PERVASIVE DATA MANAGEMENT

WIRELESS SENSOR NETWORKS AND RFID: A DATA CENTRIC OVERVIEW

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WIRELESS SENSOR NETWORKS

COMPONENTS

- THOUSANDS OF TINY LOW POWER DEVICES SPREAD OVER (POSSIBLY LARGE) PHYSICAL AREAS
- THE DEVICES MUST BE SMALL, UNOBTRUSIVE, AND CHEAP

NETWORK

- THE NETWORK MUST BE UNEXPENSIVE TO DEVELOP, DEPLOY, PROGRAM, AND EASY TO UTILIZE AND MAINTAIN
- COMPRISE A NUMBER OF SENSOR NODES AND A BASE STATION

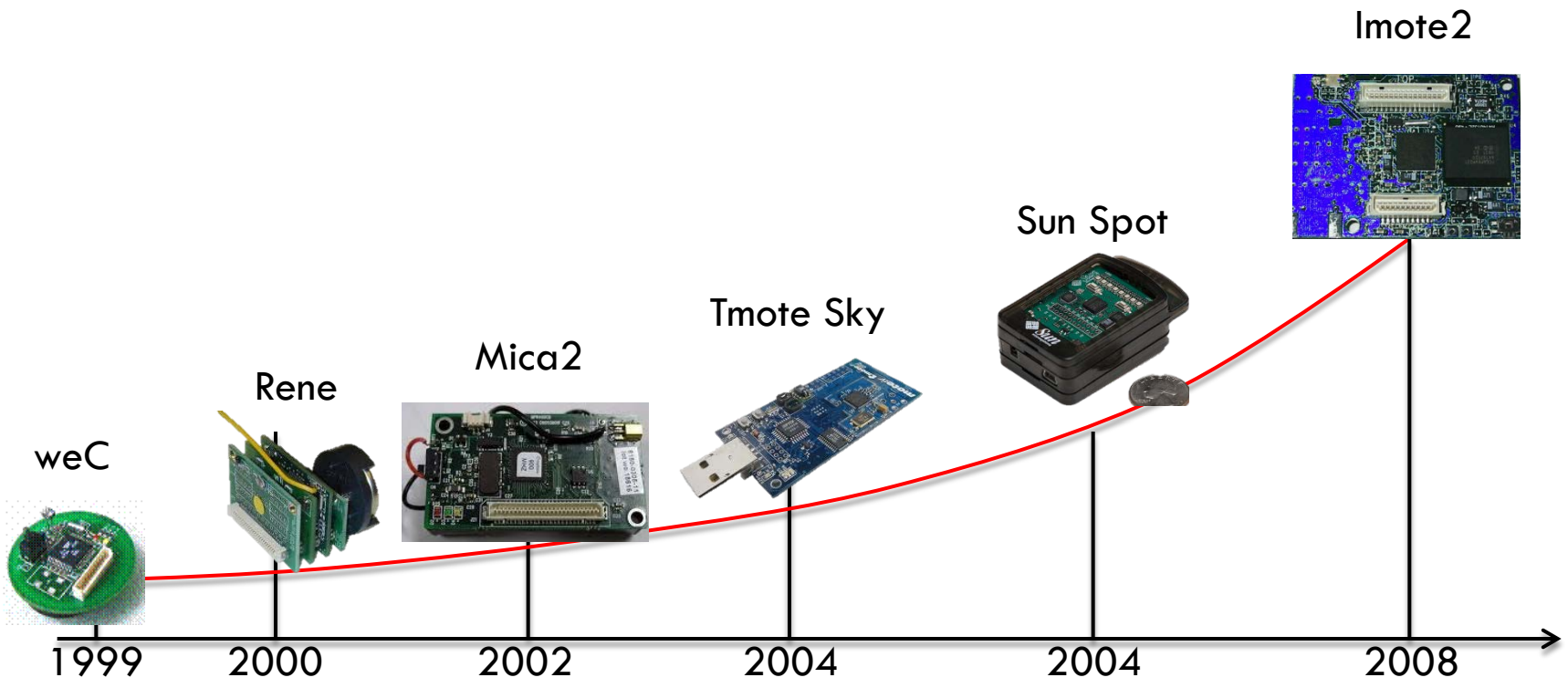
WIRELESS SENSOR NETWORKS

- SENSOR NETWORKS INVOLVE THREE AREAS:
  - SENSING
  - COMMUNICATION
  - COMPUTATION
- WSN APPLICATIONS:
  - ENVIRONMENTAL MONITORING
    - **AIR, LAND, WATER, FORESTS, …**
    - **ANIMAL BEHAVIOUR**
    - **EMERGENCIES PREVENTION AND CONTROL (fires, earthquakes, avalanches, etc.)**
  - HEALTHCARE
    - **PATIENT MONITORING**
  - COMMERCIAL
    - **VEHICLE TRACKING**
    - **LOGISTICS**
  - MILITARY AND DEFENSE
    - **SURVEILLANCE OF CITY DISTRICTS**
    - **TERRORISTIC THREATS PREVENTION**

SENSORS: SOME FEATURES

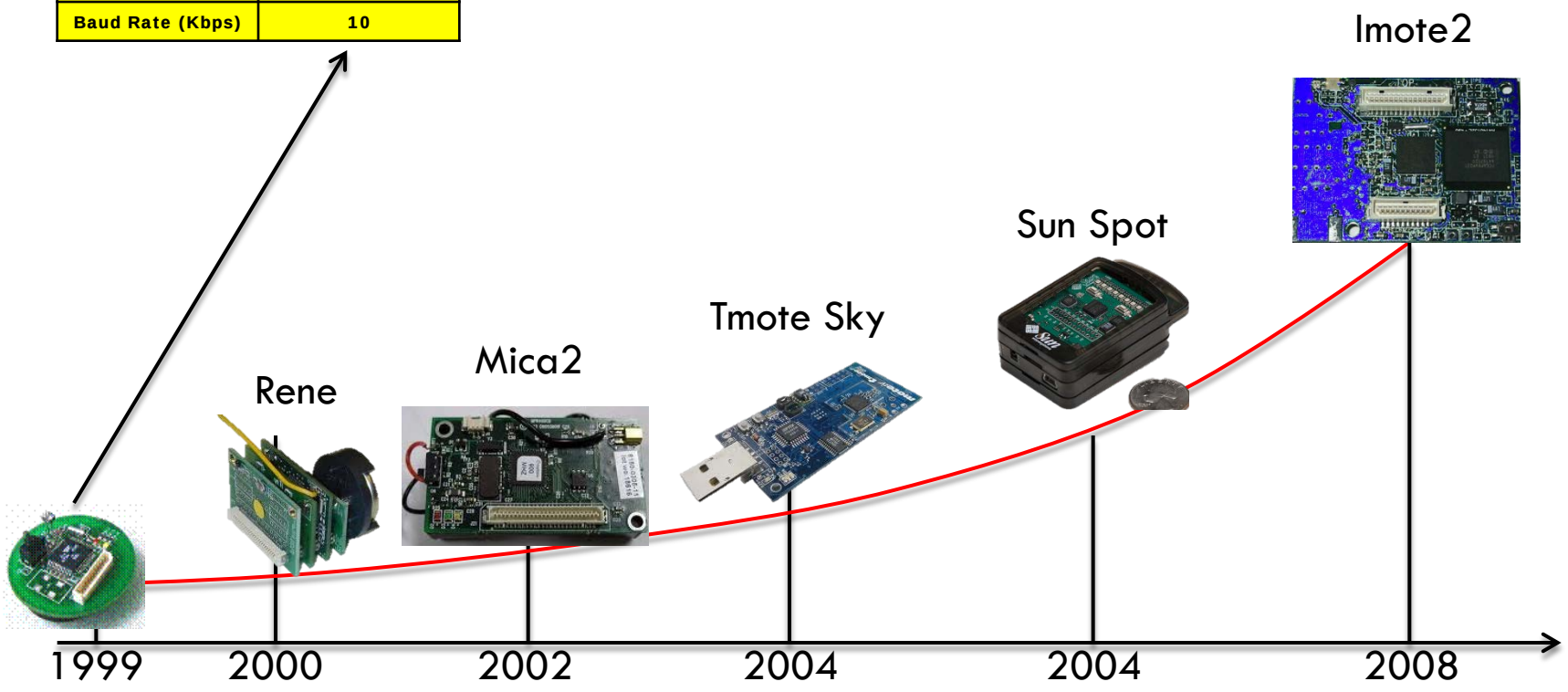
PROPERTIES	EXAMPLE AND SIZE	APPLICATION	MEMORY	OTHER
SPECIALIZED SENSING PLATFORM	SPEC (mm^3)	RF tag or specialized sensor	3K RAM	
GENERIC SENSING PLATFORM	MOTE (1-10 cm^3)	General purpose sensor and communications.	4K RAM 128K FLASH	TinyOS
HIGH-BANDWIDTH SENSING	IMOTE (1-10 cm^3)	High bandwidth sensor (video, acoustic, etc.)	64KB RAM 512KB FLASH	TinyOS, BLUETOOTH, Connectivity with cell phones
GATEWAY	STARGATE (> 10 cm^3)	High bandwidth sensor plus gateway	<512KB RAM <32MB FLASH	LINUX or WINDOWS, Serial connection to sensor network

