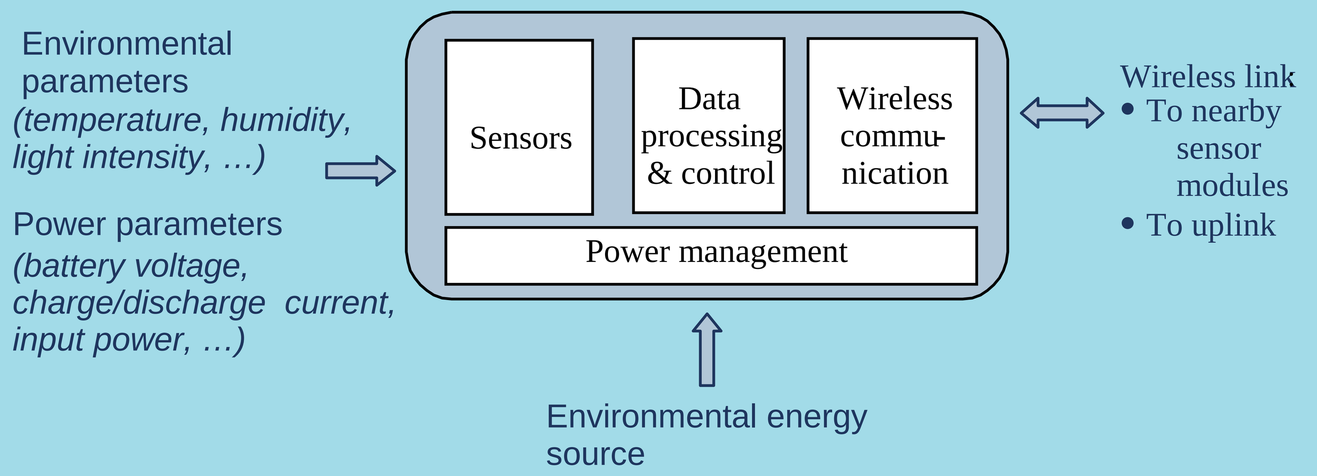
- In the first case, acknowledgements and retransmissions were disabled in order to give a baseline measurement. The transmitter and receiver were placed 6 meters apart and 100 ShockBurst packets were transmitted, with different duty cycle periods at the receiver.
- In the second set of experiments, and in spite of low wake time in the duty cycle (radio active 25% of the time) the packet delivery ratio remained high (at 96%). Thus, this configuration of the MAC protocol smoothes out the synchronization effects seen in the previous experiment, in addition to providing reliable delivery.





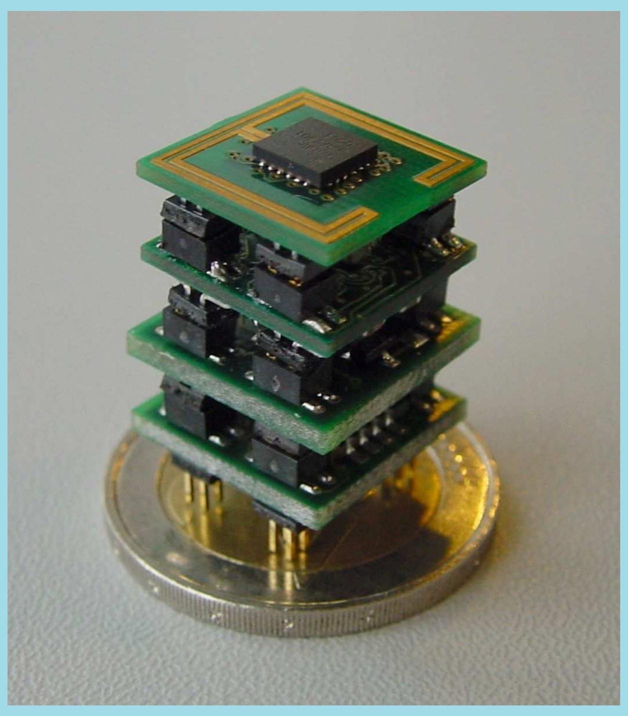
Sensor module hardware

Block schematic of autonomous wireless sensor module



Wide application range requires flexible configuration:

- Wireless, processing, sensors & power management are separate layers
- System combines general purpose layers with application-specific layers
- "Lego"-like reversible module assembly of layers allows easy experiments, upgrades and extensions



Wireless sensor module on 2 EUR coin

Example sensor module

- **Wireless layer:** Nordic nRF2401 2.4GHz FSK transceiver (18 nJ/bit) with coplanar integrated folded dipole antenna
- **Processing layer:** T.I. MSP430 low power (0.6 nJ/instruction) microcontroller with on-chip 12-bit ADC
- **Power layer:** accepts energy from compact solar cell or thermo-electric generator, target power 100-200µW
- **Sensor layer:** measures temperature (±0.4°C), relative humidity (±2%) and illumination (±3%, lux).

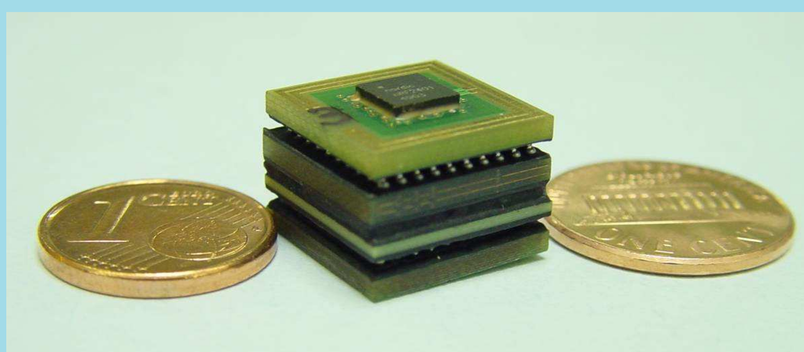
Total size: 14x14x18 mm³

Small-scale sensor network

Small scale network tests

- A small batch of 20 modules was assembled
- Experiments aimed to verify real-world network algorithm and power management behavior
- Results from small scale tests can be compared with simulations and fed back into a simulation program to predict the performance for large scale networks

Alternative hardware implementation using solder ball interconnect technology



Total size: 14x14x10 mm³

UCL imec Birkbeck UNIVERSITY OF LONDON