WSN :Hardware Platforms

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Hardware

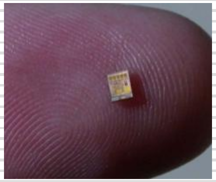
Requirements

- Cost
- Lifetime (when almost always on, when almost always off)
- Performance:
  - Speed (in ops/sec, in ops/joule)
  - Communication range (in m, in joules/bit/m)
  - Memory (size, latency)
- Capable of concurrent operation
- Flexibility
- Reliability, security, size, packaging

Types of Sensor-actuator Hardware Platforms

1. RFID equipped sensors

2. Smart-dust tags



   - typically act as data-collectors or "trip-wires"
   - limited processing and communications

3. Mote/Stargate-scale nodes

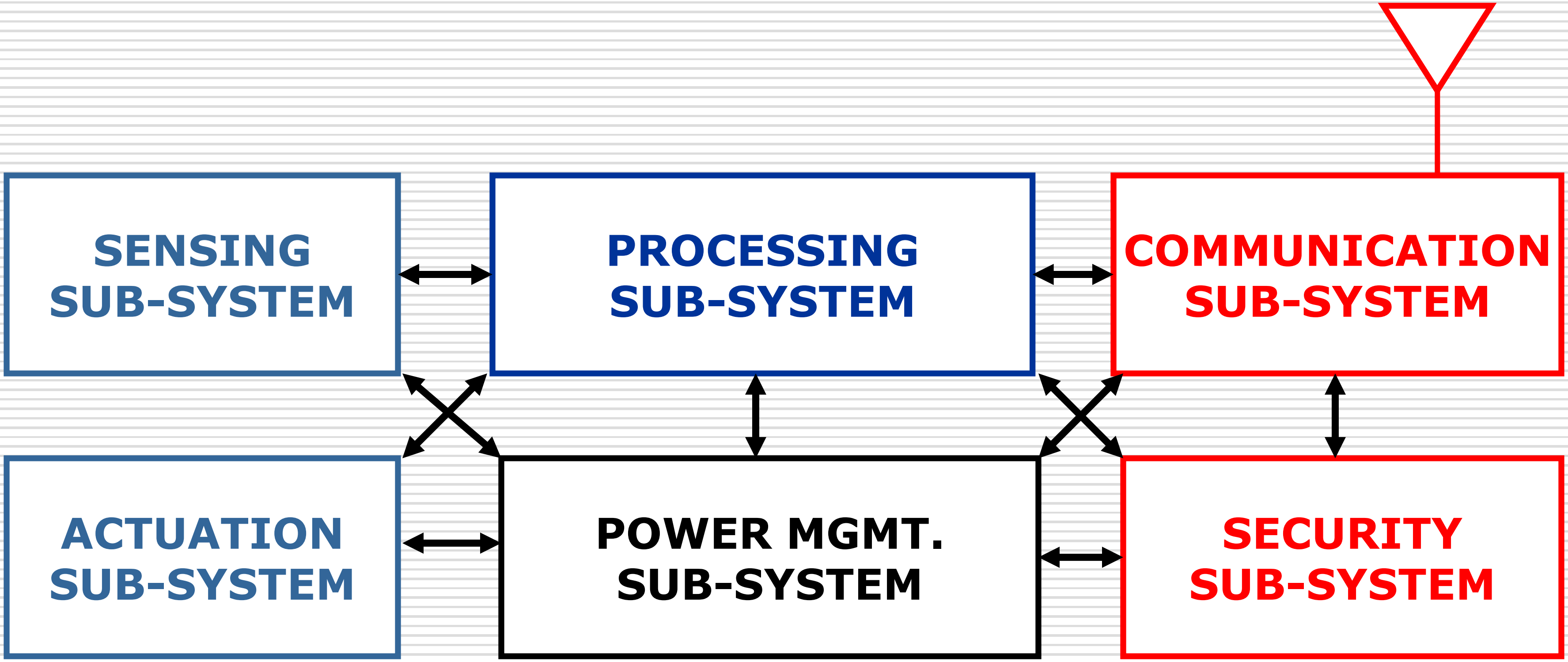
   - more flexible processing and communications

