u^b

b
UNIVERSITÄT
BERN

Internet of Things

II. Hardware Platforms

Prof. Dr. Torsten Braun, Institut für Informatik

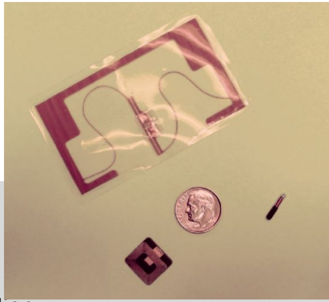
Bern, 01.03.2021

UNIVERSITÄT BERN

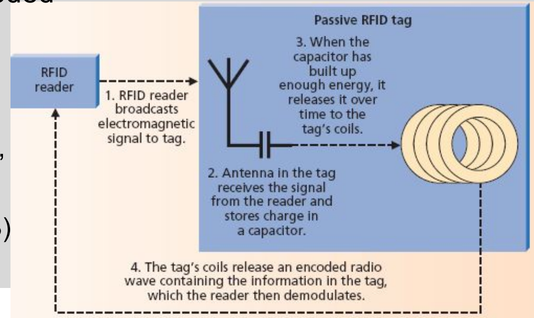
Internet of Things: Hardware Platforms

Table of Contents

1. Radio Frequency IDentification

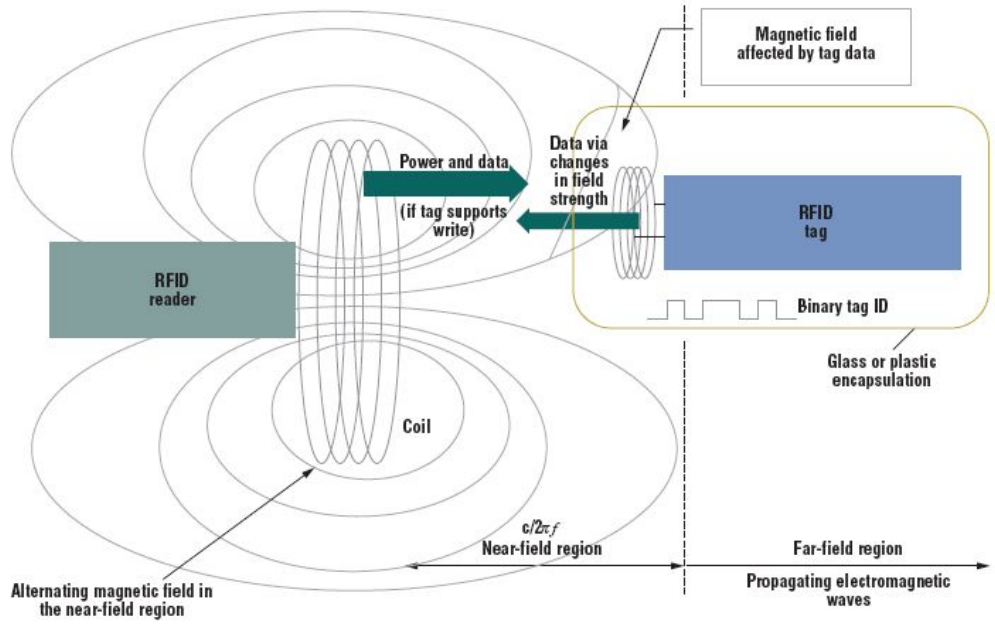


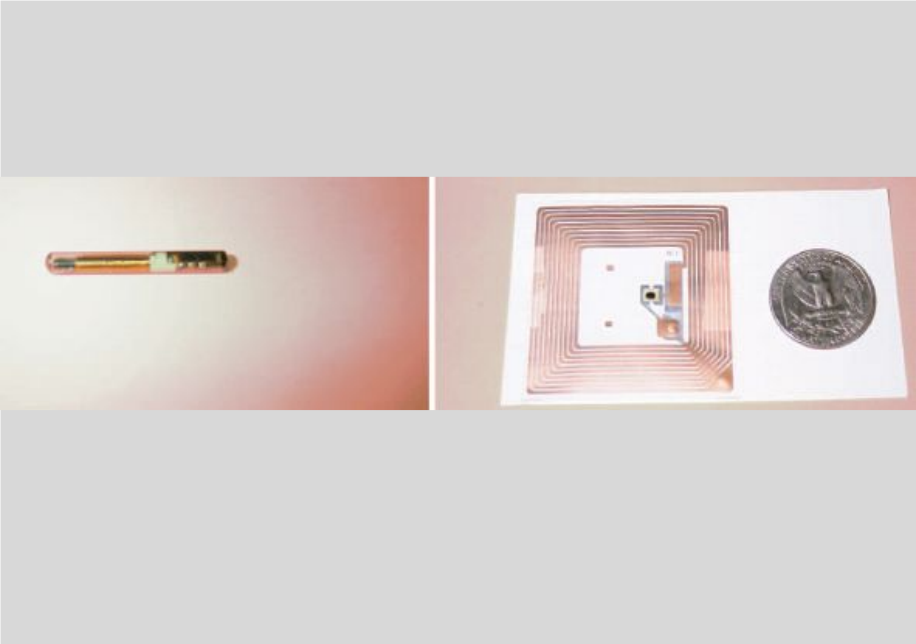
- RFID tags carry identification number read by RFID reader
- Types
  - Passive tags
    - a few KB of memory
    - consist of antenna, chip, encapsulation.
    - Energy from received signal is stored in capacitor.
  - Active tags
    - on-board battery and memory
    - stronger signal
    - 20-100 m communication range
- Communication
  - Near-field
    - distance < $c/2\pi f$, f < 100 MHz
    - Load modulation based on induction: change of current detected by reader coil
    - ISO standard 15693
  - Far-field
    - 128 kHz, 13.56, 915, 2450 MHz
    - Backscattering: reflection or absorption of signal by changing antenna resistance
- Collision avoidance needed
- Extensions
  - Sensing by integrating tags sensitive to the environment, e.g., temperature
  - EEPROM for tag IDs (size: a few KB)



