Freie Universität Berlin

Embedded Internet and the Internet of Things WS 12/13

2. Technology and platforms

Prof. Dr. Mesut Güneş
Distributed, embedded Systems (DES)
Institute of Computer Science
Freie Universität Berlin

Overview

- IRIS sensor node vs Apple iPhone
- Hardware components
- Platforms: Overview of popular hardware platforms
- Operating systems
- Summary

IRIS sensor node vs Apple iPhone

IRIS sensor node vs Apple iPhone 5

IRIS Sensor node

- Three-axis gyro
- Accelerometer
- Proximity sensor
- Ambient light sensor
- GPS
- Microphone, Camera
- Touchscreen

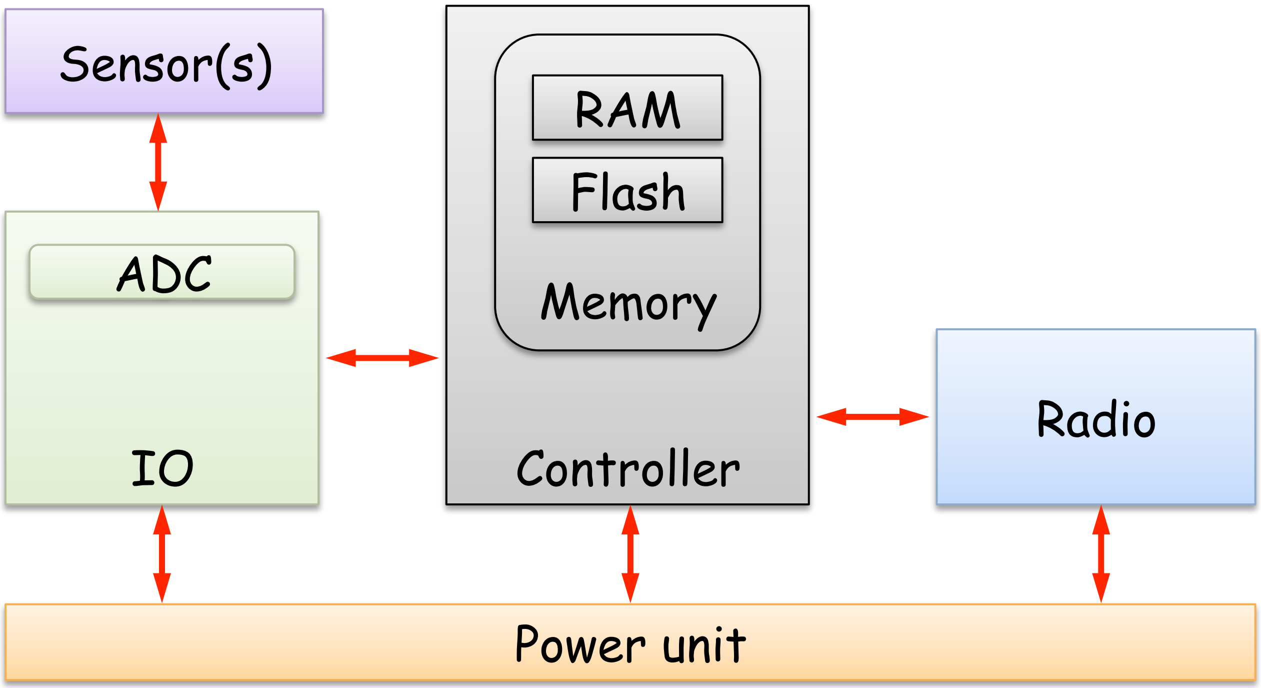
iPhone 5

8 MHz	≈1 : 125	A6: 1 GHz, 2CPUs, 3GPUs
250 kbps	≈1 : 1200	300 Mbps (802.11 n)
8 kB RAM	≈1 : 125000	1 GB RAM
128 kB Flash	≈1 : 500000	64 GB Flash

For sensor nodes the reverse of Moore's Law is valid
"cheaper with the same performance"

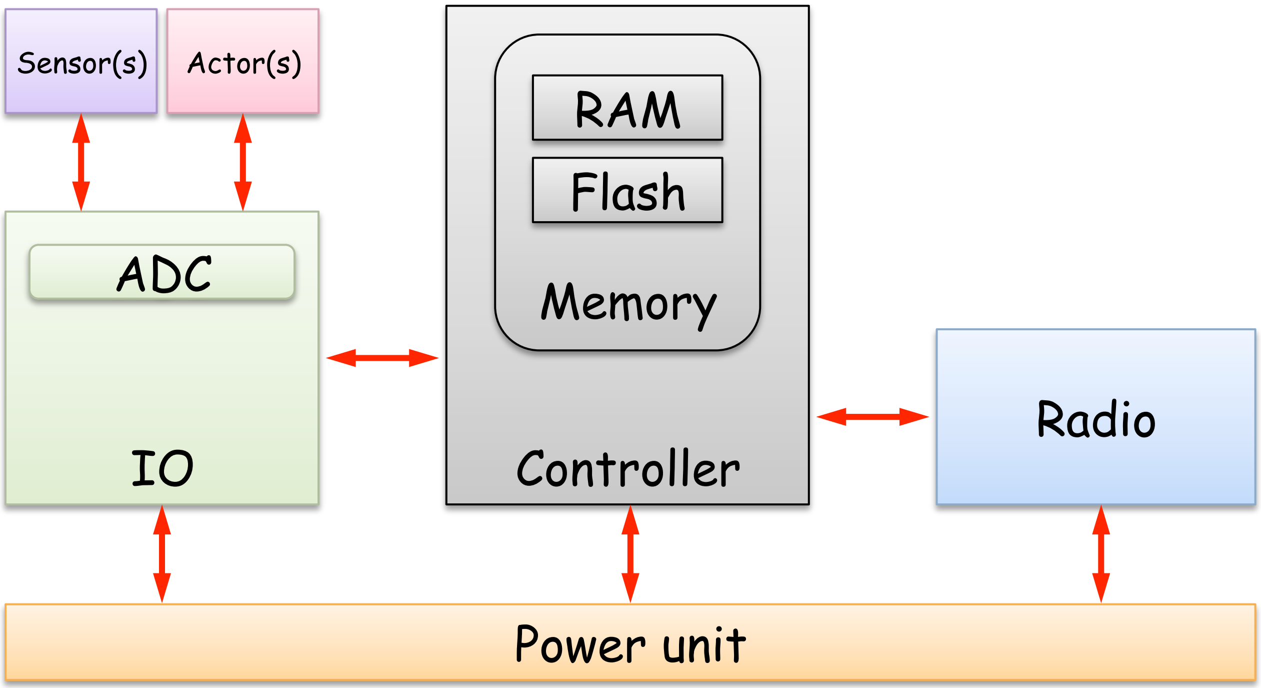
Hardware components

Hardware components



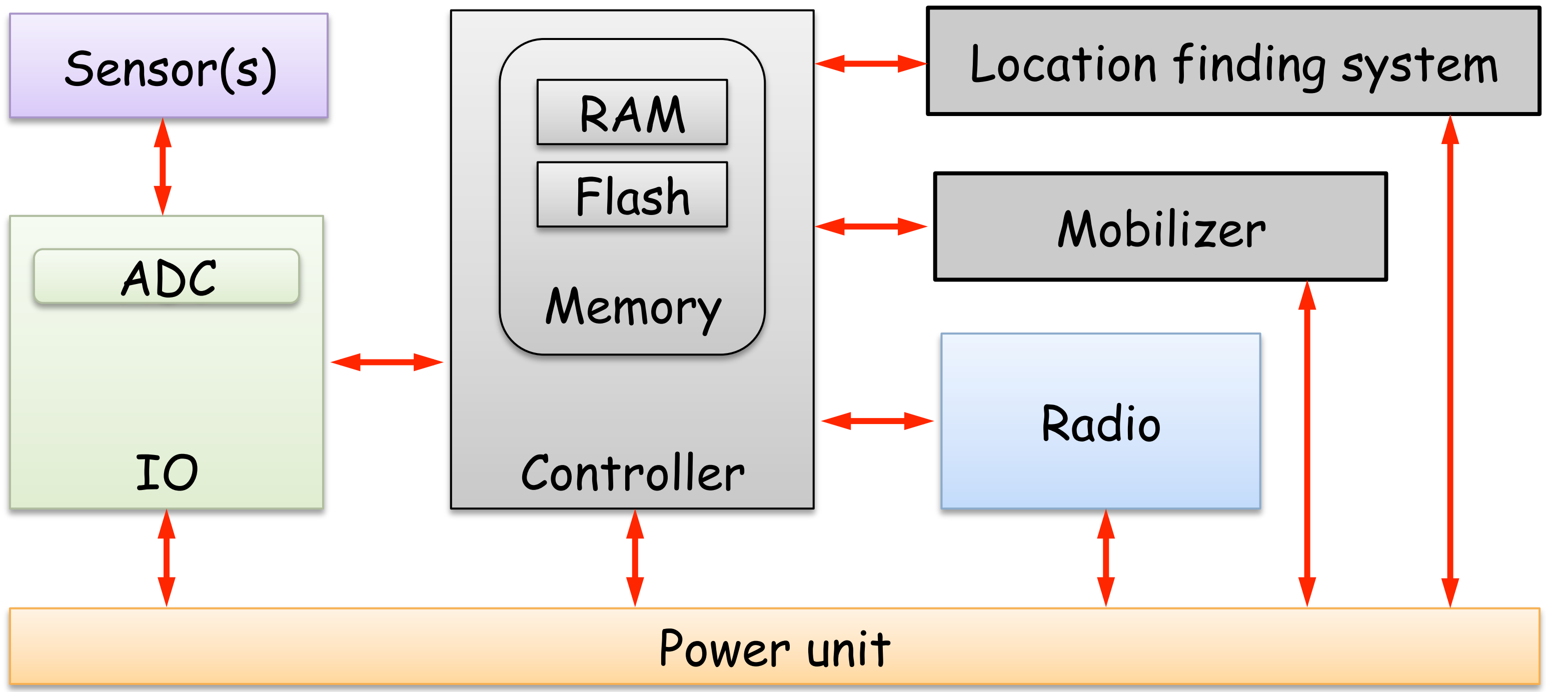
ADC = Analog-to-digital converter

Hardware components



ADC = Analog-to-digital converter

Hardware components



ADC = Analog-to-digital converter

Hardware components

- A (sensor) node consists of several components
  - Controller: Central processing unit (CPU)
  - Memory for application and data
    - Usually different memory types are used for application and data
  - Communication interface
    - Wireless radio interface with antenna
  - Sensors/Actors
    - Interface to the real world.
    - Monitoring, changing of real world phenomena.
  - Power unit
    - Power supply for all the components
  - Mobilizer
  - Location finding system

Hardware components

- Requirements of the application are design decisions for all components
  - Size (form factor)
  - Energy consumption
  - Costs
  - Sensors/Actors

- Any idea how?

Controller

[Bishop]

- Four important factors for the controller
  - Number of transistors -> size, cost, power
  - Number of clock cycles -> power
  - Time to develop -> cost, acceptance
  - Nonrecurring engineering cost (NRE) -> cost, acceptance

- Ideal: Minimize all factors at the same time!

