Overview on Wireless Sensor Networks

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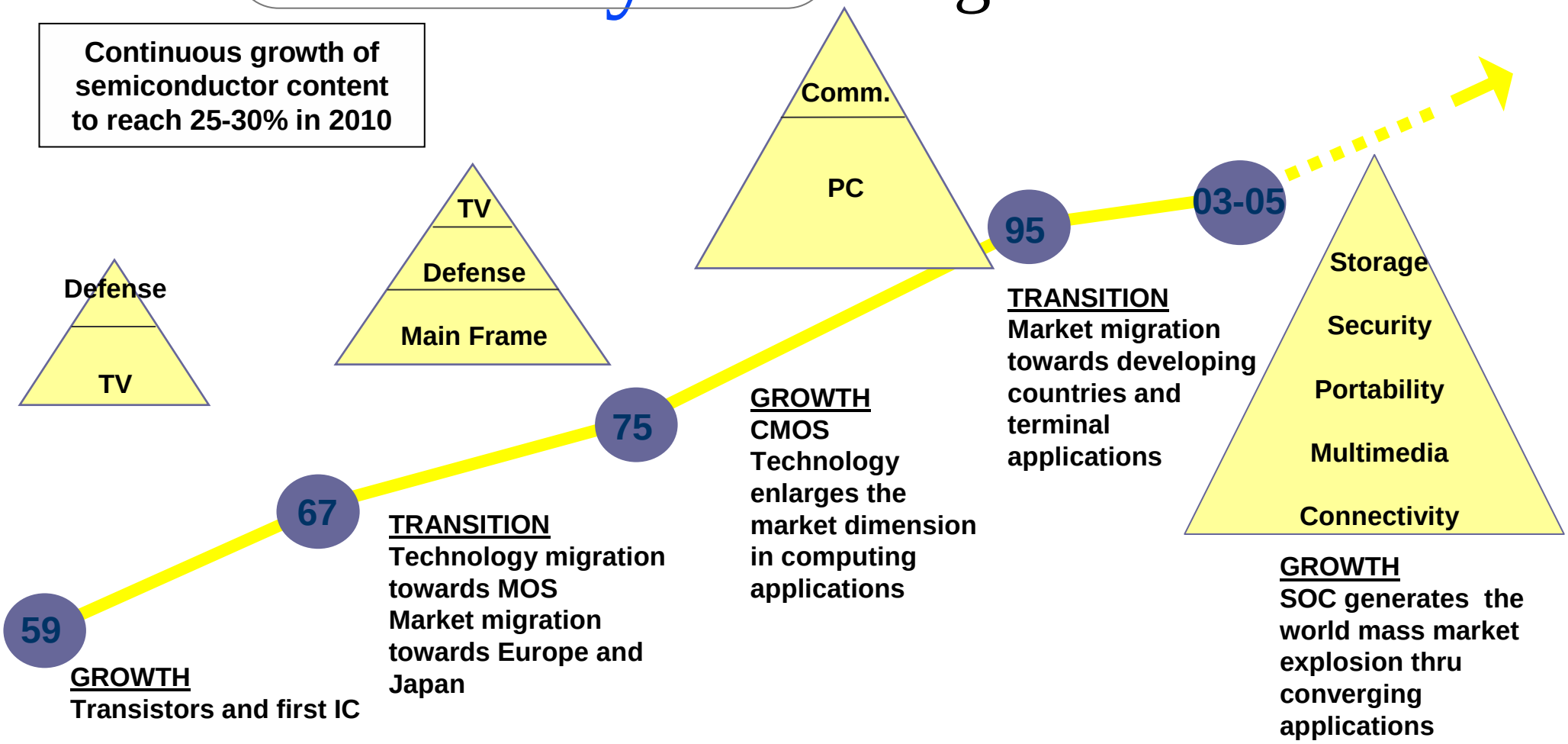
STMicroelectronics

Outline

- Introduction of STMicroelectronics
- Embedded Systems Trend
- The Vision
- Design Challenges
- Applications
- The communication standards
- WSN Prototyping activities in my group
  - The HW and SW Platforms

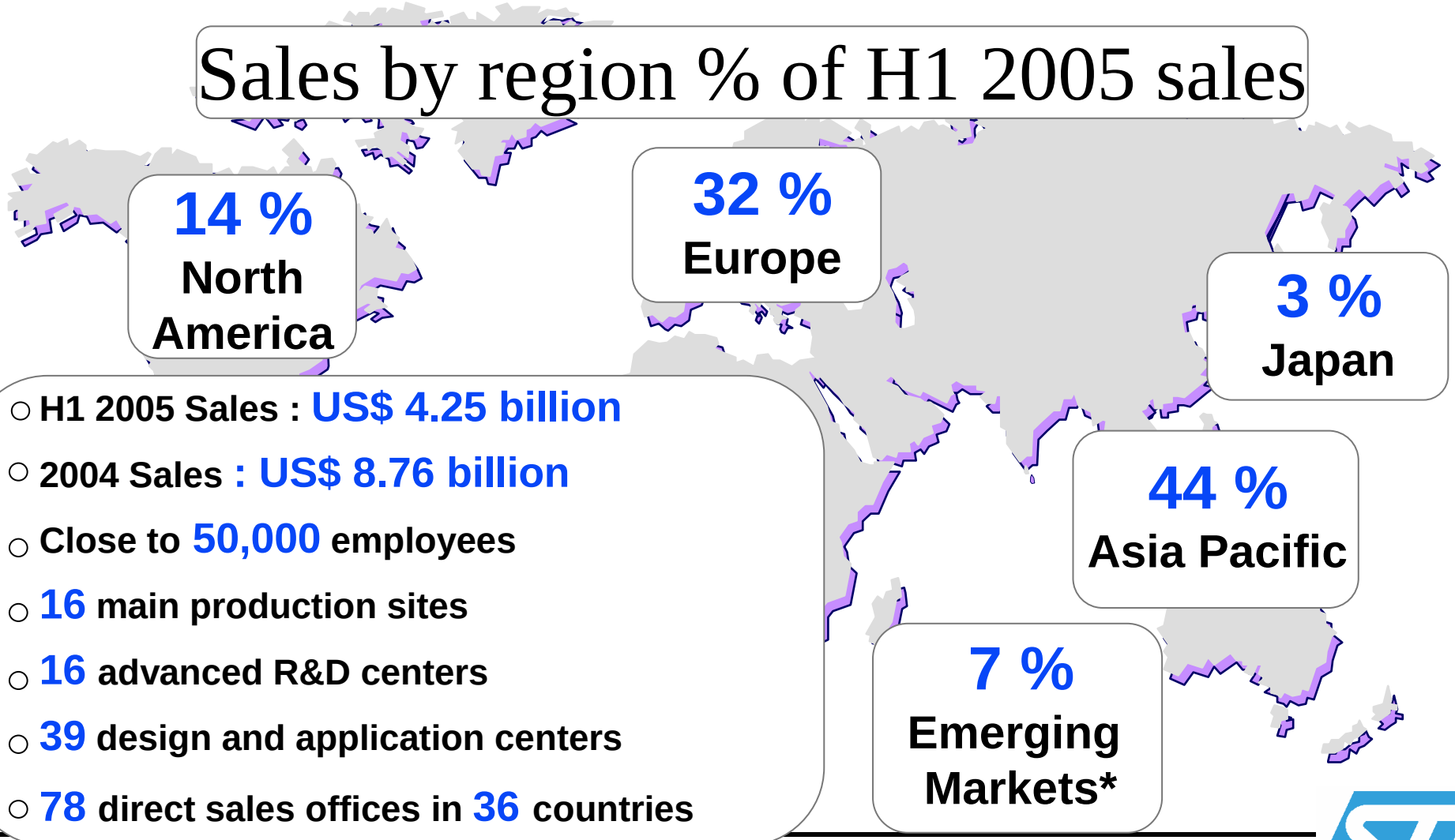
Semiconductor market cycles long term trend

