Sensor Network Hardware

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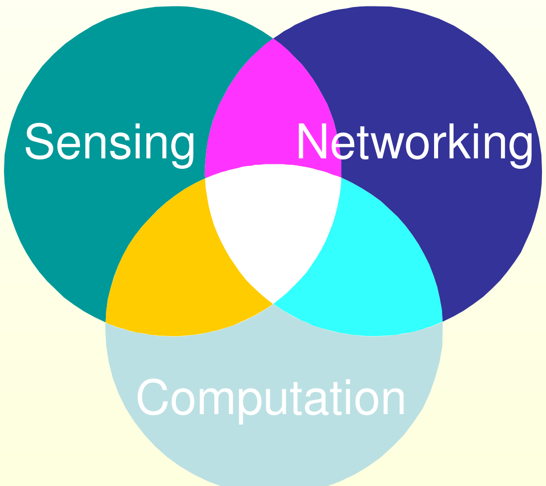

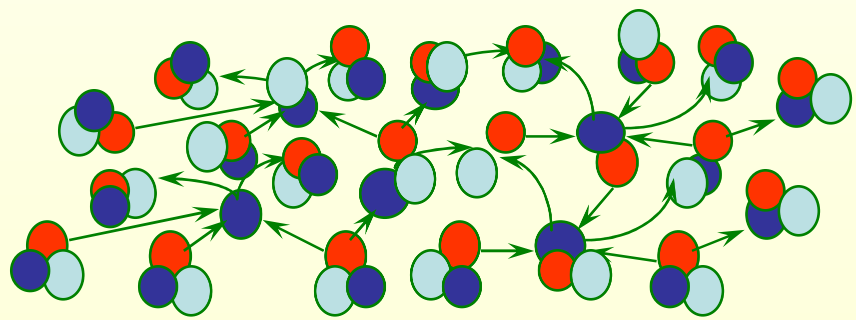

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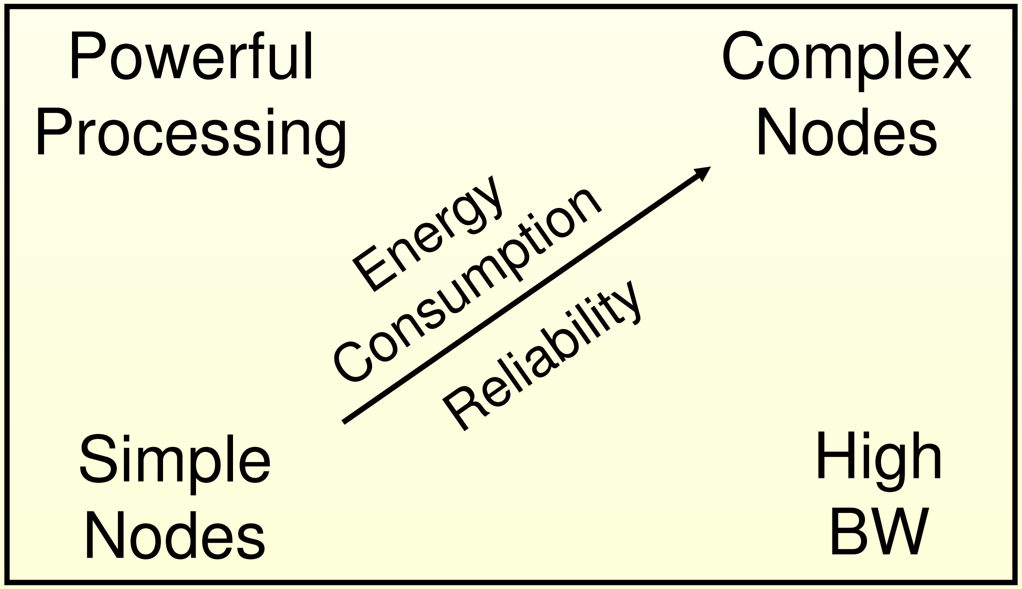
Overview

- Introduction
- Classes of Nodes
- Mobile Nodes
- Other Hardware
- Conclusions

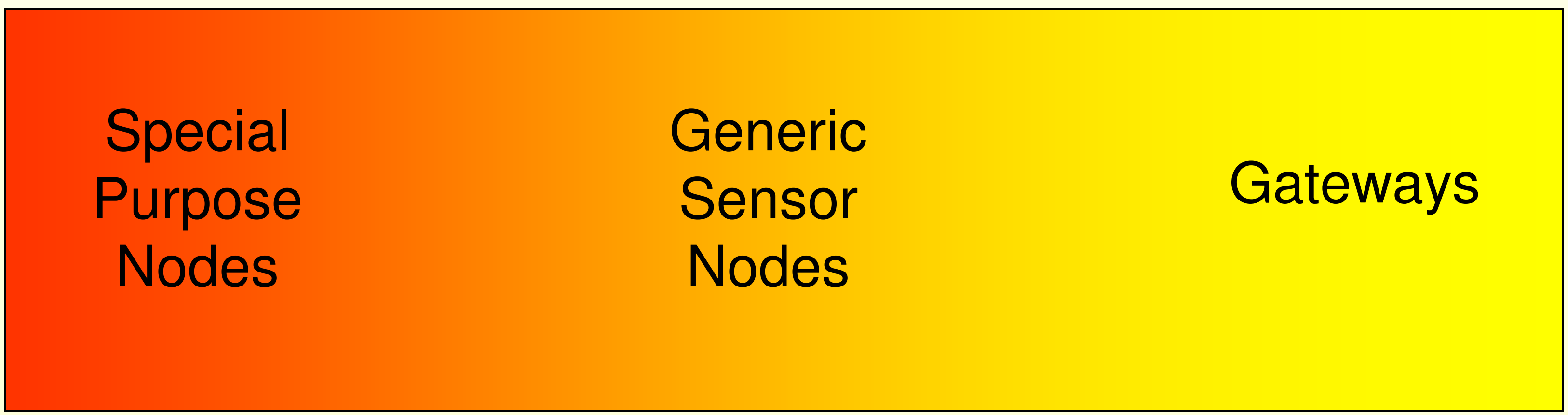
Introduction

- A large range of possibilities
- Many design choices
- "Right tool for the job"
- Classification
  - Approximate