4. More powerful gateway nodes, potentially using wall power

A Closer Look

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 mm^3	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 1-10cm^3	General-purpose sensing and communications relay	<100Kbps	<10 <0.5Mb <10Kb	3V*10–15mA	3V *10uA	1–2%
High-bandwidth sensing	Imote 1-10cm^3	High-bandwidth sensing (video, acoustic, and vibration)	~500Kbps	<50 <10Mb <128Kb	3V*60mA	3V *100uA	5–10%
Gateway	Stargate >10cm^3	High-bandwidth sensing and communications aggregation Gateway node	>500Kbs–10 Mbps	<100 <32Mb <512Kb	3V*200mA	3V *10mA	>50%

A Generic Sensor Network Architecture



Processing Subsystem

Microcontroller

- Von Neumann architecture (same address and data bus)
  - Typical 4 bit, 8 bit, 16 bit or 32 bit architectures
  - Speed 4 MHz-400MHz with 10-300 or more MIPS
- Operate at various power levels:
  - Fully active: 1 to 50 mW
  - Sleep (memory standby, interrupts active, clocks active, cpu off)
  - Sleep (memory retained, interrupts active, clocks active, cpu off)
  - Sleep (memory retained, interrupts active, clocks off, cpu off): 5uW
- Latency of wakeup is an issue
- Fixed point or floating point operations
- Multiple processors may be used (potentially on same core)
  - Could be DSP, FPGA

Processing Subsystem: Memory

- Considerations: Speed, capacity, price, power consumption, memory protection
- SRAM: typical, 0.5KB-64MB
  - Typical power consumption
    - retained: ~100ua; read/write: ~10ma if separate chip
    - retained: 2ua-100ua, read/write:~5ma if in core
- DRAM: high power consumption in retained mode
- EEPROM:4KB-512KB, often used as program store
- Flash: 256KB-1GB or beyond
  - Typical power consumption
    - retained: negligible; read/write: ~7/20ma
    - erase operation is expensive

Processing Subsystem (contd.)

- Peripheral interfaces
  (for sensors, actuators, I/O, power)
  (whether analog and digital)
  (multiple busses with bridges between them)
  - SPI: Serial Peripheral Interface
  - I2C
  - UART: Serial communication
  - USB
  - PCI

- Clocks
- Hardware Timers
- Dividers

Processing Subsystem: Peripherals

Interrupts:

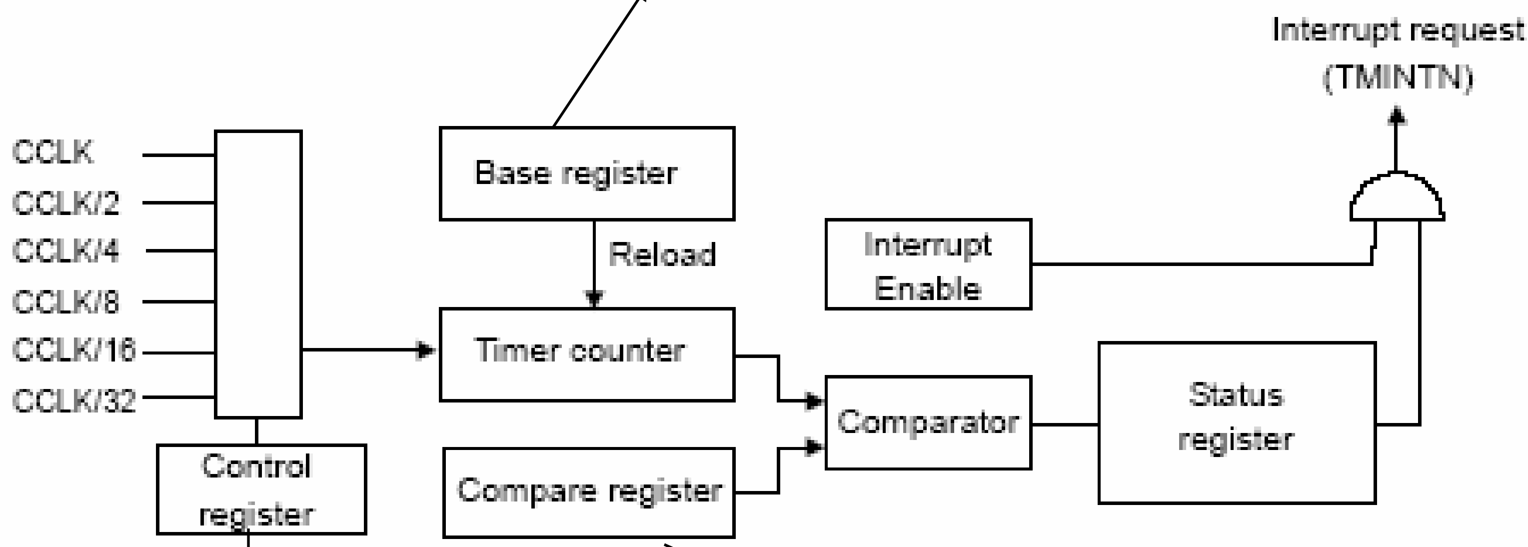
- Asynchronous breaks in program execution
  - Press of a button; expiration of a timer; completion of sensing data collection, of DMA transfer, of transmission event, …
- When interrupt occurs, processor transitions to the corresponding interrupt handler to service interrupt and then resumes execution
- Can have multiple priority levels
- Interrupts are enabled and disabled through registers for each peripheral

I/O Ports:

General Purpose Input Output pins (GPIO)

Hardware Timers

Holds the value that initializes the timer at startup



Holds value to compare against

Controls the mode (interval or one-shot)

Starts and stops the timer

Enables/disables the interrupts for this timer

Sensor Subsystem

- Multiple types of sensors may be used:
  - Environmental: pressure, gas composition, humidity, light…
  - Motion or force: accelerometers, rotation, microphone, piezoresistive strain, position…
  - Electromagnetic: magnetometers, antenna, cameras…
  - Chemical/biochemical
- Digital or analog output
- MEMS enabling size, cost and power miniaturization; nano coming
- Components:
  - Transducer
  - Analog signal conditioning circuits
  - Analog to digital conversion
  - Digital signal processing

Sensor Subsystem Considerations

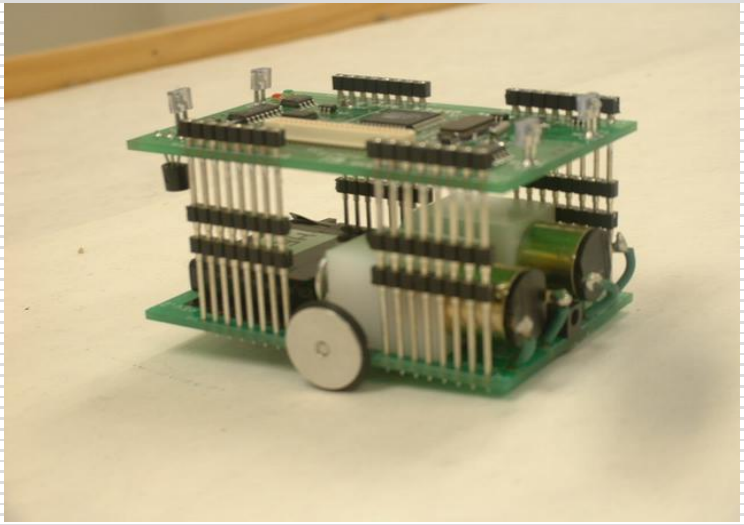
- Energy consumption in active/passive mode is relevant
- Sampling rate (1Hz or lower to 5Khz or higher)
- Signal resolution
  - ADC bits: 8, 10, 12, 16, 20 bit (affects cost)
  - On-chip or not
- Sensitivity, drift, offset
- Sensor calibration or reset frequency
- Interference, cross-talk