Continuous growth of semiconductor content to reach 25-30% in 2010



STMicroelectronics
a global semiconductor company

Sales by region % of H1 2005 sales



14 %
North America

32 %
Europe

3 %
Japan

44 %
Asia Pacific

7 %
Emerging Markets*

- H1 2005 Sales : US$ 4.25 billion
- 2004 Sales : US$ 8.76 billion
- Close to 50,000 employees
- 16 main production sites
- 16 advanced R&D centers
- 39 design and application centers
- 78 direct sales offices in 36 countries

*India, Africa, Latin America, Middle East

Complete product solutions for high growth applications

Priority segments

Computer peripherals

Digital consumer

Automotive

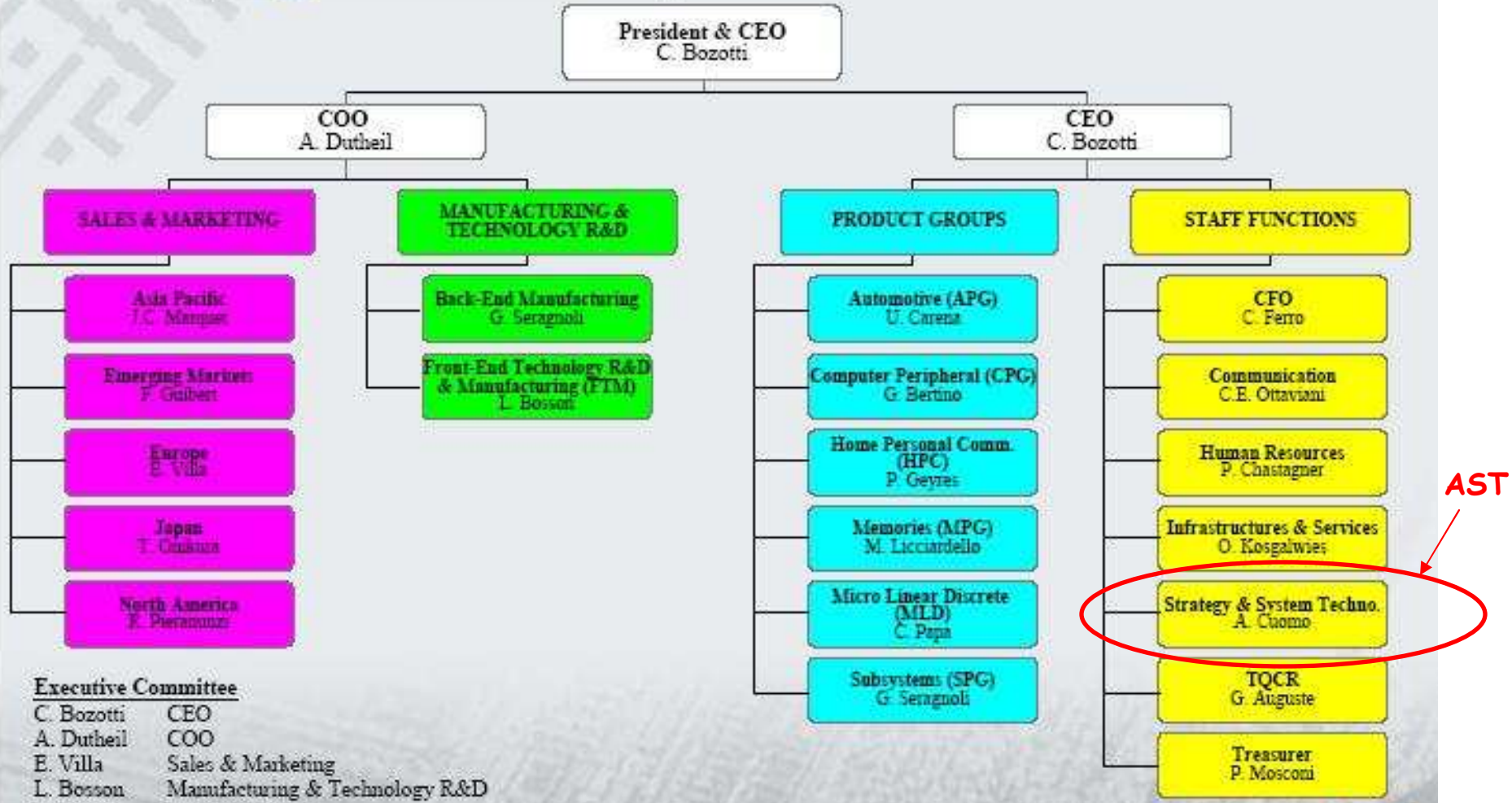
Communications

Smartcards

Focus applications

- Data storage
- Printers
- Optical mouse
- Monitors & displays
- Imaging
- Set-top boxes
- DVDs
- Digital TVs
- Digital cameras
- Digital audio
- Engine/body/safety
- Car radio
- Car multimedia
- Telematics
- Wireless
  - Connectivity
  - Mobile phone
  - Portable multimedia
- Networking
- Telephone
- Banking
- User ID
- Security