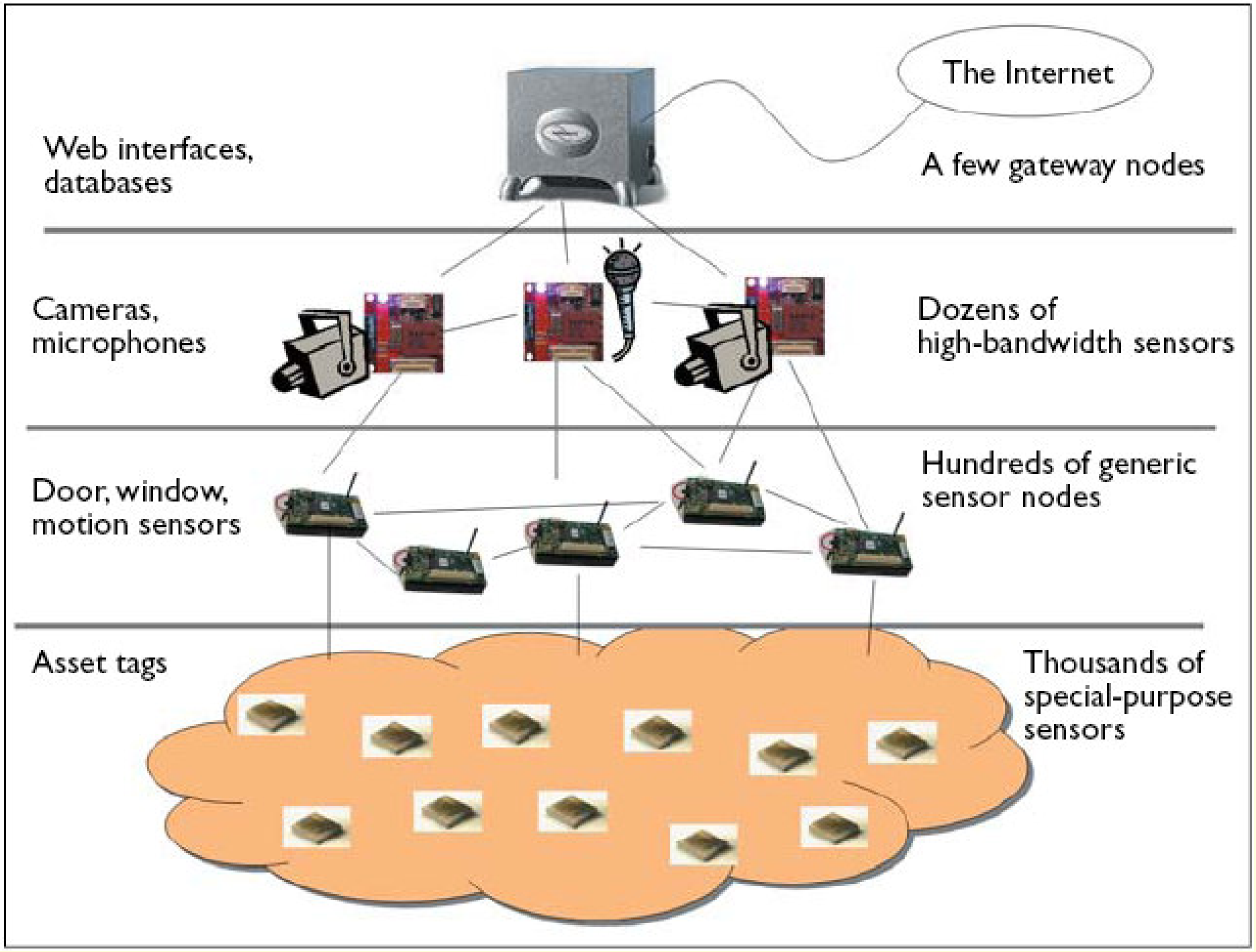


Types of Nodes

- Special purpose nodes
- Generic sensor nodes
  - Wide range of processing/communication capabilities
- Gateway nodes



Platform Classes

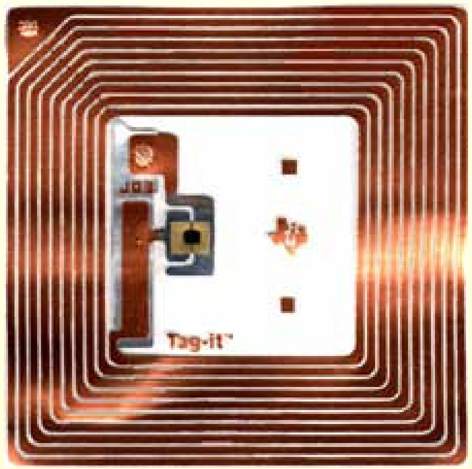


Specifications

Node Type	Sample "Name" and Size	Typical Application Sensors	Radio Bandwidth (Kbps)	MIPS Flash RAM	Typical Active Energy (mW)	Typical Sleep Energy (uW)	Typical Duty Cycle (%)
Specialized sensing platform	Spec mm³	Specialized low-bandwidth sensor or advanced RF tag	<50Kbps	<5 <0.1Mb <4Kb	1.8V*10–15mA	1.8V *1uA	0.1–0.5%
Generic sensing platform	Mote 1-10cm³	General-purpose sensing and communications relay	<100Kbps	<10 <0.5Mb <10Kb	3V*10–15mA	3V *10uA	1–2%
High-bandwidth sensing	Imote 1-10cm³	High-bandwidth sensing (video, acoustic, and vibration)	~500Kbps	<50 <10Mb <128Kb	3V*60mA	3V *100uA	5–10%
Gateway	Stargate >10cm³	High-bandwidth sensing and communications aggregation Gateway node	>500Kbs–10 Mbps	<100 <32Mb <512Kb	3V*200mA	3V *10mA	>50%

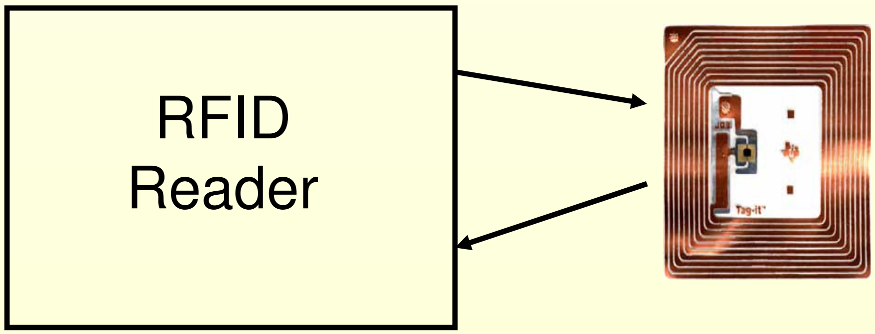
Asset Tags

- Highly integrated
- On the order of mm^3
- Examples
  - RFID
  - Smart Dust
  - System on Chip - SoC