Sensor Subsystem

- Wakeup circuits help reduce power consumption of processing
  - But startup time/power cycling latencies become an issue (~1ms-1000ms or higher)
- DMA of acquired sensor information is possible
- Connector requirements: positive contact, flexibility, robustness

Actuation Subsystem

- Types:
  - Leds, buzzers, motors, sliders, pumps, gears, solenoids…
- Energy consumption (idle: O(uW); active ~1-40 mW)
- Startup time (~1ms-1000ms or higher)
- Higher voltage planes and noise
- Coupling:
  - Opto-coupler for control communications, with encoders for feedback
  - PWM drivers



Power Management Subsystem

- Voltage regulator
  - typical ranges: 1.8V, 3.3V, 5V
  - multiple voltages for various subsystem/power levels
- Gauges for voltage or current
  - battery monitor (allows software to adapt computation)
- Control of subsystems wakeup/sleep
  - latency is key in driving down the duty cycle
- Control of platform clock rate, processor voltage
- Run auxiliary hardware components from low speed oscillators (typically 32kHz)
  - perform ADC conversions, DMA transfers, and bus operations while microcontroller core is stopped

Power Management Subsystem

- Energy source:
  - volume energy density, mass energy density
  - peak and average current (discharge rate)
  - NiCd, NiMH, LiIon, LiPolymer, fuel cells
  - DC-DC conversion

- Charger/energy harvesting/scavenging
  - solar, wind, vibration, heat
  - account for variations in supply
  - number of charge/discharge cycles have limits

- Power supply may be external

Communication Subsystem

Considerations:

- speed, range, power consumption, startup time
- energy efficiency: joules/bit/m
- signal propagation and interference characteristics
- difference between receive power versus transmit power
- not all devices need a receiver
- choice of power level
- antenna design
  - matching impedance

Communication Subsystem

CC1000 

Bluetooth 

IEEE 802.11 

Energy per bit

Startup time

Idle current

Technology	Data Rate	Tx Current	Energy per bit	Idle Current	Startup time
CC1000	76.8 Kbps	10 mA	430 nJ/bit	7 mA	Low
Bluetooth	1 Mbps	45 mA	149 nJ/bit	22 mA	Medium
802.11	11 Mbps	300 mA	90 nJ/bit	160 mA	High