1. Radio Frequency Identification

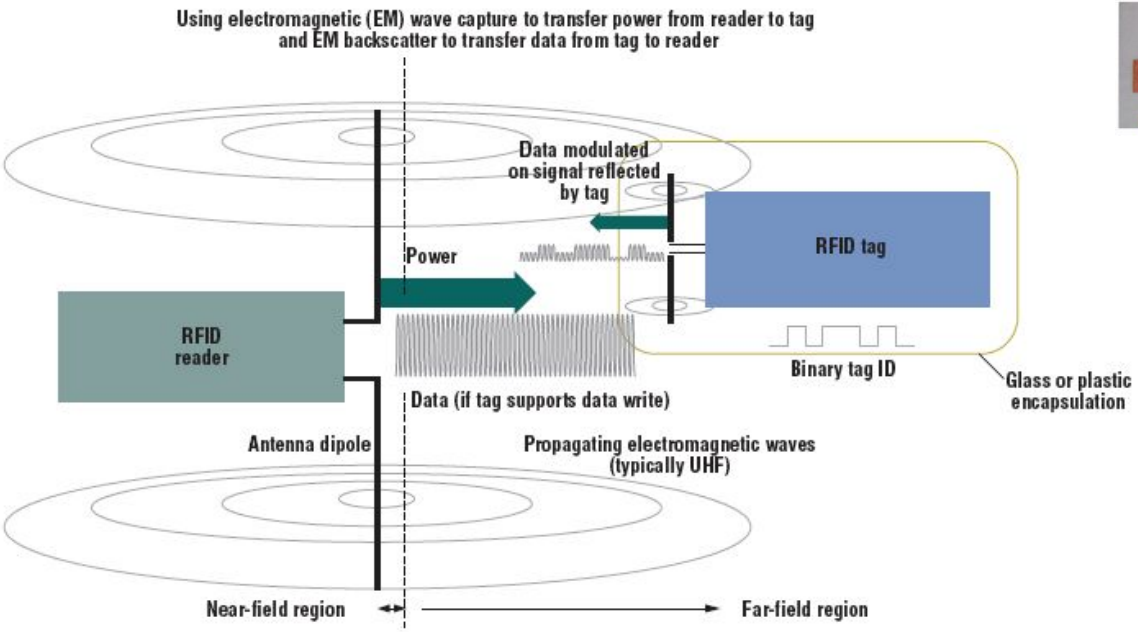
1. Near-Field Communication

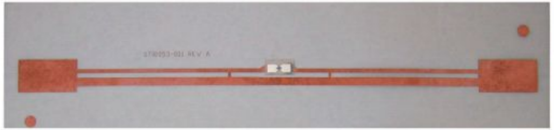




1. Radio Frequency Identification

2. Far-Field Communication





1. Radio Frequency Identification

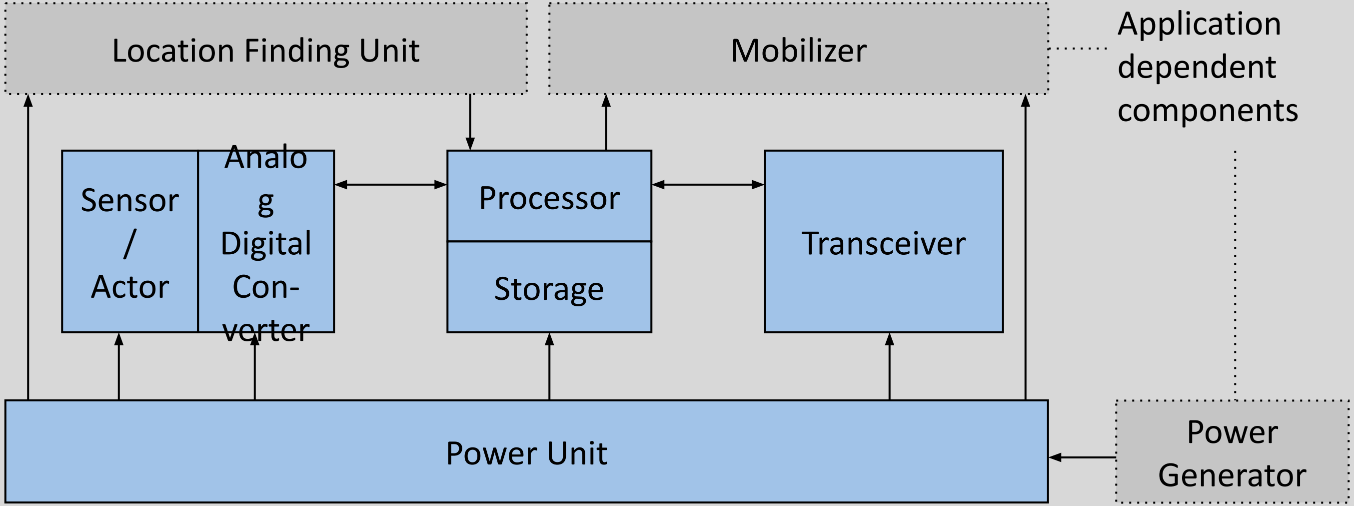
3. NFC vs RFID

- NFC
  - is one form of RFID.
  - operates at 13.56 MHz and extends the HF RFID standard.
  - supports two-way communications and peer-to-peer.

- Limited to close proximity, typically < 5 cm
- Industry body NFC Forum (www.nfc-forum.org)
  - NFC family protocols, allows storage and communication of binary data (including URLs, MIME objects).

2. Sensor Nodes

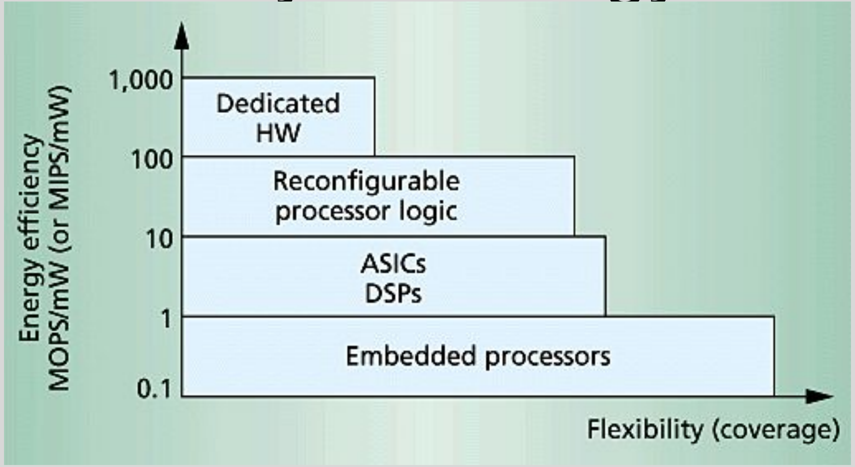
1. Sensor / Actor Node Architecture



UNIVERSITÄT BERN

2. Sensor Nodes

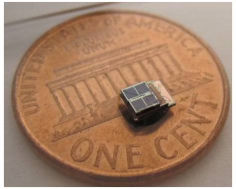
2. Processor Implementation: Flexibility vs. Energy-Efficiency



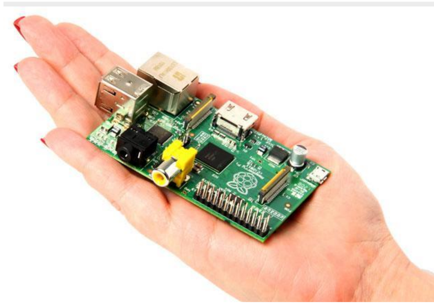
- Electrical power P = U · I
  - U: voltage [Volt, V]
  - I: current [Ampere, A]
- Energy W = P · t
- Battery capacity is often measured in Ah, i.e., how long a battery can supply a certain current with its nominal voltage.

2. Sensor Nodes

3. Sensor Node Hardware Classification



- System-on-Chip (SoC) nodes
  - Integration of CMOS, MEMS, and RF technologies on a single chip
  - Extremely low power and small sensor nodes
  - Special instruction sets, no software platforms available, limited support for (re)programming and configuration
  - Examples: Smart Dust, PicoNode
- Dedicated embedded sensor nodes
  - Commercial off-the-shelf (COTS) chip sets
  - Low power processing and communications
  - Full hardware access for programmers
  - Limited operating system support
  - C or assembler language programming
  - Examples: MICA, TelosB, Zolertia Re-Mote
- Augmented general-purpose computers
  - Sensor nodes based on embedded PCs or PDAs
  - Running COTS operating systems, middleware, and application software
  - Standard wireless communication technologies such as Bluetooth, WLAN, Zigbee
  - Wide range of sensors from microphones to cameras
  - Examples: Arduino, Raspberry Pi