RFID

- Radio Frequency Identification Tag
- Simplest “Sensor Node”
- No batteries
- Uses received RF energy and transmits data
- Limited range
- Application
  - Badges
  - Inventory Management

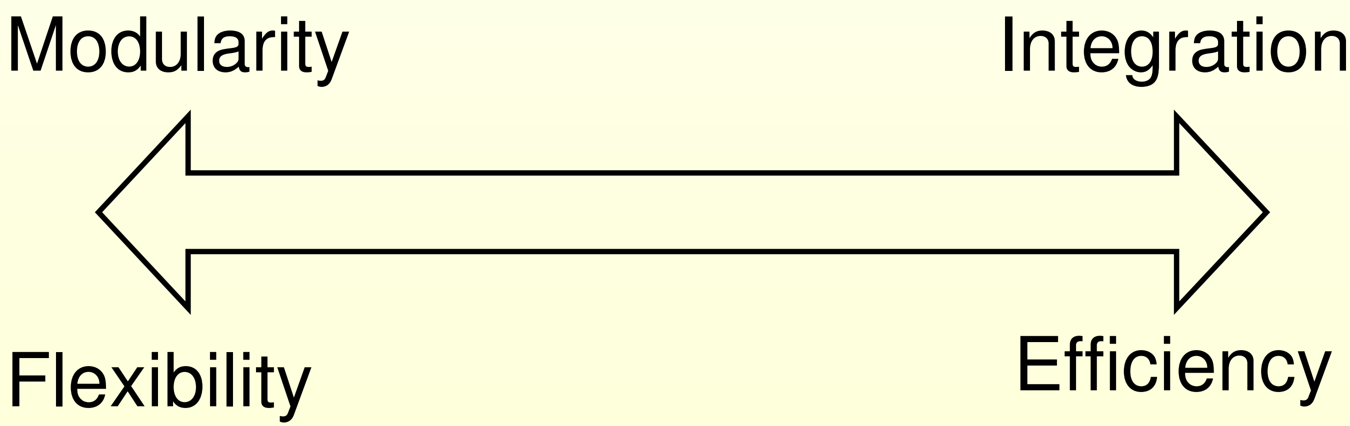


Smart Dust/SoC

- Energy efficiency by placing everything on one chip – custom ASICs
  - Radio
  - Processor
  - Sensor
- Very low energy
- Low cost in volume
- Potentially thousands of nodes

Generic Sensing Platform

- Most active area of research
- Stepping stone to Smart Dust
- Different levels of integration



Examples

- Crossbow
  - Mica series
- Dust Motes
- iMotes
- Telos Motes
- Mass Motes
- Particle Motes

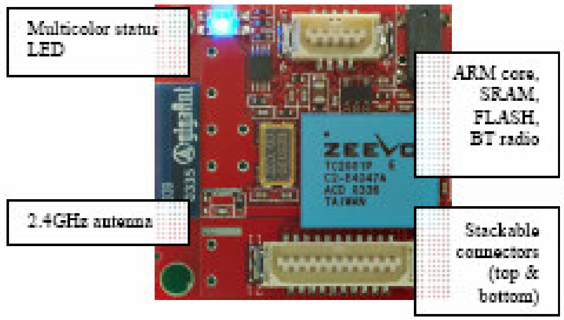
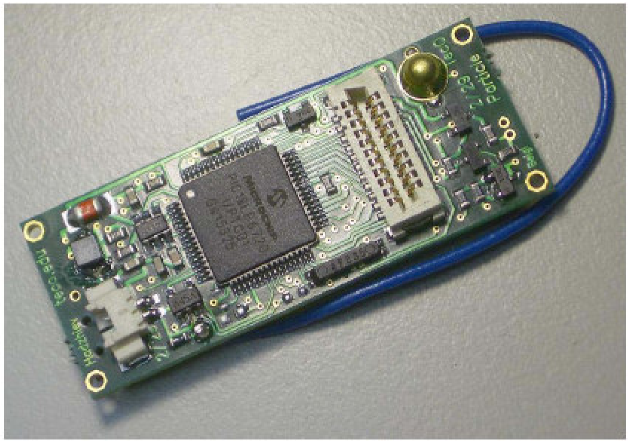
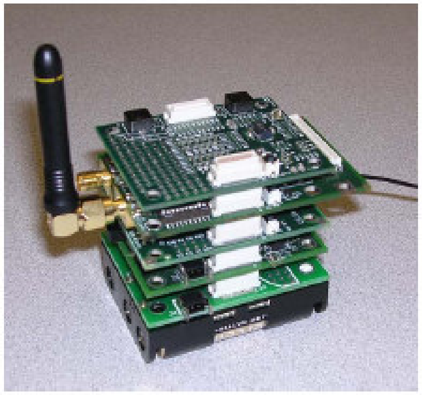
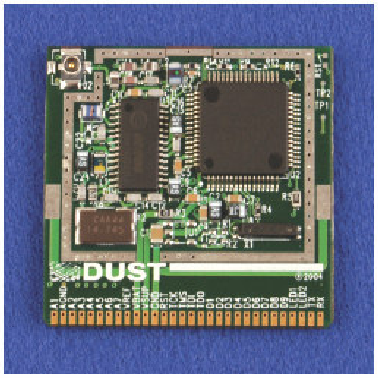