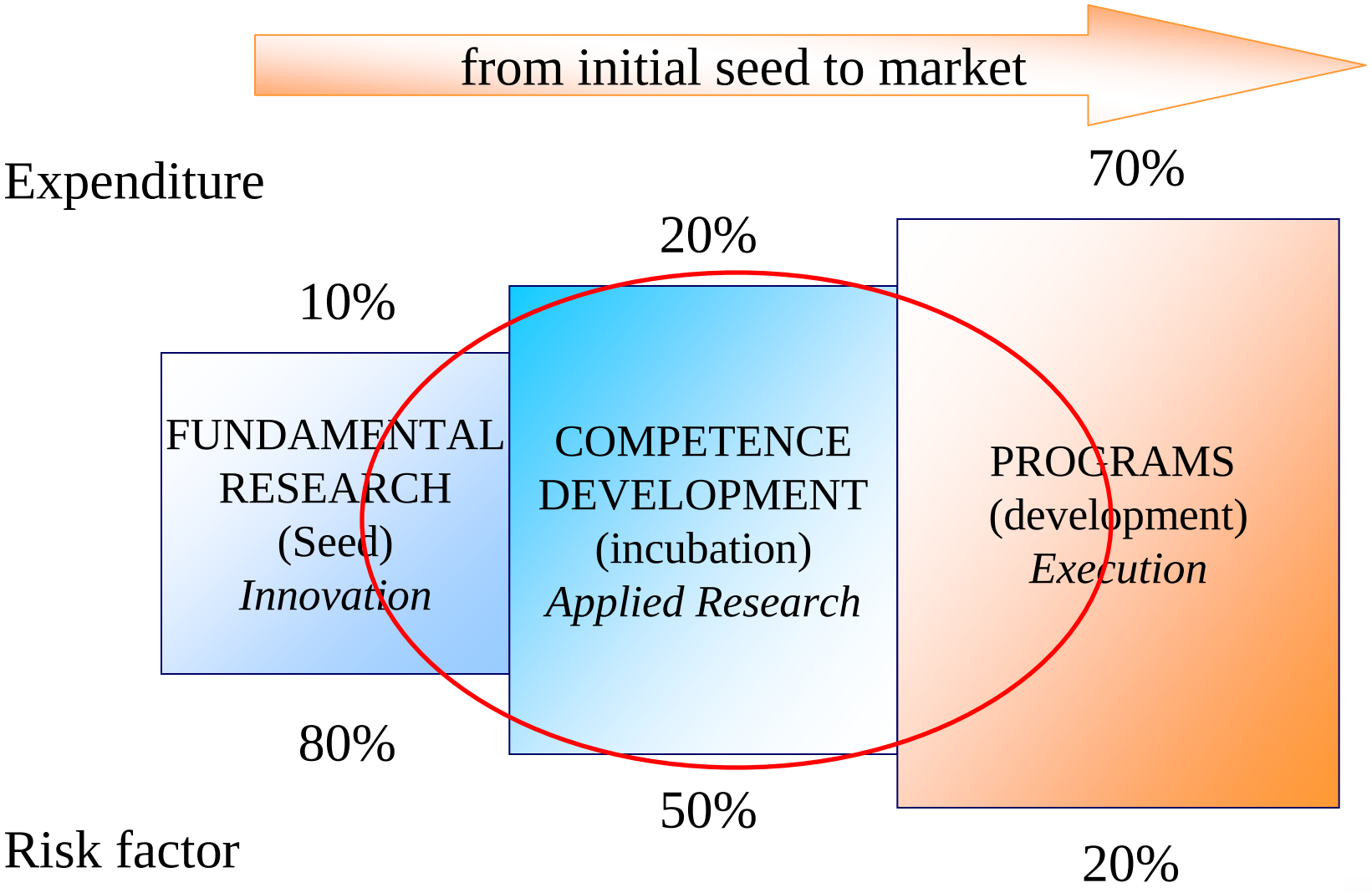
The organization



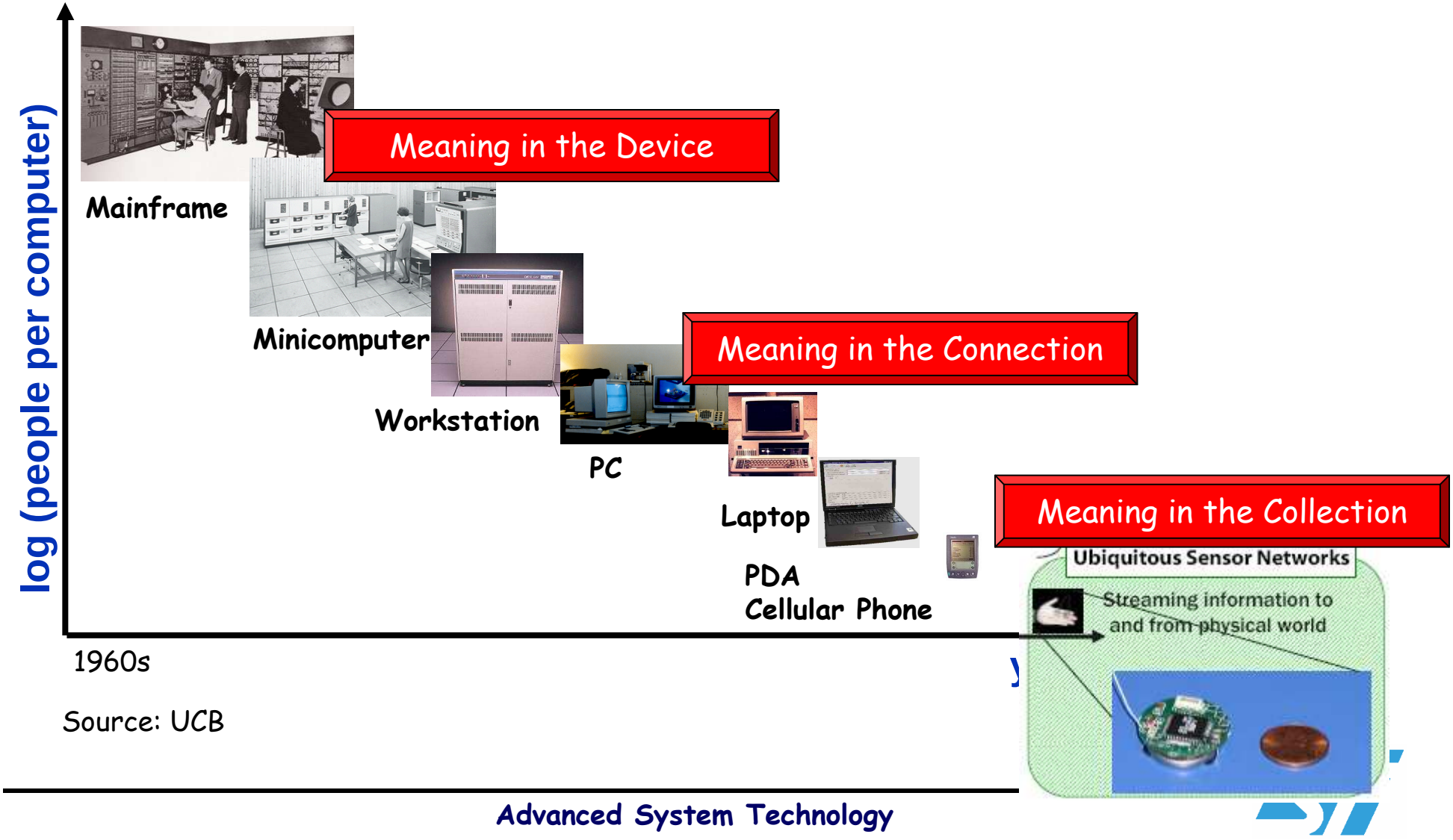
Executive Committee

C. Bozotti	CEO
A. Dutheil	COO
E. Villa	Sales & Marketing
L. Bosson	Manufacturing & Technology R&D
P. Geyres	Product Groups
C. Ferro	CFO, Treasurer, Infrastructures & Services
A. Cuomo	Strategy & Other Staff Functions

AST: research process



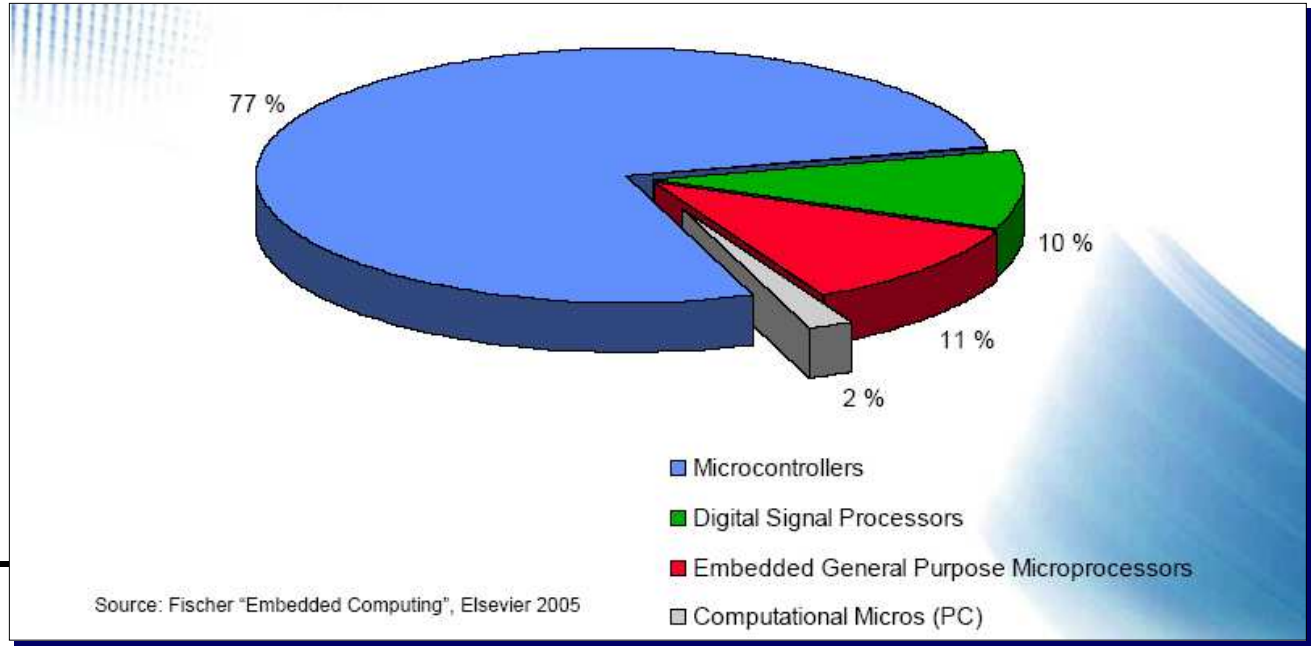
Bell's Law: A new Computer Class every 10 years



Source: UCB

Embedded System Market Outlook

- Today 90% of computing devices are in embedded systems, not in PC's
- The worldwide embedded systems market was estimated at $45.0 billion in 2004
- Expected to growth at an average annual growth rate (AAGR) of 14% over the next five years (source: Business Communications Company, Inc)
- Increase in car electronics is expected to create more than 600000 new jobs in Europe in automotive embedded systems by 2015



Embedded System R&D Effort in Europe

- Embedded Systems European R&D
  - Estimated 2005
    - Private 20 billion Euros
    - Public 250 million Euros
  - Scenario for 2010
    - Private 28 billion Euros
    - Public 700 million Euros
- Number of embedded system developers in Europe is about 150000
  - Expected to grow 10% p.a.