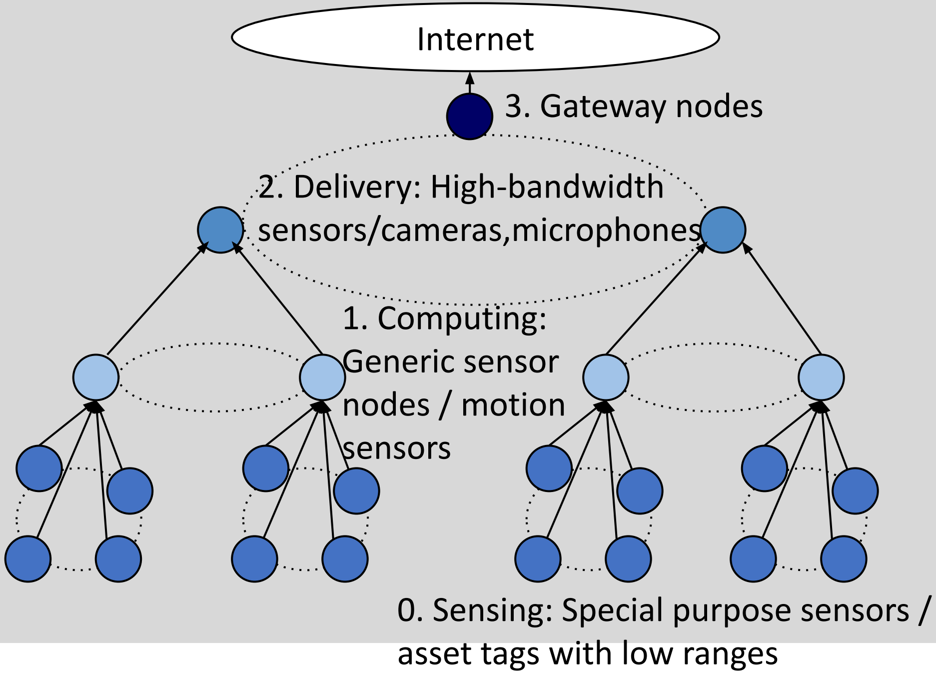


2. Sensor Nodes

4.1 Tiered Sensor Network Architecture

Compared to high-end IoT devices (e.g., smartphones, Raspberry PIs), low-end IoT devices typically

- have a factor of 10^6 less memory,
- 10^3 less CPU capacity,
- consume 10^3 less power, and
- use networks with 10^5 less throughput.



2. Sensor Nodes

4.2 Tiered Sensor Network Architecture

- Sensor nodes are connected to a general-purpose network via gateway nodes.
- Sensor networks are often heterogeneous.
  Resource-intensive roles can be assigned to resource-rich nodes.

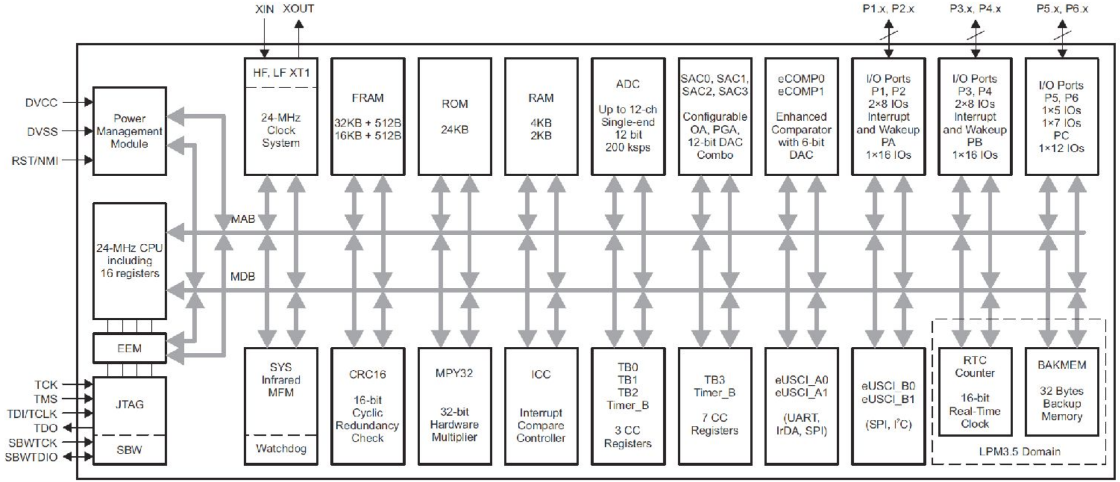
Tiered Networks with several advantages

- Cost-effectiveness
  - Special hardware required in a few nodes only
- Longevity
  - Expensive operations at nodes with line power
  - Few, simple operations by battery-powered nodes
- Scalability
  - Communication channels within a cluster
  - Interconnection of clusters by other channels

2. Sensor Nodes

5.1 TI MSP 430FR2355 MCU

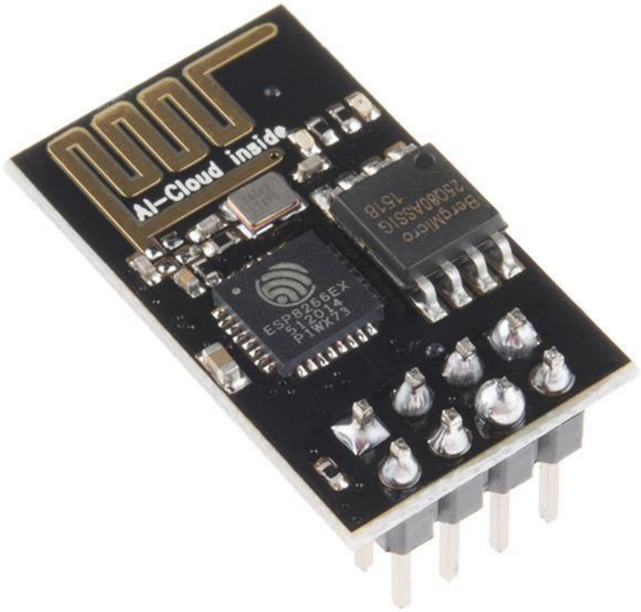
- 16 bit RISC microprocessor
- Memory
  - < 32 KB on-chip program FRAM
  - < 4KB RAM
  - 20 KB ROM library
- 12-bit A/D converters
- Multiple oscillators
  - Auxiliary clock: 32 kHz for self wake-up
  - High-speed digitally controlled oscillator (< 24 MHz)
- Operating modes at 3V (6 in total)
  - Active: 142 µA
  - Standby: 1.43 µA
  - Off (RAM is retained): 0.8 µA
- List price < 10 $



2. Sensor Nodes

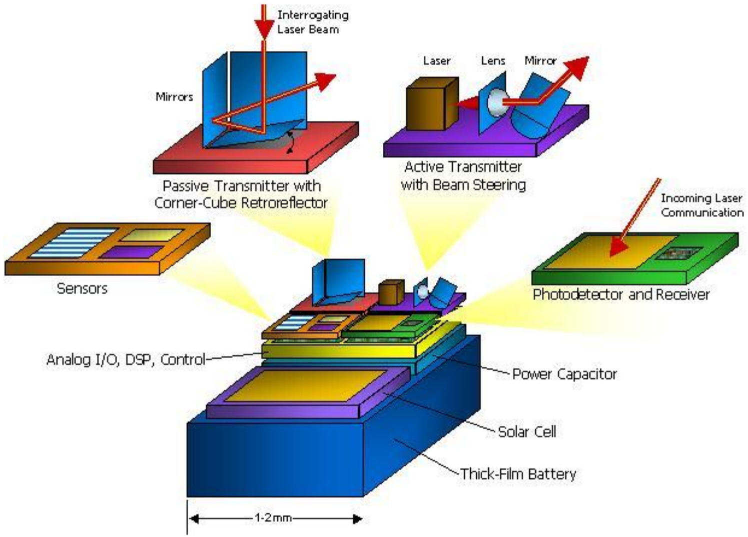
5.2 ESP8266

- low-cost Wi-Fi microchip
- full TCP/IP stack
- 32-bit RISC microprocessor running at 80 MHz
- Memory
  - 32 KB instruction RAM
  - 32 KB instruction cache RAM
  - 80 KB user data RAM
  - 16 KB system data RAM
  - External flash < 16 MB