WSN HARDWARE EVOLUTION



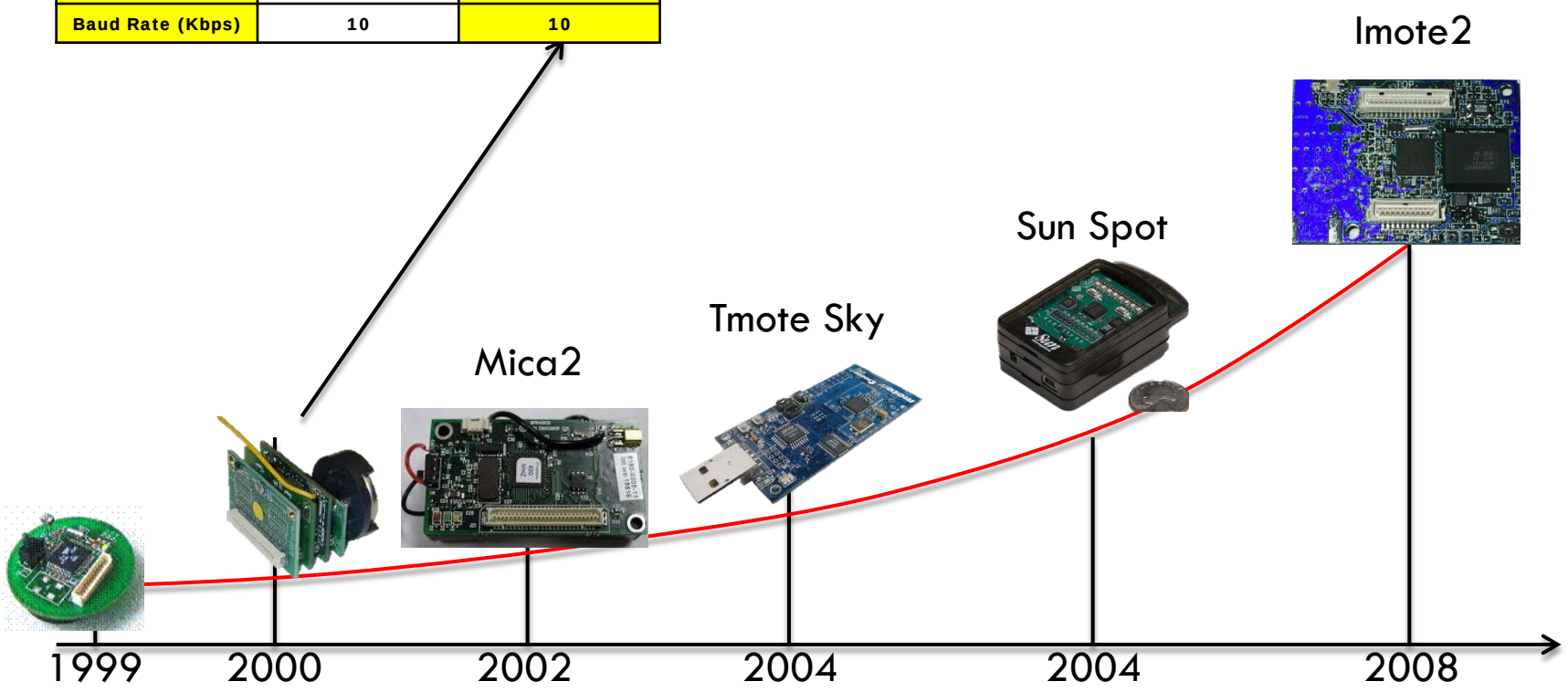
WSN HARDWARE EVOLUTION

	weC
Clock (MHz)	4
CPU	Atmel 8bit
Flash (KB)	8
RAM (KB)	0.5
Baud Rate (Kbps)	10



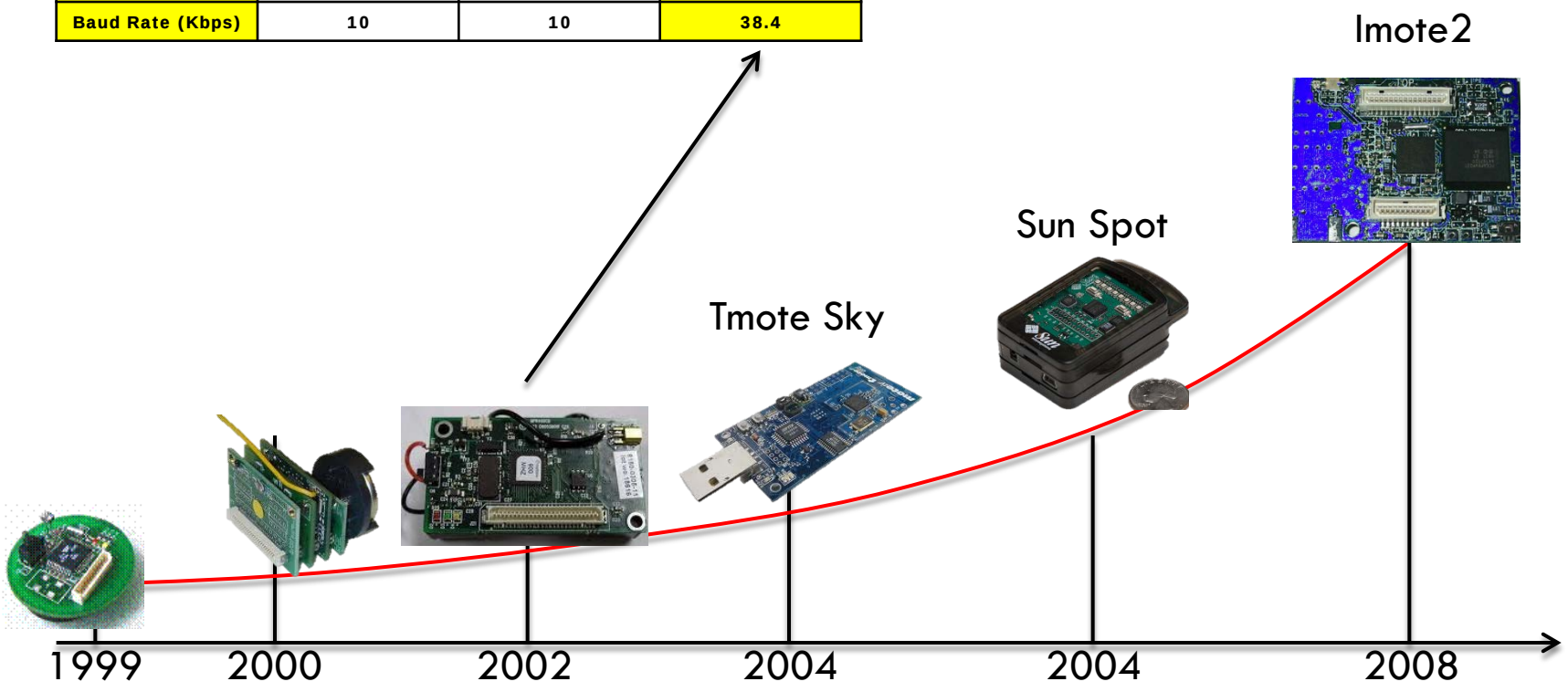
WSN HARDWARE EVOLUTION

	weC	Rene
Clock (MHz)	4	4
CPU	Atmel 8bit	Atmel 8bit
Flash (KB)	8	8
RAM (KB)	0.5	0.5
Baud Rate (Kbps)	10	10