The Long Term Vision: Ambient Intelligence

Embedded

An environment where technology is embedded, hidden in the background

Adaptive

An environment that is sensitive, adaptive, and responsive to the presence of people and objects

Context Aware

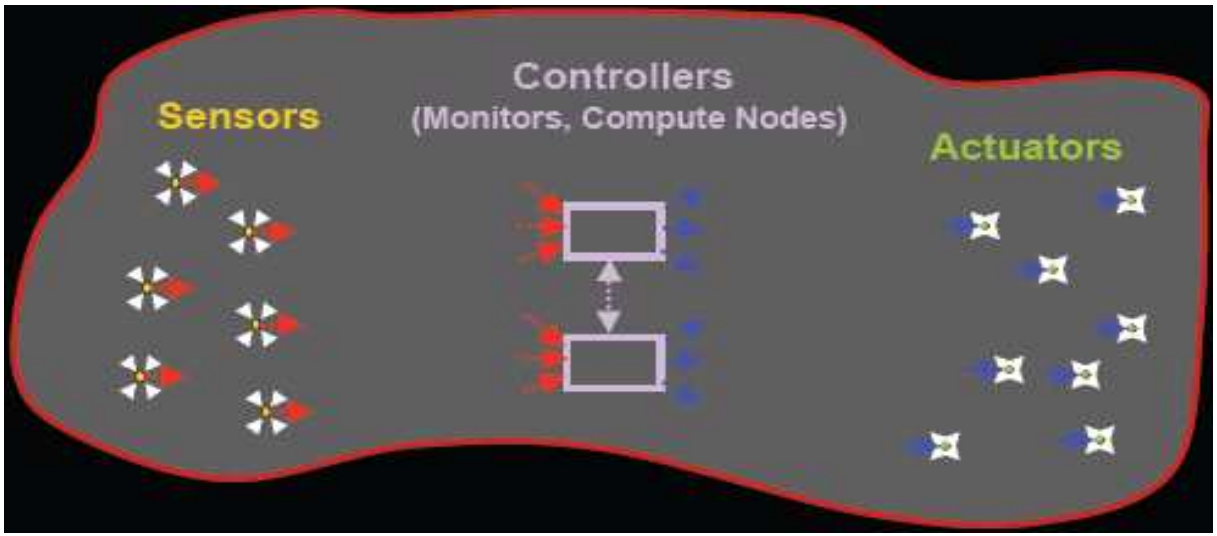
An environment that augments activities through smart not explicit assistance

Secure

An environment that preserves security, privacy and trustworthiness while utilizing information when needed and appropriate

[Source: Fred Boekhorst , Philips, ISSCC02]

Wireless Sensor and Actuator Networks as a First Incarnation



A collection of cooperating algorithms (controllers) designed to achieve a set of common goals, aided by interactions with the environment through distributed measurements (sensors) and actions (actuators) [Source: BWRC]

Berkeley Dust Mote

Berkeley Mote

[Source: Pister et others – UCB]

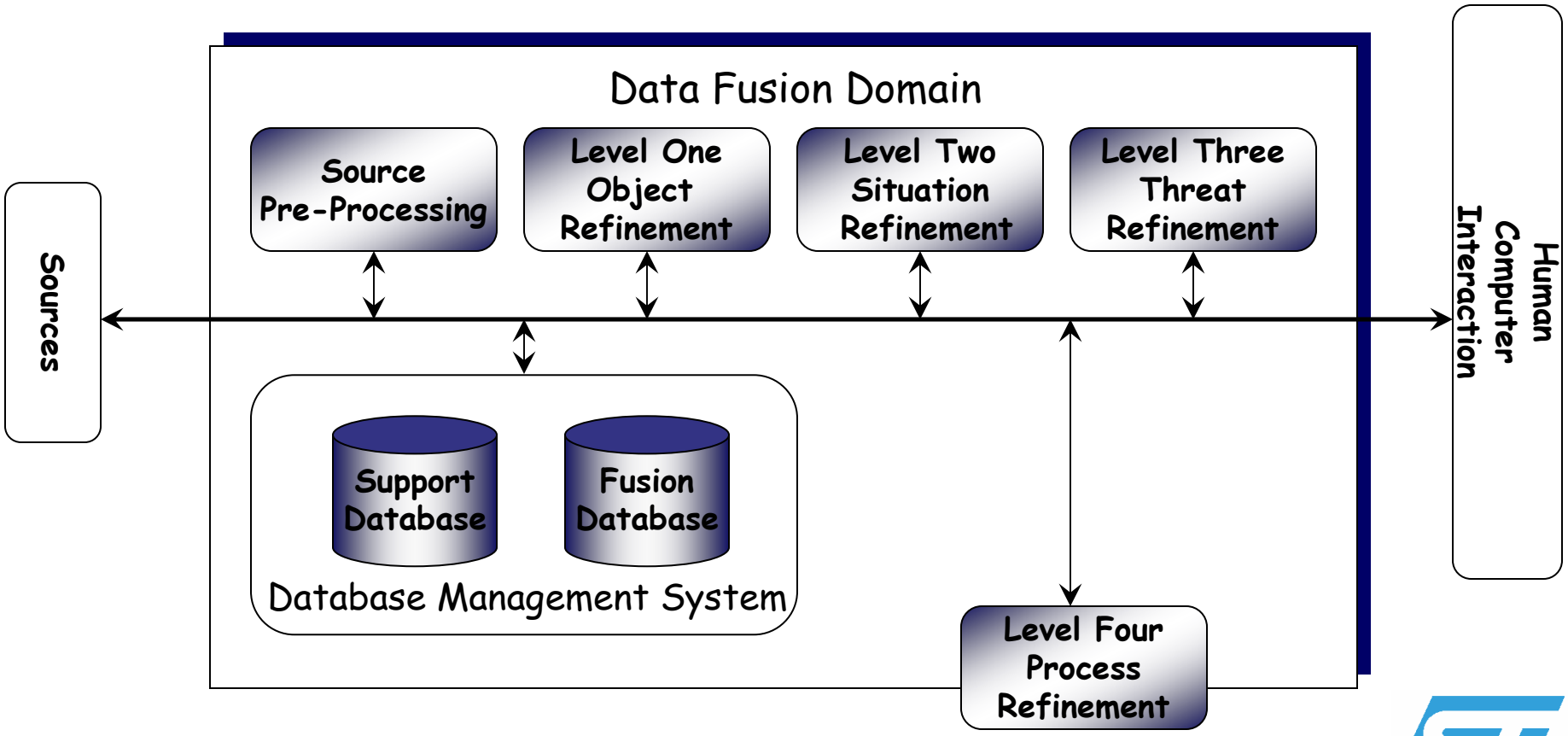
Data Fusion Domain

High Level Functions :

