A Higher Capability Sensor Node Platform Suitable for Demanding Applications

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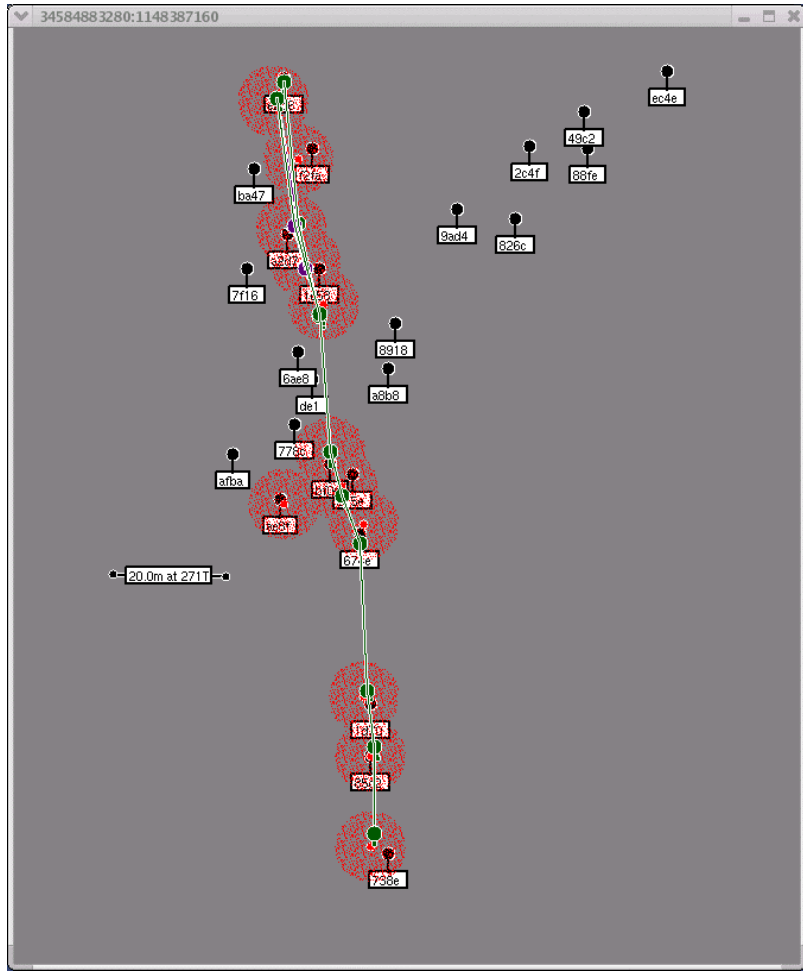
Detect and track intruders in a (supposedly) secure area

Design Guidelines

Node Spacing	**10-30m**
Node Location Accuracy	**1-5m**
Node Deployment Time	**30s**
Deployment Calibration	**none**
Deployment Planning	**none**
Lifetime	**30days**
Number of Expected Targets	**0**
Target Speed	**1-10m/s**
Target Data Bandwidth	**200-2000Byte (50Byte/track point)**
Target Data Latency	**1-20s (1-2s/hop?)**
Overhead Data Bandwidth	**0Byte/s**
Overhead Data Latency	**30s**



Translation to the Technical Problem

Hasty deployment means no infrastructure
so do everything on the nodes

Communicating (or not) is the big energy consumer
so don't (or at least not very much)
keep receiver off most of the time
keep data local until it's verified

We need to accomplish 5 major tasks on the nodes
1. **Local control of the communication schedule (mac)**
2. **It's TDMA, so we also need time synchronization**
3. **Local management of sensor data (database)**
4. **Local confirmation of intrusion (fusion)**
5. **So we also need to know the nodes location**

How much processing power?
How much memory?
How much bandwidth?
How much energy?

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State of the Art is Sort of Vague

Question	Prototype	Product
Has it been built? Or just simulated or analyzed?	Built	Analyzed
Does it work?	Yes	?
Are reported results about a complete node? Or just a subsystem or a part?	complete	complete
Do you need anything else to do the job? Possibly another larger or higher powered device.	No	No
How long is the node lifetime? Doing what? How long are the sleep intervals? What kind of batteries?	1 day personnel surveillance < 1s 2x AA Li/FeS_2	90 days personnel surveillance < 1s 2x AA Li/FeS_2
How much does it cost? Is this cost for the whole thing?	$625 yes	$250 yes
What "development aids" were used during testing? Test network? Off node processing? Power supplies? Calibration? Planning?	None	None

Prohibited Items

Starting Point

powerful processor

lots of memory

accurate location

accurate time

includes sensors

small

low power

Can we have the best of both worlds?