Figure 1. Intel Mote platform







Example System

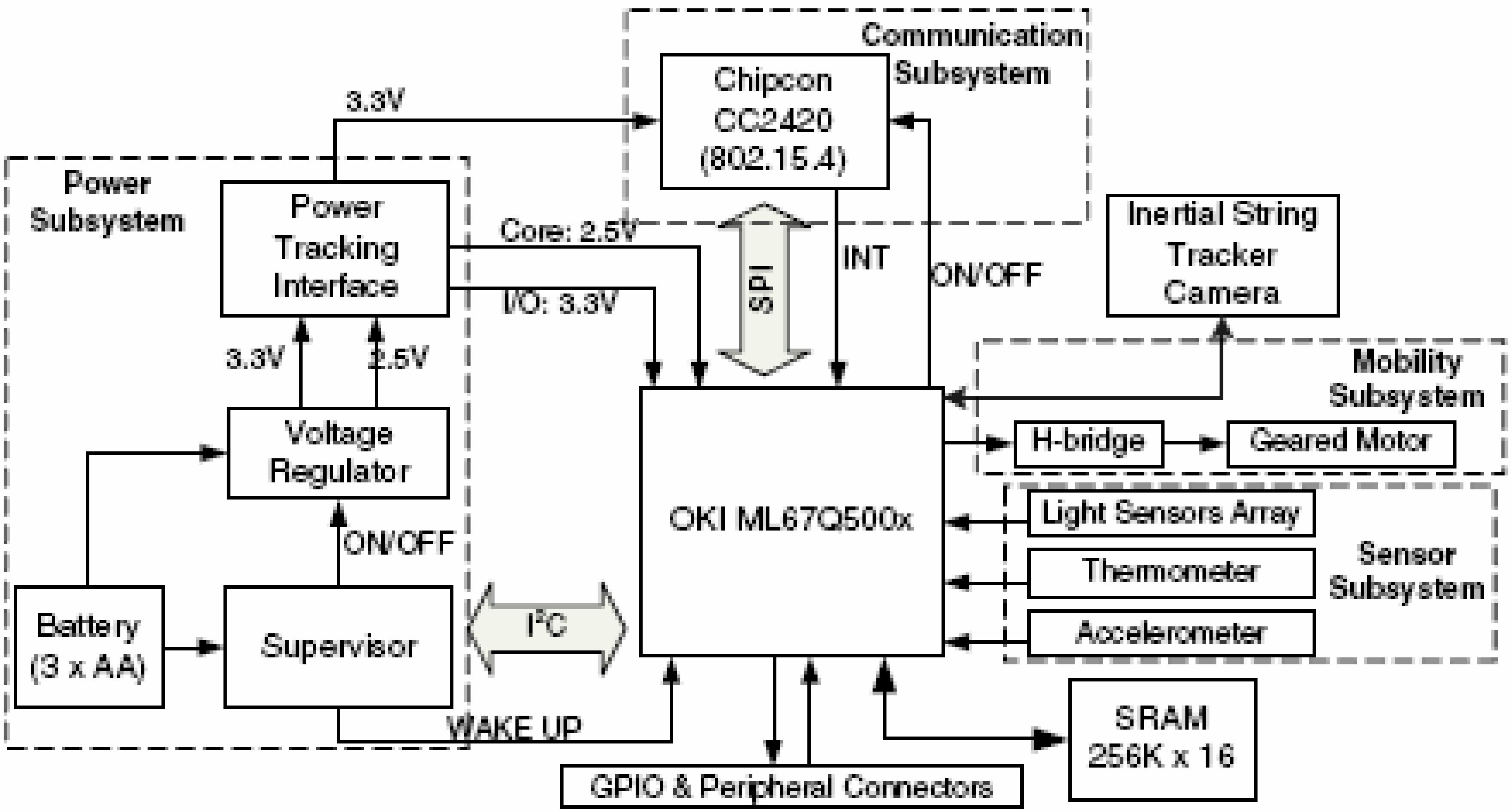


Fig. 3. The XYZ node architecture

MicaZ Motes

- TinyOS
- 16 Mhz Atmel ATMega128L
- 128 kB Program FLASH
- 512 kB Serial FLASH
- Current Draw
- 8 mA – Active Mode
- <15 uA – Sleep Mode
- Chipcon CC2420 802.15.4 Radio
- 250 kbps
- 26 Channels – 2.4 Ghz
- Current Draw – 15 mA

Range of Capabilities

- Highly integrated
  - New Chipcon chips
    - Atmel Processor + 802.15.4 radio
- Component level integration
  - Processor+radio+sensor interface (SPI, I^2C)
- Stackable architecture
  - Interfaces for radio and sensor interface

Flexibility

Mote Comparisons

Mote Type Year	WeC 1998	René 1999	René2 2000	Dot 2000	Mica 2001	Mica2Dot 2002	Mica 2 2002	Telos 2004
Microcontroller								
Type	AT90LS8535		ATmega163		ATmega128			TI MSP430
Program memory (KB)	8		16		128			48
RAM (KB)	0.5		1		4			10
Active Power (mW)	15		15		8		33	3
Sleep Power (μW)	45		45		75		75	15
Wakeup Time (μs)	1000		36		180		180	6
Nonvolatile storage								
Chip	24LC256				AT45DB041B			ST M25P80
Connection type	I^2C				SPI			SPI
Size (KB)	32				512			1024
Communication								
Radio	TR1000				TR1000	CC1000		CC2420
Data rate (kbps)	10				40	38.4		250
Modulation type	OOK				ASK	FSK		O-QPSK
Receive Power (mW)	9				12	29		38
Transmit Power at 0dBm (mW)	36				36	42		35
Power Consumption								
Minimum Operation (V)	2.7		2.7		2.7			1.8
Total Active Power (mW)	24				27	44	89	41
Programming and Sensor Interface								
Expansion	none	51-pin	51-pin	none	51-pin	19-pin	51-pin	16-pin
Communication	IEEE 1284 (programming) and RS232 (requires additional hardware)							USB
Integrated Sensors	no	no	no	yes	no	no	no	yes

Fig. 2. The family of Berkeley motes preceeding Telos and their capabilities

Radio Choices

Type	Narrowband				Wideband		
Vendor Part no.	RFM TR1000	Chipcon CC1000	Chipcon CC2400	Nordic nRF2401	Chipcon CC2420	Motorola MC13191/92	Zeevo ZV4002
Max Data rate (kbps)	115.2	76.8	1000	1000	250	250	723.2
RX power (mA)	3.8	9.6	24	18 (25)	19.7	37(42)	65
TX power (mA/dBm)	12 / 1.5	16.5 / 10	19 / 0	13 / 0	17.4 / 0	34(30)/ 0	65 / 0
Powerdown power (μA)	1	1	1.5	0.4	1	1	140
Turn on time (ms)	0.02	2	1.13	3	0.58	20	*
Modulation	OOK/ASK	FSK	FSK,GFSK	GFSK	DSSS-O-QPSK	DSSS-O-QPSK	FHSS-GFSK
Packet detection	no	no	programmable	yes	yes	yes	yes
Address decoding	no	no	no	yes	yes	yes	yes
Encryption support	no	no	no	no	128-bit AES	no	128-bit SC
Error detection	no	no	yes	yes	yes	yes	yes
Error correction	no	no	no	no	yes	yes	yes
Acknowledgments	no	no	no	no	yes	yes	yes
Interface	bit	byte	packet/byte	packet/byte	packet/byte	packet/byte	packet
Buffering (bytes)	no	1	32	16	128	133	yes *
Time-sync	bit	SFD/byte	SFD/packet	packet	SFD	SFD	Bluetooth
Localization	RSSI	RSSI	RSSI	no	RSSI/LQI	RSSI/LQI	RSSI

* Manufacturer's documentation does not include additional information.