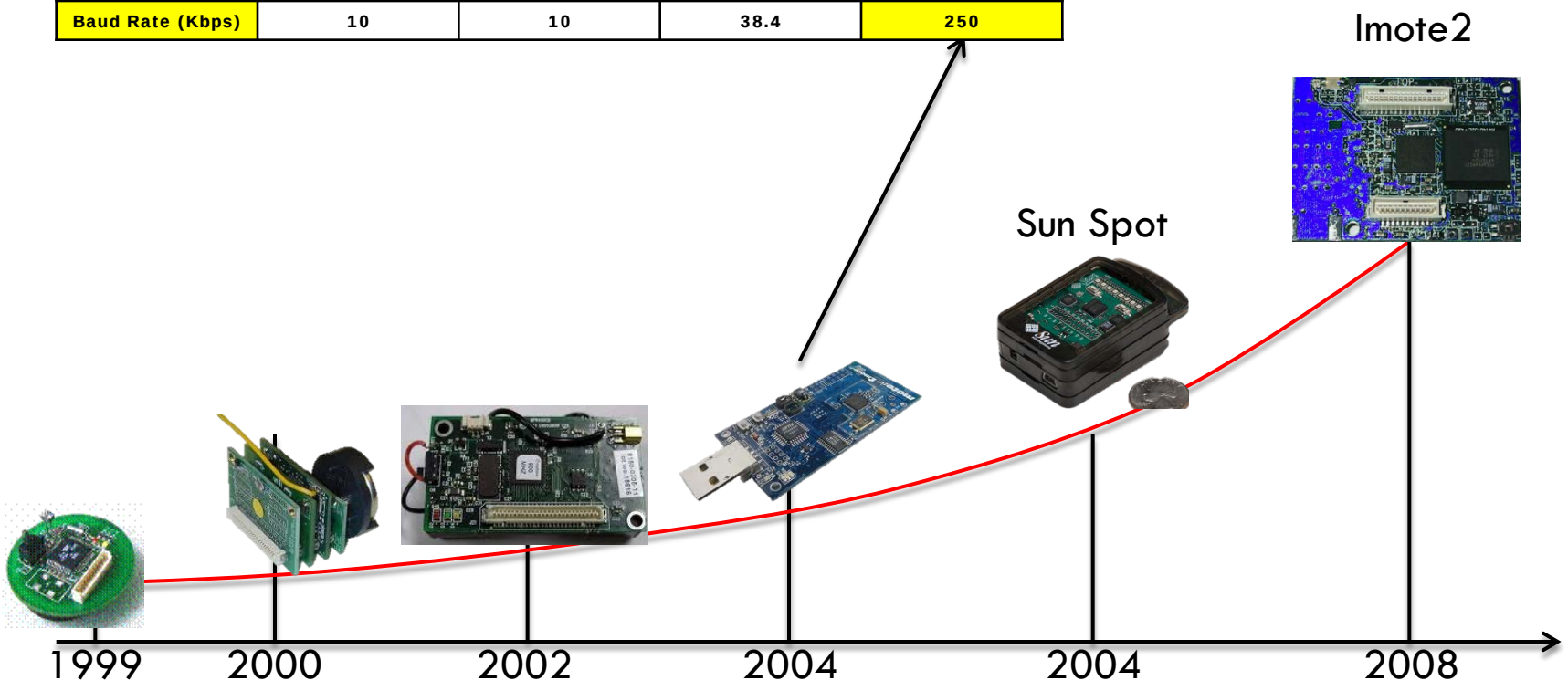
WSN HARDWARE EVOLUTION

	weC	Rene	Mica2
Clock (MHz)	4	4	8
CPU	Atmel 8bit	Atmel 8bit	Atmel 8bit
Flash (KB)	8	8	128
RAM (KB)	0.5	0.5	4
Baud Rate (Kbps)	10	10	38.4



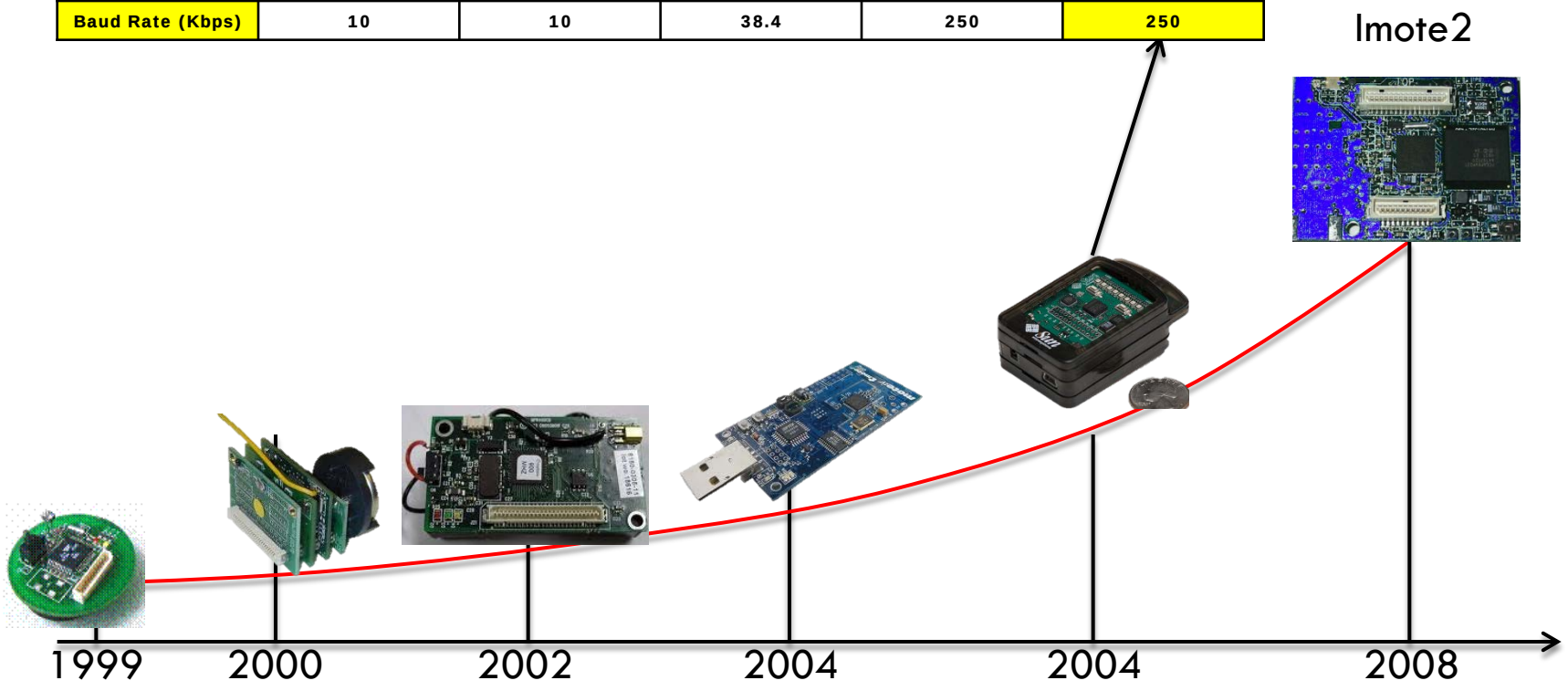
WSN HARDWARE EVOLUTION

	weC	Rene	Mica2	Tmote SKY
Clock (MHz)	4	4	8	8
CPU	Atmel 8bit	Atmel 8bit	Atmel 8bit	TI 16bit
Flash (KB)	8	8	128	48
RAM (KB)	0.5	0.5	4	10
Baud Rate (Kbps)	10	10	38.4	250



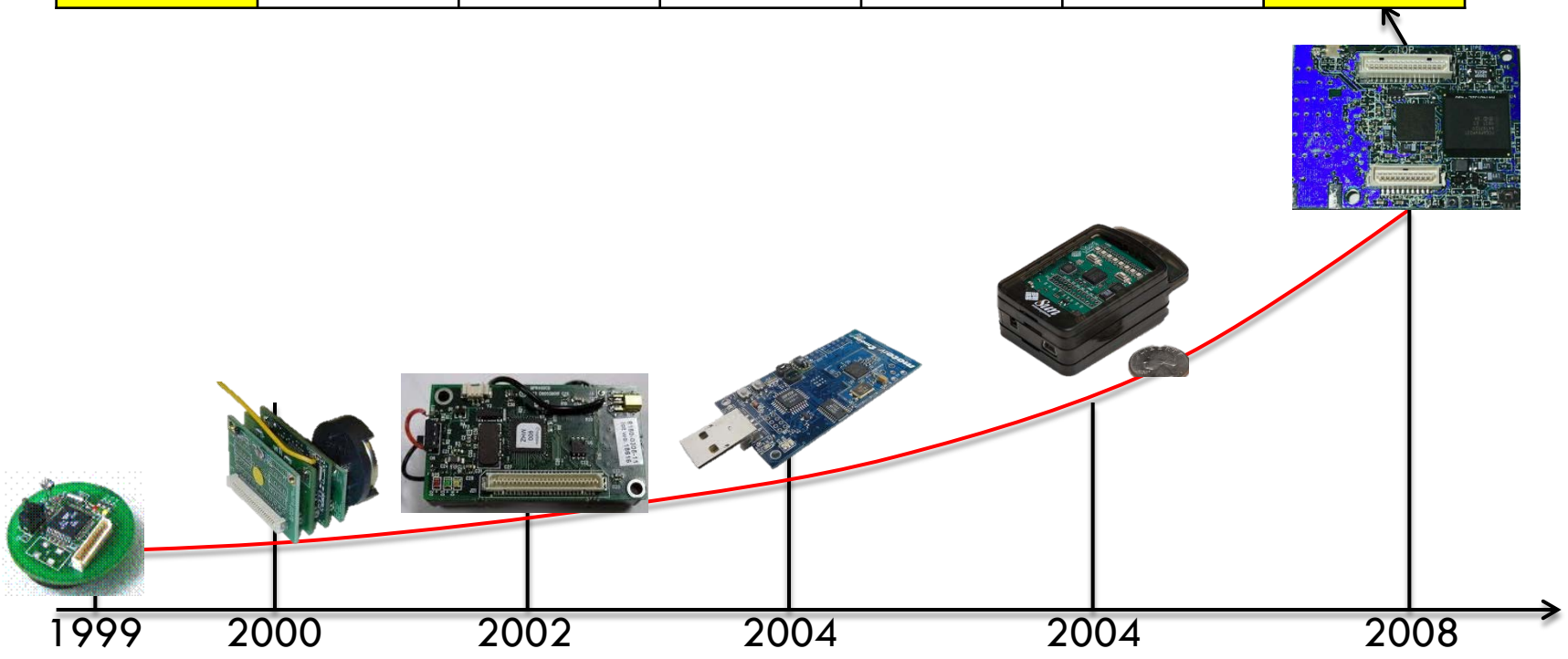
WSN HARDWARE EVOLUTION

	weC	Rene	Mica2	Tmote SKY	Sun Spot
Clock (MHz)	4	4	8	8	180
CPU	Atmel 8bit	Atmel 8bit	Atmel 8bit	TI 16bit	ARM 32bit
Flash (KB)	8	8	128	48	4096
RAM (KB)	0.5	0.5	4	10	512
Baud Rate (Kbps)	10	10	38.4	250	250