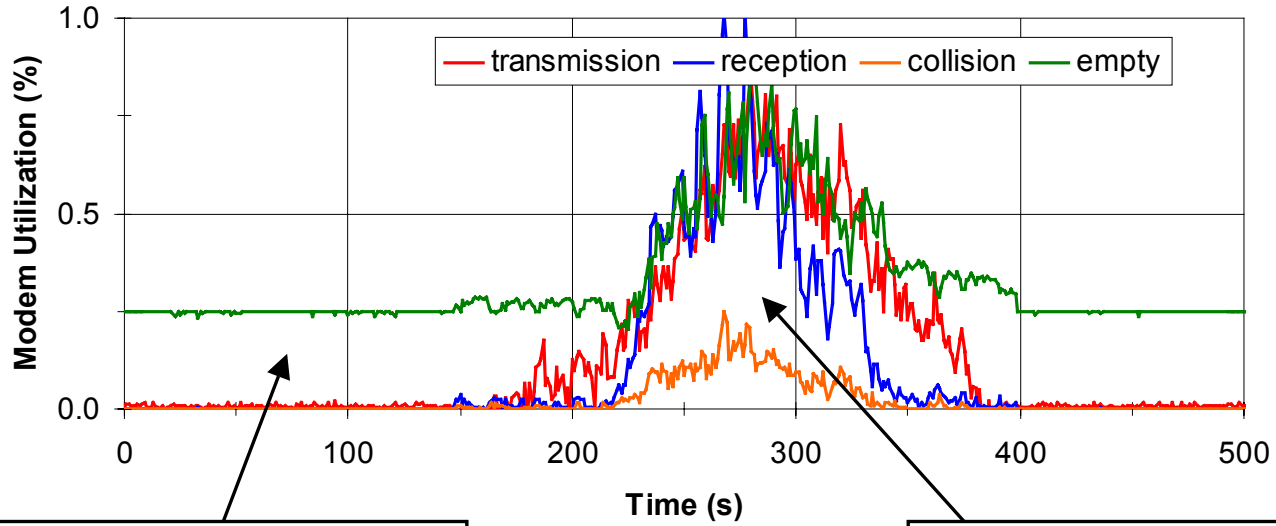
Prototype Node

Parts List

	Prototype		
Function	**Part**	**Size (mm^2)**	**Cost ($)**
Processor	Altera EPXA1F484C3	625	60.00
Program Memory	Intel GE28F320C3BD70	49	6.08
Data Memory	Micron MT48V8M16LFB4-8	64	9.48
Timing	Epson SG-350-SCF 20.00 m-m	9	2.27
Modem	Chipcon CC2400	49	3.98
T/R Switch	Hittite HMC484MS8G (2x)	18	9.96
PA	RFMD RF5189SR	9	3.12
LNA	RFMD RF2373SR	12	2.00
Antenna	GigaAnt 3030A6111-01	48	3.00
GPS	ublox TIM-LA	625	52.70
GPS Antenna	Laipac GLP1-MMCX	625	13.00
Compass	Honeywell HMC1052/HMC1051Z	38	11.06
Sensor	GloLab PIR325/FL65	80	4.52
ADC	Microchip MCP3208-CI/SL	90	2.63
Power Supply	Maxim MAX1566ETL	40	3.51
Other	340 miscellaneous parts		70.51
PCB Fabrication	3 boards: $64.00+$26.87+$30.30		121.17
PCB Assembly	3 boards: $33.75+$22.45+$71.10		127.30
Packaging	Case		117.00
TOTAL			623.29

Costs based on 100 unit build.