2. Sensor Nodes

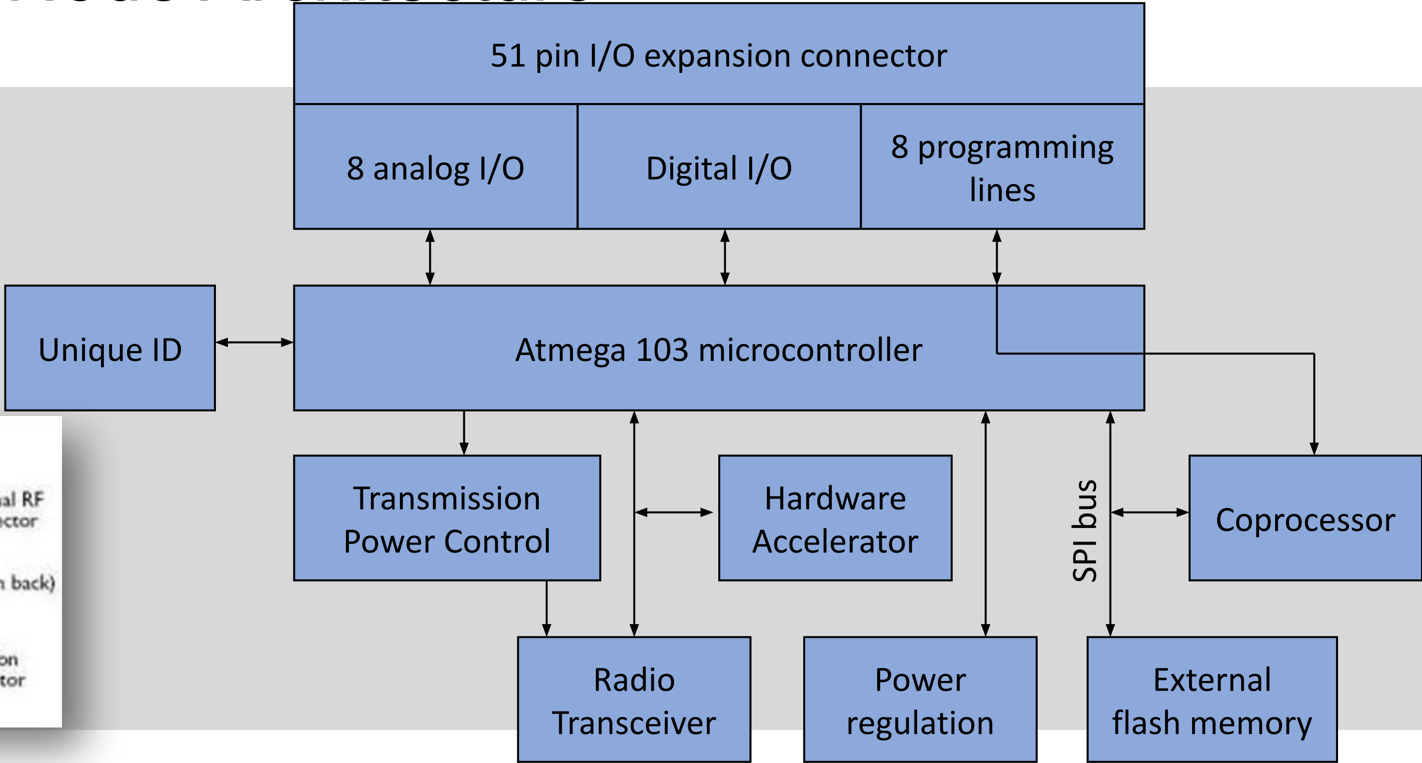
6.1 Smart Dust

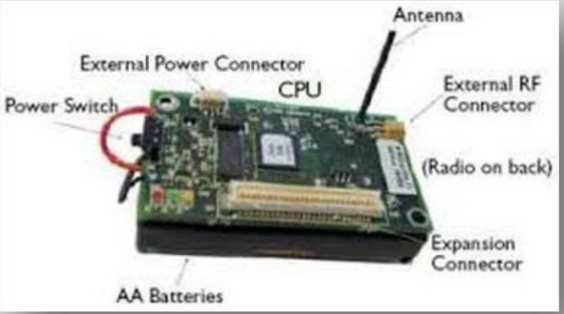


- Integrated circuit with sensor signal processing, communication, control, data storage, energy management
- Optical communications
  - Passive
    - No onboard light source
    - Dependent on mirror position, light is reflected (1) or not (0).
  - Active
    - Active steered laser uses on-board light source to send beam towards intended receiver.

2. Sensor Nodes

6.2.1 MICA Node Architecture





UNIVERSITÄT BERN

2. Sensor Nodes

6.2.2 MICA Mote Power Consumption

Component	Rate	Startup time	Current consumption
MCU active	4 MHz	n/a	5.5 mA
MCU idle	4 MHz	1 µs	1.6 mA
MCU suspend	32 kHz	4 ms	< 0.02 mA
Radio transmit	40 kHz	30 ms	12 mA
Radio receive	40 kHz	30 ms	1.8 mA
Photoresistor	2 kHz	10 ms	1.235 mA
Temperature	2 Hz	500 ms	0.150 mA

2. Sensor Nodes

6.3 TelosB

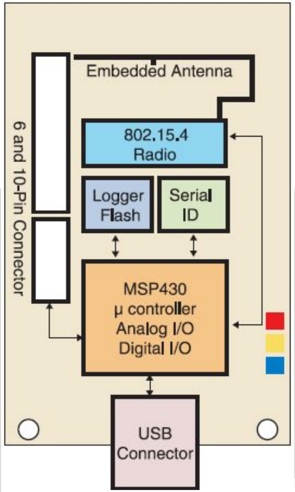
> based on TI MSP 430 processor (8 MHz)

> 10 KB RAM

> IEEE 802.15.4 compliant RF transceiver, < 250 kbps

> 1MB external Flash memory for data logging

> Programming and data collection via USB



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

2. Sensor Nodes

6.4 Zolertia Re-Mote

- 2 Radios for short and long range applications up to 20 km
  - ISM 2.4-GHz IEEE 802.15.4 & Zigbee compliant radio.
  - ISM 863-950-MHz ISM/SRD band IEEE 802.15.4 compliant radio.
- Processor: ARM Cortex-M3 32 MHz clock speed, 512 KB flash and 32 KB RAM
- Networking: 6LowPAN support
- 150 nA current using shutdown mode.
- supported in OSs such as Contiki and RIOT
- Sensors: Temperature and Humidity, Light, Barometer, Passive Infrared Motion, Moisture, Loudness, Rotary Angle, Rotation, Accelerometer & Gyroscope, Gas, Weather Meter, Dust (optical)

UNIVERSITÄT BERN

2. Sensor Nodes

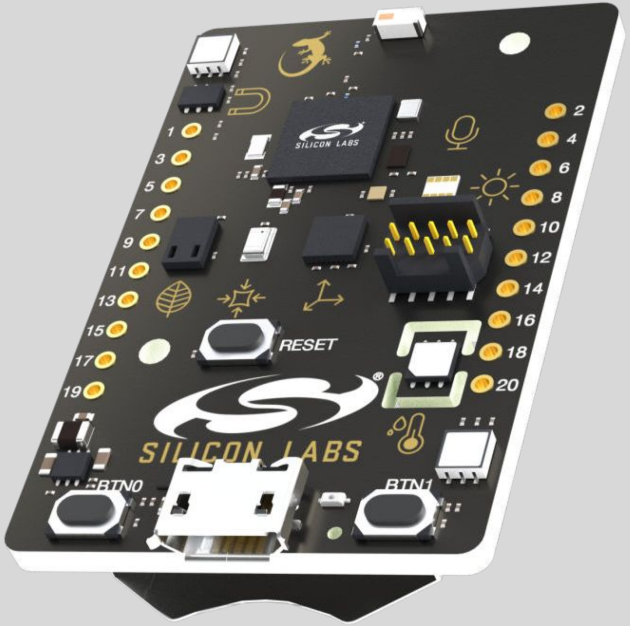
6.5 Arduino nano 33 IoT

- low power 32-bit SAMD21 ARM CPU
- 48 MhZ clock speed
- WiFi and Bluetooth by NINA-W102 low power chipset operating in 2.4GHz range
- secure communication ensured by ECC608 crypto chip
- 256 KB CPU flash memory
- 32 KB SRAM
- Sensors
  - 9 axis inertial sensor
  - Humidity and temperature
  - Barometer
  - Microphone
  - Gesture, proximity, light colour and intensity

