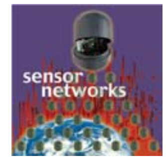
WiseNET

(Or, how to make a sensor net node that lasts as long as your battery's shelf life)

Motivation

- Goal: sensor network hardware that can run for 2-5 years off a single 1.5V AA alkaline battery.
- This means average power less than 10-100 µW.
- Typical commercial radio transceivers require > 10mW



Outline

- WiseMAC Protocol
  - Optimized for low duty cycle operation
- Optimized Radio Transceiver
  - Low power
- System On Chip design

Communication Power Consumption

- How to communicate when nodes sleep most of the time?
- Design MAC to reduce wasted power due to:
  - Idle listening
  - Overemitting
  - Overhearing
  - Collisions

Preamble Sampling

- Carrier Sense, Multiple Access
- Preamble Sampling
  - I.e. don't listen all the time, just sample and wait for a preamble
  - Sampling = measure received signal strength
- (This isn't the new part…)

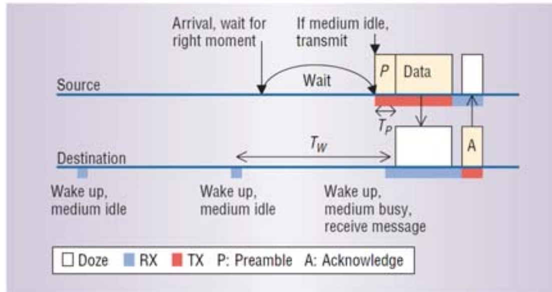
Fixed-Length Preamble

- All nodes sample medium with same period, independent offsets.
  - If busy, listen until receive packet or not busy.
- Transmitter sends preamble longer than sampling period before each packet.
- + Low power for low traffic
- - Power overhead for long preamble
  - xmit, plus rcv for all nodes that hear preamble

WiseMAC: Minimized Preamble

- Nodes also send time to next sample in acknowledge packets.
- Nodes maintain table of offsets for common destination nodes.
- Duration of wake-up preamble adjusted to cover maximum drift between clocks.

WiseMAC Preamble Minimization



WiseNET Wakeup Preamble Size

- Tp = min(4θTc, Tw)
- Tp = duration of the preamble
- θ = frequency tolerance of time-based quartz
- Tc = interval between communications
- Tw = sampling period
- Covers potential drift between clocks

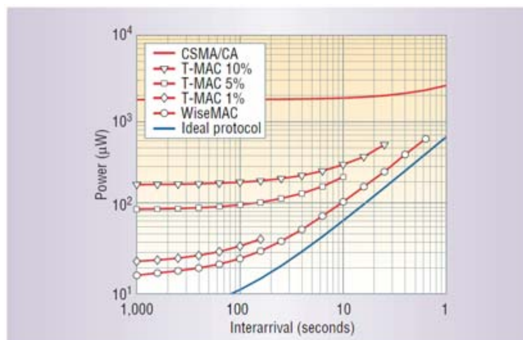


Figure 2. Lattice multihop topology simulation. The results show average power consumption as a function of the network's node traffic. The T-MAC protocol can provide either low-power consumption in low-traffic conditions or high throughput.

Power Comparison

- CSMA limited at low traffic
  - Receiver never turned off
- T-MAC
  - Choose duty cycle
  - Drops packets at low duty cycles, so get either low power in low traffic or high throughput
- WiseNET is ultralow-power for low traffic, efficient for high traffic.

Radio Design

- Transceiver is biggest power drain in the sensor node.
- WiseMAC is designed for low duty cycle operation. Optimize the transceiver, too.

Radio Design Choices

- Chose high constant transmit power (max allowed in Europe for 434MHz ISM)
  - Nodes usually listen a lot, transmit rarely
- Dual-band, multi-channel to reject strong interference
- Reduce energy consumption and wakeup time in receive mode.

Dual-Band, Multi-Channel

- 433MHz ISS, 868 MHz SRD
- Avoid interference from other sources.
- Why not 2.4GHz? (popular, globally available) Power.
  - 50% of receiver power due to circuits operating at the carrier frequency, and power is proportional to the frequency.

Receiver Power

- Receiver power much larger for RF blocks
  - Current directly related to frequency of operation or required bandwidth.
  - These are also the blocks that wake up quickly.
- Turn-on time varies inversely with frequency.
- So save power by waking up baseband components first, then RF circuits.