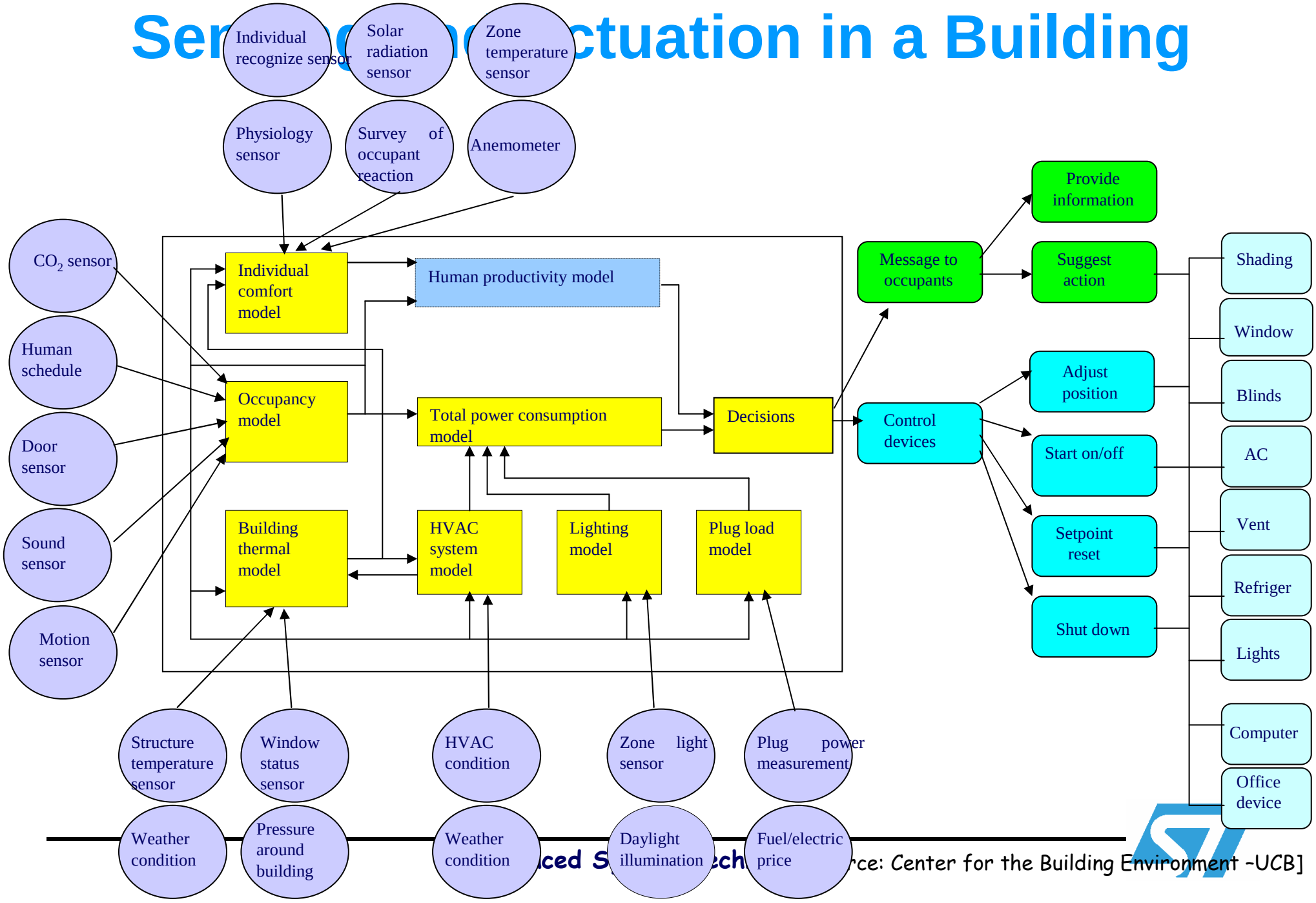
Detection (existence, velocity, locationing),
Tracking, Target Identification,
Behaviour analysis, Situation Assessment…

Techniques:

Coordinate Transforms, Gating Techniques, Kalman Filters, Neural networks, Pattern Recognition, FuzzyLogic, Linear Programming, …….