WSN HARDWARE EVOLUTION

	weC	Rene	Mica2	Tmote SKY	Sun Spot	Imote2
Clock (MHz)	4	4	8	8	180	13-416
CPU	Atmel 8bit	Atmel 8bit	Atmel 8bit	TI 16bit	ARM 32bit	ARM 32bit
Flash (KB)	8	8	128	48	4096	32M
RAM (KB)	0.5	0.5	4	10	512	256k+ 32M(ext)
Baud Rate (Kbps)	10	10	38.4	250	250	250



WSN SOFTWARE EVOLUTION

YEAR	OS	Architecture	Multitasking	Real-time	Memory Manag.	Progr. Paradigm	Progr. Language
2000	**TinyOS**	**Monolithic**	**No**	**No**	**Static**	**Event driven**	**NesC**
2004	**Contiki**	**Modular**	**Yes**	**No**	**Dynamic**	**Threads and events**	**C**
2005	**Nano-RK**	**Monolithic**	**Yes**	**Yes**	**Static**	**Threads**	**C**
2005	**SOS**	**Modular**	**No**	**No**	**Dynamic**	**Event driven**	**C**
2005	**Mantis**	**Modular**	**Yes**	**No**	**Dynamic**	**Threads**	**C**
2008	**LiteOS**	**Modular**	**Yes**	**No**	**Dynamic**	**Threads and events**	**LiteC++**

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2008	**LiteOS**	**Modular**	**Yes**	**No**	**Dynamic**	**Threads and events**	**LiteC++**

From simple implementation
towards feature-rich operating system
(thanks to parallel hardware evolution)

HW: MOTES (1)

- TINY MICROCONTROLLER-BASED SYSTEMS WITH EMBEDDED SENSORS AND WIRELESS COMMUNICATION
- KEY CONSTRAINTS:
  - BATTERY POWER
    - **POWER IS THE MOST PRECIOUS RESOURCE: IT IS OFTEN IMPOSSIBLE TO REPLACE OR RECHARGE BATTERIES ONCE A MOTE HAS BEEN DEPLOYED**
  - LIMITED SYSTEM RESOURCES
    - **RAM**
    - **PROCESSING POWER**
    - **NON-VOLATILE STORAGE**
    - **BANDWIDTH**

Software needs to take these into account

HW: MOTES (2)

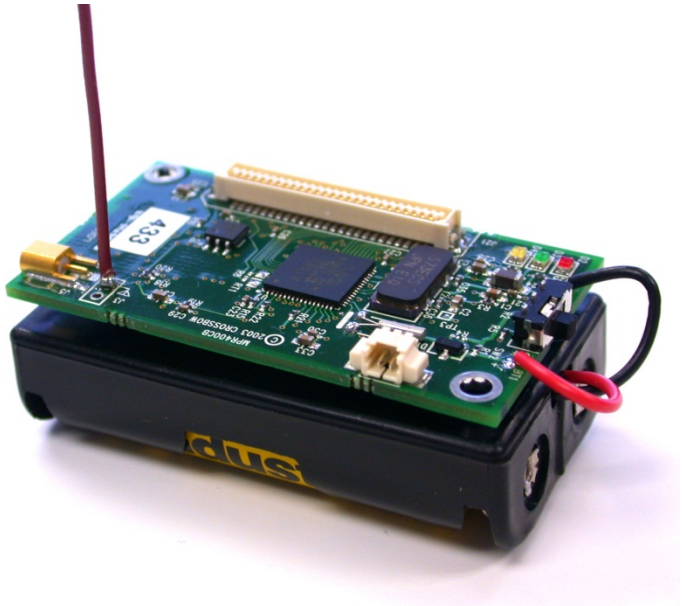
FURTHER CONSTRAINTS:

- WSNs MAY HAVE THOUSANDS OF NODES
- NODES THEMSELVES DO NOT HAVE A NOTION OF NODE PROXIMITY
- NODES' TRASMISSION MAY INTEFER WITH ONE ANOTHER: COLLISIONS
- BATTERY FAILURES
- SENSOR CALIBRATION

Software needs to take these into account

MOTES: THE Mica2 PLATFORM

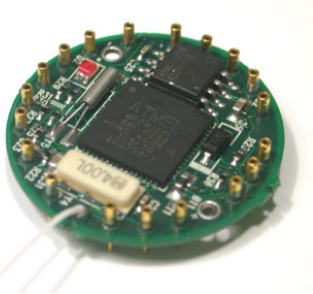
- Developed at UC Berkeley
- Powered by two AA batteries
- Atmel ATmega128L μC
  - 8 MHz
  - 4KB EEPROM
  - 4KB RAM
  - 128KB Program Flash memory
- Chipcon CC1000 multichannel radio
  - Range of up to 150-300 m.



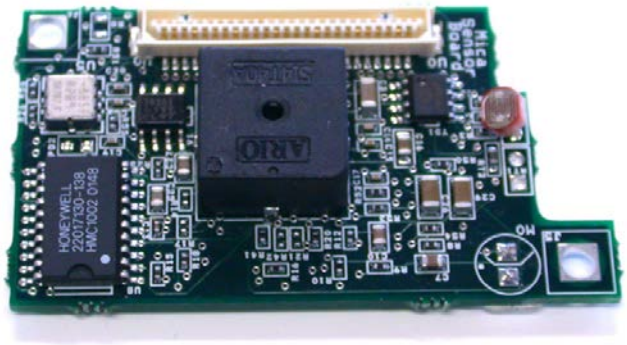
MOTES: THE Mica2 PLATFORM

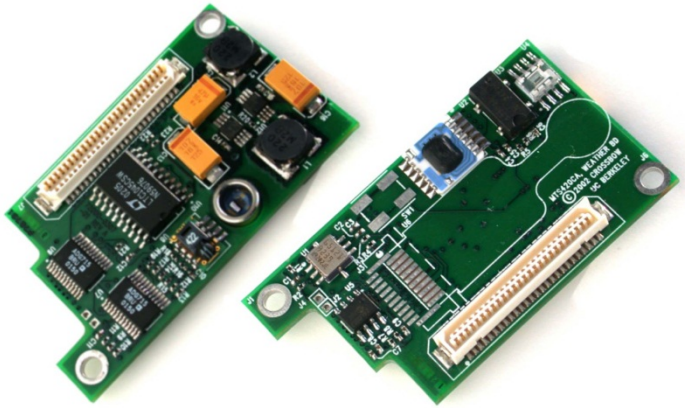
- Mica2Dot

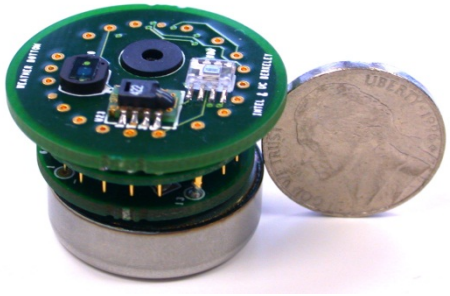
  Basically the same features, smaller size, fewer sensor options