Simulated Modem Usage



Quiescent state

1 fan-in, contention managed, receive opportunity per frame

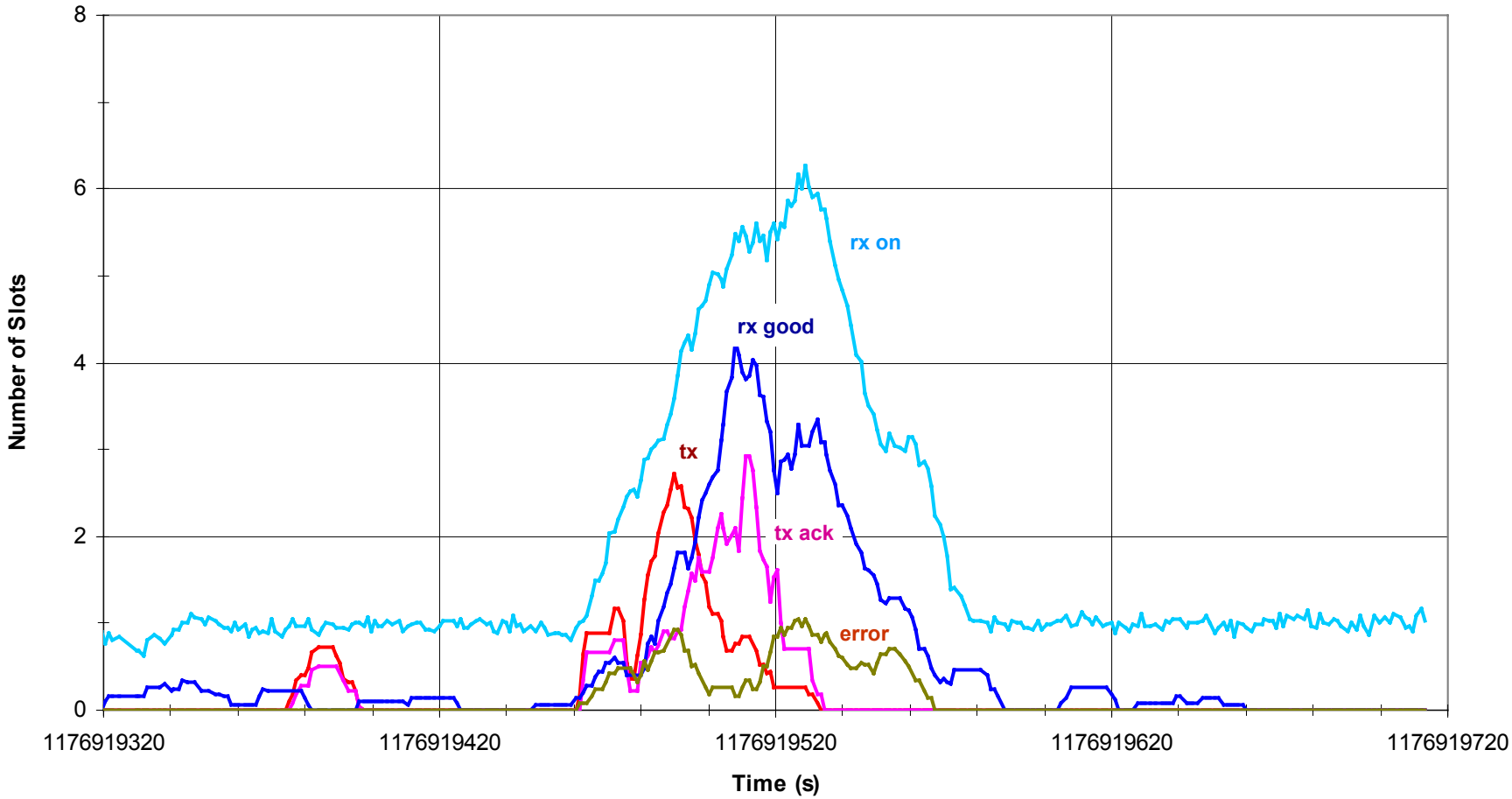
Tracking

broadcast slot created by detection or impending track

	Tx (%)	Rx good (%)	Rx collision (%)	Rx empty (%)
Network Formation	0.129	0.039	0.011	0.180
Quiescent	0.007	0.000	0.000	0.247
Tracking (average)	0.283	0.215	0.044	0.411
Tracking (maximum)	0.840	1.020	0.248	0.855

Data averaged over 100 simulated nodes.
1 slot = 0.25%.

Actual Modem Usage



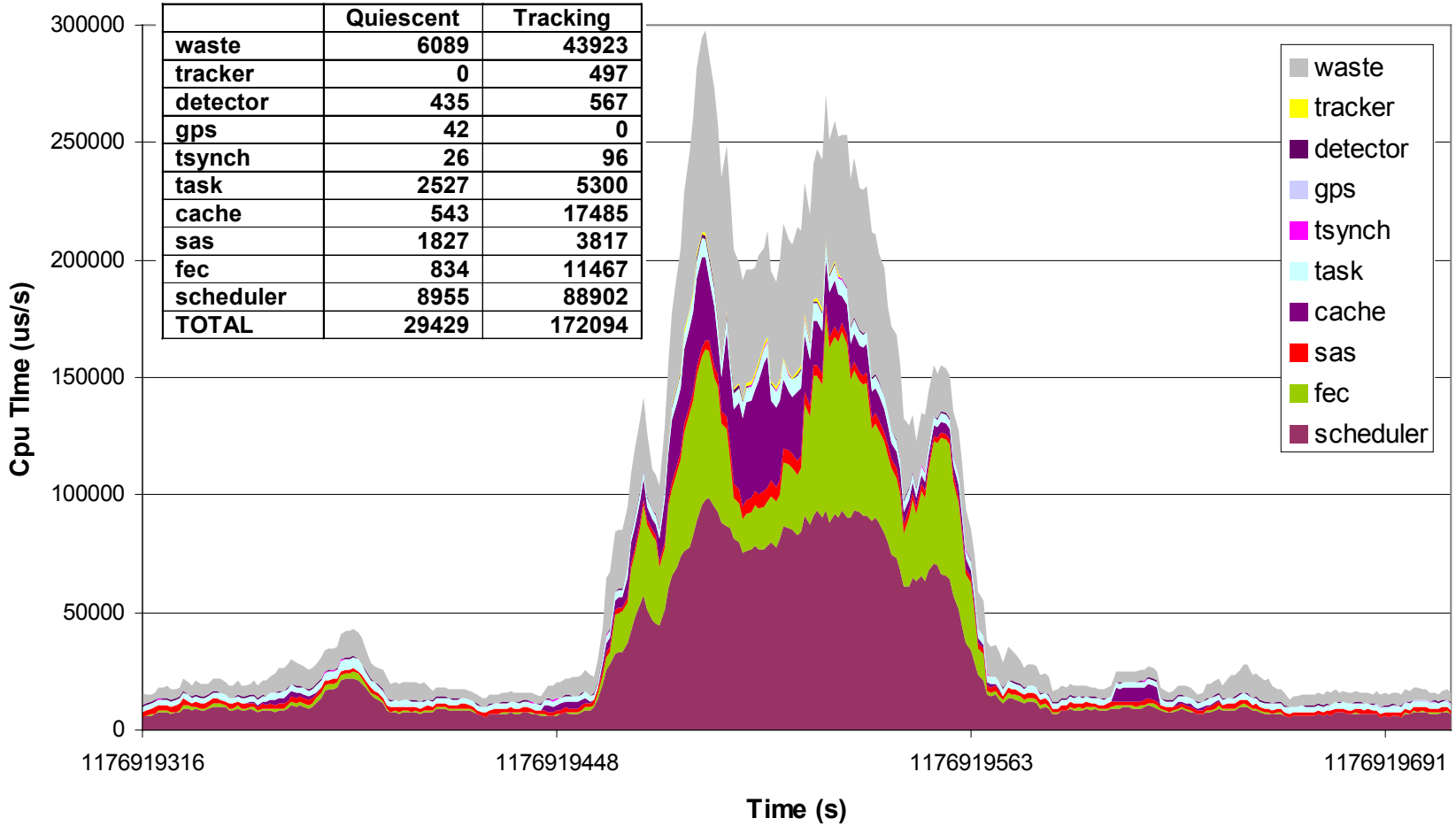
Data collected from centrally located node with 5 neighbors.
1 slot = 0.25%