Security Subsystem

Some COTS radios offer security features

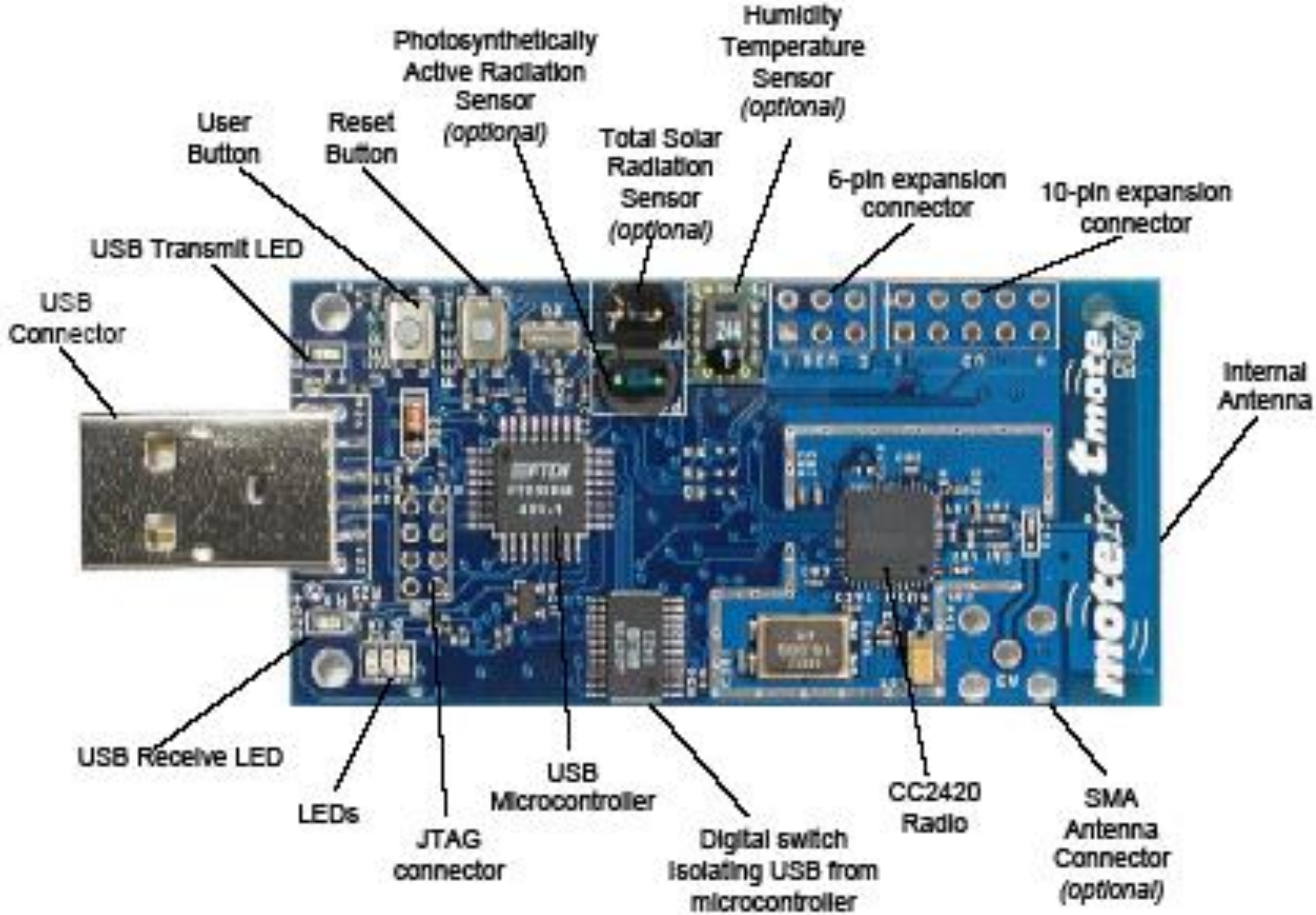
Type	Narrowband				Wideband		
Vendor Part no.	RFM TR1000	Chipcon CC1000	Chipcon CC2400	Nordic nRF2401	Chipcon CC2420	Motorola MC13191/92	Zeevo ZV4002
Max Data rate (kbps)	115.2	76.8	1000	1000	250	250	723.2
RX power (mA)	3.8	9.6	24	18 (25)	19.7	37(42)	65
TX power (mA/dBm)	12 / 1.5	16.5 / 10	19 / 0	13 / 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.