- Different sensor boards for Mica2 and Mica2D



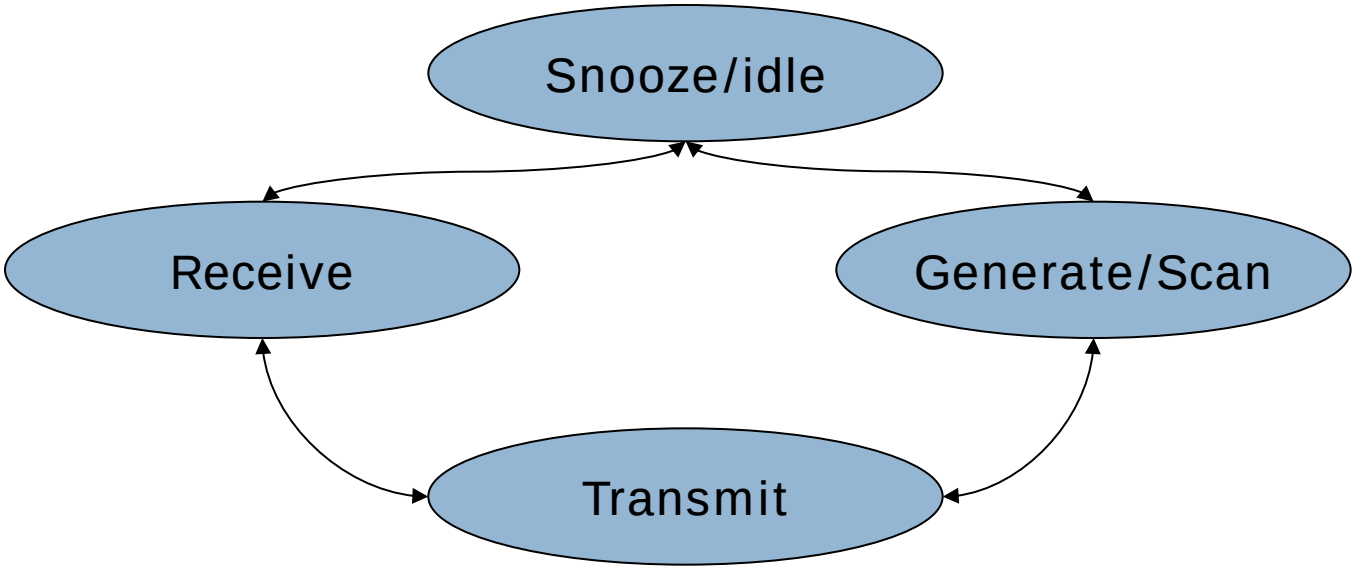




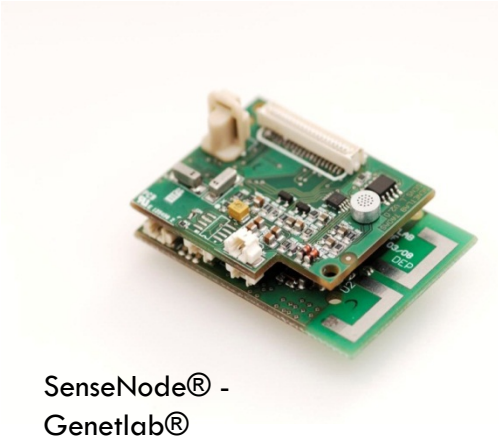
MOTES: AVAILABLE SENSORS

- Part of the Crossbow development kit:
  - MTS310 Sensor Board (for Mica2): includes Acceleration, Magnetic, Light, Temperature, Acoustic sensors.
  - MDA500, Mica2DOT data acquisition board: allows easy access to the microcontroller I/O pins to hook up sensors
- Other sensors:
  - MTS420A: offers weather monitoring sensors such as humidity, barometric pressure, temperature and light, in addition to a GPS module.
  - MTS500: Weather monitoring module for Mica2DOT: offers temperature, humidity, barometric pressure, and light sensors.

STATE DIAGRAM OF A MOTE

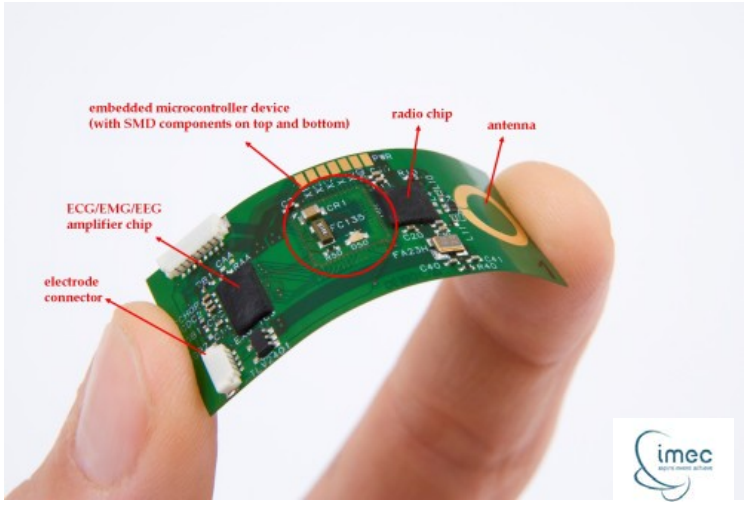


OTHER SENSORS



SenseNode® - Genetlab®

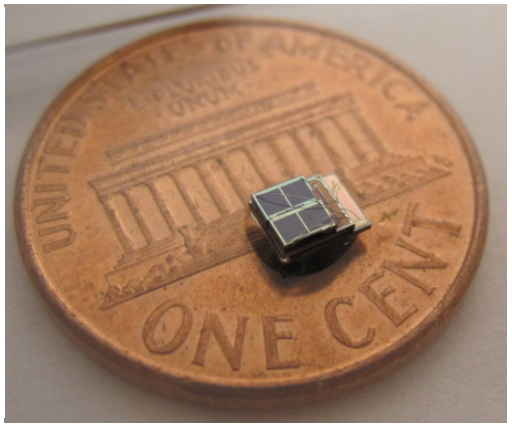
Program Flash Memory
48 kB on chip
Acoustic
Piezzo Microphone
Data RAM
10 kB on chip
Electret Microphone
Flash Measurement
1 MB external
Magnetic
3 axis Inductive
Serial Communications
2 × USART
Seismic/Vibration
± 1.2 g accelerometer



MicroStrain®

Node support	**V-Link®-mXRS™, SG-Link®-mXRS™, G-Link®-MXRS™, DVRT-Link™-mXRS™, TC-Link®-6CH-mXRS™, TC-Link®-1CH-mXRS™, EH-Link®, SG-Link® OEM-S, TC-Link® OEM all legacy 2.4 GHz wireless nodes**
Power consumption	**65.6 mA - 8 active node channels operating at 256 Hz Legacy Low Duty Cycle with analog outputs active 45.7 mA - Idle**
Radio frequency (RF) transceiver carrier	**2.4 GHz direct sequence spread spectrum, license free worldwide (2.405 to 2.480 GHz) – up to 16 channels, radiated power programmable from 0 dBm (1 mW) to 16 dBm (39 mW)**
Range for bi-directional RF link	**16 dBm (39 mW) Extended Power with range up to 2 kilometers (not available in Europe) 10 dBm (10 mW) Standard Power with range up to 1 kilometer 0 dBm (1 mW) Low Power with range up to 70 meters**
Dimensions	**88 mm x 70 mm x 20 mm without antenna**
Weight	**126 grams**

The University of Michigan has squeezed a solar cell, rechargeable battery, and CPU-based data acquisition system into 9mm³ (2.5x3.5x1mm).



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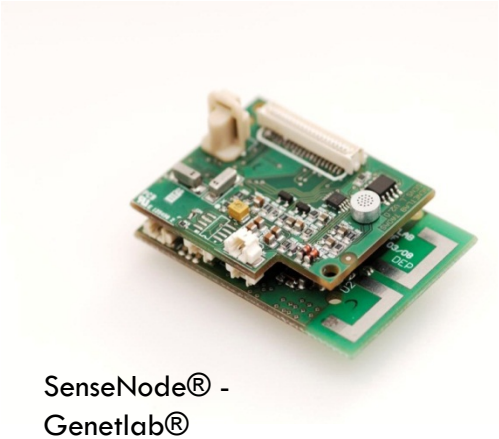

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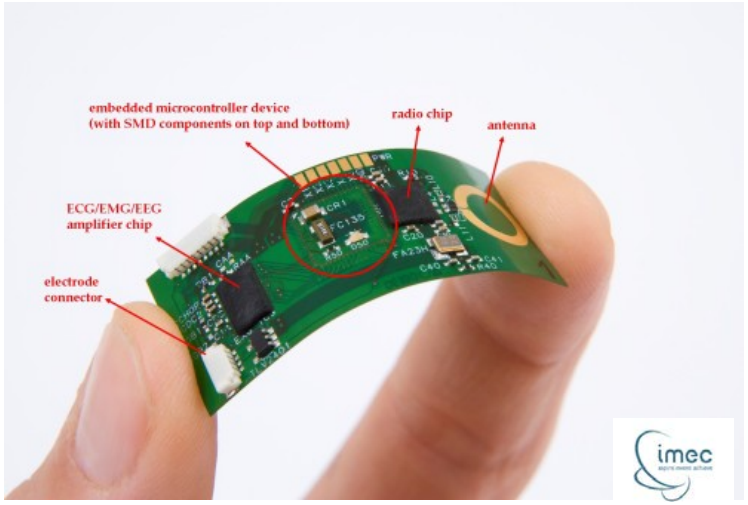