Fantastic Data

Actual Processor Usage

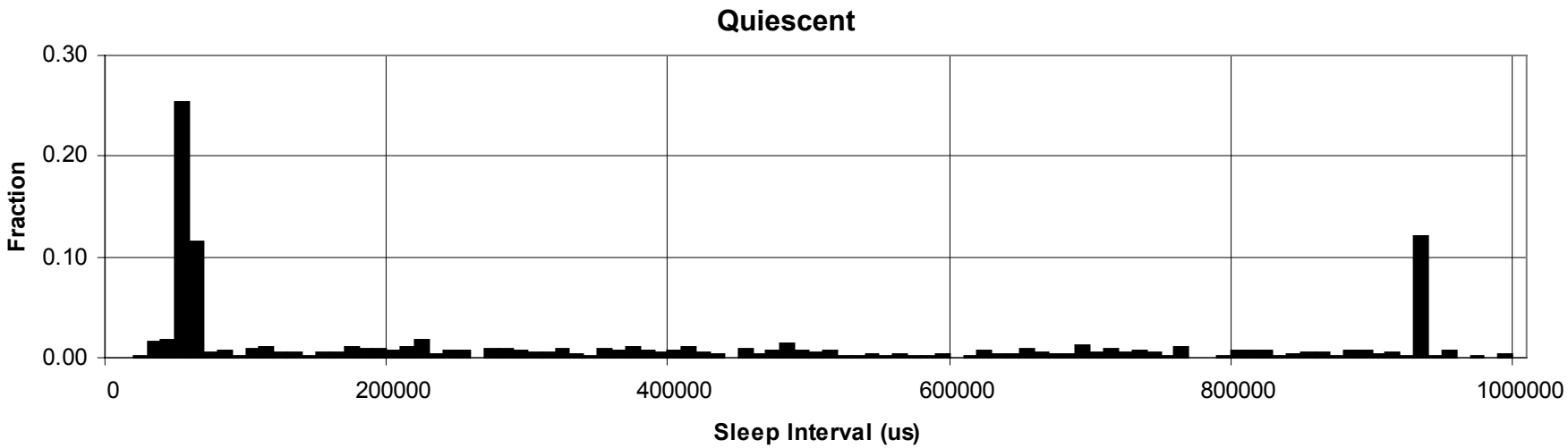
Mean Processor Usage

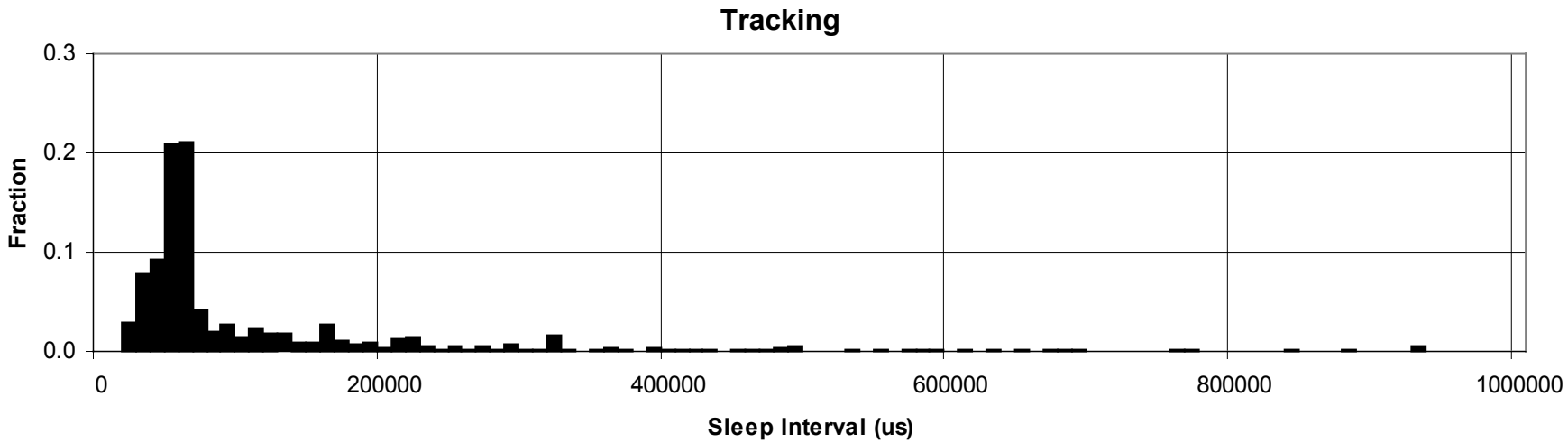
	Quiescent	Tracking
waste	6089	43923
tracker	0	497
detector	435	567
gps	42	0
tsynch	26	96
task	2527	5300
cache	543	17485
sas	1827	3817
fec	834	11467
scheduler	8955	88902
TOTAL	29429	172094



Some fec time logged as part of scheduler. Sum is correct, but fec should be higher and scheduler should be lower.

Actual Sleep Interval





Prototype Memory Usage

Function	Program Memory (kB)	Data Memory (kB)
Operating System	39	5
Location and Timing	43	1
Communication	100	11
Information Management	118	2
Application	35	1
SUBTOTAL	335	20
Test	43	13
TOTAL	378	33

Information management data memory grows to accommodate data records.