Controller

- The controller is the Central Processing Unit (CPU) of the device
- Different architectures possible
  - Microcontroller (MCU)
    - Resource constrained compared to desktop processors
    - Software controlled, general purpose
  - Digital Signal Processor (DSP)
    - Processing of large data streams, parallelizing
    - Hard-wire basic functions
  - Field-Programmable Gate Arrays (FPGA)
    - Special hardware, expensive
    - Limit coding to configuration
  - Application-Specific Integrated Circuits (ASIC)
    - Special hardware designed only for one application
    - Possibly embedding several MCU or DSP cores

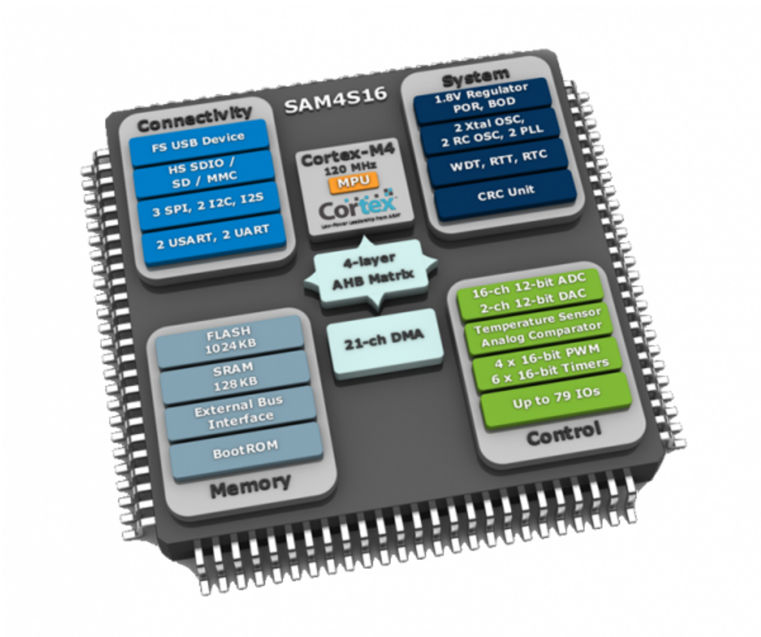
Controller

[Adams]

	Time to Market	Perfor-mance	Price	Develop-ment Ease	Power	Feature Flexibility
MCU	Excellent	Fair	Excellent	Good	Fair	Excellent
DSP	Excellent	Excellent	Good	Excellent	Excellent	Excellent
FPGA	Good	Excellent	Poor	Excellent	Poor	Good
ASIC	Poor	Excellent	Excellent	Fair	Good	Poor

Controller

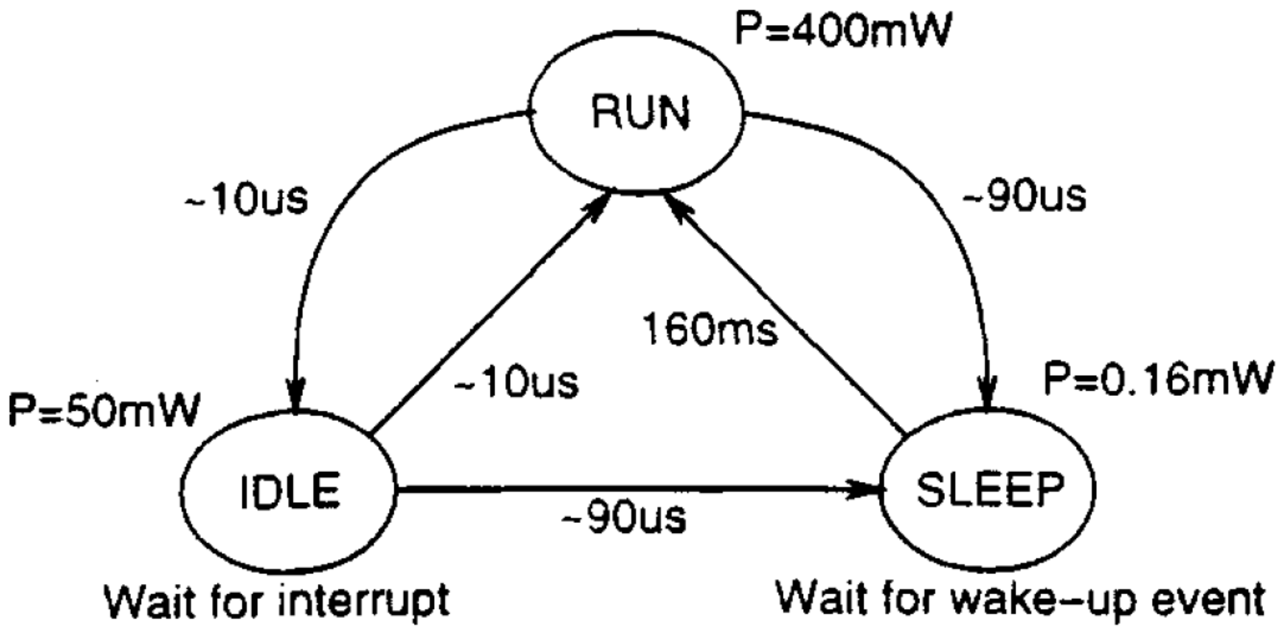
- Tasks of the controller
  - Running of (real time) data processing and communication protocols
  - Perform and control the application program
  - Energy management of the node
    - Different operation modes available (active, idle, listen, sleep, etc.)



Controller

[Benini]

- Energy management of controller
  - Example: Power state machine of StrongARM-1100

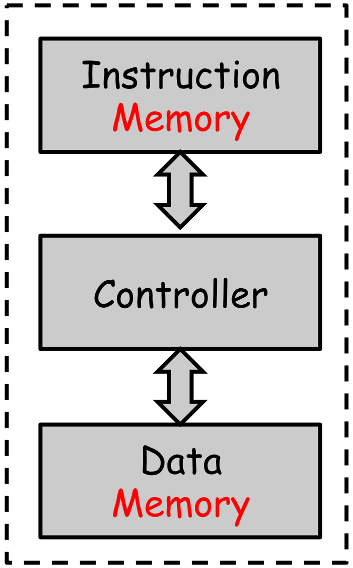


Controller: Overview of some popular MCUs

	Atmega1281	TI MSP430	PIC 18F6720	ARM7TDMI-S	ARM926EJ-S
	8 bit RISC	16 bit RISC	16 bit RISC	32 bit RISC	32 bit RISC
RAM	8 kB	10 kB	4 kB	98 kB	1 MB
Flash	128 kB Program 512 kB Data (Serial Flash) 4 kB EEPROM	48 kB	128 kB Program 512 kB File system 1 kB EEPROM	512 kB	8 MB
Max. Freq.	8 MHz	8 MHz	20 MHz	Up to 72 MHz	400 MHz
Power-consumption	Active: 8 mA Sleep: < 8 µA	Active: 1.8 mA Sleep: 5.1 µA	Active: 8 mA		20-144 mA Sleep: 65 µA
Platform	IRIS	TelosB MSB-H30	Particle	MSB-A2	Sun SPOT (Rev 8.0)
Price	~12 €	~5 €	~5 €		

Memory

- Properties
  - Often different program and data memory
    -> Harvard architecture
  - No memory management unit (MMU) available
  - Size of memory varies
    - May depend on the application



- Types of memory
  - Random Access Memory (RAM)
    - Store temporarily sensor data and messages
  - Electrically Erasable Programmable Read-Only Memory (EEPROM)
    - Stores the program code
    - Operates on bytes
  - FLASH Memory
    - Non-volatile memory
    - Stores the program code
    - Stores data if RAM too small or protection against power loss required
    - Operates on blocks (read, write)
    - High delay and energy consumption

Communication interface

- Communication interface is required to exchange data with other devices
- Typical communication media
  - Radio
  - Infrared (IR)
    - Directed / undirected
  - Ultrasonic
    - More in military applications
  - Sound
    - Underwater communication

- Communication interface has high energy consumption
  - Radio interface consumes the most energy usually

Communication interface: Radio

- ISM bands defined by the ITU.R

Frequency Range		Bandwidth	Center Frequency
6.765 MHz	6.795 MHz	30 kHz	6.78 MHz
13.553 MHz	13.567 MHz	14 kHz	13.56 MHz
26.957 MHz	27.283 MHz	326 kHz	27.12 MHz
40.66 MHz	40.70 MHz	40 kHz	40.68 MHz
433.05 MHz	434.79 MHz	1.84 MHz	433.92 MHz
902 MHz	928 MHz	26 MHz	915 MHz
2.4 GHz	2.5 GHz	100 MHz	2.45 GHz
5.725 GHz	5.875 GHz	150 MHz	5.8 GHz
24 GHz	24.25 GHz	250 MHz	24.125 GHz
61 GHz	61.5 GHz	500 MHz	61.25 GHz
122 GHz	123 GHz	1 GHz	122.5 GHz
244 GHz	246 GHz	2 GHz	245 GHz

Communication interface: Radio

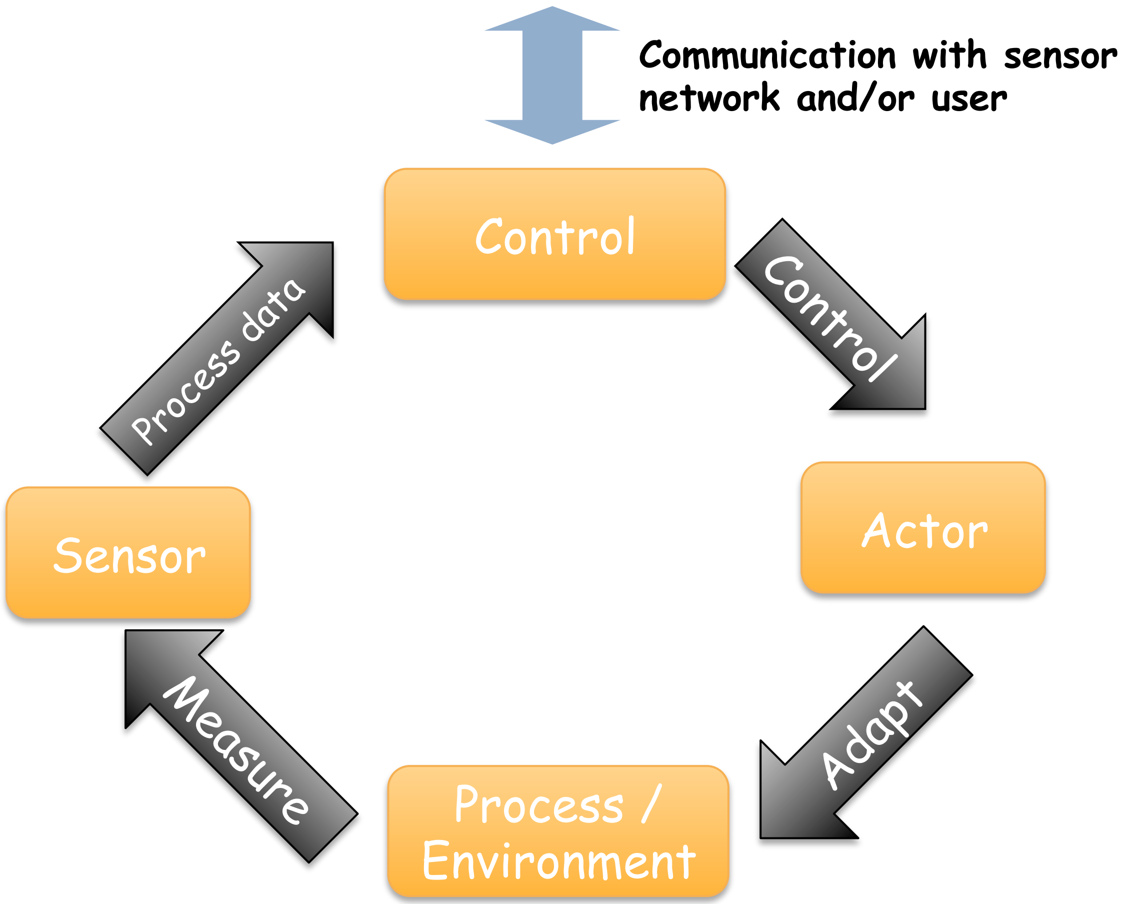
- Overview of popular radio interface technologies
  - IEEE 802.15.4 / ZigBee
  - IEEE 802.11b (WLAN)
  - Bluetooth
  - 868 MHz Derivate (e.g. TR1001)