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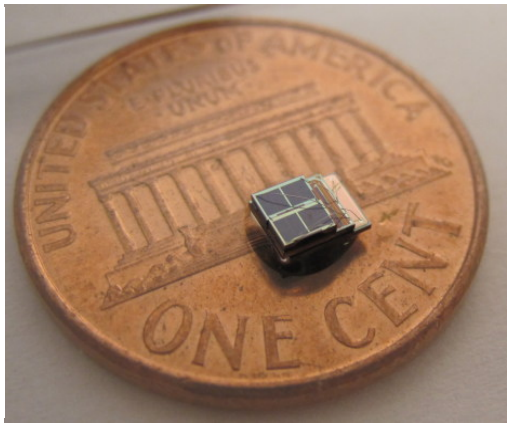
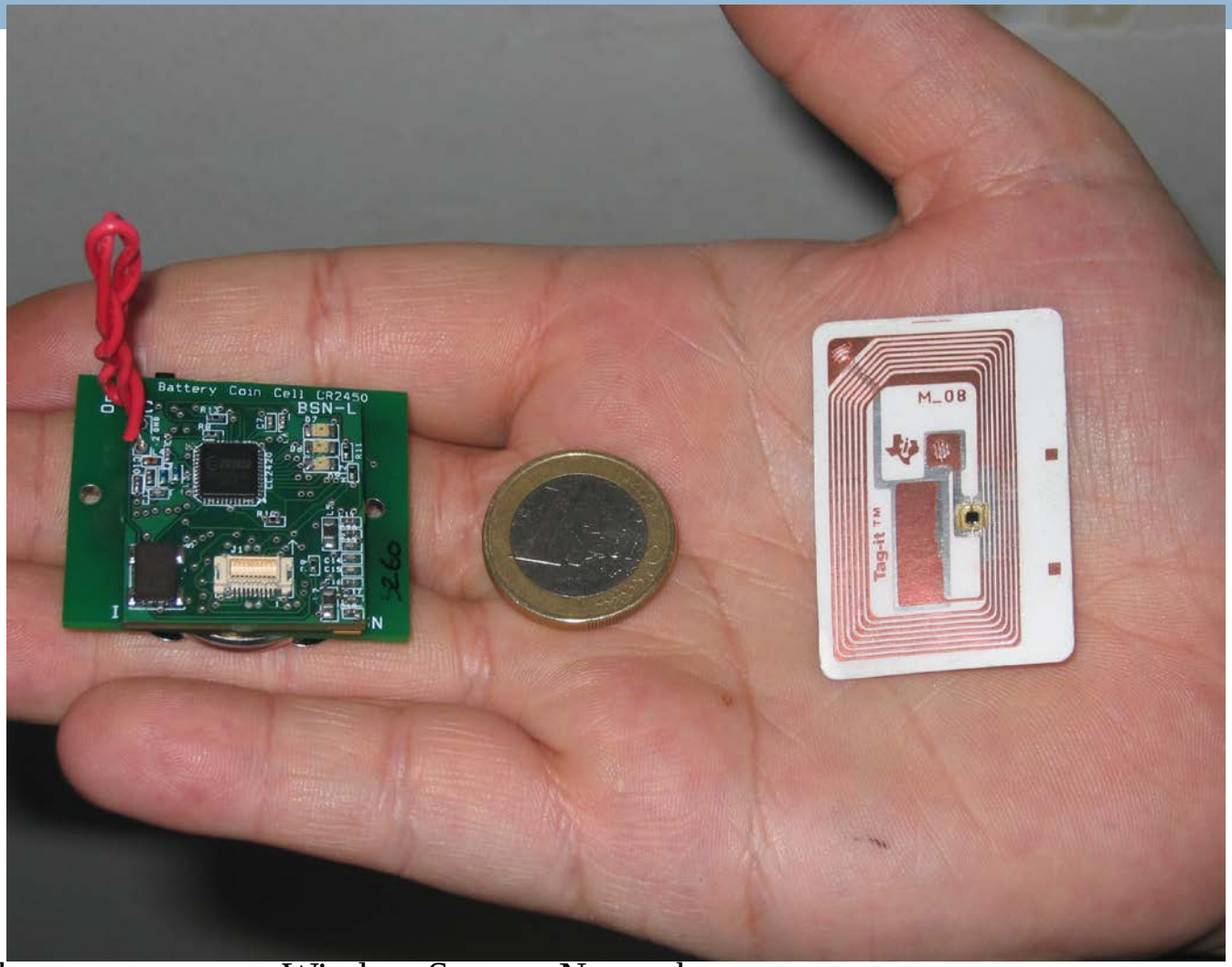


 Wi

RADIO FREQUENCY IDENTIFICATION TAG (RFID)

- LOW END IN THE SENSORS CAPABILITIES SCALE
- TWO COMPONENTS SYSTEMS
  - READER
    - ENERGY SOURCE
    - R/T ACTIVE DEVICE
  - TRASPONDER (TAG)
    - UNIQUE ID
    - SMALL PROCESSING CAPABILITY
    - SMALL ON-CHIP STORAGE
    - R/T ANTENNA

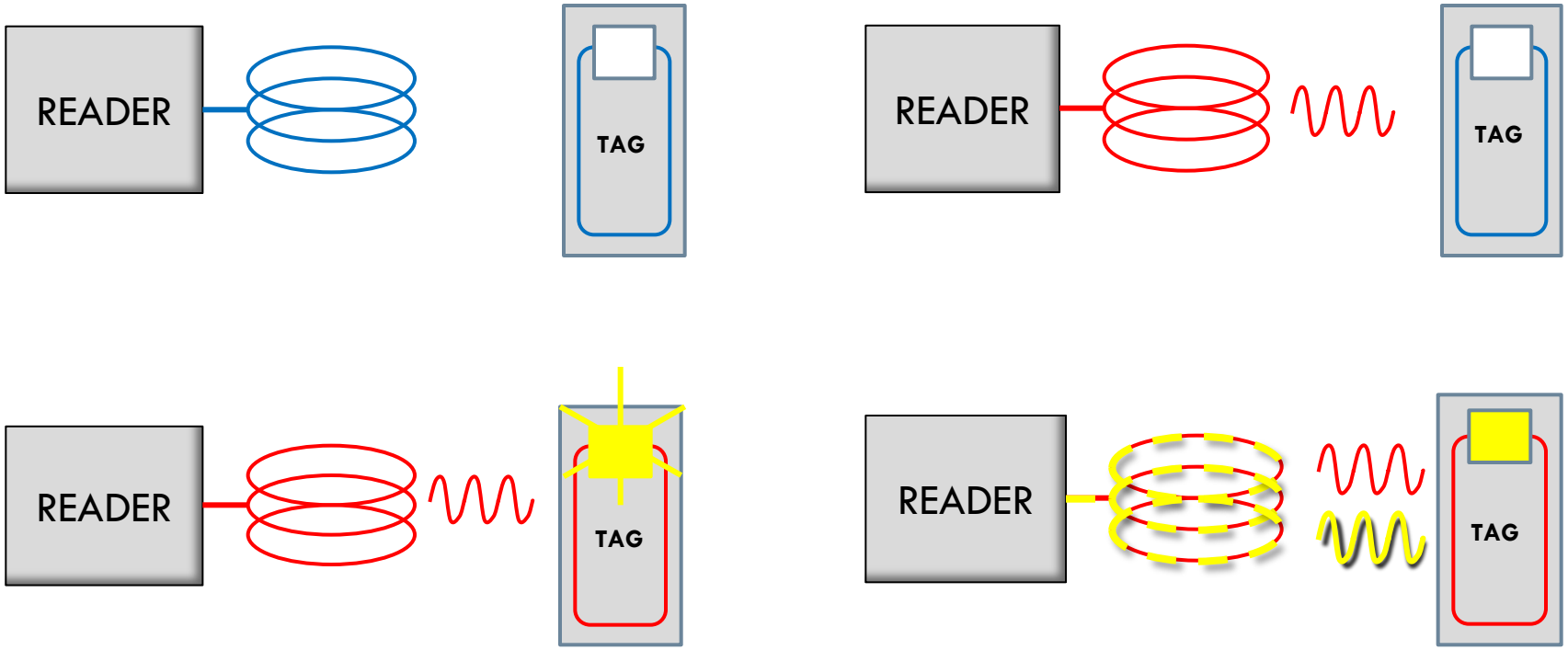
SENSORS COMPARISON



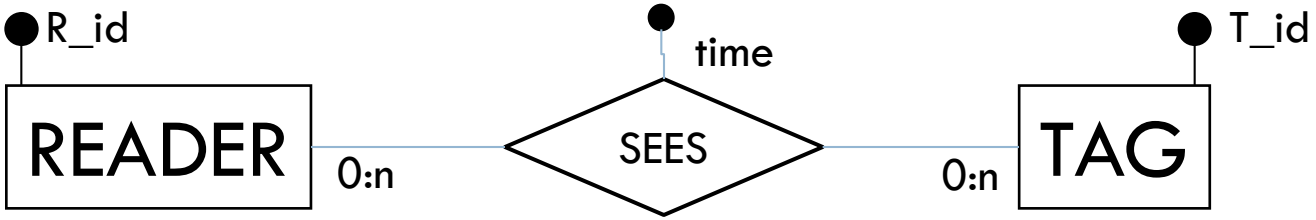
TAG CLASSIFICATION

- **POWER SOURCE**
  - ACTIVE (e.g. ARVA avalanche rescue system)
  - PASSIVE (no power source on tag)
  - SEMIPASSIVE (e.g. Telepass)
- **MEMORY**
  - READ ONLY
  - READ/WRITE
- **FREQUENCY**
  - LF (125 – 134 kHz)
  - HF (13.56 MHz)
  - UHF (868 – 956 MHz)
  - MW (2.45 GHz)

RFID SYSTEM OPERATION



MODELING AND QUERYING AN RFID SYSTEM



rfidsys

R_id	T_id	time
R1	T15	t1
R1	T54	t5
R1	T15	t7
R2	T22	t2
R2	T15	t3
R2	T81	t4
R3	T15	t5
R3	T22	t6

Which Tags passed
under Reader R1
in the last ten minutes?

```
SELECT  T_id
FROM  rfidsys
WHERE  R_id=R1 AND time IN
        (SELECT(time, T_id)
        FROM  rfidsys
        WHERE  (t-time) < 10)
```