Estimated Energy Consumption

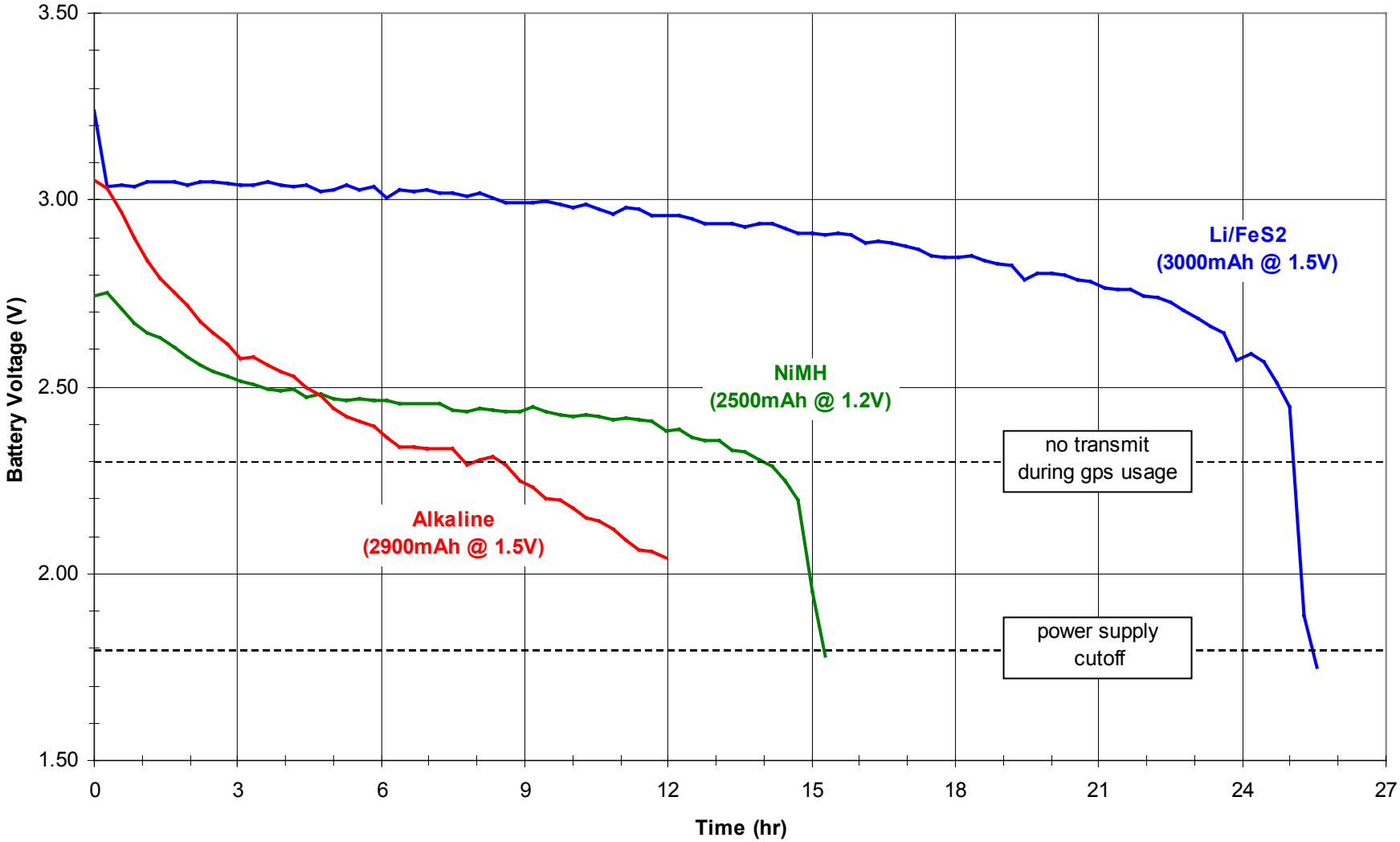
		Prototype		
Item	State	Peak Energy (mW)	Duty Cycle	Average Energy (mW)
Processing/Memory		**603.820**	**0.357143**	**215.650**
processor	fast	603.820	0.050000	30.191
	slow	195.220	0.950000	185.459
Communication		**599.280**	**0.000995**	**0.596**
modem	idle	43.130	0.002200	0.095
	tx	65.830	0.000200	0.013
	rx	86.260	0.002000	0.173
power amplifier	ps=a	556.150	0.000200	0.111
low noise amplifier		102.150	0.002000	0.204
Location/Timing		**351.850**	**0.022796**	**8.021**
gps receiver	acq	324.610	0.006667	2.164
	track	313.260	0.016667	5.221
antenna/lna		27.240	0.023333	0.636
Sensing		**1.135**	**1.000000**	**1.135**
pir		1.135	1.000000	1.135
magnetometer		63.560	0.000000	0.000
temperature		0.000	0.003333	0.000
battery		0.000	0.003333	0.000
TOTAL		**1556.085**	**0.144852**	**225.402**

Battery Type			Lifetime (day)
Alkaline (2900mAh @ 1.5V)			1.553
NiMH (2500mAh @ 1.2V)			1.109
Li/FeS2 (3000mAh @ 1.5V)			1.664

Peak energy measured. Duty cycle estimated.

Fantastic Data

Actual Energy Consumption



Not Good Enough!