Communication interface: Radio

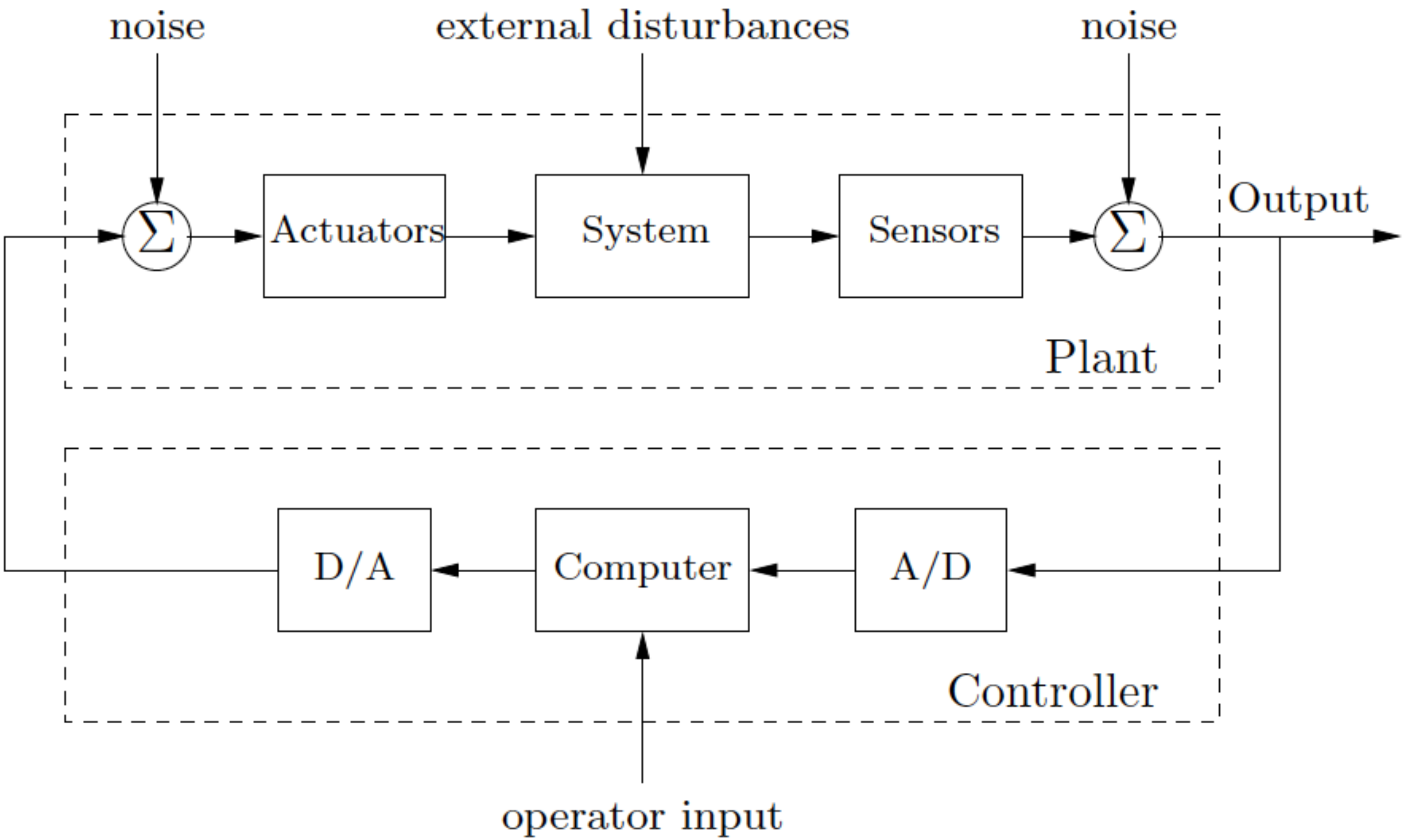
	ZigBee / IEEE 802.15.4	Bluetooth	868 MHz Derivative	Near field communication	IEEE 802.11b
Frequency	2.4 GHz	2.4 GHz	868 MHz	13.56 MHz	2.4 GHz
Data rate	250 kbps	732 kbps-2.1 Mbps	40-150 kbps	424 kbps	11 Mbps
Communication range	30-100 m	1-100 m	300 m Outdoor	<10 cm	300 m Outdoor 90 m Indoor
Energy consumption (send, receive)	10-20 mA	30 mA	25 mA	<15 mA	120-180 mA
Energy consumption (sleep)	20 μA				

Sensors / Actors

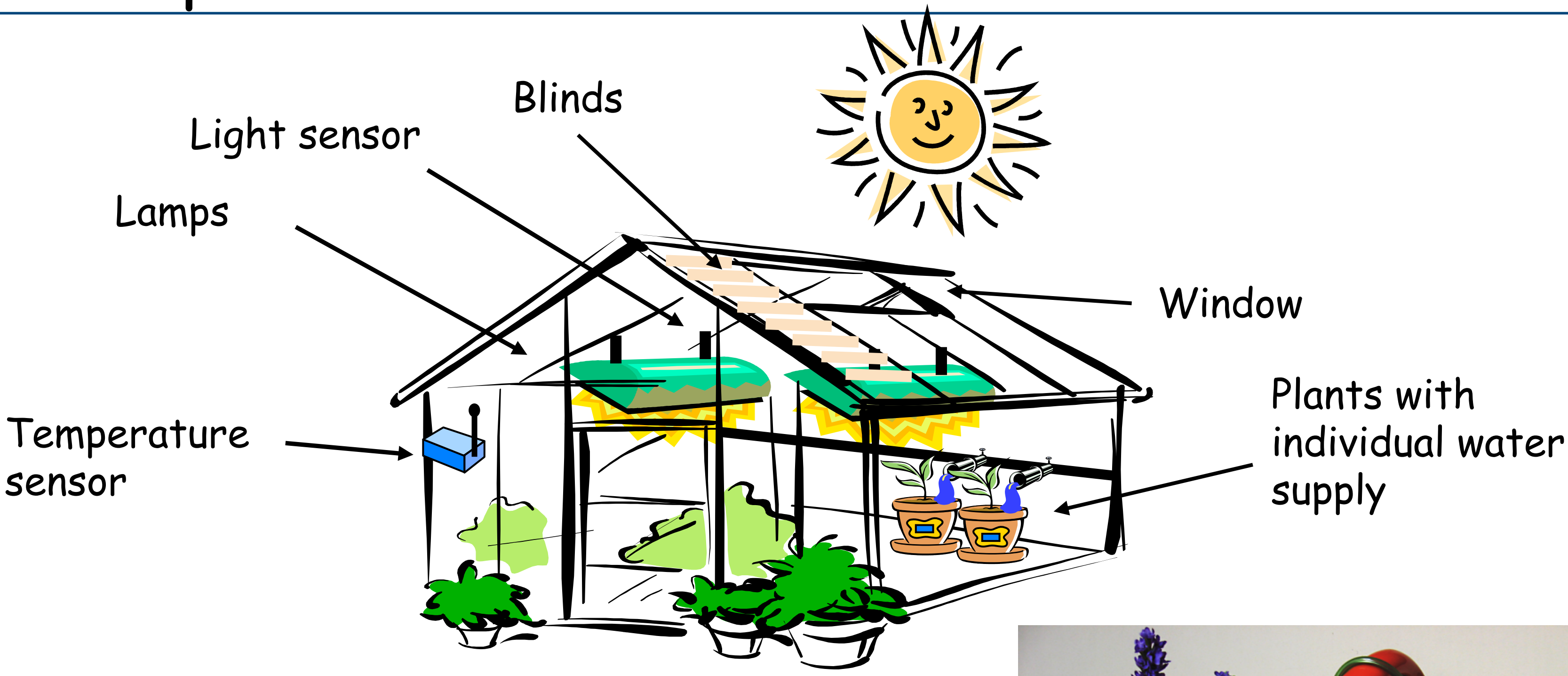
- Interface between digital and real world

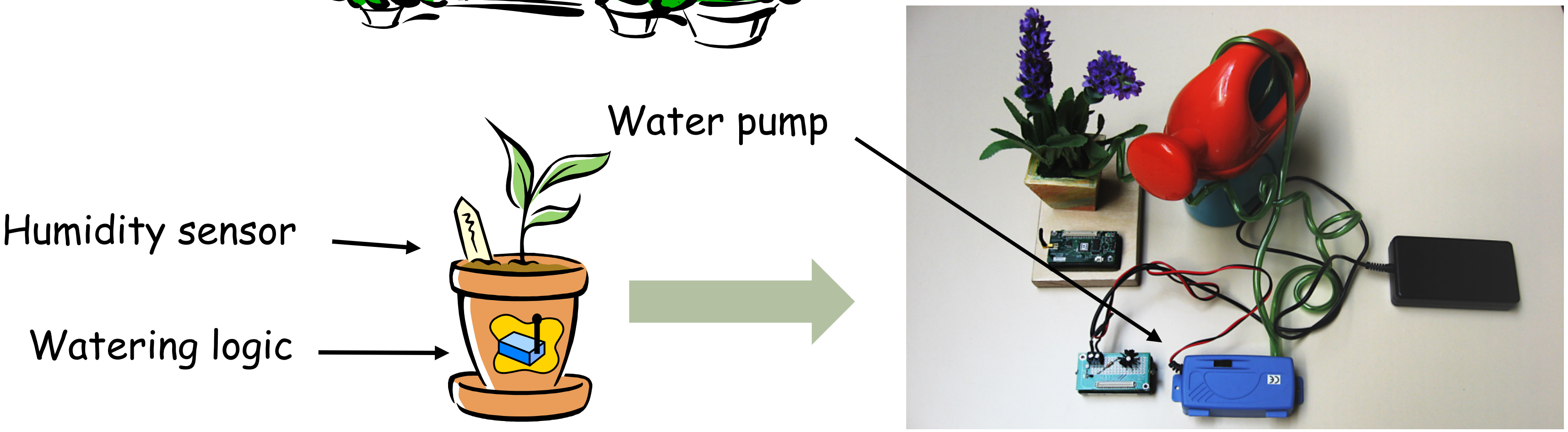


Sensors / Actors



Sensors / Actors
Example: Smart Greenhouse





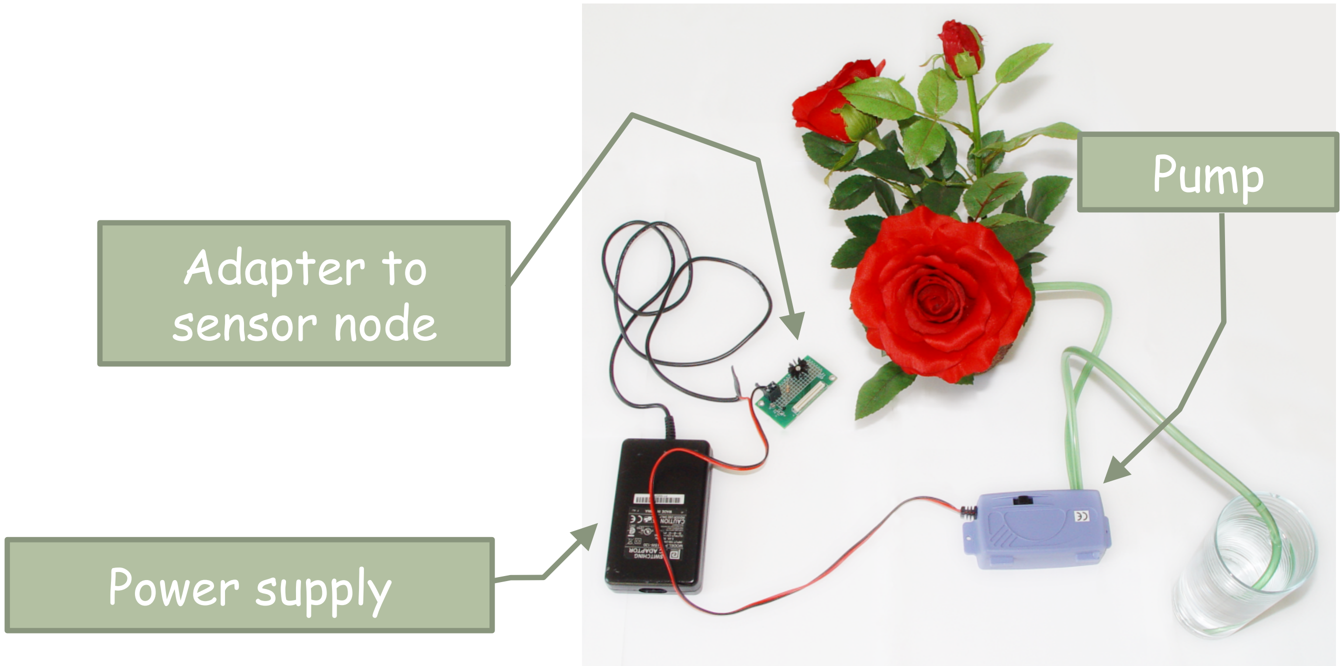
Sensors

Calibration?