2. Sensor Nodes

6.6 Thunderboard Sense

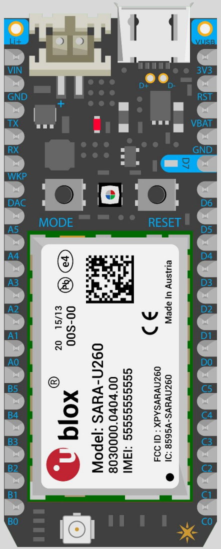
- EFR32MG12 Mighty Gecko Wireless SoC with 38.4 MHz operating frequency
- 1024 kB flash memory and 256 kB RAM
- Sensors
  - Relative humidity and temperature
  - UV index and ambient light
  - Hall effect
  - Indoor air quality gas sensor
  - 6-axis inertial sensor
  - Barometric pressure
  - MEMS microphone
- 2.4 GHz BLE

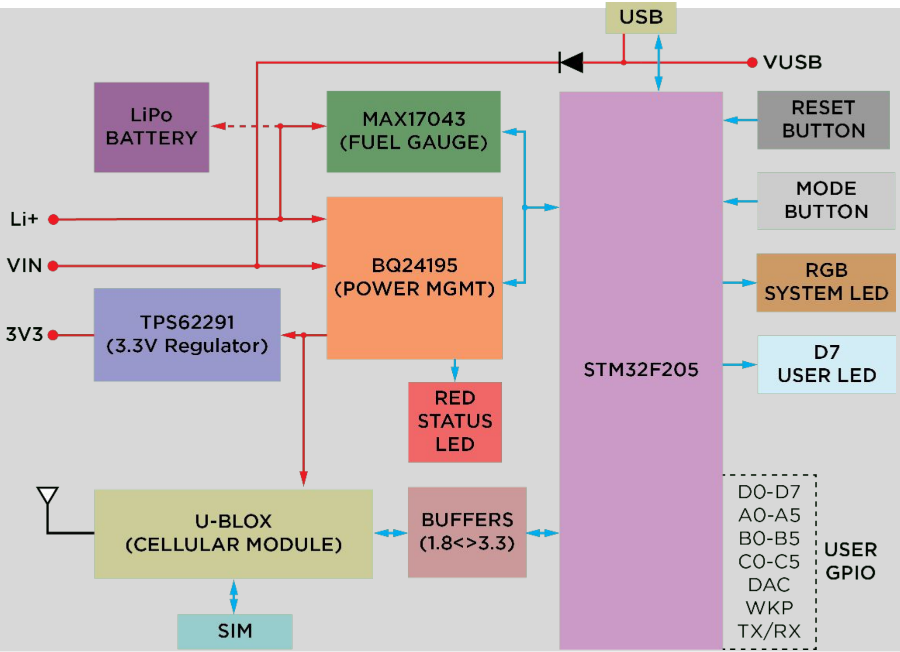


2. Sensor Nodes

6.7 Particle Electron

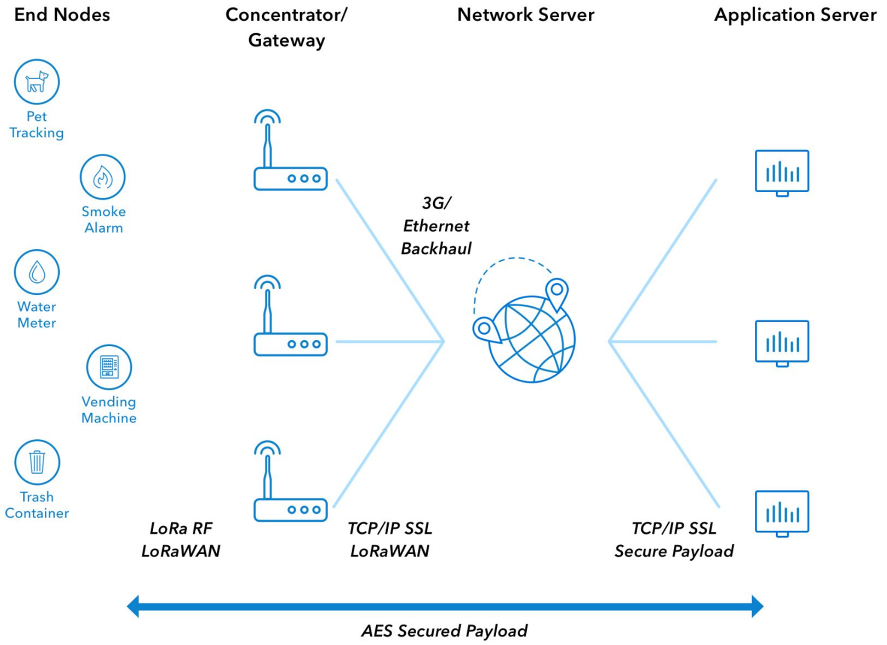
- STM32F205RGT6 120MHz ARM Cortex M3 micro-controller
- 2G/3G module
- 1 MB flash memory
- 128 KB RAM





2. Sensor Nodes

6.8 The Things Network



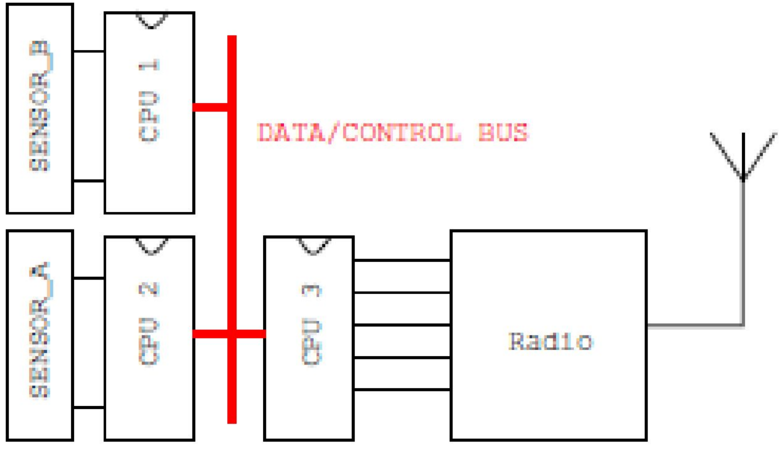
Things Uno is based on Arduino Leonardo with Microchip LoRaWAN module.

Gateways are routers equipped with a LoRa concentrator.

2. Sensor Nodes

7. Multi-Processor Sensor Nodes

- Single processor architecture is often designed for worst case and overprovisioned.
- Approach: multiple simpler processors in a multi-processor sensor node architecture
- Advantages
  - Configuration flexibility and energy savings
  - Clock speeds according to processor tasks
  - Parallel task execution