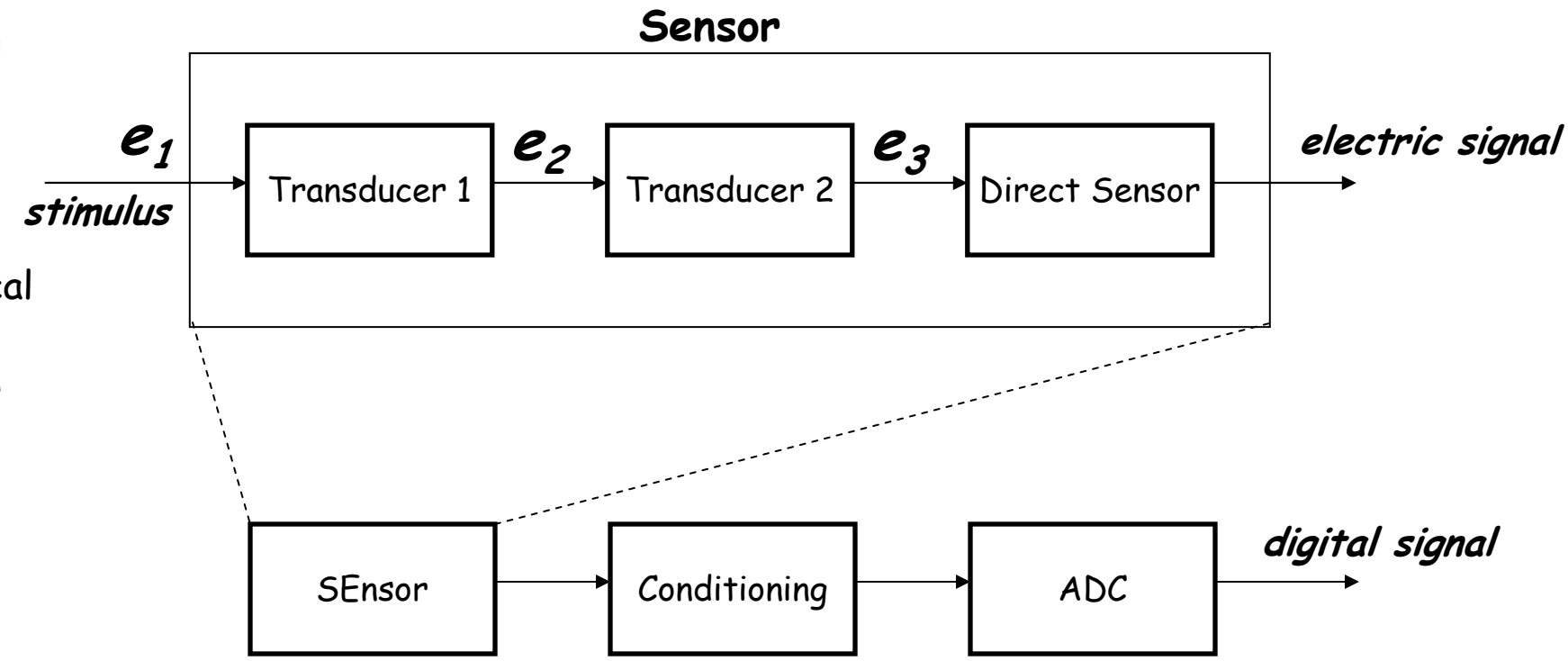
Sensing and Actuation in a Building



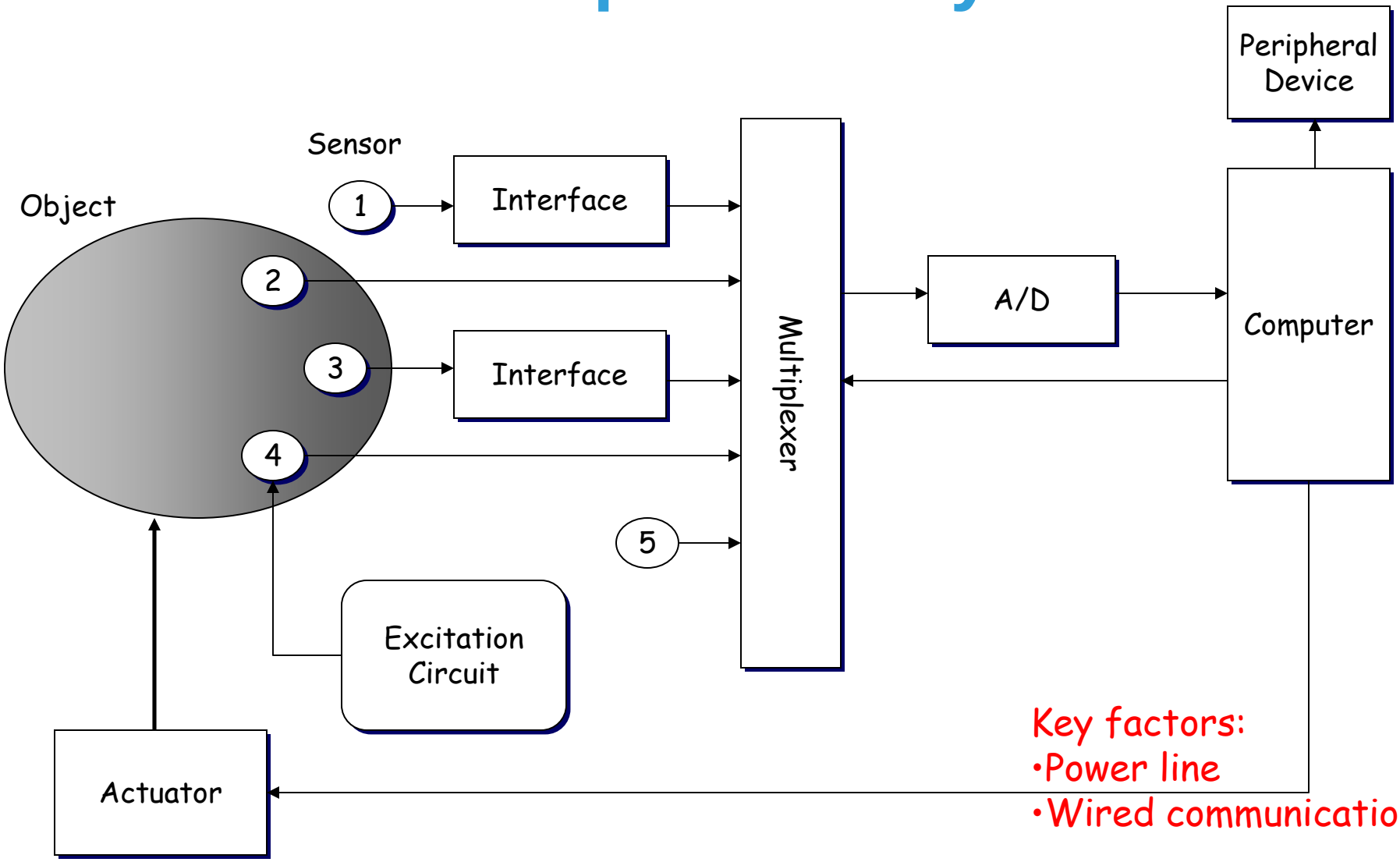
Sensors

- A sensor is a device that receives a stimulus and responds with an electrical signal

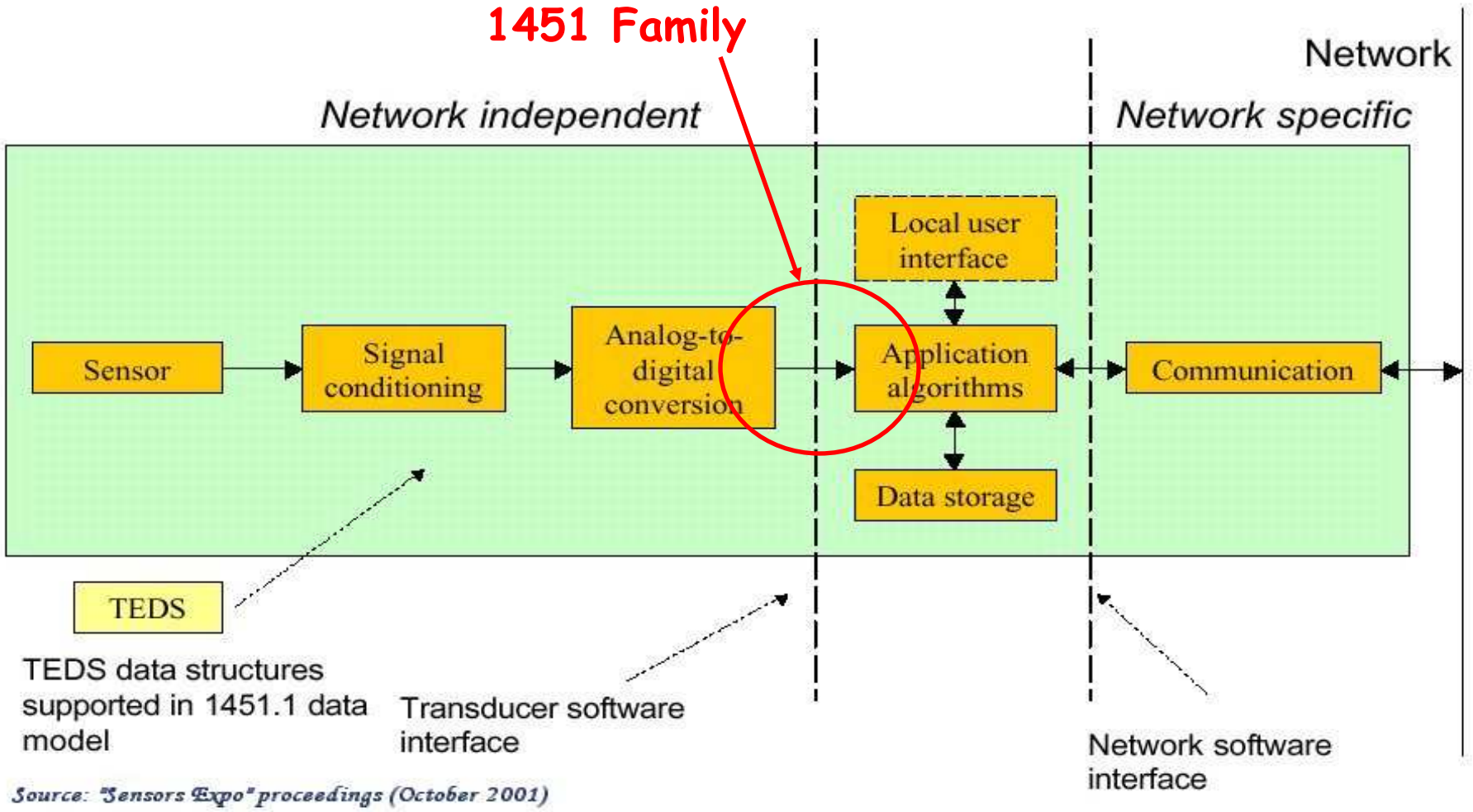
- Acoustic
- Biological
- Chemical
- Electric
- Magnetic
- Optical
- Mechanical
- Viscosity
- Radiation
- Thermal