- Different criteria for classification
  - Context (activity, position)
  - Used technology (infrared, ultrasonic, induction, sound)
  - Technical aspects (magnetic, mechanical, electrical)
  - Logical operation (integrated, active, passive)
  - Measured value (temperature, pressure, acceleration)
  - Spatial distance (contactless, contact, omnidirectional)
  - Information dimension (one dimension, multidimensional)
  - Application area (…)
- Analog-digital conversion of sensor data required
  - Analog Digital Converter (ADC) required
  - Often integrated into the microcontroller

Actors

- Purpose
  - Translate signals to actions
  - Counterpart to sensors
  - Event generation by actors
  - Actors are usually developed for one applications
  - Example: Water pump in greenhouse



Power supply

- Energy is the most critical resource in a battery operated device (sensor node, “thing”)
- Energy supply has two tasks

1) Provision of electrical energy
   - Typically with batteries
   - In future also fuel cells

2) Conversion of other energy forms
   - Extraction of energy from the environment
   - -> Energy harvesting

Energy consumption of sensor nodes

- Energy characteristic of the components
  - Radio interface consumes the most energy
    - Ratio of energy requirements of CPU / radio interface
    - Model

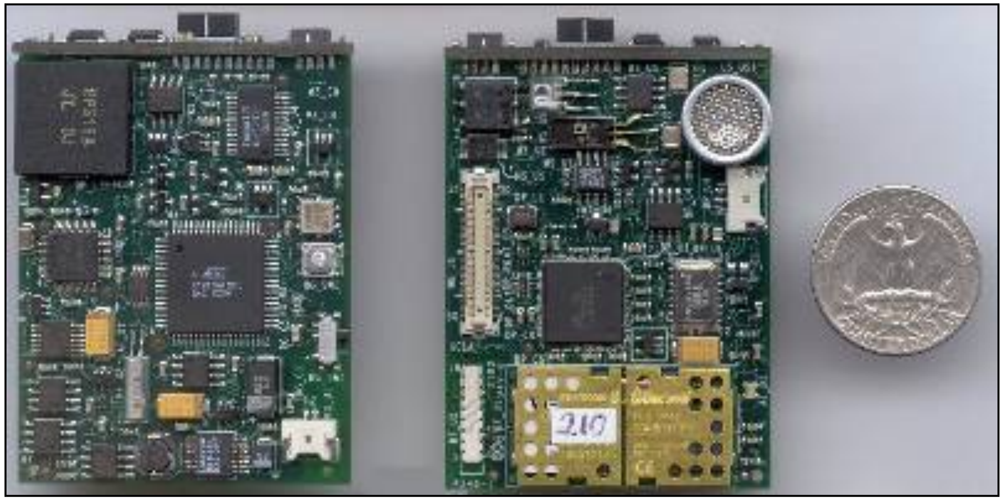
      E(1 Instruction of CPU) : E(Sending of 1 bit) ≈ 1:1500 – 1:2900

    - Send and receive operations are roughly equal expensive
    - Best energy consumption reduction: switch-off radio
  - Flash-Memory has high energy requirements
    - Write operation ~900 times more expensive than read operation
  - Processor not so critical
    - Typically several power modes available
    - -> Adaption of energy consumption to the operation
  - Sensors / Actors
    - Varies between components and difficult to predict

Example: Ratio of energy consumption

[Park]

- Sensor node
  - iBadges
    - 8-Bit RISC Microprocessor (ATmega128L Atmel)
    - Bluetooth



- Data analysis on the sensor node or base station
  - Tradeoff between communication and processing
  - Ratio of energy consumption

$$E_{DSP} : E_{ATMEGA} : E_{BT} = 1 : 4.75 : 1585$$

- -> Reduction of energy by more processing and less data transmission (Bluetooth)

Provisioning of energy

- Batteries
  - Cheap
  - Easy to use
  - Rechargeable batteries available
    - Lithium Ion batteries with high capacity
    - Charging is simple and easy
  - Size of batteries is a problem
    - AA battery defines the size of many devices
  - Environment (temperature) has influence on the capacity

5 cm

1.4 cm

- In future fuel cell possible
- Currently also MEMS (Micro Electro Mechanical Systems) are used in research

Energy harvesting

- Capacity of battery limits the lifetime of the device
  - Battery depletion -> Device cannot work
    -> (Sensor) network cannot work
  - Idea: recharge the batteries during operation
  - Use energy from the environment

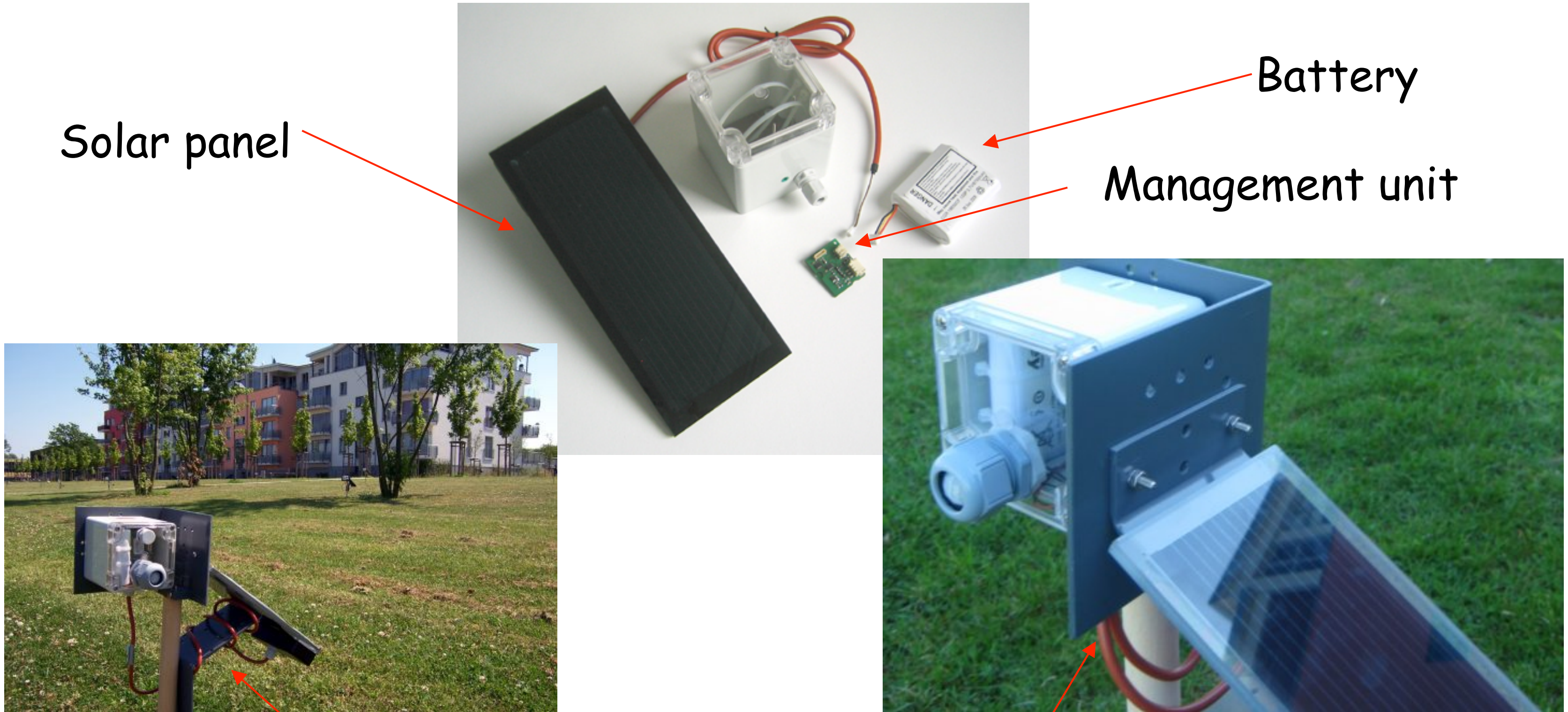
What is the network lifetime?

- Current approaches
  - Photovoltaic
    - Solar modules for sensor nodes
  - Thermoelectric generators
    - Conversion of temperature differences to energy
  - Kinetic energy conversion
    - Piezo-electric principle already tested for shoes
  - MEMS gas turbines
    - Convert air- or fluid streams

Photovoltaic

[Krüger]

- Solar modules for sensor nodes
  - Additional controller for the energy management



Photovoltaic

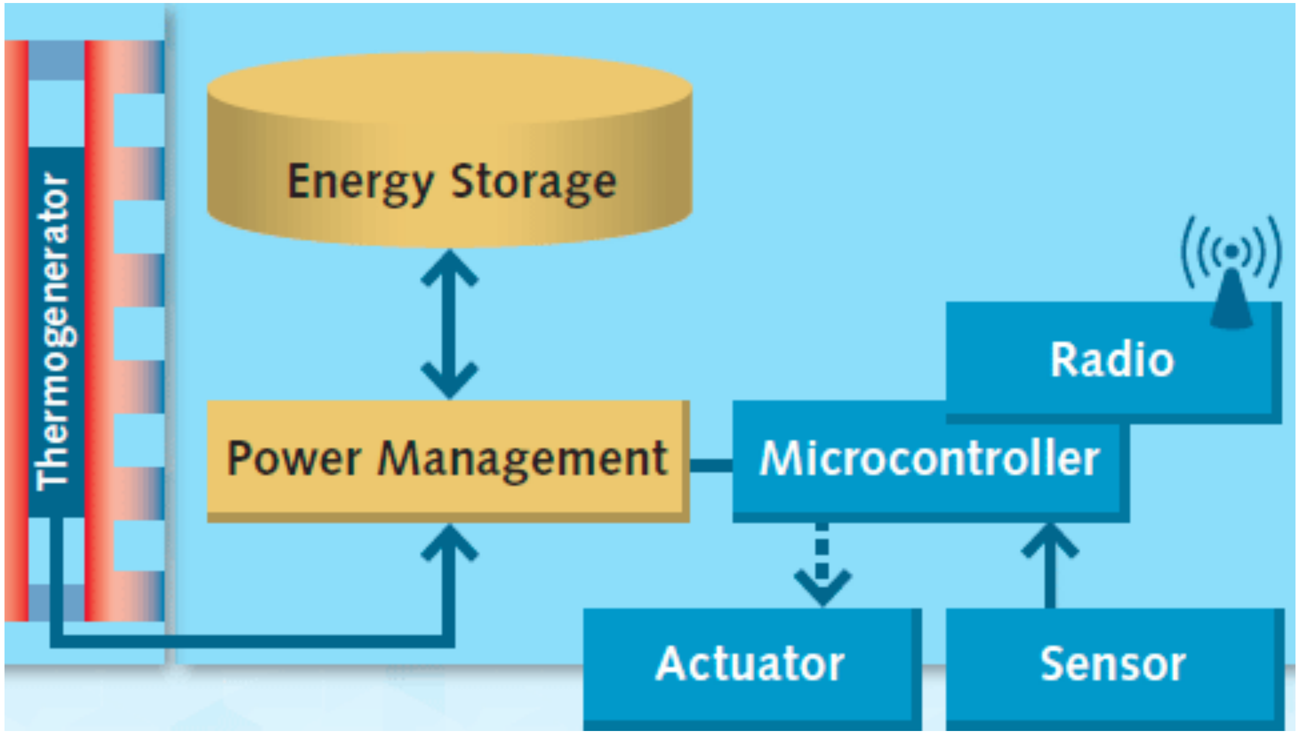
- Advantages of photovoltaic
  - Energy comes for “free” and is “available unlimited”

- Disadvantages
  - Solar panels are expensive (~100 €)
  - Depends on season/weather
  - Depends on location
    - Shadow vs sun
    - Angle of the sun rays important
  - Solar panels are large in comparison to device

Thermoelectric generators

[micropelt]

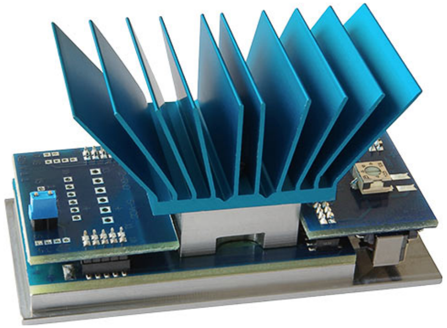
- Use of temperature difference for energy conversion based on *Seebeck effect*
  - Use of thermo electric generators



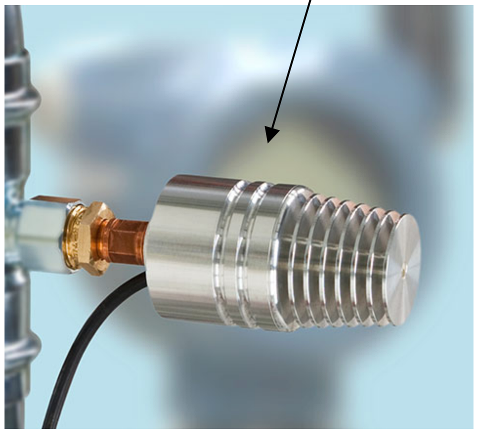
Thermoelectric generators

[micropelt]

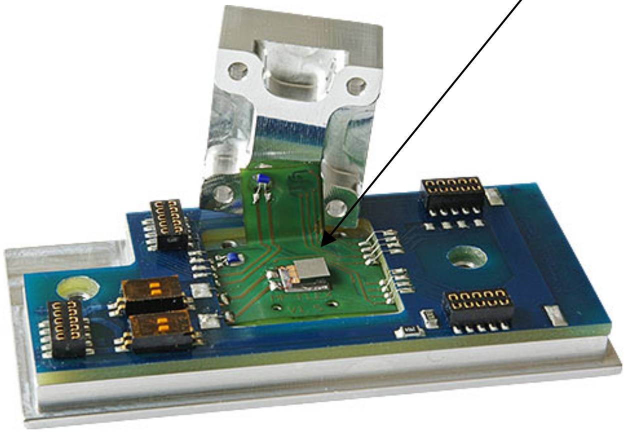
TE-Power PLUS Evaluation Kit



TE-Power PROBE for use with fluids



MPG-D751 Thermo generator Chip.