Fig. 3. Capabilities of current COTS radios suitable for WSNs, their features, and power profile.

Processor Choices

Manufacturer	Device	RAM (kB)	Flash (kB)	Active (mA)	Sleep (μA)	Release
Atmel	AT90LS8535	0.5	8	5	15	1998
	Mega128	4	128	8	20	2001
	Mega165/325/645	4	64	2.5	2	2004
General Instruments	PIC	0.025	0.5	19	1	1975
Microchip	PIC Modern	4	128	2.2	1	2002
Intel	4004 4-bit	0.625	4	30	N/A	1971
	8051 8-bit Classic	0.5	32	30	5	1995
	8051 16-bit	1	16	45	10	1996
Philips	80C51 16-bit	2	60	15	3	2000
Motorola	HC05	0.5	32	6.6	90	1988
	HC08	2	32	8	100	1993
	HCS08	4	60	6.5	1	2003
Texas Instruments	TSS400 4-bit	0.03	1	15	12	1974
	MSP430F14x 16-bit	2	60	1.5	1	2000
	MSP430F16x 16-bit	10	48	2	1	2004
Atmel	AT91 ARM Thumb	256	1024	38	160	2004
Intel	XScale PXA27X	256	N/A	39	574	2004

Power Costs

Operation	Telos	Mica2	MicaZ
Minimum Voltage	1.8V	2.7V	2.7V
Mote Standby (RTC on)	5.1 μA	19.0 μA	27.0 μA
MCU Idle (DCO on)	54.5 μA	3.2 mA	3.2 mA
MCU Active	1.8 mA	8.0 mA	8.0 mA
MCU + Radio RX	21.8 mA	15.1 mA	23.3 mA
MCU + Radio TX (0dBm)	19.5 mA	25.4 mA	21.0 mA
MCU + Flash Read	4.1 mA	9.4 mA	9.4 mA
MCU + Flash Write	15.1 mA	21.6 mA	21.6 mA
MCU Wakeup	6 μs	180 μs	180 μs
Radio Wakeup	580 μs	1800 μs	860 μs

Memory

- How much?
- Internal or external?
- How long is storage required?
- Permanent memory
  - More energy consumption
  - In network reprogramming
- Temporary memory
  - Does not last as long

High Bandwidth Sensing

- More complex sensors
  - Audio
  - Video
- Requires
  - More processing power
  - More bandwidth
- Motivation
  - More interesting applications

Sensor Examples

- Audio
  - Microphones
- Images
  - Cameras
- Video
  - Multiple images
- Interfaces
  - Must be sufficiently fast

Sensor	Sampling Range	Bit rate
Audio	4 – 128 kHz	~10 kbps
Image	64 - 320000 pix/imag	~10 kbpp
Video	1 – 30 frames/sec	~1 Mbps

Applications

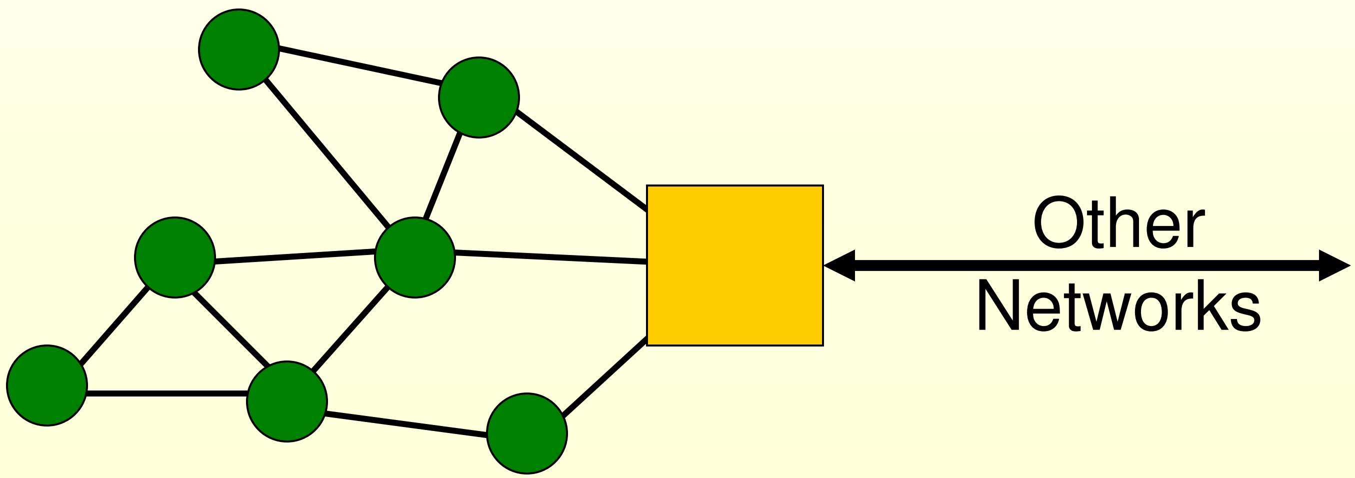
- Surveillance/Security
  - Cameras have traditionally been used
- Consumer Applications
  - People like Audio/Video
- Higher level processing
  - Face recognition
  - Deeper understanding of environment - AI

Gateways

- Miniature PCs
- Connection to Internet
- Can have multiple radios
- Stargate
- Embedded Linux

Grey Area

- When does a high BW node become a gateway?
- Placement
  - Gateway – connected to other networks
  - High power nodes – within the sensor network