WiseNET Optimizations

- Flexible wake-up sequence
  - Low frequency reference clock
  - Baseband path of channel filters, limiters, & RSSI.
  - Frequency synthesizer
  - Intermediate frequency amplifiers
  - RF frequency low-noise amplifier & mixers

WiseNET Optimizations

- Use RSSI to determine whether to power up rest of the broadband receive chain
  - I.e. if there's no signal, don't process it
- Minimize wakeup time for baseband and intermediate frequencies.
  - Deep submicron process, trade speed for power.
  - Circuit tricks to wake up the baseband fast.

Fast Rx/Tx Turnaround

- You're burning power when switching from Rx to Tx or vice versa, so do it fast.
- WiseNET shares the core (intermediate frequency) circuitry for the receivers and transceivers, so there's very little turnaround time.

WiseNET—SOC

- Custom System-On-Chip (SOC)
- Most sensor node functionality on a single chip to reduce power consumption.
  - Sensing, processing, storing, communicating

WiseNET Node Architecture

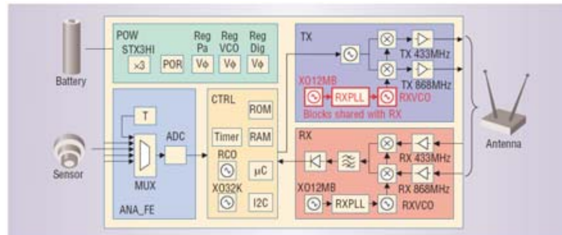
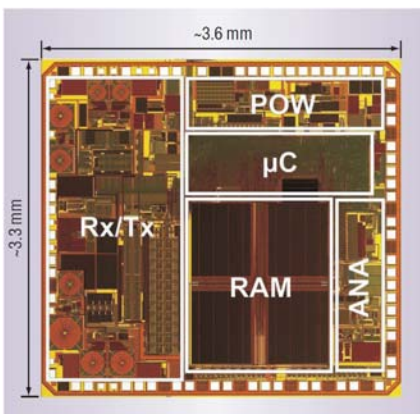


Figure 3. Generic WiseNET SoC building blocks. In addition to the ultralow-power dual-band radio transceiver (Tx and Rx), the architecture includes a sensor interface with a signal conditioner and two analog-to-digital converters (ANA FE), a digital control unit based on a Cool-RISC microcontroller (μC) with on-chip low-leakage memory, several time-basis and digital interfaces, and a power management block (POW).



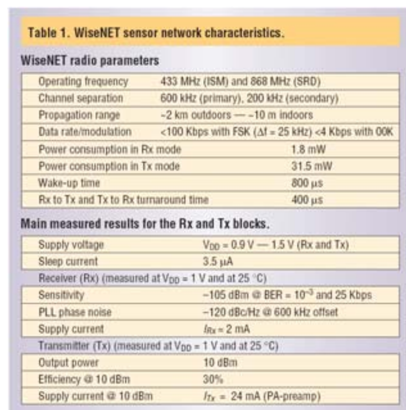


Table 1. WiseNET sensor network characteristics.

WiseNET radio parameters

Operating frequency	433 MHz (ISM) and 868 MHz (SRD)
Channel separation	600 kHz (primary), 200 kHz (secondary)
Propagation range	~2 km outdoors — ~10 m indoors
Data rate/modulation	<100 Kbps with FSK (Δf = 25 kHz) <4 Kbps with OOK
Power consumption in Rx mode	1.8 mW
Power consumption in Tx mode	31.5 mW
Wake-up time	800 μs
Rx to Tx and Tx to Rx turnaround time	400 μs

Main measured results for the Rx and Tx blocks.

Supply voltage	V_{DD} = 0.9 V — 1.5 V (Rx and Tx)
Sleep current	3.5 μA
Receiver (Rx) (measured at V_{DD} = 1 V and at 25 °C)	
Sensitivity	−105 dBm @ BER = 10^{-3} and 25 Kbps
PLL phase noise	−120 dBc/Hz @ 600 kHz offset
Supply current	I_{Rx} = 2 mA
Transmitter (Tx) (measured at V_{DD} = 1 V and at 25 °C)	
Output power	10 dBm
Efficiency @ 10 dBm	30%
Supply current @ 10 dBm	I_{Tx} = 24 mA (PA-preamp)

Bottom Line

- WiseNET transceiver with WiseMAC protocol consumes 25uW when forwarding 56-byte packets every 100 seconds.
- For comparison, Motes…
  - 24mW in receive mode
  - SMAC or TMAC, 10% duty cycle => 2.4mW

To Sum Up…

- SystemOnChip design
- WiseMAC protocol
  - Minimal preamble size reduces xmit and receive overhead.
  - Preamble filtering reduces overhearing.
- Cool radio transceiver
  - Low power.
  - Efficient wakeup.
  - Quick turnaround between Rx and Tx.