Data Acquisition System

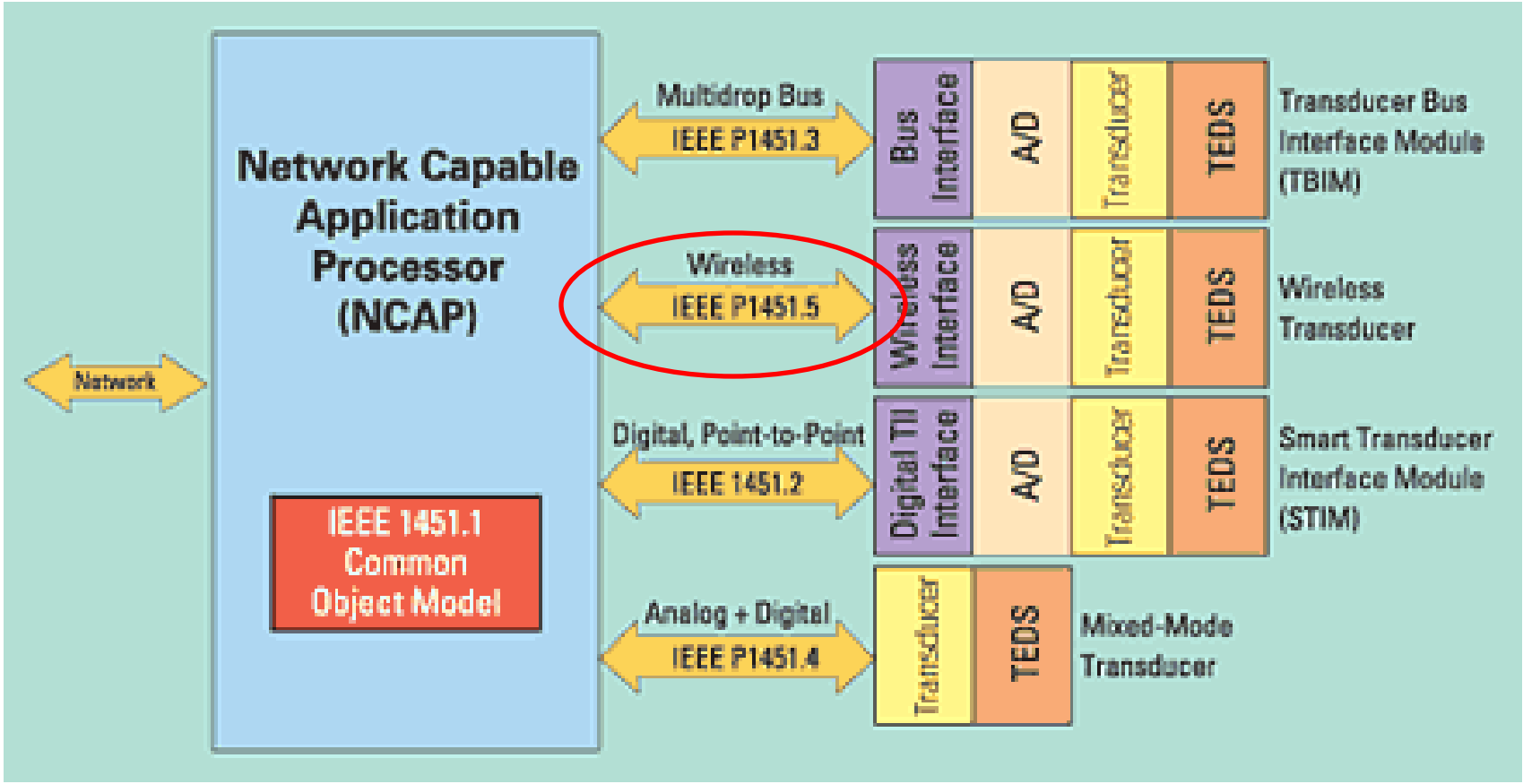


Sensors get aware…



Source: "Sensors Expo" proceedings (October 2001)