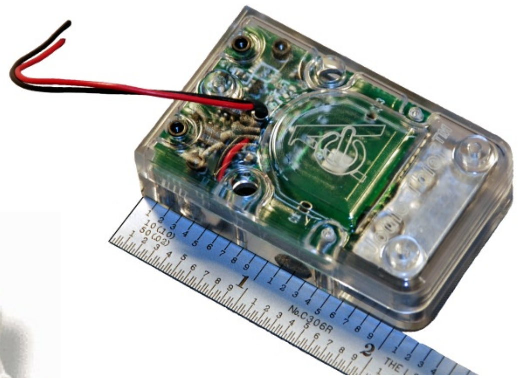
Thermoelectric generators

- Advantages
  - Cheap
  - Energy comes for “free” and is “available unlimited”

- Disadvantages
  - Temperature difference has to be known and large
    - 35°C ~3600 mAh (or 2-4 AA Batteries)

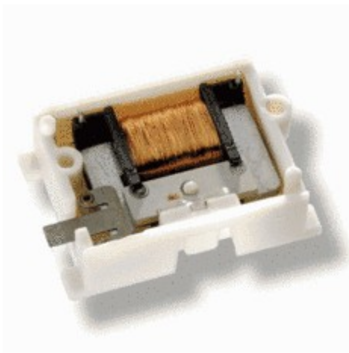
Kinetic energy conversion

- Use of kinetic energy for energy-harvesting
- Various forms of kinetic energy
  - Rotation
  - Linear movement
  - Vibration/impacts
  - Flow



[joulethief]

[perpetuum]



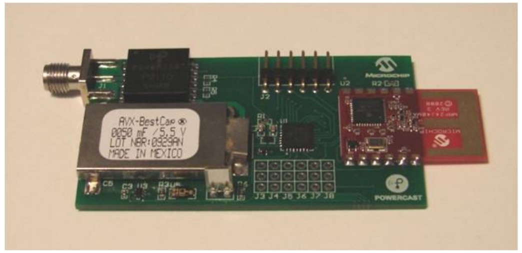
[EnOcean]

Kinetic energy conversion

- Advantages
  - Cheap
  - Energy comes for “free” and is “available unlimited”
- Disadvantages
  - Continuous movement required

Other approaches

- Piezo-Effect
  - e.g. in shoes
- Radio waves
  - Sensor prototypes exists
- Laser, acoustic, …
- What else can be used?



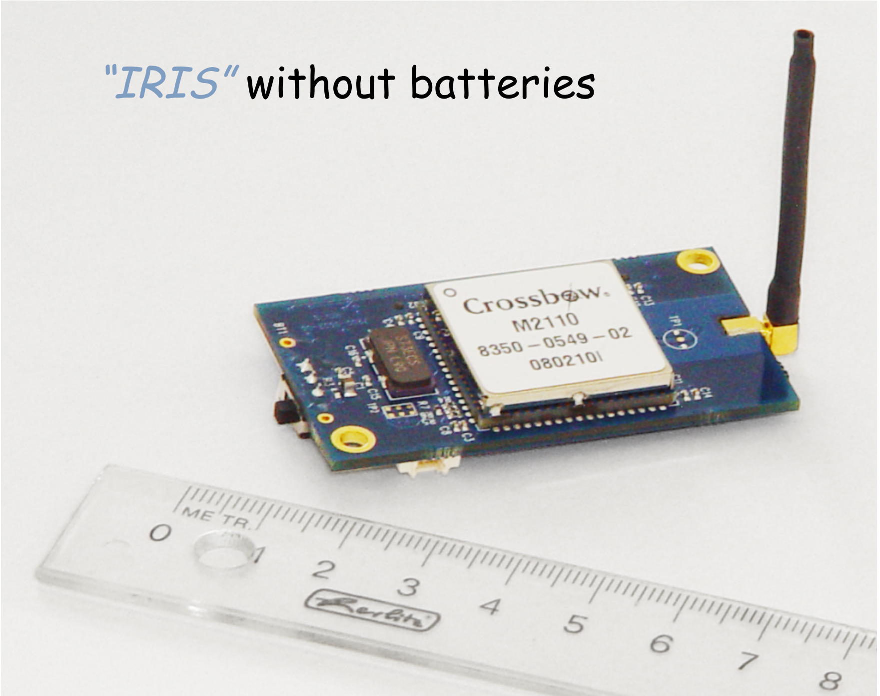
Platforms

Platforms: Overview of popular platforms

Platform	Microcontroller	Radio chip
AVRraven	ATMEGA1284p, ATMEGA3290p	AT86RF230
BTnode	ATMEGA128L	CC1000
EyesIFX v1 / v2	MSP430F149, MSP430F1611	TDA5250
iMote, iMote2	ARM core, ARM 7TDMI, ARM 11	Bluetooth, CC2420
Lotus	ARM7 Cortex M3	AT86RF231
MICA, MICA2/MICAz, Cricket, MICA2Dot, **IRIS**	ATMEGA103, ATMEGA 128, ATMEGA128L, **ATMEGA1281**	TR1000, CC2420, **AT86RF230**
Particle, **DINAM**	**PIC18F720**, **PIC18F14K22**	**TR1001**
ScatterWeb MSB	**MSP430F1612IPM**	**CC1020**
Shimmer	MSP430F1611	CC2420
SunSPOT	**ARM926EJ-S**	**CC2420**
Telos, TelosB, T-Mote Sky	MSP430	CC2420
Tinynode	MSP430	SX1211

Platforms: IRIS Motes

- Processor
  - XM2110CA based on Atmel ATmega1281
  - 8 bit Microcontroller
  - 8 MHz
  - Compute power similar to 8088 CPU from the original IBM PC (~1982), but reduced energy consumption
- Radio chip
  - AT86RF230
  - IEEE 802.15.4
  - ZigBee compatible
  - 2.4 GHz, 250 kbps, up to 300 m (outdoor), up to 50 m (indoor)
- Memory
  - 4 kB EEPROM
  - 8 kB RAM
  - 128 kB program Flash Memory
  - 512 kB measurement Flash Memory

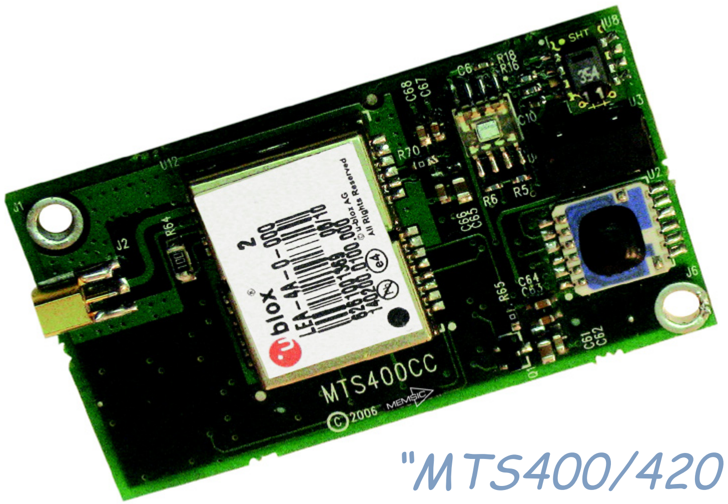


Platforms: IRIS Motes

- Size and weight
  - 5.8 x 3.2 x 0.7 cm
  - Without batteries & sensor board: 18 g
- Energy supply
  - 2 x AA batteries to provide required voltage
  - Microcontroller: 8 µA (sleep), 8 mA (active)
  - Radio chip: 15.5 mA (receive), 17.4 mA (send), 1.5 mA (idle), 0.02 µA (sleep)
- Periphery
  - Sensor boards, UART, 10bit AD-converter, Digital IO, I2C, SPI Bus, JTAG ICE, 51 Pin Connector
- Producer
  - MEMSIC (formerly Crossbow)
- Programing and accessories
  - NesC (C-Derivat) -> TinyOS Operating System
  - MoteWorks: Platform for developing sensor network applications
- Costs
  - 134$ / without sensor board

Platforms: IRIS Motes

- Sensors
  - Onboard: 3 LEDs
  - Additional sensor boards
    - Light
    - Temperature
    - Humidity
    - Barometric pressure
    - Accelerometer
    - GPS
    - Analog and digital I/O interfaces
    - Memory for data



"MTS400/420"

Platforms: Sun SPOT

- Processor ARM926EJ-S
  - 32 bit
  - 400 MHz
  - Floating-point unit
- Radio chip
  - CC2420
  - IEEE 802.15.4 conform,
  - ZigBee compatible
  - 2.4 GHz, 250 kbps, up to 100 m range
- Memory
  - 1 MB RAM
  - 8 MB Flash
- Size and weight
  - 4x7x2.3 cm incl. batteries and sensor board, 54 g

Platforms: Sun SPOT

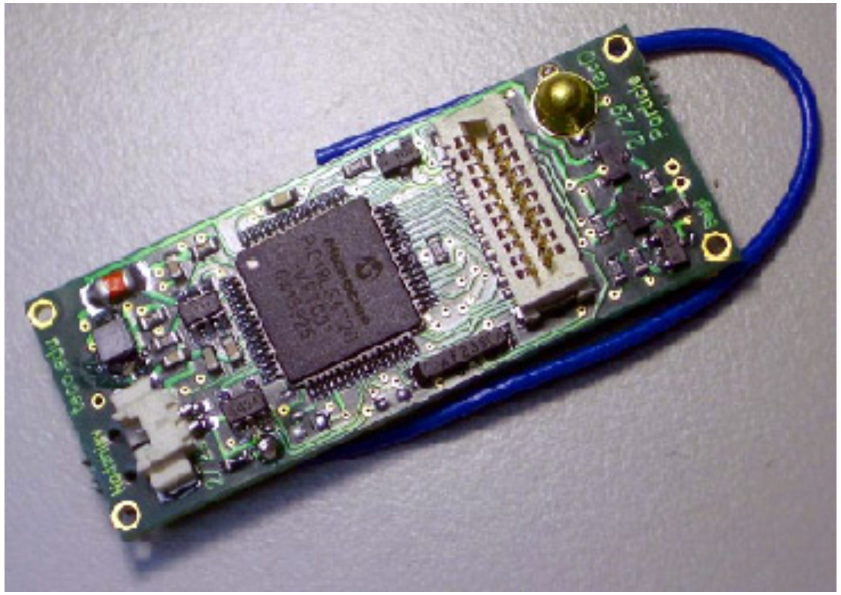
- Energy supply
  - Li-Ion battery, 770 mAh
  - Energy consumption: 65 µA in deep sleep mode
  - Runtime:
    - ~7h (Radio chip and processor active)
    - ~900d (deep sleep)
  - 8-bit Microcontroller Atmel Atmega168 for energy management
- Periphery
  - Sensor board, accelerometer, 8x3-color LEDs, 2 programmable buttons, Temperature sensor, Light sensor, Digital and Analog I/O, AD-Converter, USB-Interface
- Programming
  - Java (Midlets)
- Producer
  - Sun Labs, Oracle, California
- Accessories
  - JVM Squawk, Support for developer tools (Eclipse, Netbeans)
- Costs
  - As set: 315 € for 2 nodes + base station

Platforms: Sun SPOT

- Sensors/Actors
  - Onboard: Temperature sensor
  - Additionally
    - Digital and analog I/O
    - RGB light sensor
    - RGB LEDs
    - Accelerometer
    - Speaker
    - IR Transceiver

Platforms: Particle

- Processor
  - PIC 18F720
  - 20 MHz
  - 8 bit
- Radio chip
  - TR1001
  - 125 kbps
  - 868.35 MHz
- Memory
  - On-Chip
    - 4 kB RAM
    - 128 kB Flash
    - 1 kB EEPROM
  - Extern
    - 500 kB Flash for data
    - File system: ParticleFS
- Size
  - 4.5x2.7 cm incl. batteries