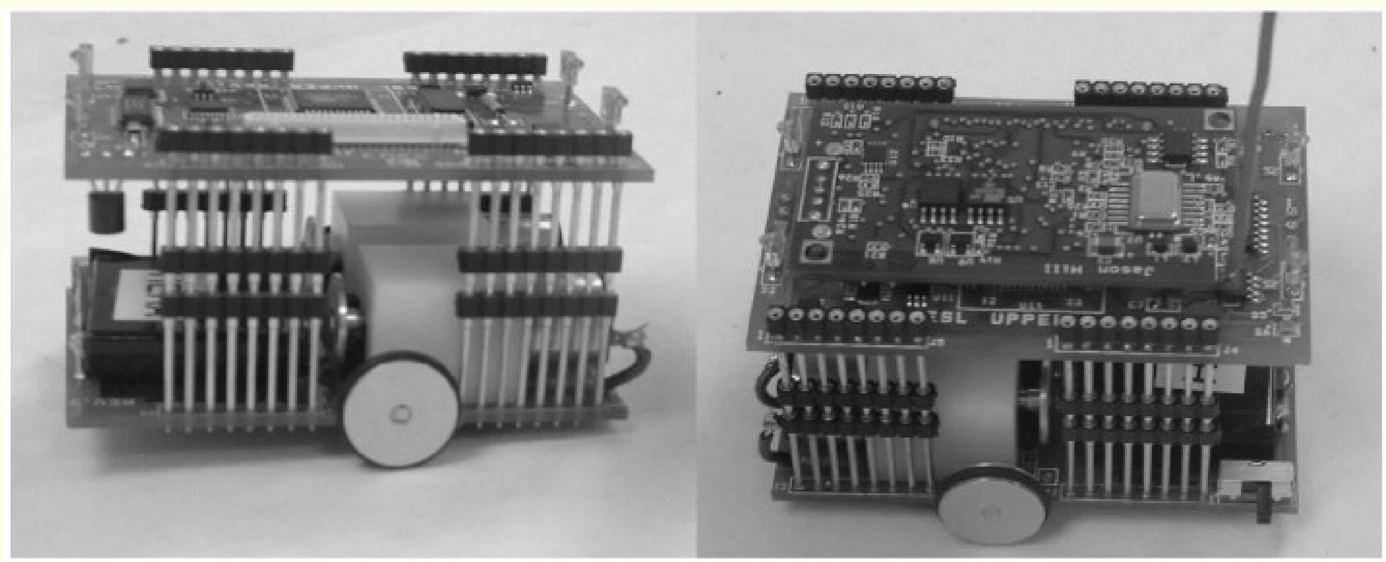


Summary

Node	CPU	Power	Memory	I/O and Sensors	Radio	Remarks
Special-purpose Sensor Nodes						
Spec 2003	4–8Mhz Custom 8-bit	3mW peak 3uW idle	3K RAM	I/O Pads on chip, ADC	50–100Kbps	Full custom silicon, traded RF range and accuracy for low-power operation.
Generic Sensor Nodes						
Rene 1999	ATMEL 8535	.036mW sleep 60mW active	512B RAM 8K Flash	Large expansion connector	10Kbps	Primary TinyOS development platform.
Mica-2 2001	ATMEGA 128	.036mW sleep 60mW active	4K RAM 128K Flash	Large expansion connector	76Kbps	Primary TinyOS development platform.
Telos 2004	Motorola HCS08	.001mW sleep 32mW active	4K RAM	USB and Ethernet	250Kbps	Supports IEEE 802.15.4 standard. Allows higher-layer Zigbee standard. 1.8V operation
Mica-Z 2004	ATMEGA 128		4K RAM 128K Flash	Large expansion connector	250Kbps	Supports IEEE 802.15.4 standard. Allows higher-layer Zigbee standard.
High-bandwidth Sensor Nodes						
BT Node 2001	ATMEL Mega 128L 7.328Mhz	50MW idle 285MW active	128KB Flash 4KB EEPROM 4KB SRAM	8-channel 10-bit A/D, 2 UARTS Expandable connectors	Bluetooth	Easy connectivity with cell phones. Supports TinyOS. Multihop using multiple radios/nodes.
Imote 1.0 2003	ARM 7TDMI 12-48MHz	1mW idle 120mW active	64KB SRAM 512KB Flash	UART, USB, GPIO, I^2C, SPI	Bluetooth 1.1	Multihop using scatternets, easy connections to PDAs, phones, TinyOS 1.0, 1.1.
Gateway Nodes						
Stargate 2003	Intel PXA255		64KNSRM	2 PCMICA/CF, com ports, Ethernet, USB	Serial connection to sensor network	Flexible I/O and small form factor power management.
Inrysnc Cerfcube 2003	Intel PXA255		32KB Flash 64KB SRAM	Single CF card, general-purpose I/O		Small form factor, robust industrial support, Linux and Windows CE support.
PC104 nodes	X86 processor		32KB Flash 64KB SRAM	PCI Bus		Embedded Linux or Windows support.

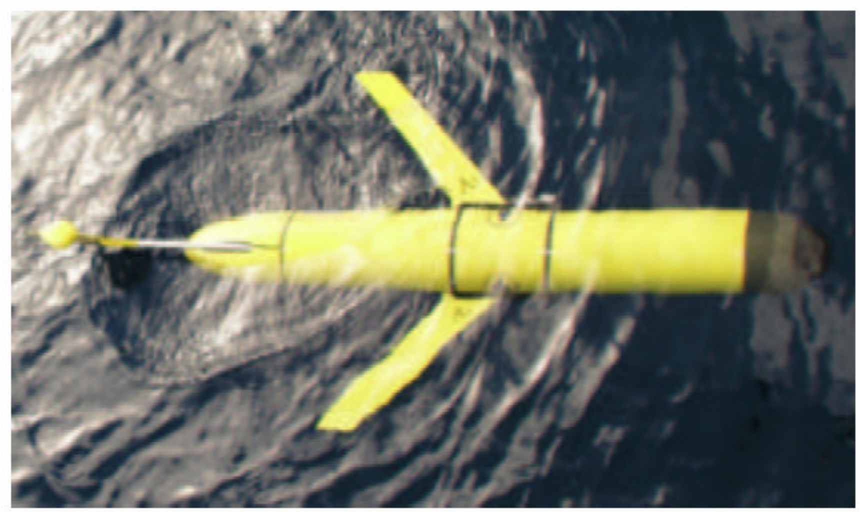
Mobile Nodes

- Sensor mote on wheels
- Robotics
  - Range of sizes
  - Distributed robotics/telerobotics
- Newest work in very small mobile motes