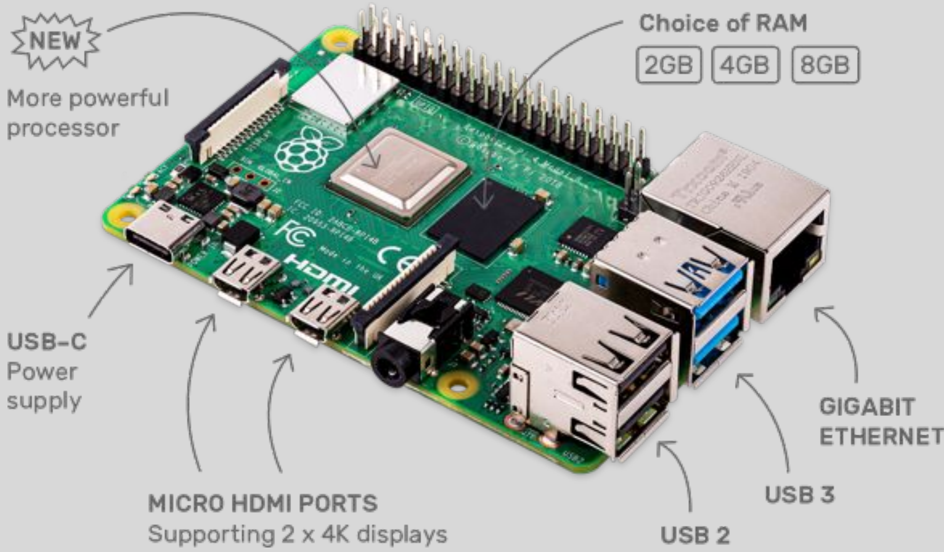


UNIVERSITÄT BERN

2. Sensor Nodes

7.1 Raspberry Pi 4

- Quad Core 1.5 GHz ARM 64bit CPU
- 2-8 GB SDRAM
- Wireless LAN (2.4/5 GHz) and Bluetooth Low Energy
- Gigabit Ethernet
- 40-pin extended General-Purpose I/O
- 4 USB ports
- Camera and display port
- Micro SD port for loading operating system and storing data



2. Sensor Nodes

7.2 Pycom GPy

- Processor Tensilica Xtensa dual-core 32-bit LX6, up to 600 MIPS
- Memory: RAM: 520KB + 4MB; External Flash: 8MB.
- Communication
  - Bluetooth, WiFi, Cellular: single chip for both Long Term Evolution Cat. M and Narrow Band - IoT of 3rd Generation Partnership Project release 13.
- Energy Consumption
  - 3.5-5 V input power, deep sleep 24 µA, idle 60 mA, LTE Transmit max. 285 mA.
- Programmed in micro python; no low level programming skills required

2. Sensor Nodes

7.3 Jetson Nano

- Quad core ARM Cortex-A57 processor
- Machine learning and video encoding/decoding support
- 4 GB RAM, 16 GB flash memory
- Gigabit Ethernet, BLE or WiFi with external modules

3. Energy Consumption

1. Energy Sources

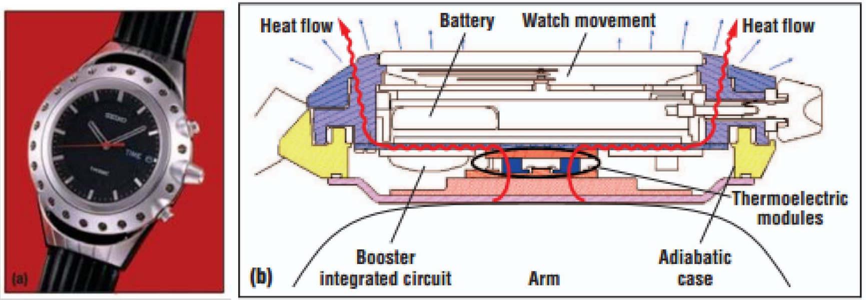
Energy source	Power density	Energy density
Batteries (zinc-air)		1050 -1560 mWh/cm^3
Batteries (rechargeable lithium)		300 mWh/cm^3 (3 - 4 V)
Solar (outdoors)	15 mW/cm^2 (direct sun) 0.15mW/cm^2 (cloudy day)	
Solar (indoors)	0.006 mW/cm^2 (standard office desk) 0.57 mW/cm^2 (< 60W desk lamp)	
Vibrations	0.01 - 0.1 mW/cm^3	
Acoustic noise	3E-6 mW/cm^2 at 75 Db 9.6E-4 mW/cm^2 at 100 Db	
Passive human-powered systems	1.8 mW (shoe inserts)	
Nuclear reaction	80 mW/cm^3 1E6 mWh/cm^3	

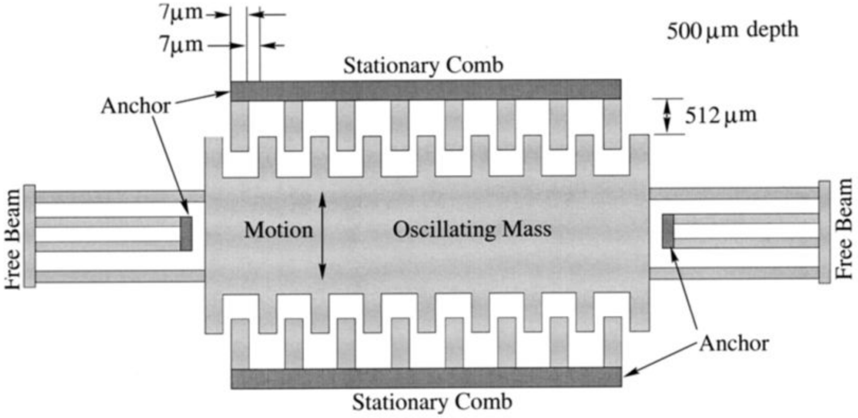
b UNIVERSITÄT BERN

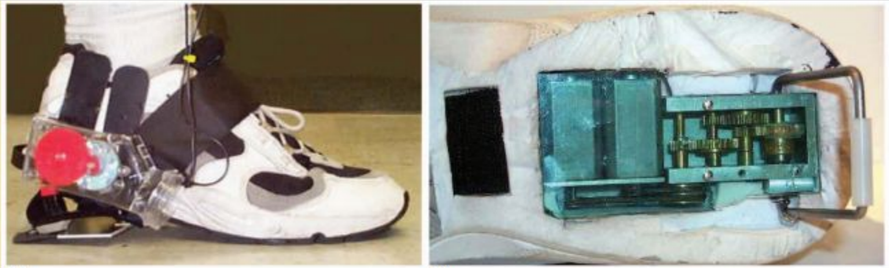
3. Energy Consumption

2. Energy Scavenging / Harvesting

- Photovoltaic
- Temperature gradients
- Vibrations
- Pressure variations
- Flow of air / liquid





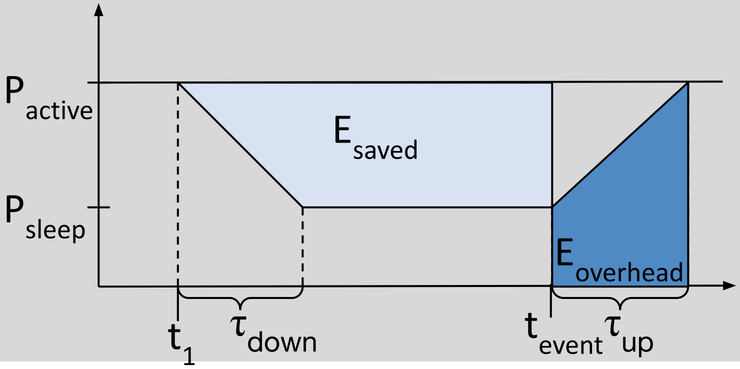


(a) (b)

3. Energy Consumption

3.1 Energy Saving for Sleep Modes

- $E_{saved} = (t_{event} - t_1)\, P_{active} - \left(\tau_{down}\, (P_{active} + P_{sleep})/2 + (t_{event} - t_1 - \tau_{down})\, P_{sleep}\right)$
- $E_{overhead} = \tau_{up}\, (P_{active} + P_{sleep})/2$
- Sleep mode is only beneficial for $E_{saved} > E_{overhead}$