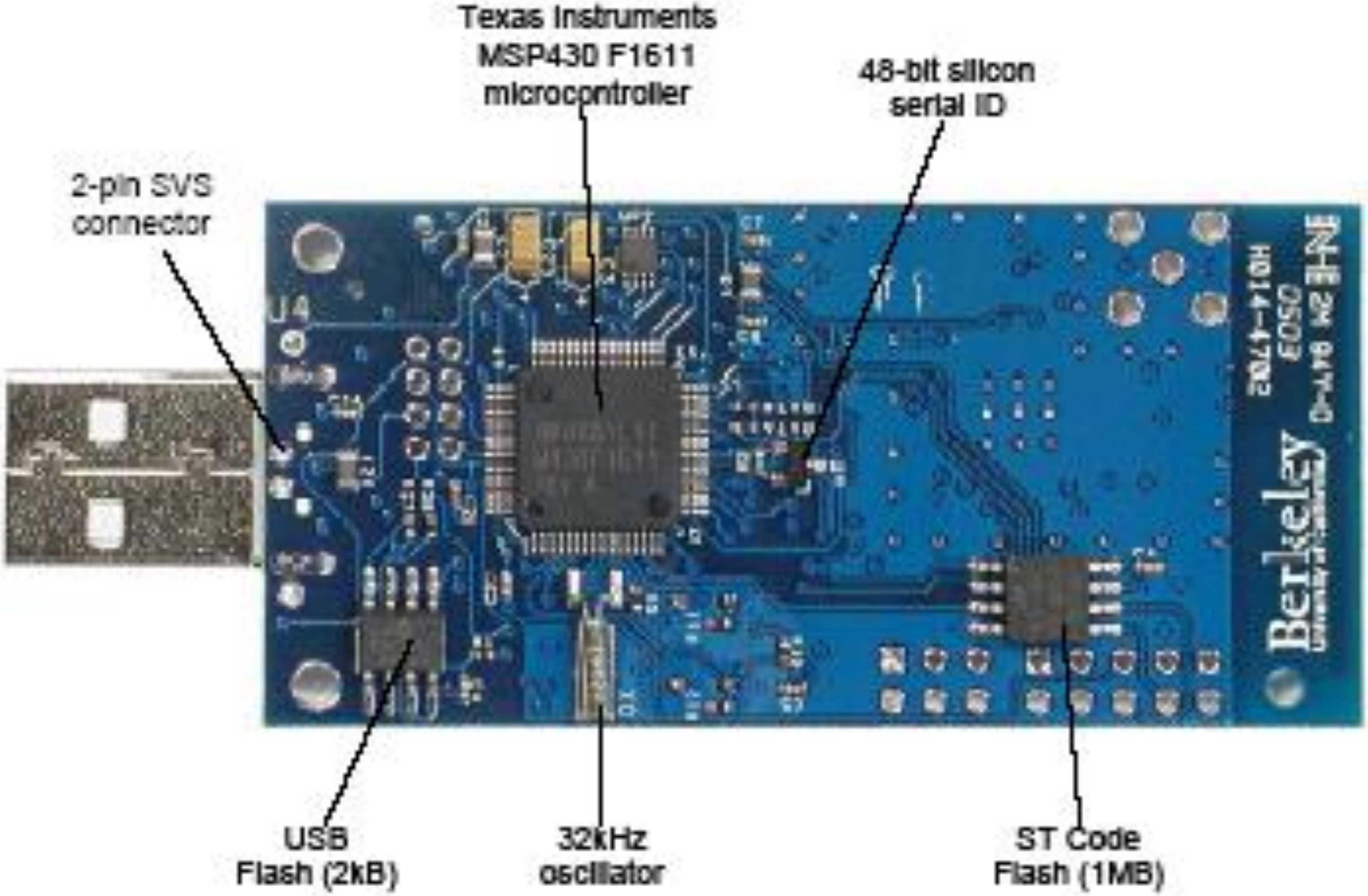
TMote (Telos)

- Standards Based
  - USB
  - IEEE 802.15.4
    - CC2420, 250kbps at 2.4GHz
- Features:
  - TI MSP430:
    - 10kB RAM, 4Mhz 16-bit RISC, 48K Flash
    - 12-bit ADC and DAC (200ksamples/sec)
    - DMA transfers while CPU off
  - Integrated antenna
  - Standard IDC connectors