We want a lifetime of at least 30 days

- processor/memory energy consumption is the big problem
- GPS receiver energy consumption is secondary
- communication and sensor are not a problem

We want it to be smaller

- 3 board stack is very wasteful
- power supply (including batteries) is biggest subsystem
- processor/memory is second biggest subsystem
- GPS receiver module is third

We want it to cost less

- biggest cost is PCB fabrication and assembly
- processor/memory is second
- GPS is close third

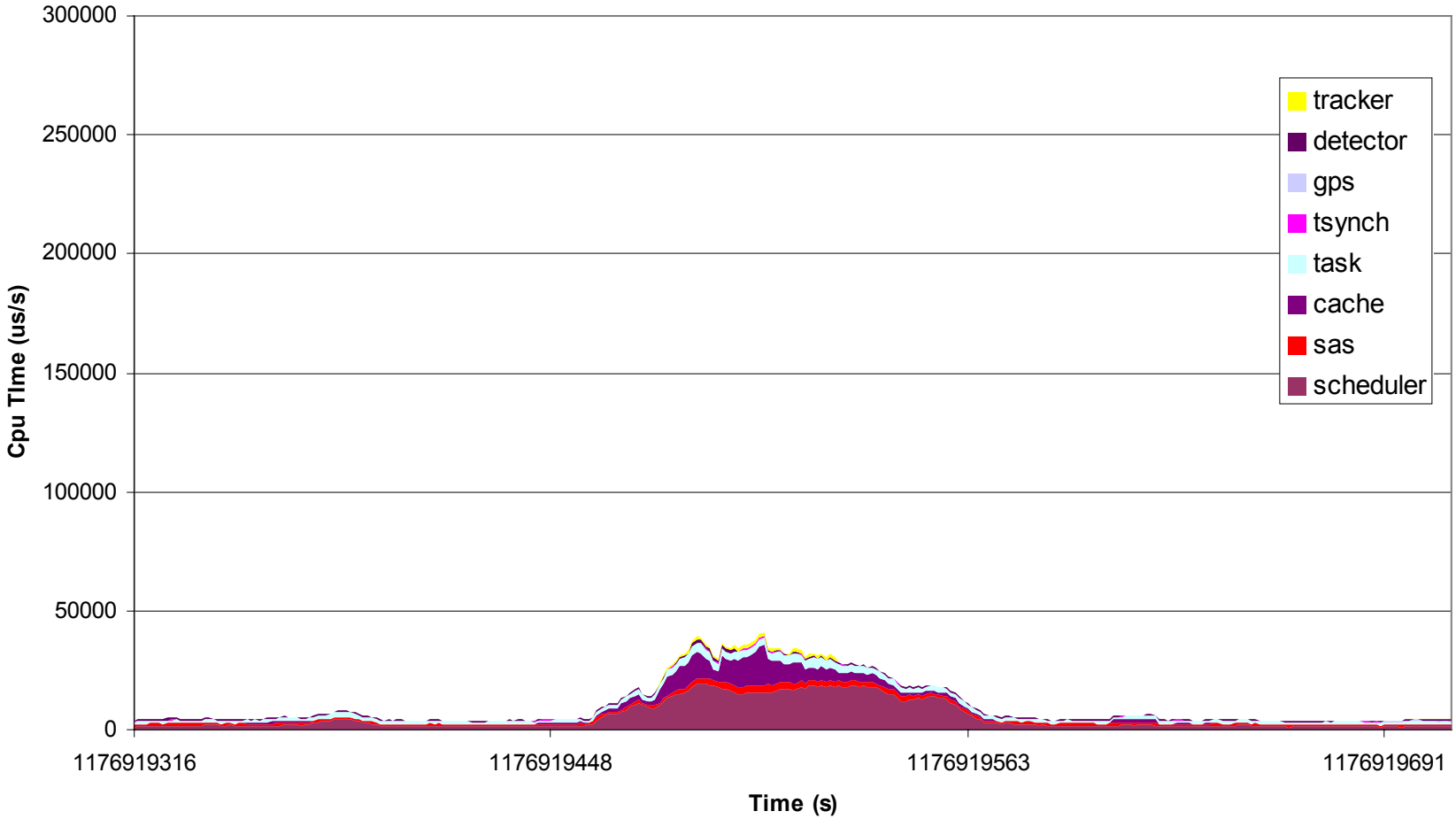
Integrated Processing Core/Memory/ADC/etc.

- Cheaper and smaller
- Eliminate many signal nets (reduce PCB complexity)
- Eliminate many ancillary parts (capacitors)