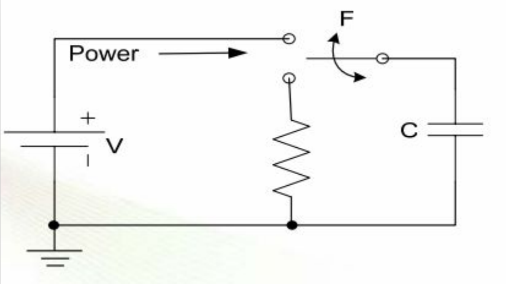


3. Energy Consumption

3.2 Energy Dissipation - Dynamic Voltage Scaling

Static

- Leakage of current to ground at all times
- Approach: shut down components

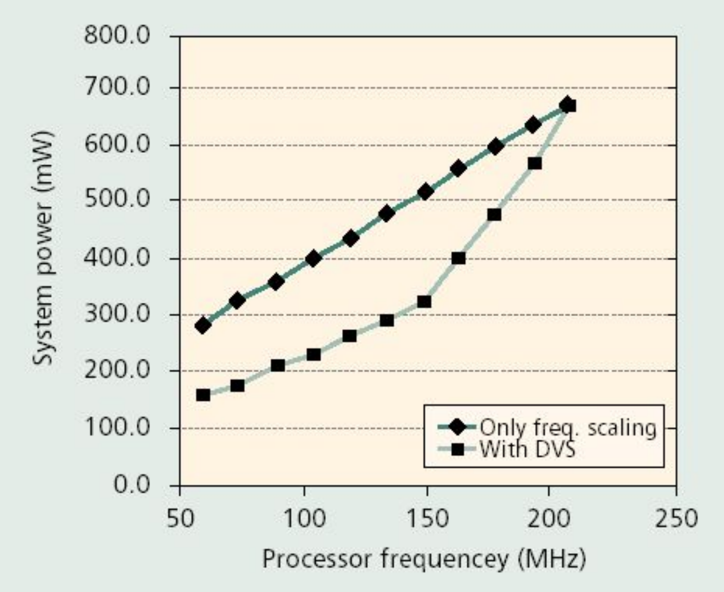


Dynamic

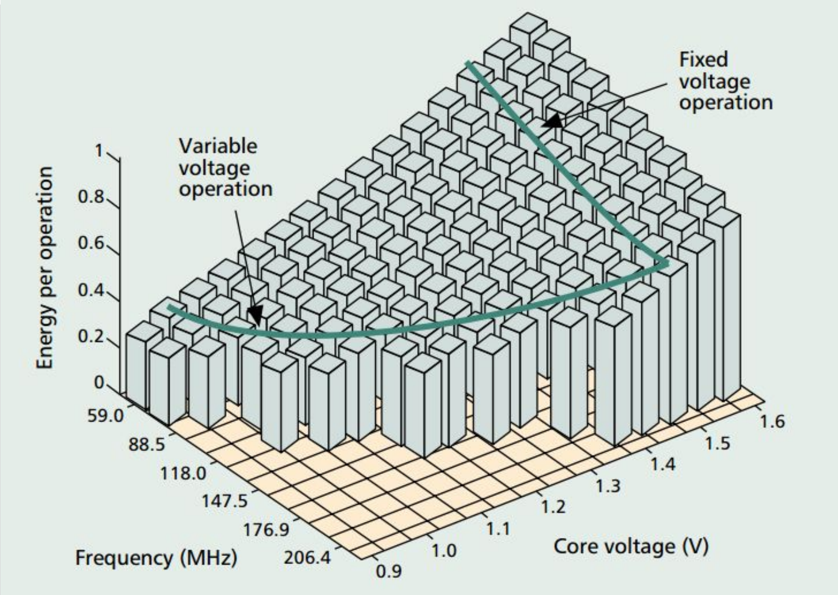
- Switching power dissipated by capacitor is $P_{dynamic} = C \cdot F \cdot V^2$
  - C: capacity
  - F: frequency with which the voltage is switched across the capacitor
  - V: supply voltage
  - Power goes up by square of the voltage and linearly with frequency
  - Example: reduction of switching power by a factor of 4 by reducing the voltage by ½
- Approach: Dynamic Voltage Scaling
  - method of reducing the average power consumption in embedded systems
  - accomplished by reducing the switching losses of the system by reducing the frequency and voltage of the system.

3. Energy Consumption

3.3 Dynamic Voltage Scaling



processor: µAMPS

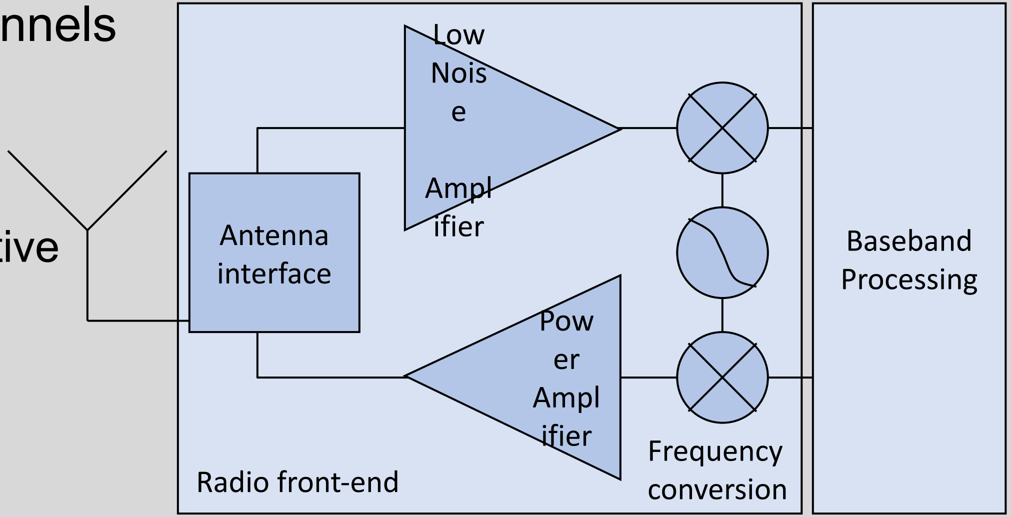


Processor: Intel StrongARM SA-1100

3. Energy Consumption

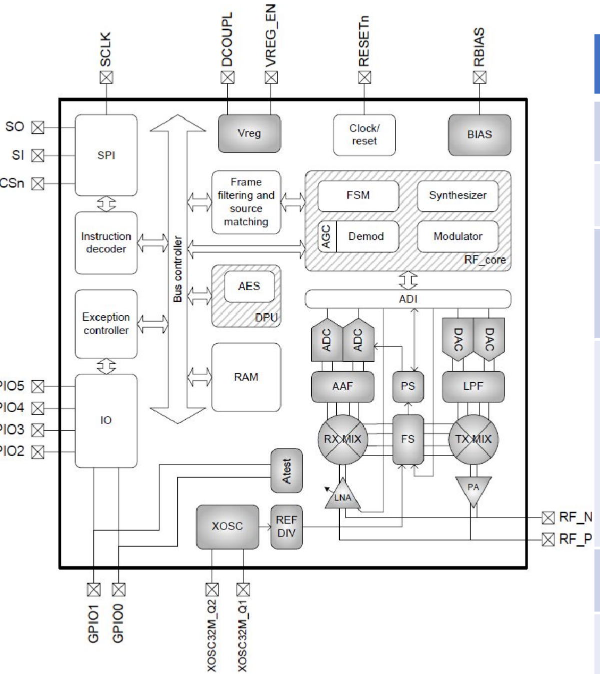
4.1 Transceiver Tasks

- Service to upper layer (packet, byte, bit interface)
- Support of several frequency channels
- State changes
  - Transmit: active transmit part
  - Receive: active receive part
  - Idle: ready to receive, but not active
  - Sleep: switched off
- Modulation
- Coding
- Carrier sensing