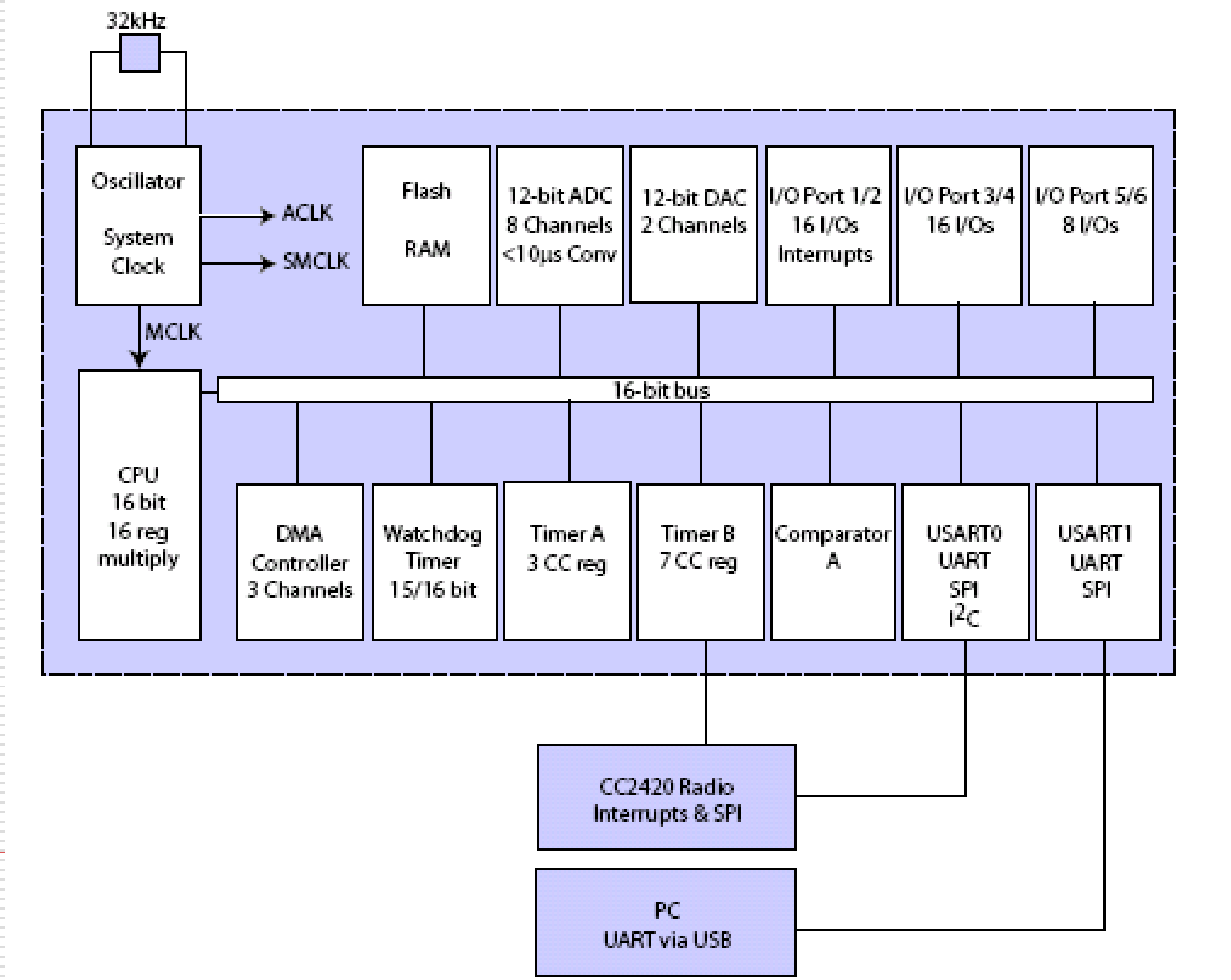
Front of Mote



Back of Mote


Texas Instruments
MSP430 F1611
microcontroller
48-bit silicon
serial ID
2-pin SVS
connector
USB
Flash (2kB)
32kHz
oscillator
ST Code
Flash (1MB)

Block Diagram



TMote Power Consumption

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

Manufacturers of Sensor Nodes

- Intel Research
  - Stargate2, iMote
- Crossbow (www.xbow.com)
  - Mica2 mote, Micaz, Dot mote and Stargate Platform
- Moteiv (www.moteiv.com)
- Ember (www.ember.com)
  - Integrated IEEE 802.15.4 stack and radio on a single chip
- Millenial Net (www.millenial.com)
  - iBean sensor nodes
- Dust Inc
  - Smart Dust
- Cogent Computer (www.cogcomp.com)
  - XYZ Node (CSB502) in collaboration with ENALAB@Yale
- Sensoria Corporation (www.sensoria.com)
  - WINS NG Nodes