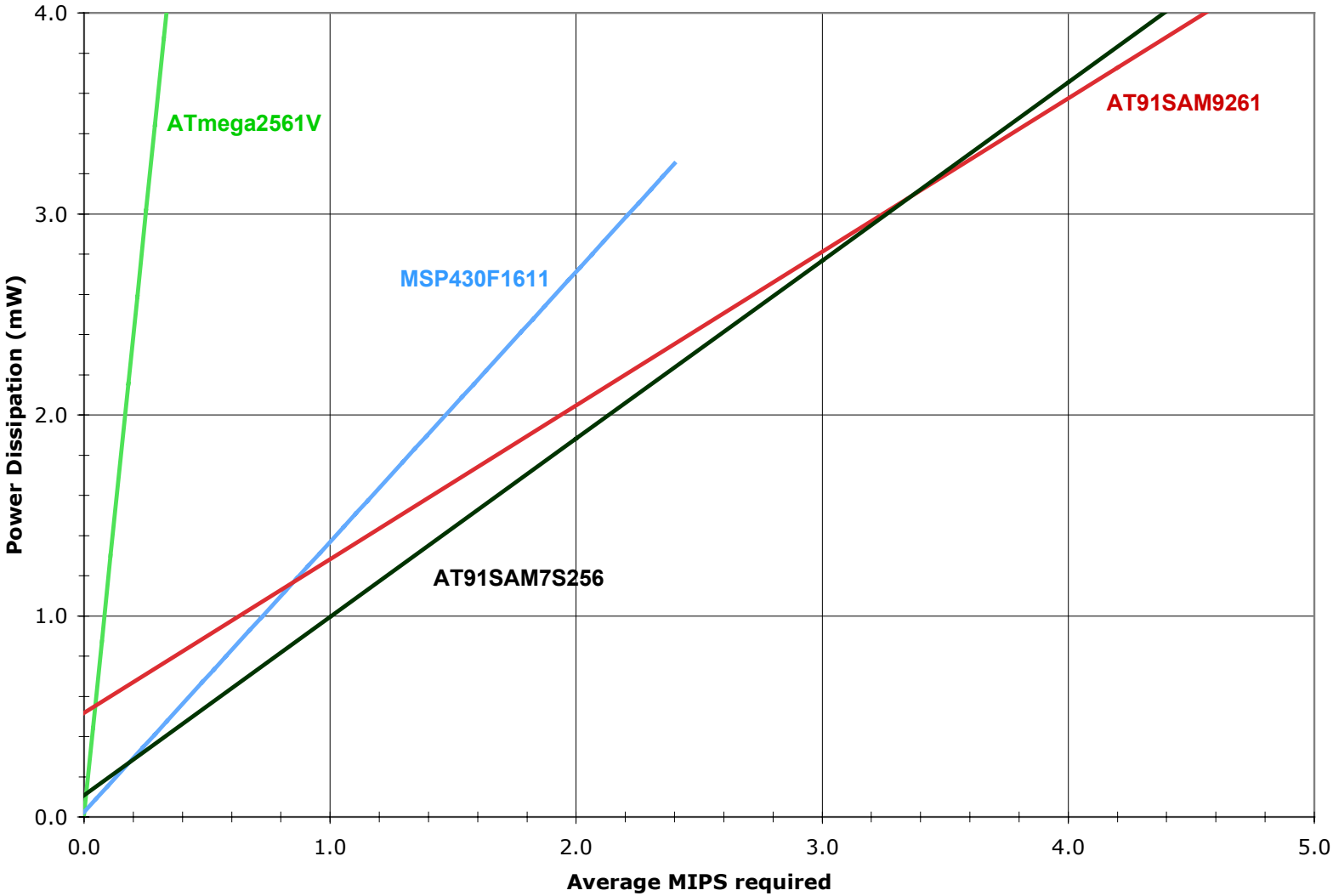
- Lots of choices available. Which one is right for us?
  - AVR
  - MSP430
  - ARM7
  - ARM9
  - more

- How much processing power do we really need?
- How much memory do we really need?

Predicted Processor Usage



Processor Performance



Fantastic Data

Parts List

	Prototype			Product		
Function	Part	Size (mm^2)	Cost ($)	Part	Size (mm^2)	Cost ($)
Processor	Altera EPXA1F484C3	625	60.00	Atmel AT91SAM7S256	81	8.70
Program Memory	Intel GE28F320C3BD70	49	6.08	included with processor		
Data Memory	Micron MT48V8M16LFB4-8	64	9.48	included with processor		
Timing	Epson SG-350-SCF 20.00 m-m	9	2.27	Abracon ABM8-16.000MHz-B2-T	8	1.50
Modem	Chipcon CC2400	49	3.98	Chipcon CC2500	16	2.66
T/R Switch	Hittite HMC484MS8G (2x)	18	9.96	NEC UPG2214TB (2x)	4	0.56
PA	RFMD RF5189SR	9	3.12	NEC UPG2314T5N	3	2.00
LNA	RFMD RF2373SR	12	2.00	Maxim MAX2641	9	0.80
Antenna	GigaAnt 3030A6111-01	48	3.00	GigaAnt 3030A6111-01	48	3.00
GPS	ublox TIM-LA	625	52.70	ublox NEOS-4S	200	55.00
GPS Antenna	Laipac GLP1-MMCX	625	13.00	Zhengyuan Electric DAM1575C	324	13.00
Compass	Honeywell HMC1052/HMC1051Z	38	11.06	deleted		
Sensor	GloLab PIR325/FL65	80	4.52	Panasonic AMN44122	150	26.74
ADC	Microchip MCP3208-CI/SL	90	2.63	included with processor		
Power Supply	Maxim MAX1566ETL	40	3.51	Maxim MAX8621	16	3.70
Other	340 miscellaneous parts		70.51	70 miscellaneous parts (est)		20.00
PCB Fabrication	3 boards: $64.00+$26.87+$30.30		121.17	1 board (est)		30.00
PCB Assembly	3 boards: $33.75+$22.45+$71.10		127.30	1 board (est)		30.00
Packaging	Case		117.00	Case (est)		60.00
TOTAL			623.29			257.66

Costs based on 100 unit build.