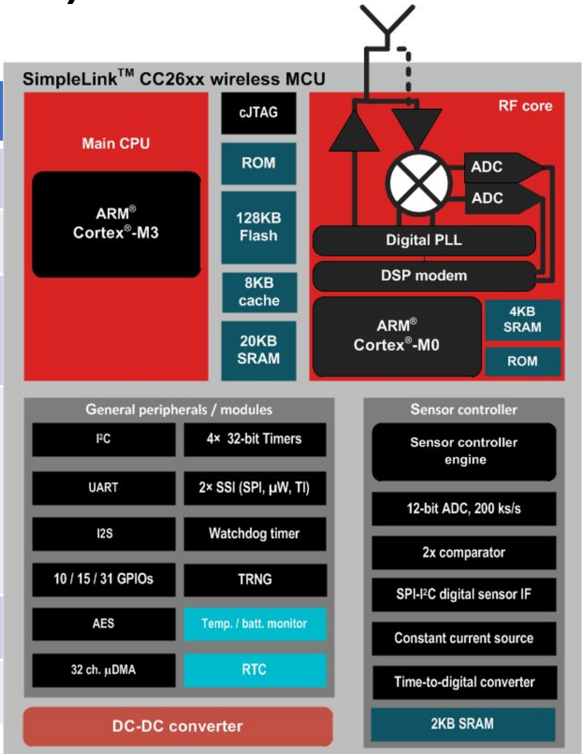


3. Energy Consumption

4.2 Zigbee Transceiver (IEEE 802.15.4)



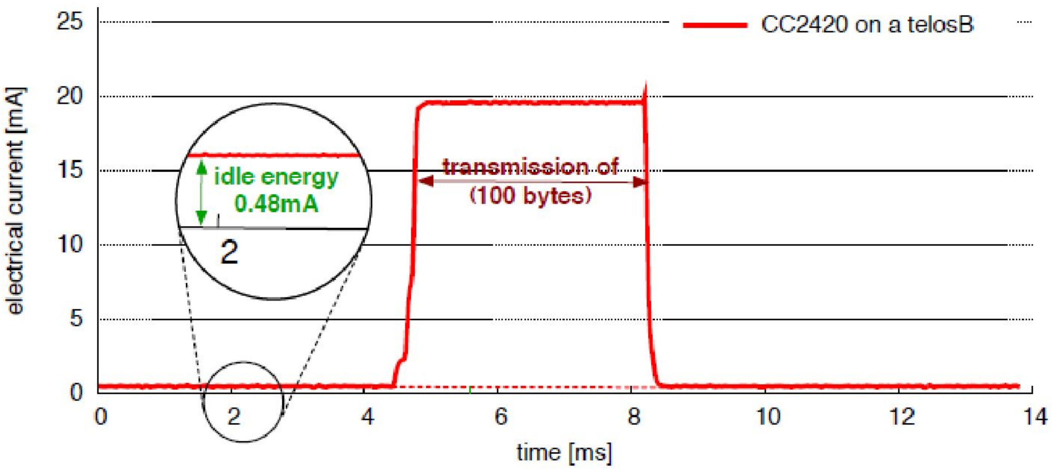
	CC2420	CC2520	CC2630
Voltage	2.1-3.6 V	1.8-3.8 V	
Tx current	17.4 mA	25.8 mA	9.1 mA
Rcv current	18.8 mA	18.5 mA	5.9 mA
Lowest power current (sleep)	0.25 µA	0.3 µA	0.1 µA
LoS range	125 m	400 m	?
Bit rate	250 kbps		



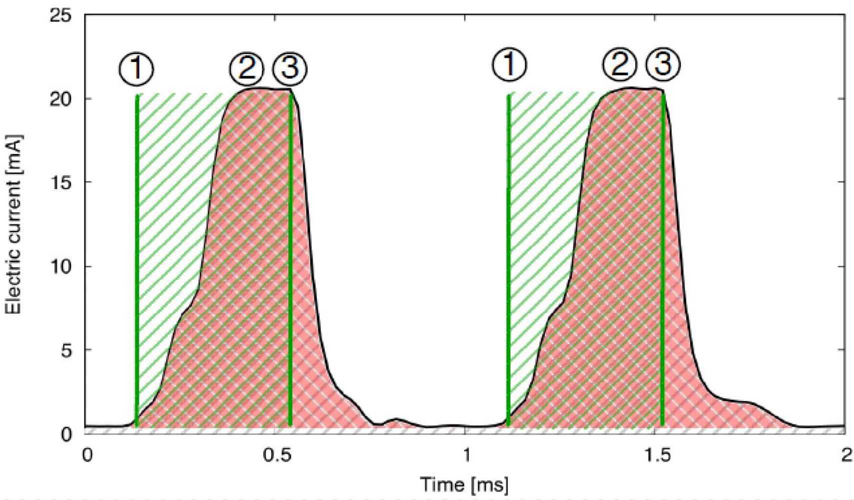
3. Energy Consumption

4.3 Energy Consumption for Transmitting/Receiving

100 bytes transmission
(CC2420 Transceiver / TelosB)



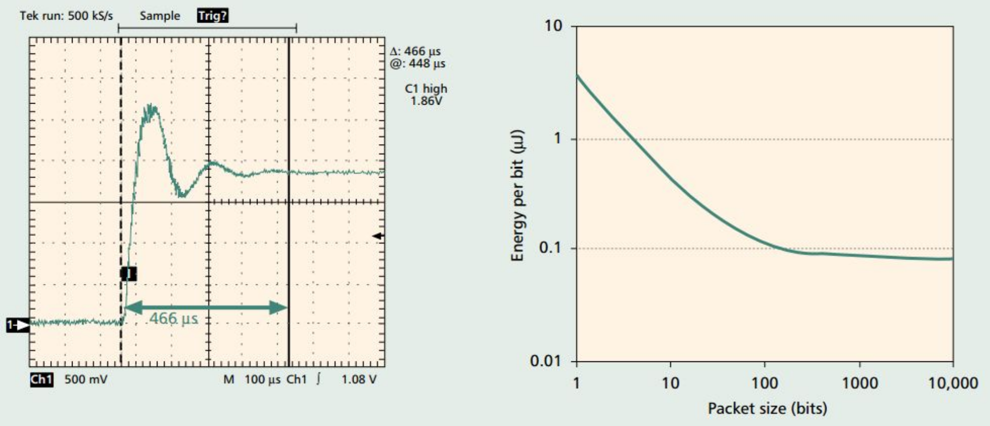
Channel Check Assessment



UNIVERSITÄT BERN

3. Energy Consumption

4.4 Startup Costs for Transmission



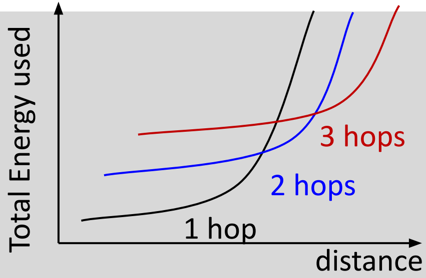
Sensor node: µAMPS

- Today’s transceivers require an initial startup time on the order of hundreds of microseconds, during which transients in the analog electronics need to settle.
- Substantial amounts of energy are consumed during the startup period.
  The average energy cost per transmitted bit decreases with increasing packet size.

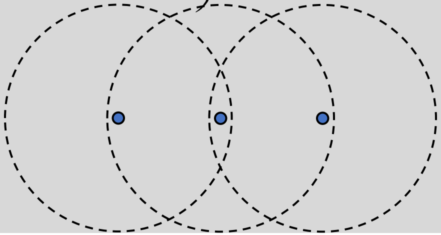
3. Energy Consumption

5. Multi-Hop Communication

- $E \sim d^n$
- E: energy required for communication,
  d: distance, n: path loss factor
- h: number of hops
- hop distance = d / h
- E(h,d): Energy needed for multi-hop communication, depending on how many hops are used
- α: sum of distant-independent components of communication power, e.g., receiver, bias current, startup
- β: sum of distant-dependent terms, e.g. power amplifier, path loss



$$E(h,d) = h\left(\alpha + \beta\left(\frac{d}{h}\right)^n\right)$$



UNIVERSITÄT
BERN

Thanks

for Your Attention

Prof. Dr. Torsten Braun, Institut für Informatik

Bern, 01.03.2021