RFID DATA CENTRIC APPLICATIONS

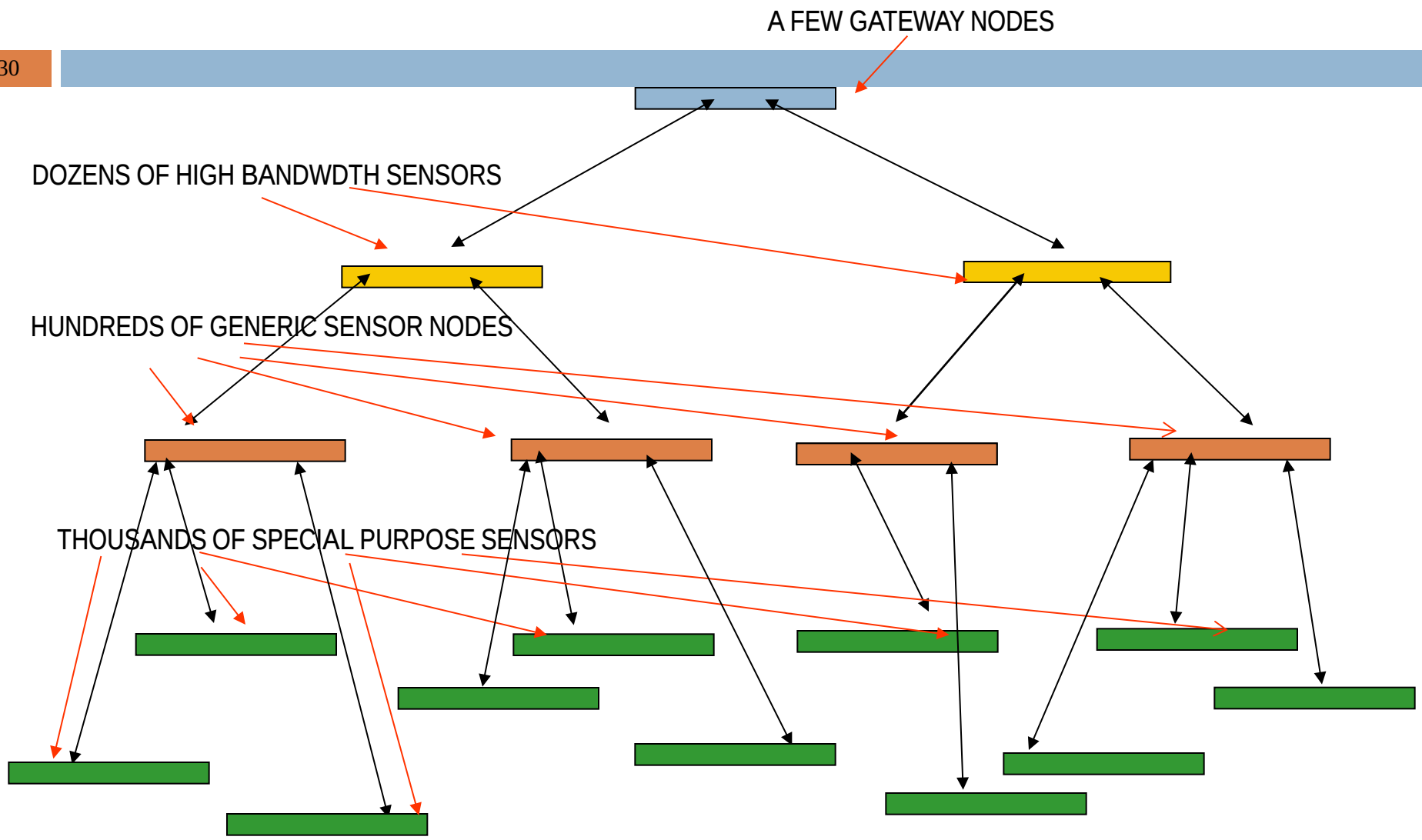
- GOODS LOGISTICS
  - ANIMALS TAGGING
  - PRODUCTION CONTROL
  - PRODUCT TRACKING
    - **AIRPORT LUGGAGE MANAGMENT**
    - **WAREHOUSES MANAGEMENT**
- ACCESS CONTROL AND TICKETING
  - ELECTRONIC TICKETING
    - **SKIPASS**
    - **TELEPASS**
    - **PUBLIC TRANSPORTATION**
  - SECURITY APPLICATIONS
    - **PEOPLE IDENTIFICATION**
    - **ELECTRONIC PASSPORT**
- TECHNOLOGY ENHANCEMENT
  - PRODUCT MAINTENANCE

PROPERTIES OF SENSOR NETWORKS

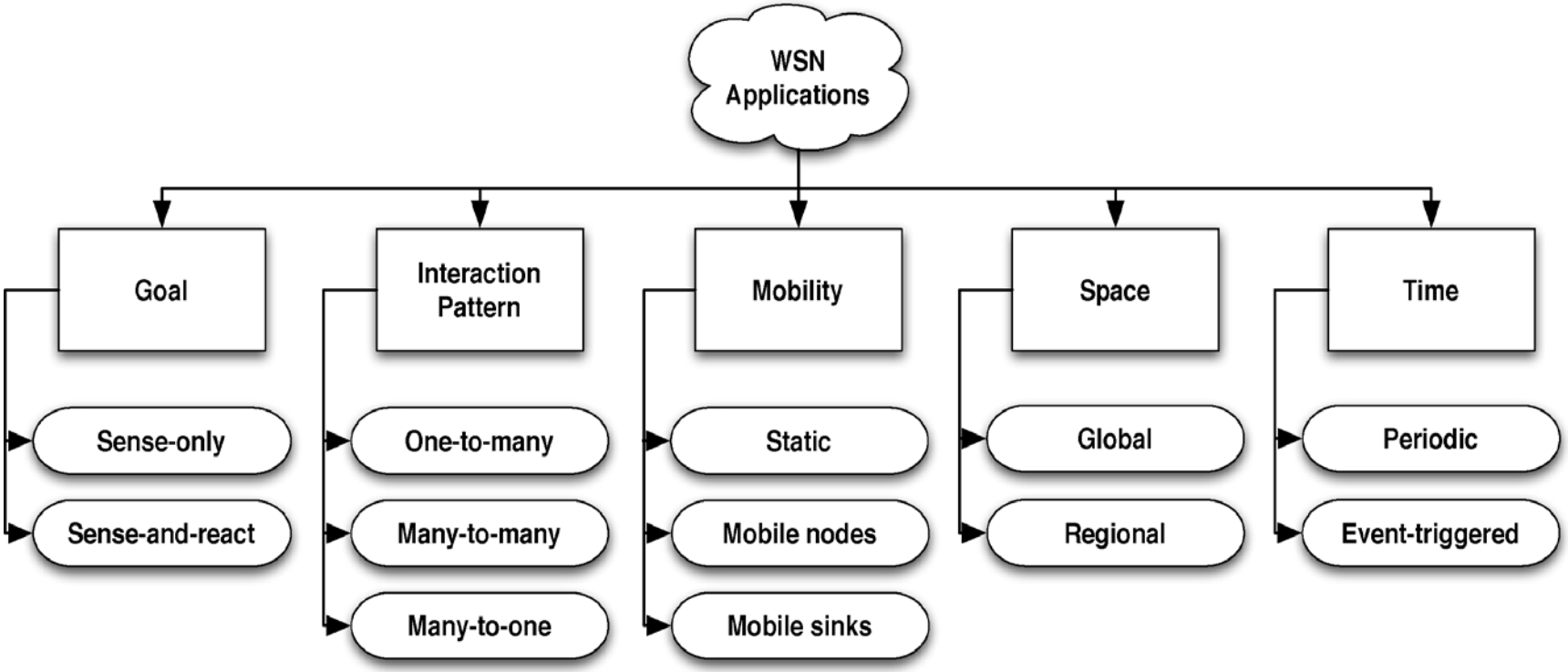
- NODES HAVE A GENERAL-PURPOSE CPU AND SOME STORAGE SPACE
- SINCE:
  - COMMUNICATION CONSUMES MORE ENERGY THAN COMPUTATIONS
  - COMMUNICATION LINKS MAY BREAK FREQUENTLY DUE TO ENVIRONMENTAL INTERFERENCES AND NOISE

→ WE WANT TO REDUCE THE AMOUNT OF COMMUNICATION TRAFFIC AMONG NODES BY PREPROCESSING THE LOCAL DATA

A HIERARCHICAL WSN ARCHITECTURE



WSN APPLICATIONS



From: L. Mottola, G. P. Picco, ACM Computing Surveys, Vol. 43, No. 3, April 2011

WSN SOFTWARE PLATFORMS

TinyOS	**U.C. Berkeley**	**•Event-diven programming •nesC**
SOS	**UCLA**	**•Event-diven programming •C**
Mantis	**U. Boulder**	**•Preemptive multithreading •C**
Contiki	**Swedish Institute of Computer Science (SICS)**	**•Event-diven programming •Multithreading •C**
LiteOS	**University of Illinois**	**•C •Real time •UNIX**

TinyOS

TinyOS IS A SORT OF OPERATING SYSYEM, WHICH IS SIMPLY A LIBRARY THAT PROVIDES A NUMBER OF CONVENIENT SOFTWARE ABSTRACTIONS, INCLUDING COMPONENTS TO

- MODULATE PACKETS OVER THE RADIO LINK,
- READ SENSOR VALUES FOR DIFFERENT SENSOR HARDWARE,
- SYNCHRONIZE CLOCKS BETWEEN A SENDER AND RECEIVER AND
- PUT THE HARDWARE INTO A LOW-POWER STATE.