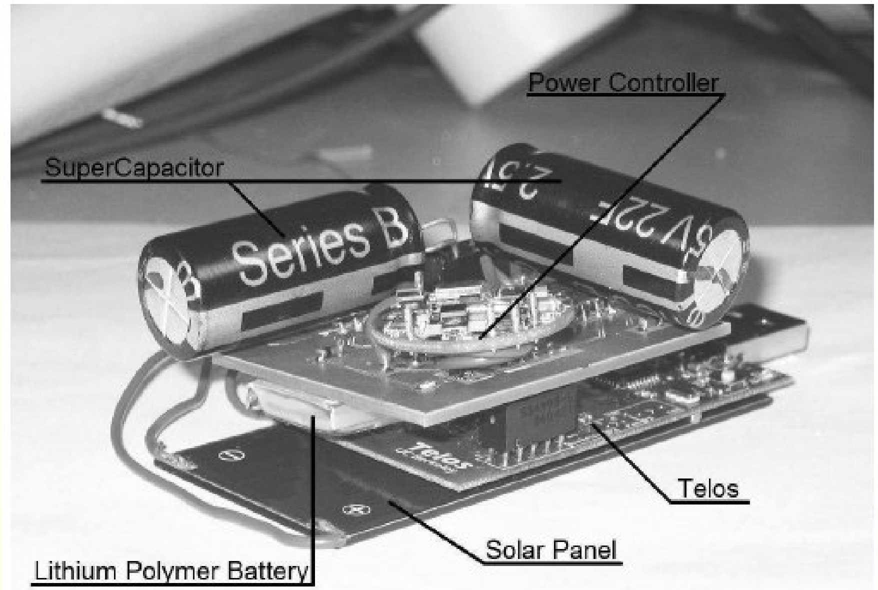
Other Mobile Nodes

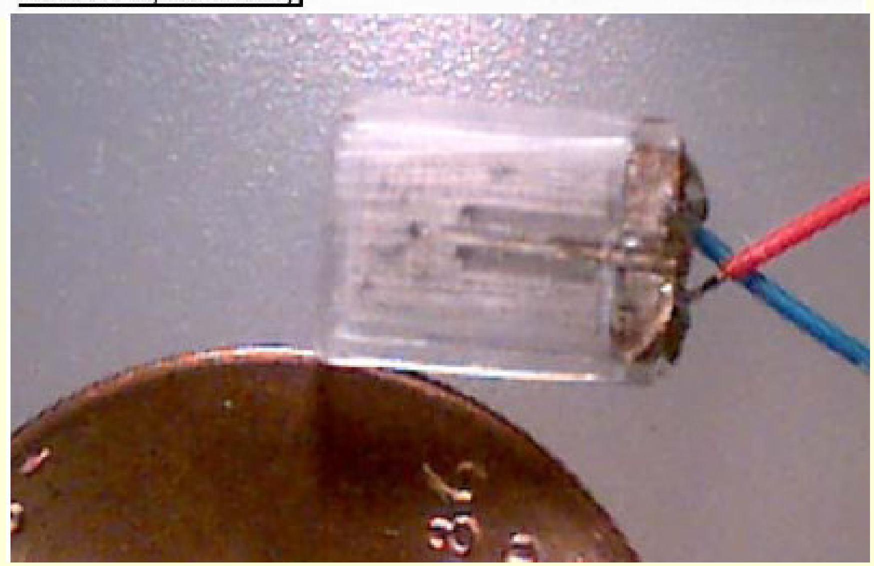
- Other mediums
  - Aircraft
  - Underwater schools of motes
  - Ground motes
- Larger "nodes" – UAV's
- Fewer nodes
- Energy less of an issue
  - Physical movement overshadows communication costs



Energy Harvesting/Scavenging

- Extend lifetime
- Solar Cells
  - Size
  - Efficiency
  - Availability of light source
- Kinetic Energy
  - Sporadic
  - Low yield
  - Consistent vibrations