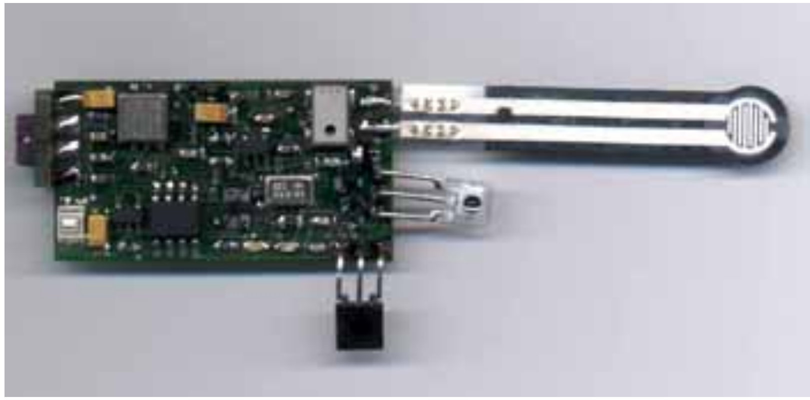
Platforms: Particle

- Energy supply
  - Flexible w.r.t. voltage: 0.9 V – 3.3 V
  - AAA, 2xAAA, AA
- Periphery
  - 21 pin interface with I2C, SPI, Serial (625 kbps), Parallel bus, Analog interface, Interrupt interface, Digital I/O
- Programming
  - C
- Producer
  - TeCO, KIT (formerly spin-off: Particle Computer GmbH)
- Accessories
  - X-Bridge, Programming adapter, breakout board
- Costs
  - 120 € per node, with batteries 130 €

Platforms: Particle

- Sensors and actors
  - LCD
  - Accelerometer
  - Pressure sensor
  - Light- / IR
  - LEDs
  - Temperature
  - Microphone
  - Analog interface
  - Digital I/O
  - Speaker

"Particle LCD AddOn"



"spart Sensor Board"

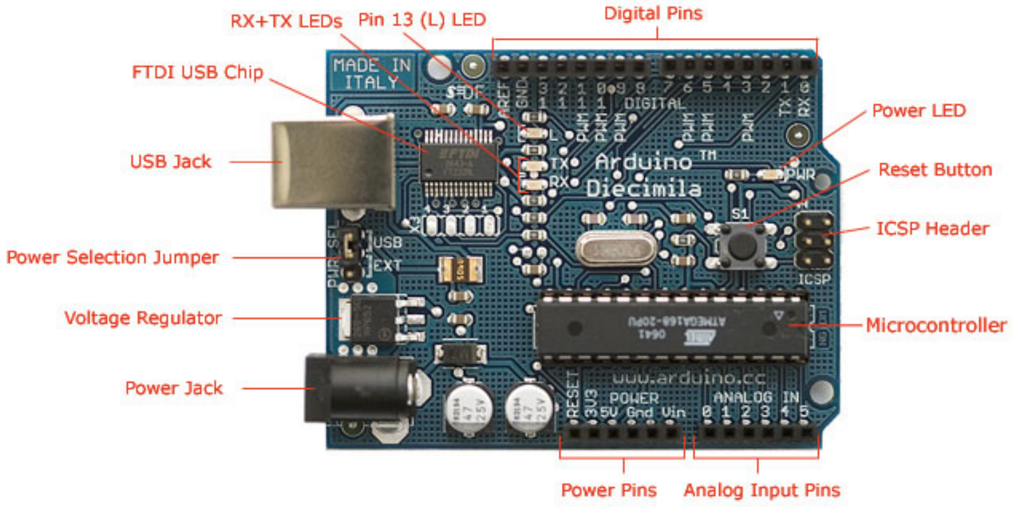
Platforms: DINAM

- Platform + SDK
- Rapid Prototyping of wireless sensor networks
- Approach: “simple things must be simple [to develop]”
- Platform contains development tools
  - Web interface to sensor node
  - Programming with C64 BASIC in the Web-Browser (AJAX IDE)
  - Installing of the development environment unnecessary -> simplifies the development process

- Combination from
  - Sensor node: PIC18F14K22 8bit Microcontroller 16 MIPS, 512 B RAM, 256 B EEPROM, 16 kB ROM
    Light-, Temperature-, Accelerometer sensor + 4 analog interfaces
  - WSN to Ethernet Bridge: Embedded Webserver provides DINAM IDE

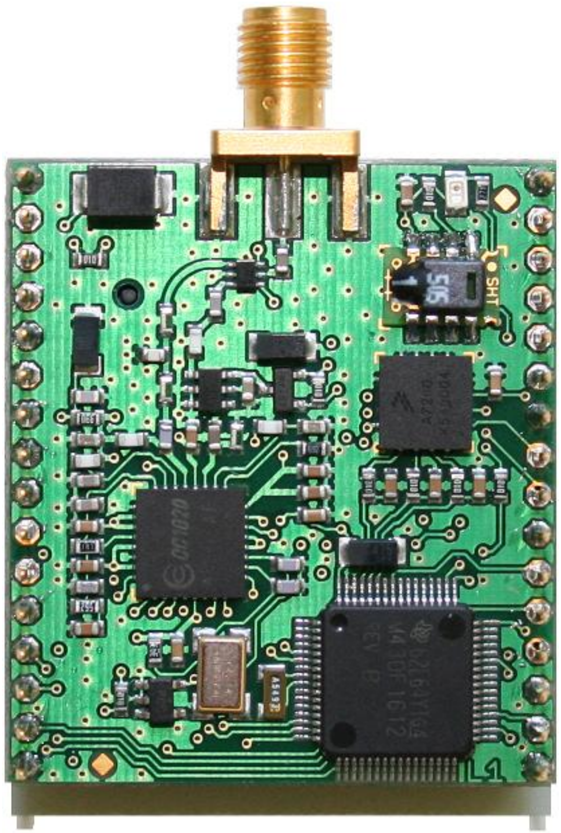
Platforms: Arduino

- Simple platform for sensing and control the environment
- Open source hardware
- Hardware
  - Processor: ATmega328 (Atmel)
  - Clock Speed 16 MHz
  - Digital I/O Pins 14
  - Analog Input Pins 6
  - Flash Memory 32 KB
  - SRAM 2 KB
  - EEPROM 1 KB



Platforms: ScatterWeb MSB

- Modular Sensor Board (MSB)
- Processor
  - MSP430F1612IPM
  - 8 MHz
  - 16 Bit
- Radio chip
  - CC1020
  - 868MHz
  - Up to 153.6 kbps
  - Up to 1 km (outdoor)
- Memory
  - 55 kB Flash
  - 5 kB RAM
  - SD-Card interface
- Size
  - 4.1x3.6 cm (without batteries)



Platforms: ScatterWeb MSB

- Energy supply
  - 3 x AAA batteries
  - Energy consumption of the radio chip ~19 mA (send and receive)
- Periphery
  - Sensor boards, UART, 10 bit AD-converter, Digital IO, I2C, SPI Bus, JTAG ICE
- Programing
  - ScatterWeb .NET SDK
- Producer
  - Formerly ScatterWeb GmbH Berlin / FU Berlin
- Accessories
  - Sensor board, carrier board
  - Product line for the industry „ScatterNode“ with ScatterGate, Evalboard and ScatterRights (Software framework)
- Costs: ~120 € / Node (Historical)

„ScatterWeb Starterkit“

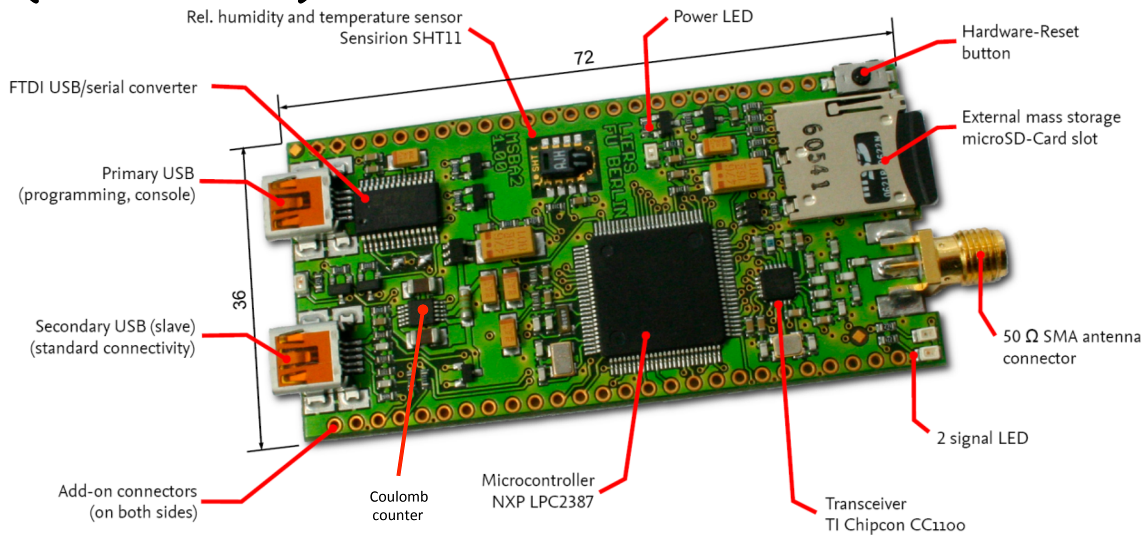
Platforms: ScatterWeb MSB

- Sensors/Actors
  - Onboard
    - Accelerometer, Temperature, and Humidity
    - LEDs
  - Additional sensor boards
    - Buttons
    - Piezo signal generator
    - PIR (Passive Infrared Sensor)
    - IR Transceiver
    - Microphone
    - I/O Ports
    - Joystick
    - Display

"ScatterWeb Embedded Sensor Board"

Platforms: ScatterWeb MSB-A2

- Wireless sensor node (MSB-A2)
  - LPC-2387 ARM7
    - 98 kB RAM
    - 512 kB Flash
  - Chipcon CC1100
    - 10dBm
    - ISM band at 868-870 MHz
    - Data rate ≤500kbps
  - Coulomb counter for battery depletion measurement
  - GPIO pins
  - mini USB 2.0 port
  - microSD-card socket
  - Micro kernel operating system



Operating systems

Operating systems

[Farooq]

- An operating system (OS) acts as a resource manager
- OS multiplexes system resources in
  - time and
  - space

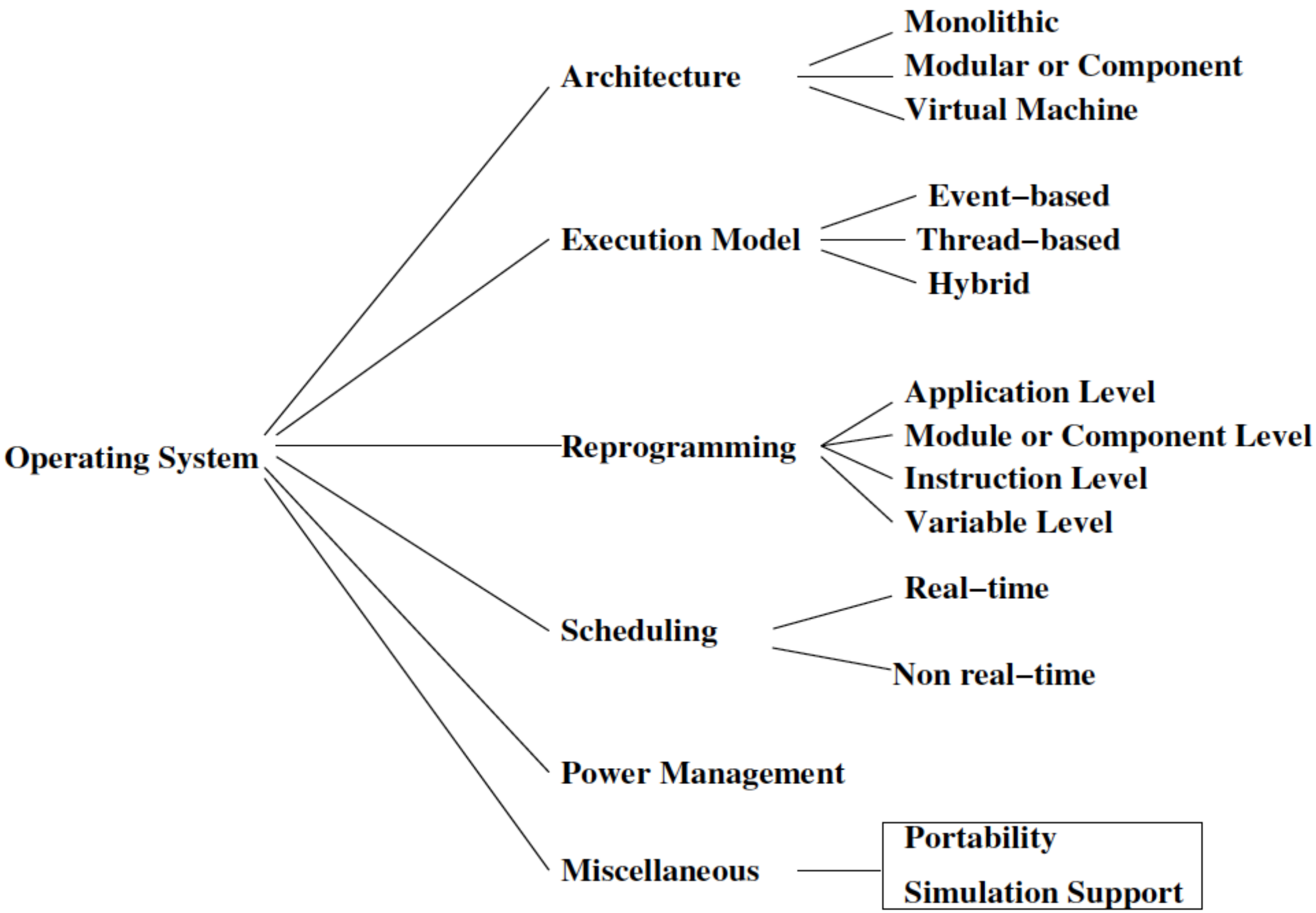
- Properties of an OS
  - Architecture
  - Programming model
  - Scheduling
  - Memory management and protection
  - Communication protocols
  - Resource sharing
  - Support for real-time applications