Estimated Energy Consumption

		Prototype			Product		
Item	State	Peak Energy (mW)	Duty Cycle	Average Energy (mW)	Peak Energy (mW)	Duty Cycle	Average Energy (mW)
Processing/Memory		603.820	0.357143	215.650	45.000	0.052322	2.355
processor	fast	603.820	0.050000	30.191	45.000	0.050000	2.250
	slow	195.220	0.950000	185.459	0.110	0.950000	0.105
Communication		599.280	0.000995	0.596	247.500	0.001007	0.249
modem	idle	43.130	0.002200	0.095	33.000	0.002200	0.073
	tx	65.830	0.000200	0.013	71.280	0.000200	0.014
	rx	86.260	0.002000	0.173	42.240	0.002000	0.084
power amplifier	ps=a	556.150	0.000200	0.111	214.500	0.000200	0.043
low noise amplifier		102.150	0.002000	0.204	17.490	0.002000	0.035
Location/Timing		351.850	0.022796	8.021	270.600	0.002141	0.579
gps receiver	acq	324.610	0.006667	2.164	231.000	0.000278	0.064
	track	313.260	0.016667	5.221	125.400	0.003056	0.383
antenna/lna		27.240	0.023333	0.636	39.600	0.003333	0.132
Sensing		1.135	1.000000	1.135	0.660	1.000000	0.660
pir		1.135	1.000000	1.135	0.660	1.000000	0.660
magnetometer		63.560	0.000000	0.000	0.000	0.000000	0.000
temperature		0.000	0.003333	0.000	0.000	0.003333	0.000
battery		0.000	0.003333	0.000	0.000	0.003333	0.000
TOTAL		1556.085	0.144852	225.402	563.760	0.006817	3.843
Battery Type				Lifetime (day)			Lifetime (day)
Alkaline (2900mAh @ 1.5V)				1.553			94.326
NiMH (2500mAh @ 1.2V)				1.109			65.053
Li/FeS2 (3000mAh @ 1.5V)				1.664			97.579

Prototype peak energy measured. Duty cycle estimated.

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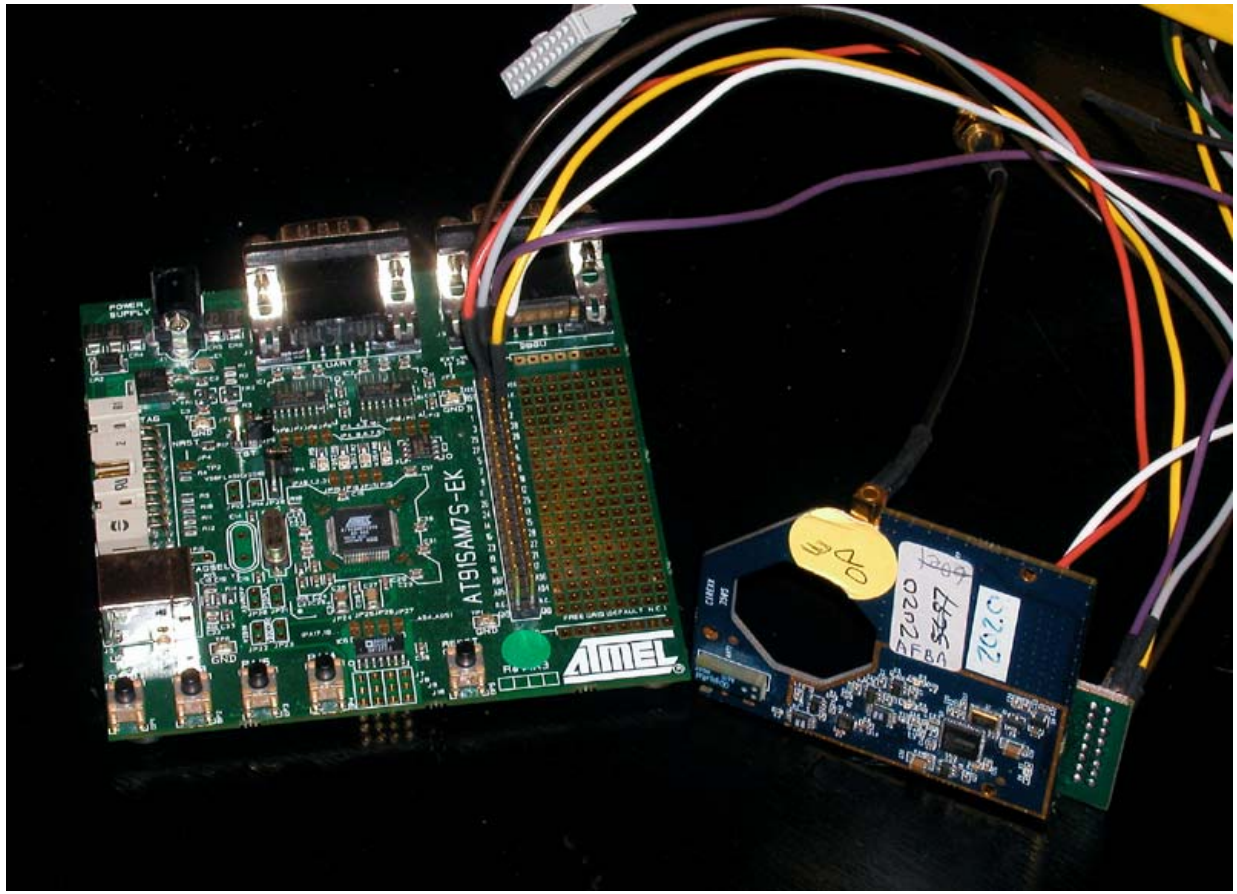
Product peak energy estimated. Duty cycle estimated.

Development System



Conclusions

A moderate size processor doesn't invariably cause short lifetime

- **you can shut it off quickly (provided you pick the right one)**
- **if you need a lot of processing, faster processors are more efficient**
- **memory may be more of a constraint than processing power**

A power amplifier may be helpful

- **allows larger node spacing, which can reduce overall cost**
- **match the communication range to the detection range**

GPS receivers can provide good location and time synchronization

- **use them carefully and they are not a big energy drain**
- **they are very expensive**
- **accuracy is also not as good as generally claimed (±3m generally, but wild excursions of ±30m occur)**

A small integrated product is a lot cheaper to build

- **avoid multiple board designs**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