TinyOS LANGUAGES

- **nesC**:
  - EXTENSION OF THE C LANGUAGE AIMED AT NETWORKED EMBEDDED SYSTEMS, SUCH AS MOTES.
  - TinyOS IS WRITTEN IN nesC, ITS STRUCTURE IS CLOSELY RELATED TO nesC'S FEATURES

- **Maté**:
  - A TINY BYTECODE INTERPRETER THAT RUNS ON TOP OF TinyOS.
  - A TINY COMMUNICATION-CENTRIC VIRTUAL MACHINE DESIGNED FOR SENSOR NETWORKS.
  - A HIGH LEVEL INTERFACE ALLOWING COMPLEX PROGRAMS TO BE VERY COMPACT SO REDUCING THE COST OF CODE TRANSMISSION

TinyOS FILE SYSTEM

- Matchbox
  - PROVIDES THE BASIC FILE OPERATIONS ON MOTES FLASH-BASED STORAGE
    - **CONFIGURATION SETTING DATA**
    - **VIRTUAL MACHINE PROGRAMS**
    - **SENSOR READINGS VALUES**
  - DESIGN GOALS
    - **RELIABILITY**
      - DETECT DATA CORRUPTION (crc)
      - PREVENT META-DATA CORRUPTION
      - LOW RESOURCE CONSUMPTION
      - FLASH OPTIMIZATION (WEAR-LEVELING)

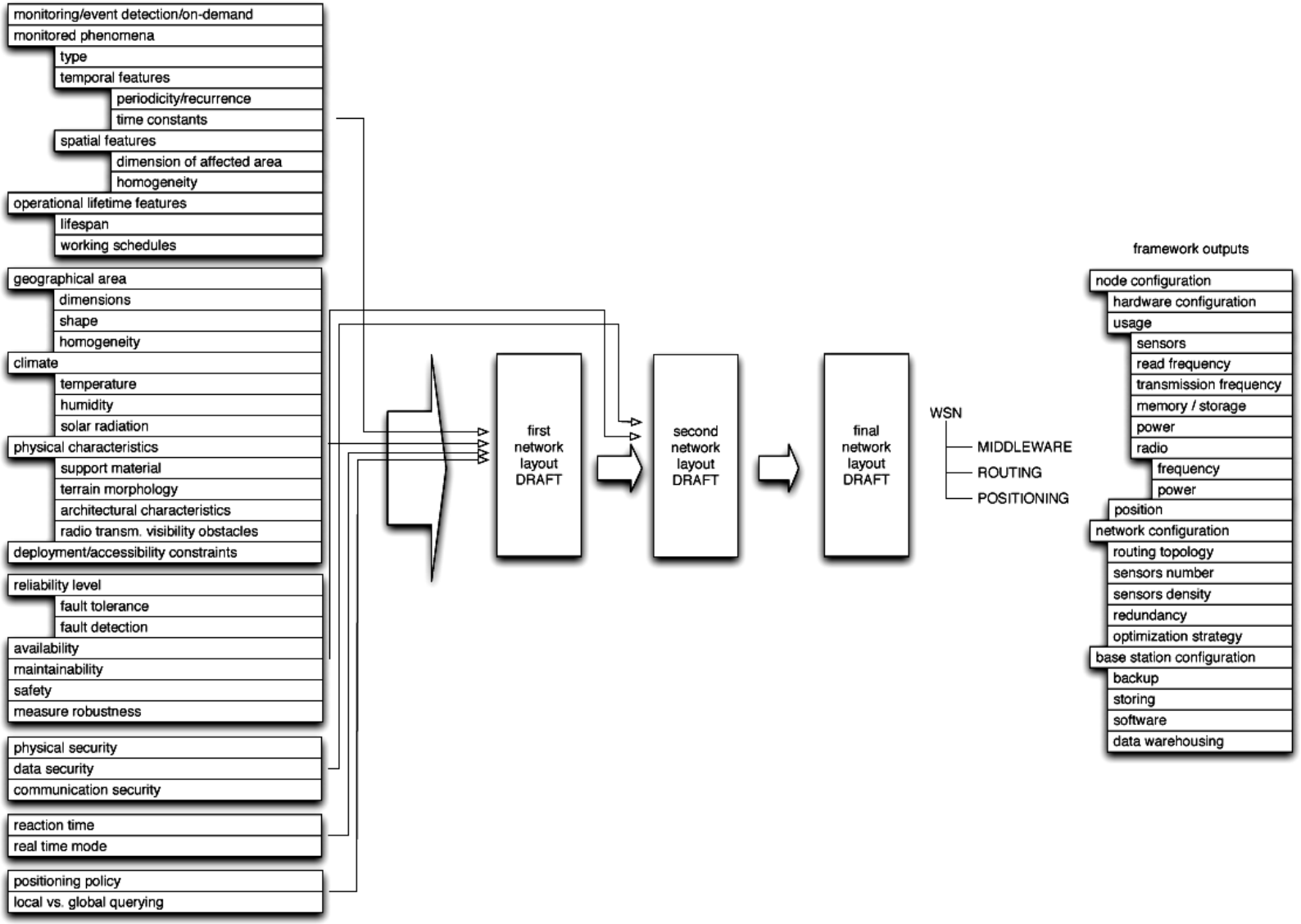
TinyOS FILE SYSTEM

- Matchbox **LIMITATIONS**
  - ONLY **FLAT** FILE STRUCTURE
  - ONLY **SEQUENTIAL** ACCESS TO FILES
  - **NO MULTIPLE** READERS AND WRITERS ON THE SAME FILE
  - ONLY **ONE** FILE OPEN FOR **READING** AND **ONE** OPEN FOR **WRITING**
  - ONLY **ONE REQUEST AT-A-TIME** (no queues)
  - NO BUILT-IN **SECURITY** MECHANISM

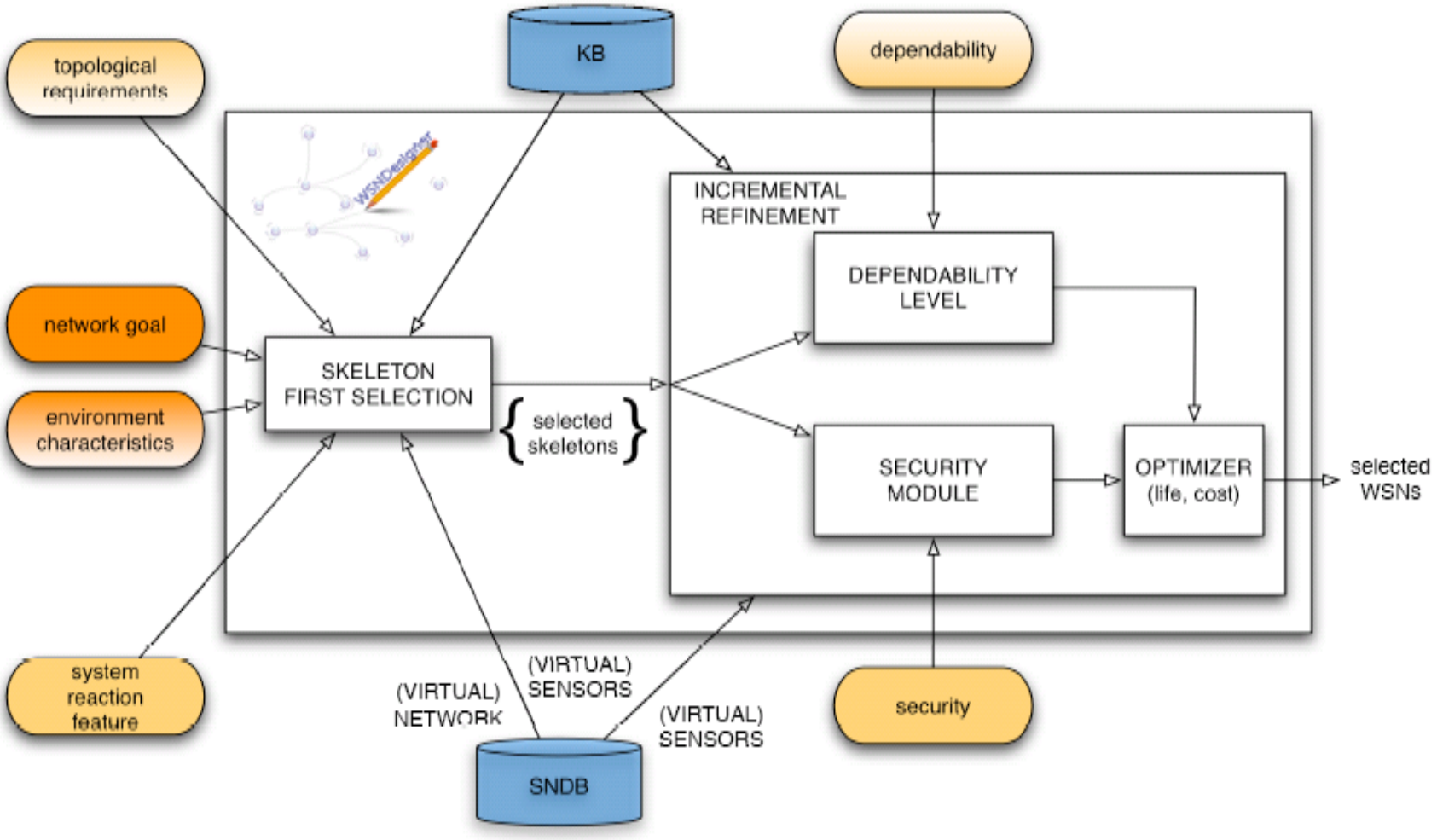
OTHER FLASH FILE SYSTEMS

- ELF (MANTIS)
  - LOG STRUCTURED (WRITE-APPEND) FOR WEAR LEVELING
  - RANDOM READ FACILITY
  - HIERARCHICAL DIRECTORY
  - GARBAGE COLLECTION
  - CRASH RECOVERY
- TFFS (TAU)
  - PRUNED VERSIONED B-TREE
  - TRANSACTIONS SUPPORT
  - FOCUS ON RECOVERABILITY
- EmStar (Stargate, iPAQ H3100, TinyOS)
  - FOR LINUX MICROSERVERS

WSN DESIGN VARIABLES



WSN CONFIGURATION TOOL



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