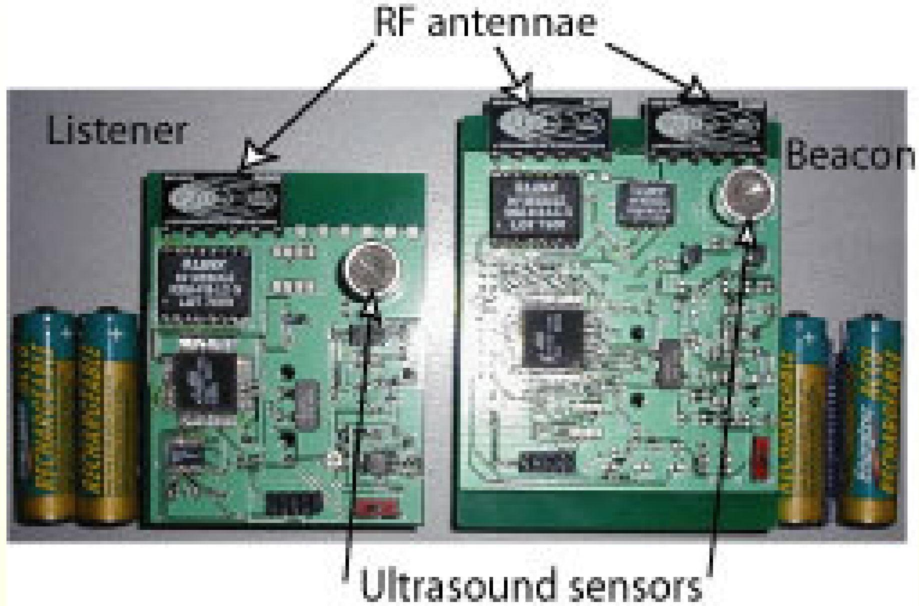


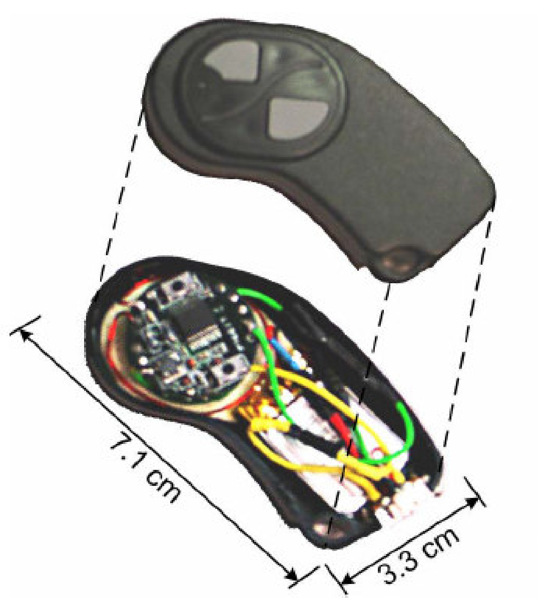
Energy Sources

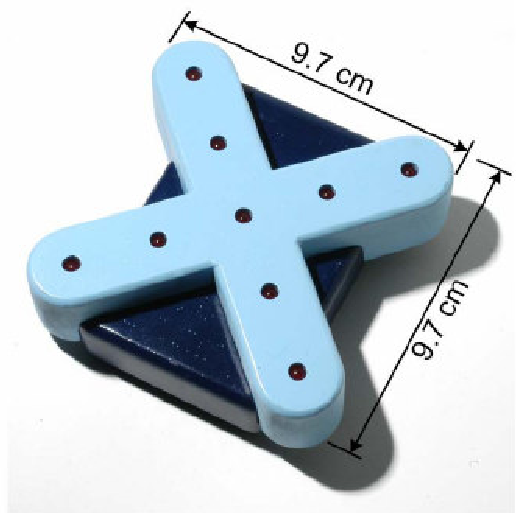
Comparison of Energy Scavenging Sources			
	Power Density (μW/cm^3) 1Year lifetime	Power Density (μW/cm^3) 10 Year lifetime	Source of information
Solar (Outdoors)	15,000 - direct sun 150 - cloudy day	15,000 - direct sun 150 - cloudy day	Commonly Available
Solar (Indoors)	6 - office desk	6 - office desk	Experiment
Vibrations	100 - 200	100 - 200	Experiment and Theory
Acoustic Noise	0.003 @ 75 Db 0.96 @ 100 Db	0.003 @ 75 Db 0.96 @ 100 Db	Theory
Daily Temp. Variation	10	10	Theory
Temperature Gradient	15 @ 10 °C gradient	15 @ 10 °C gradient	1997
Shoe Inserts	330	330	Starner 1996 Shenck & Paradiso 2001
Batteries (non-recharg. Lithium)	89	7	Commonly Available
Batteries (rechargeable Lithium)	13.7	0	Commonly Available
Gasoline (micro heat engine)	403	40.3	Mehra et. al. 2000
Fuel Cells (methanol)	560	56	Commonly Available

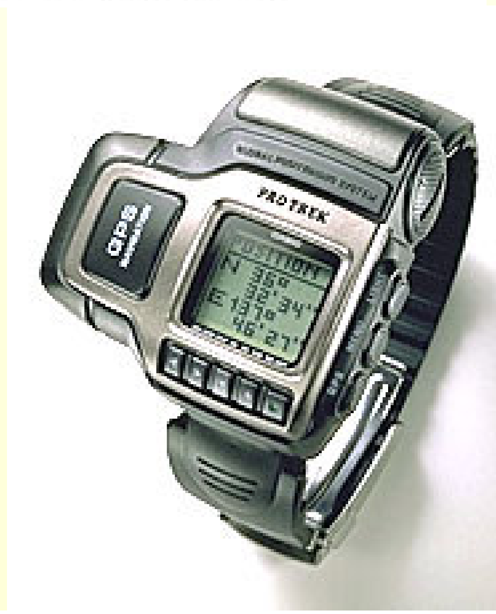
Extra Hardware

- CRICKET
- GPS
- RFID Reader
- Structural Monitoring Sensor/Actuator



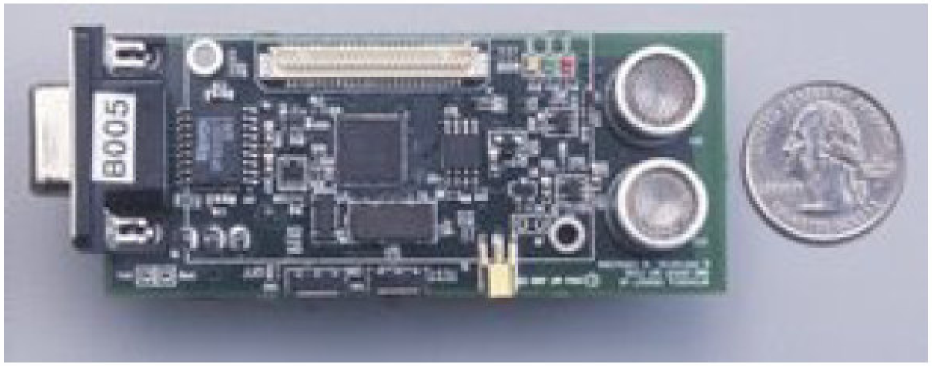


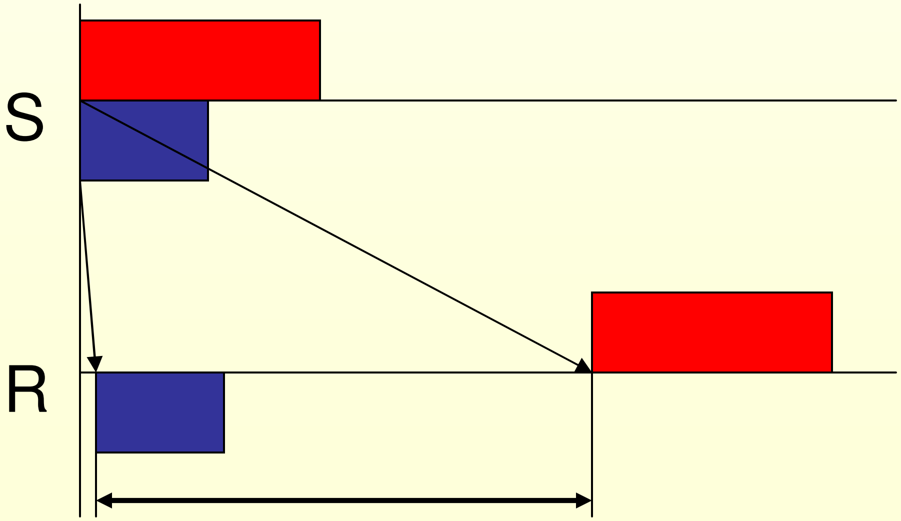




CRICKET

- Ranging system
- Ultrasonic + Radio
- Benefits
  - Accurate
  - Simple Processing
- Drawbacks
  - Limited range ~10 m
  - Not low power





Conclusions

- Many different platforms
- Different capabilities
- Design choices motivated by algorithm
- Hardware get smaller, cheaper, etc.
- Battery size becomes limitation
- Hardware will not provide complete solution

Platform References

XYZ: A Motion-Enabled, Power Aware Sensor Node Platform for Distributed Sensor Network Applications

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