ECE 471 – Embedded Systems
Lecture 26

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Announcements

- Project Update
- Remember to return your gumstix hardware by finals
- Course Evals

HW#5 Review

- Unexpected results: ATLAS not much better than naïve on Cortex A8
- ATLAS is an optimized BLAS (linear algebra) that tries to auto-optimize. When setting it up you let it run, trying lots of parameters to the various functions. After a while (hours?) it produces a library based on its experimental findings
- There can be faster BLAS libraries. goto for example,

which is hand-optimized x86 assembly

- Why is Cortex A8 so bad? Well the vfp unit apparently is really bad (Cortex A9 is much better). Also we are doing DGEMM and neon (SIMD support) is only single-precision?

- On ARM Cortex A9 pandaboard there is a noticeable performance increase (5.5s to 1.57s) using ATLAS, but that might mostly be due to having multiple processors

Brief Final Exam Review

- 6 questions?
- ARM assembly
- Definition of embedded systems
- Hard/Soft Realtime
- Bus tradeoff question
- Security Related Question

- Power/Performance question, like HW#5

Wireless Sensor Networks

- Low-power, scatter about and forget
- Report stats to central server
- Need to last long time and not use much energy
- Science Fiction element. For example, see *A Deepness in the Sky* by V. Vinge.

Uses for large sensor networks?

- military
- precision agriculture
- civil engineering: traffic / bridge sensing / industrial
- research: biology / environmental

Sensor Types

- *Survey of Hardware Systems for Wireless Sensor Networks*, Hempstead, Lyons, Brooks, and Wei, 2008.

- Very Low Frequency
  Temperature, Atmos Pressure – 0.17 - 1Hz

- Low Frequency
  Heart Rate – 0.8 - 3Hz
  Volcano Infrasound – 20 - 80 Hz
  Seismic – 0.2 - 100Hz

- Mid Frequency
  Earthquake Vibrations – 100 - 160Hz
  ECG (Heart) – 100-250Hz

- High Frequency
  Breathing – 100 - 5kHz
  Industrial – 40kHz
  Audio (human speaking) – 15-44kHz
  Audio (muzzle shock) – 1MHz
  Video (digital television) – 10MHz

Sensor Deployments

- Great Duck Island Maine – looking for rare seabirds
- Industrial – listen for failures in chip fab
- Volcano Monitoring
- Countersniper

Commodity Systems

- Off-the shelf

- if sampling is low and have good sleep behavior, can be competitive

Event Driven

- Handle events in hardware

Application Acceleration

- Hardware assist of detection, lowering energy use (General Purpose computing often wastes energy)

Some Implementations

- Berkeley: Motes, Renee, Mica, Dot
- Rockwell: WINS – ARM 32bit
- MIT: uAMPS, Cricket
- UCLA: iBadge, Medusa – 40MHz ARM
- U-Washington: SpotON
- U Tokyo U**3

- USC: ROBOMOTE
- Berkeley: Smart Dust?

Energy Saving Schemes

- Same as we've seen on larger systems
- DVFS, leakage mitigation, etc, as seen on bigger
- *Improving Energy Efficiency of Personal Sensing Applications with Heterogeneous Multi-Processors* (Heterogeneous)
- Concentration on low-power transmitters

MICA

- MICA: A Wireless Platform for Deeply Embedded Networks, Hill and Culler 2002
- peer-to-peer networking
- microamps of power. Last years on AA or coin cell. 100x less than cellphone
- not depend on outside architecture. Cell phones depend on high-powered base stations with fast connectivity

- network protocol... IEEE 802.11b might only take 25-100mW to transmit but processing the protocol can take up to 2000mW for high data rates

- Bluetooth maybe more suitable, but still take 115mW to communicate with a master node

- cell phone protocols optimize for latency. deep embedded can tradeoff latency and bandwidth. If only sampling every few minutes as is, delaying transfer by a few seconds not as critical

- have highly configurable software radio

- 1.25x2.25 inch, size of two double A batteries
- standby current on level of microamps
- thermal, barometric, magnetic, light, infrared, acceleration, vibration, acoustics
- 8-bit ATMEGA128, 4MHz, 128K flash rom, 4kB static RAM, 48GPIOS, SPI bus, 3 timers
- radio transmitter max outputs 0.75mW, (1/1000 of cell phone) while drawing 21mW. can transmitting up to 115kBPS

- 200 feet range, receive takes 15mW (whether receiving or not)

- 4Mbit flash chip for holding data

- Maxim 1678 DC/DC converter. Constant 3.3V supply. Can boost up from 1.1V, good as 50% of alkaline batteries below 1.2V. Boost converter can be disabled in ultra-low-power mode

- 51 pin expansion bus

Component	Active	Idle
CPU	16.5mW	30uW
Radio	21/15 mW	0
Silicon ID	0.015mW	0
External Flash	45mW	30uW
LED	10mW	0

- pooled operating. Radio packet start requires 3MIPS. Sensor reading 2MIPS. Partitioned system would require provisioning for both (5MIPS). Shared system get by with 3MIPS.

- RAW radio interface allow varied interfaces. Bluetooth or other have no control, can only queue up packets.
- can detect noise and auto-adjust transmit power
- provide some accelerators for the radio, based on existing microcontroller functionality
- low-power wakeup
- time synchronization
- estimate distance based on signal strength

- timed notify, say will turn back on in 5min to update report. master node has to turn on early and wait longer to account for clock drift

Other Implementations

- MICA2 – 7MHz
- TI MSP340 – 16bit, 2mA at 8MHz and 3.0V, few uamps at sleep, 750pJ/instruction
- Smart Dust – 0.25um process (low leakage) 1V and 500kHz, 12pJ/insn

Operating Systems

- Not run Linux
- Why need to run any OS at all? Why not program direct to hardware?

TinyOS

- Initially ran with only 512 bytes of RAM
- special language, nesC
- Not use threads, as threads need stack per process, waste RAM
- Components, state machine.
- Tasks can run to completion, but OS low-level tasks can preempt

Asynchronous Systems

- Necchi, Asynch 2006.
- Asynchronous ATMel compatible
- No clock, so no need to wait for PLL to spin up
- 14pJ/Insn at 1.2V
- 2.7pJ/Insn at 0.51V

WiseNet

- *WiseNET: An Ultralow-Power Wireless Sensor Network Solution* Enz, El-Hoiydi, Decotignie, Peiris, 2004.
- Issues that waste energy:
  - idle listening – waiting when no one is transmitting
  - over-emitting – transmitting and no one listening
  - over hearing – decoding a message not meant for you
  - collision
- Single 1.5V battery

- Lower frequency bands. 2.4GHz band requires more energy 2.4GHz at .18 micrometer process require 1.8V

SNAP/LE

- *An Ultra Low-Power Processor for Sensor Networks*, Ekanayake et. al., 2004.
- MEMS – self powered circuits (vibration), or solar powered, or RF powered
- SNAP/LE
- 16-bit processor, designed for sensor work
- 218pJ/ins at 1.8V and as little as 23pJ/ins at 0.6V

- chart of Energy per instruction