Operating systems: Properties

- Architecture
  - monolithic
  - micro-kernel
  - virtual machine
  - layered
- Programming model
  - event driven
  - multithreaded
- Scheduling
  - Round robin
  - Priority
- Memory management
  - static memory management
  - dynamic memory management
- Communication protocols
  - inter-process communication within a (sensor) node
  - inter-node communication
- Resource sharing
  - event based
  - virtualization
  - serial access
- Support for real-time applications

Operating systems: Properties

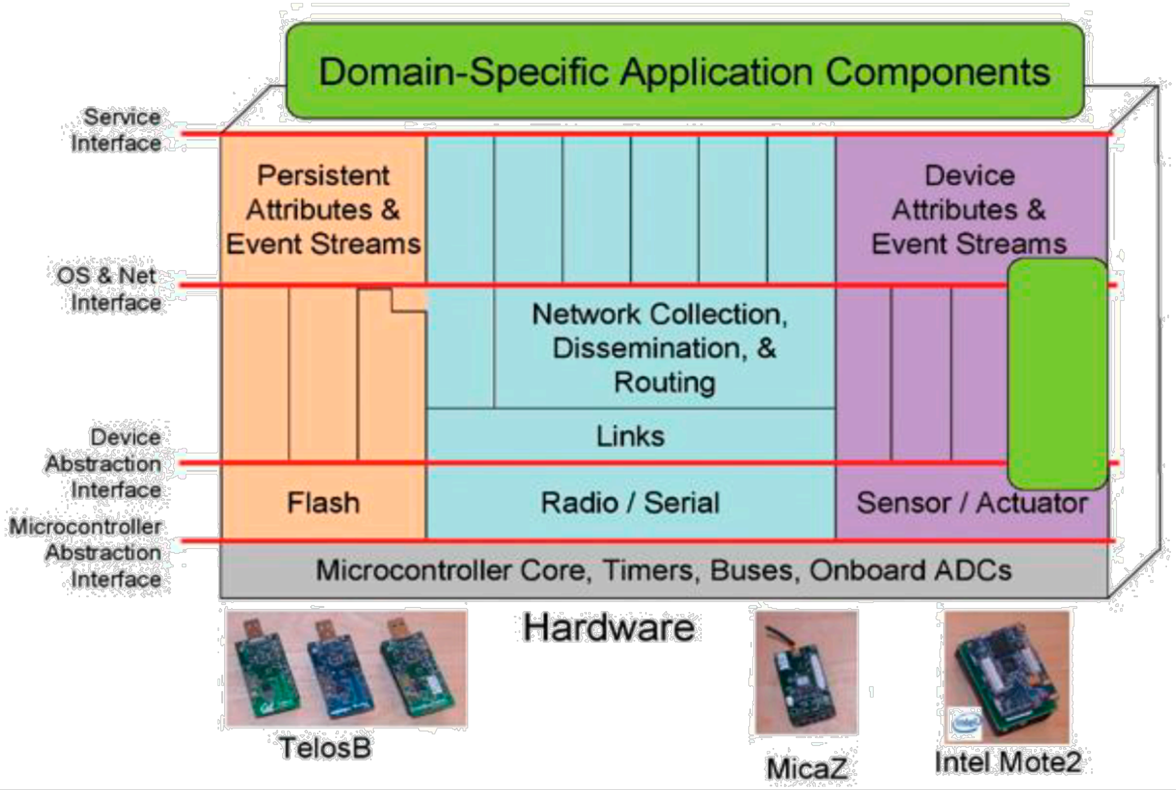
[Reddy]



Operating systems: TinyOS

[tinyos]

- Open source, flexible, component based, and application-specific operating system
- Footprint of 400 bytes
- Monolithic architecture using component model



Operating systems: TinyOS

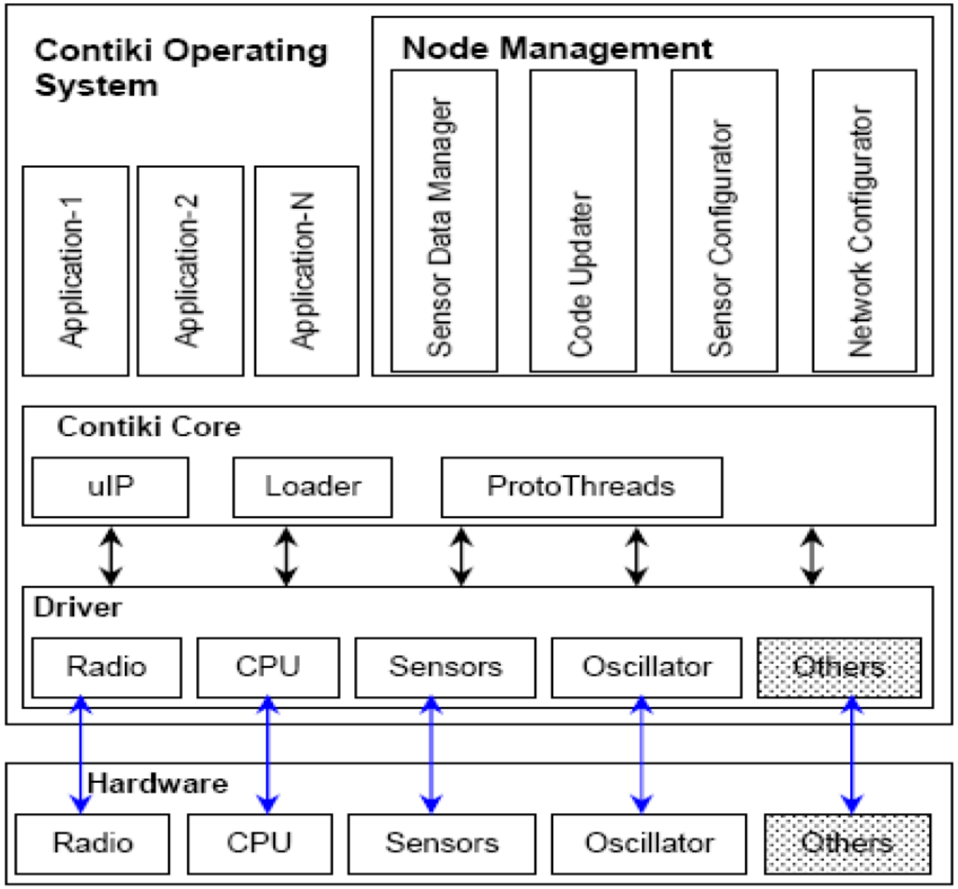
[tinyos]

- Components have three computational abstractions
  - commands
  - events
  - tasks
- Scheduling
  - Earlier version: Non-preemptive FIFO scheduling
  - Later added: Earliest Deadline First (EDF) for real-time
- The TinyOS component library includes
  - network protocols (TYMO, dissemination)
  - MAC (TDMA, TDMA/CSMA, B-MAC, …)
  - distributed services
  - sensor drivers
  - data acquisition tools
- Simulation support: TOSSIM
- File system and Database (TinyDB) support

Operating systems: Contiki

[contiki]

- Lightweight open source OS written in C
- A typical Contiki configuration consumes 2 kB of RAM and 40 kB of ROM
- Modular architecture
- Event-driven kernel
- Preemptive multitasking
- Stack-less and lightweight threads: Protothreads
- Dynamic memory management
- Dynamic linking



Operating systems: Contiki

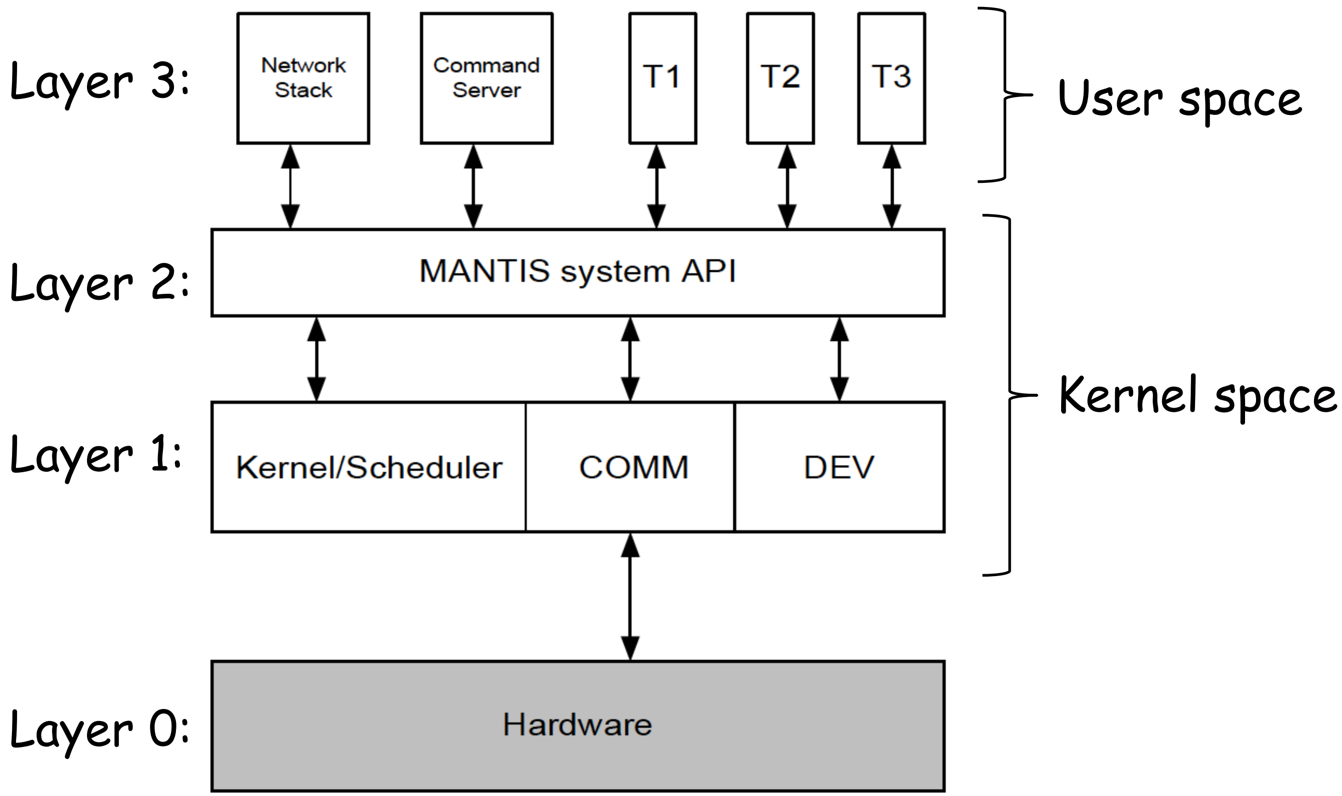
[contiki]

- Rich set of communication protocols -> IPv4, IPv6, TCP
- Additional stack: Rime providing
  - single hop unicast
  - single hop broadcast
  - multi-hop communication
  - best effort and reliable transmission
- In multi-hop communication applications can run their own routing protocol
- No multicast support
- No support for real-time applications
- Simulation support: Cooja
- Coffee File System

Operating systems: MANTIS

[mantis]

- MultimodAl system for NeTworks of In-situ wireless Sensors (MANTIS)
- MANTIS Operating System (MOS)
- Layered architecture



Operating systems: MANTIS

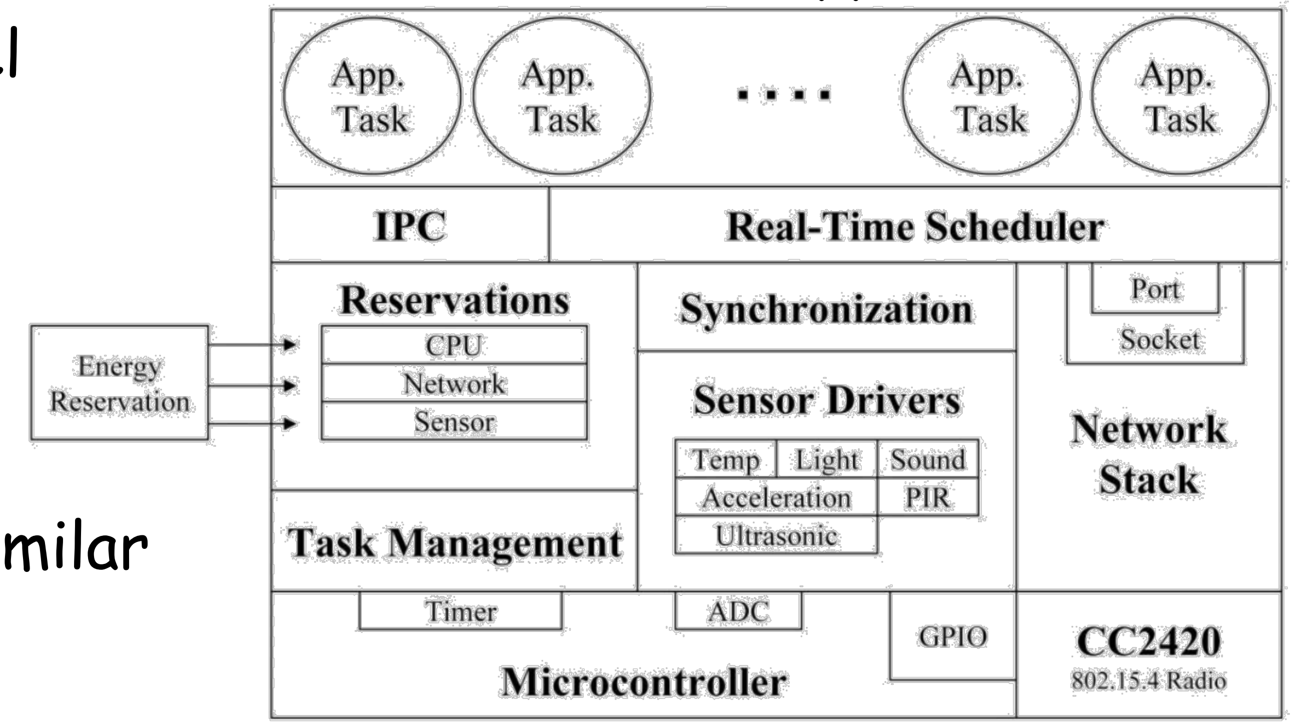
[mantis]

- MOS kernel handles only the timer interrupt
- Preemptive priority-based multitasking
  - Number of threads fixed
- Default thread stack in MOS is 128 bytes
- MOS kernel needs 500 bytes
- Dynamic memory management, but not memory protection
- Support for custom routing and transport layer protocols
- No support for multicast
- Simulation support: AVRORA
- Unix like shell

Operating systems: Nano-RK

[nanork]

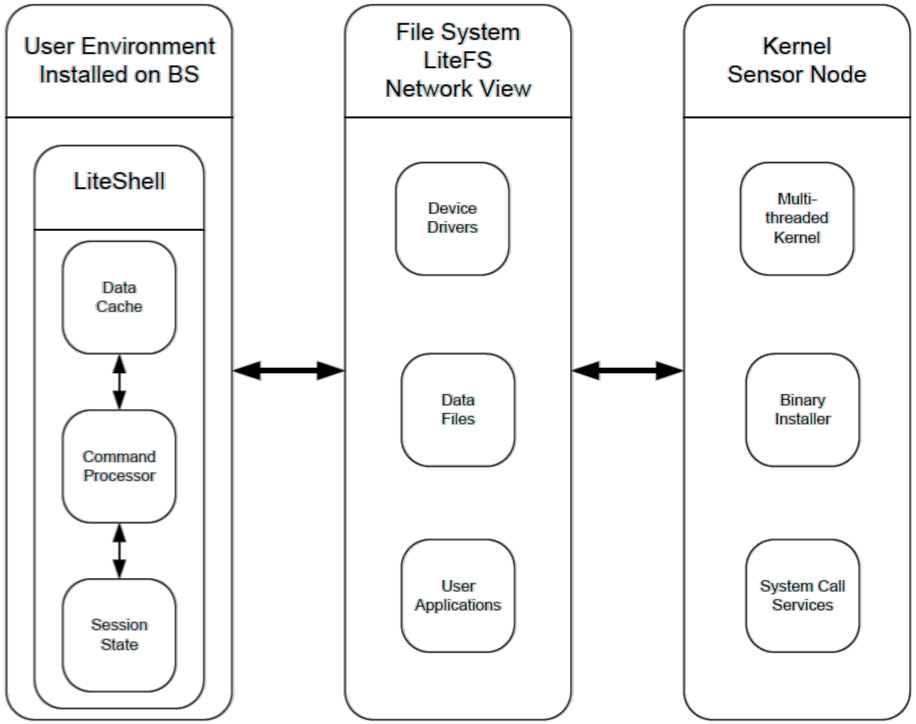
- Preemptive multitasking real-time OS for WSNs
  - Easier to program, since known from traditional OS
  - Priority scheduling at two levels
- Nano-RK uses 2 kB of RAM and 18 kB of ROM
- Nano-RK supports hard and soft real-time applications
- Monolithic kernel architecture
- Static memory management
- Lightweight networking protocol stack similar to sockets



Operating systems: LiteOS

[liteos]

- Unix-like operating system for WSNs
- Multitasking OS / multithreading
  - Round robing scheduling / priority scheduling
- Dynamic memory allocation
- Hierarchical file system
- OO programming
  -> LiteC++
- Unix-like shell
- Three components
  - LiteShell -> resides on a base station or PC
  - LifeFS -> mounts all neighboring nodes as a file
  - Kernel



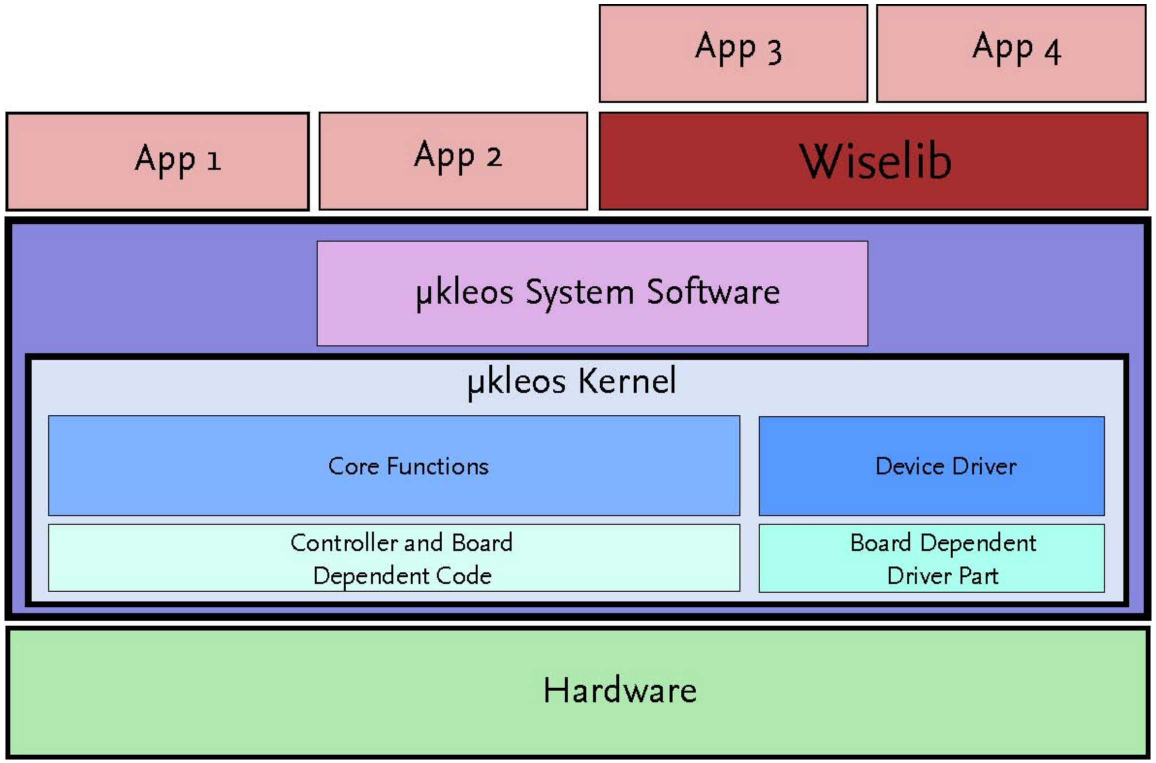
Operating systems: µkleos

[µkleos]

- µkleos is a microkernel architecture for WSN
- Tickless, preemptive scheduler
- Modular design, easy portable
- Existing ports for:
  - MSB-A2
  - MSB-430H
  - eZ430-Chronos
- http://www.ukleos.org

Operating systems: μkleos

- Real time and multithreading capable
- Written in pure ANSI C
- Supports generic frameworks like Wiselib



Operating systems: Summary

[Farooq]

OS/ Feature	Architecture	Programming model	Scheduling	Support for Real-time Applications
TinyOS	Monolithic	Primarily event Driven, support for TOS threads has been added	FIFO	No
Contiki	Modular	Protothreads and events	Events are fired as they occur. Interrupts execute w.r.t. priority.	No
MANTIS	Layered	Threads	Five priority classes and further priorities in each priority class	To some extent at process scheduling level (implementation of priority scheduling within different processes types).
Nano-RK	Monolithic	Threads	Rate monotonic and rate harmonized scheduling.	Yes
LiteOS	Modular	Threads and Events	Priority based round robing scheduling.	No
µkleos	Microkernel	Threads	Tickless, preemptive scheduling with priorities.	No

Operating systems: Summary

[Farooq]

OS/ Feature	Memory Management and Protection	Communication Protocol Support	Resource Sharing
TinyOS	Static memory Management with memory protection.	Active Message	Virtualization and Completion Events
Contiki	Dynamic memory management and linking. No process address space protection.	uIP and RIME	Serialized Access
MANTIS	Dynamic memory management supported but use is discouraged, no memory protection.	At kernel level COMM layer. Networking Layer is at user level. Application is free to use custom routing protocols.	Through semaphores.
Nano-RK	Static memory management and no memory protection.	Socket like abstraction for networking.	Serialized access through mutexes and semaphores. Provide an implementation of priority ceiling algorithm for priority inversion.
LiteOS	Dynamic memory management and it provides memory protection to processes.	File based communication.	Through synchronization primitives.
µkleos	Static and dynamic memory management, no memory protection.	6LoWPAN w/ TCP/UDP	Through mutexes.

Summary

Summary

- Embedded systems are “different”
  - Important criteria -> Hardware
- Nodes have reduced resources
  - Energy is the resource
    - Radio interface is the energy consumer
    - Radio switch-off is the best way to save energy
  - Typical dimensions of resources
    - Memory (8 KB – 1 MB RAM)
    - Operating frequency (8 MHz – 400 MHz)
    - Radio interface (40 kbps – 2 Mbps)
    - Energy (8 μA – 100 mA)
- Various platforms are available
- Development tools are not standardized

Summary

- Operating systems are also “different”
  - Desktop OS vs Embedded OS vs WSN OS
  - Energy efficiency
  - Real-time capability
  - Programming model
  - Hardware is more visible

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