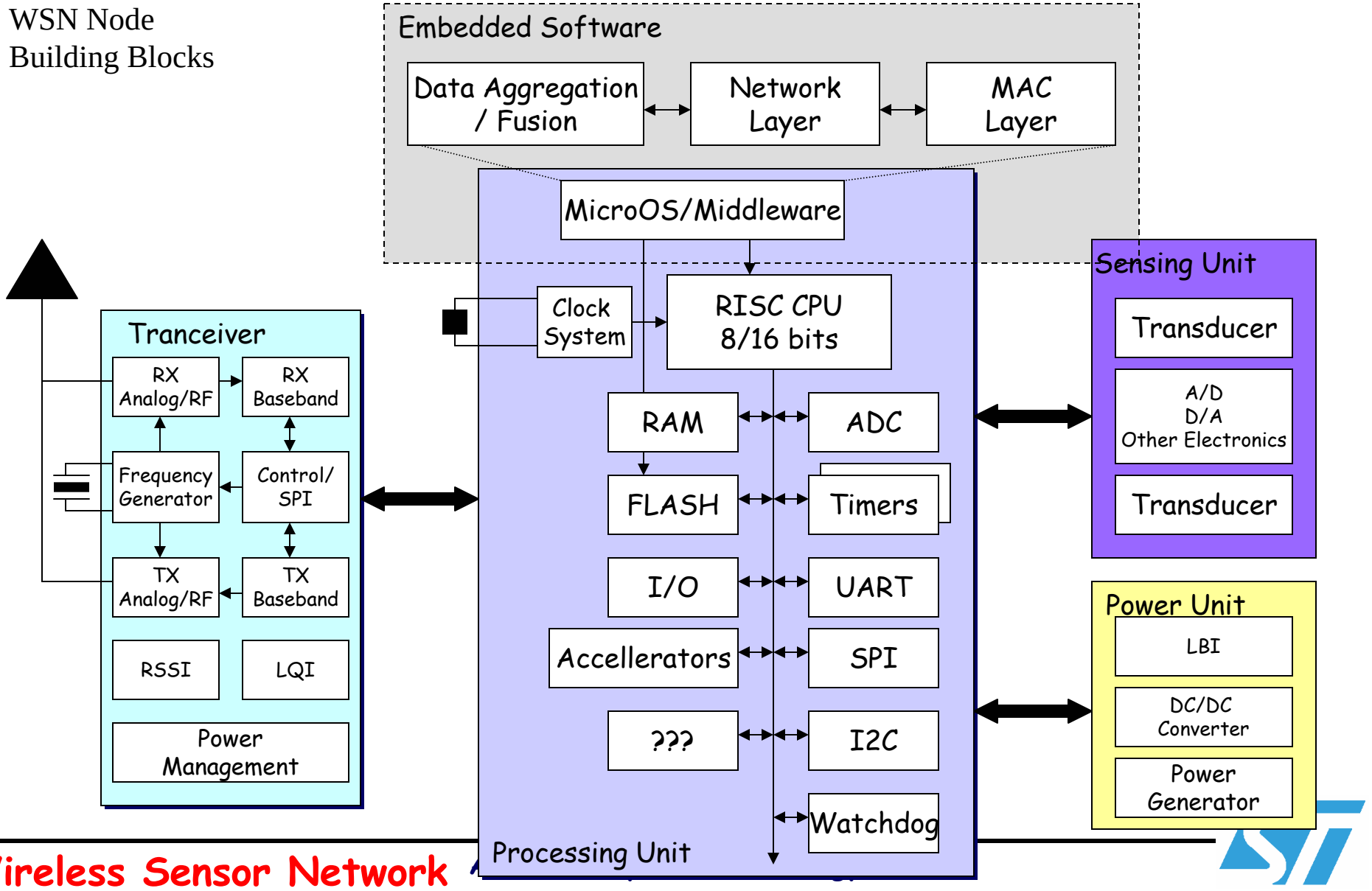
… talkative …



Wireless Sensor

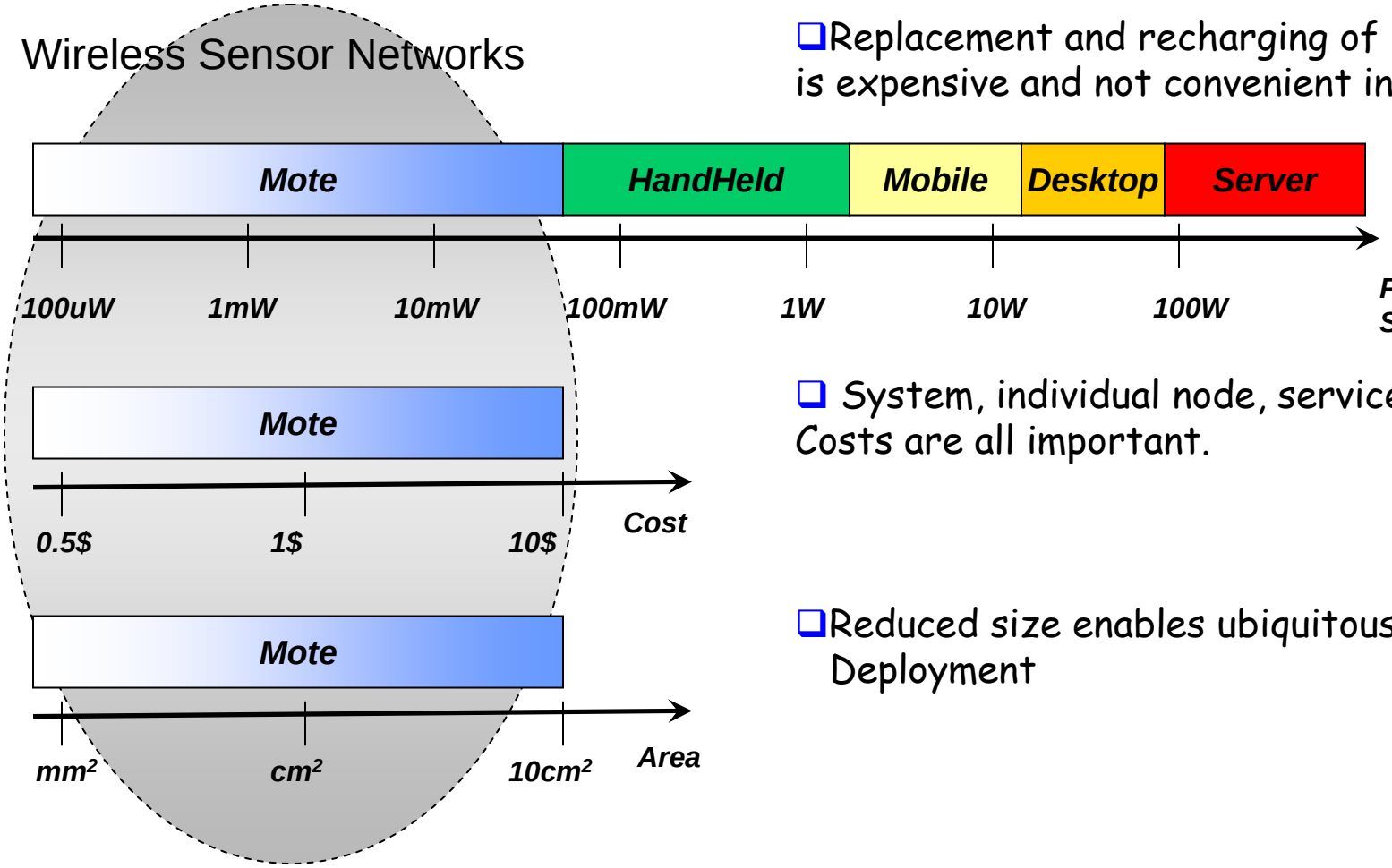
… smart!

WSN Node
Building Blocks



Wireless Sensor Network

WSN mote design constraints: Power, Cost, Size



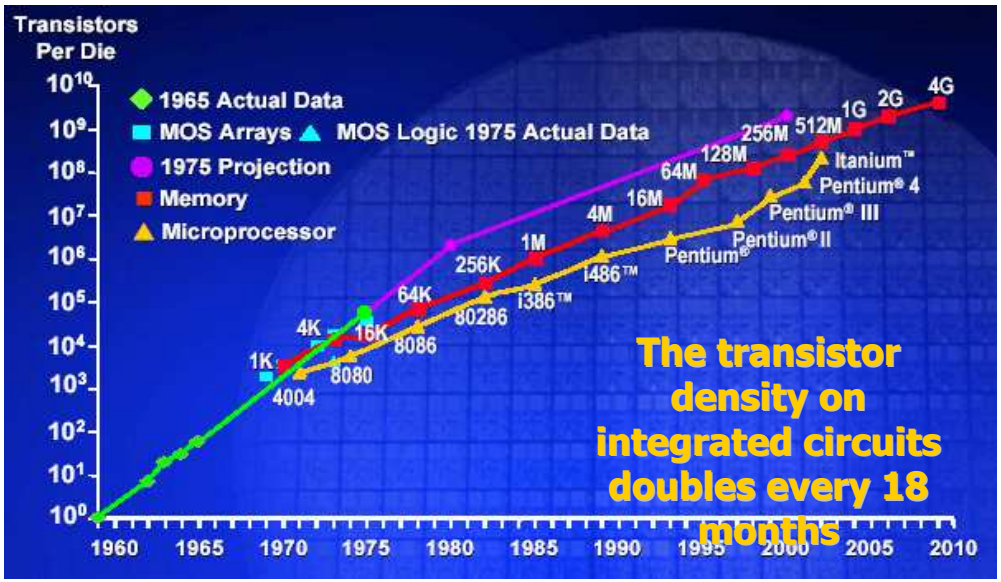
- Replacement and recharging of batteries is expensive and not convenient in many scenarios

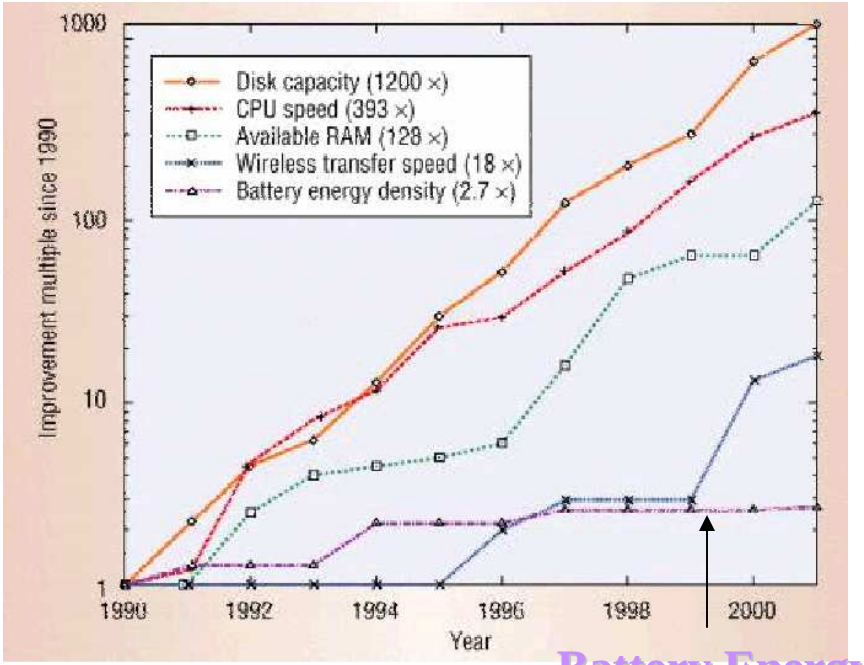
- System, individual node, service, battery Costs are all important.

- Reduced size enables ubiquitous Deployment

Disappearing Electronics

Moore's Law





Battery Energy density too LOW!

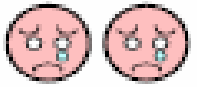
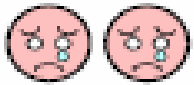
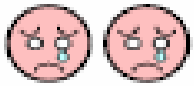
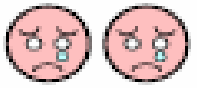
Low Power and Energy Aware Design is a Key Constraint

Technology Domain
- ✓Batteries
- ✓Energy Scavenging
- ✓Packaging
- ✓.....

Hardware Domain
- ✓Ultra-low power processors with low standby power
- ✓Ultra-low power radios
- ✓Power Management
- ✓.....

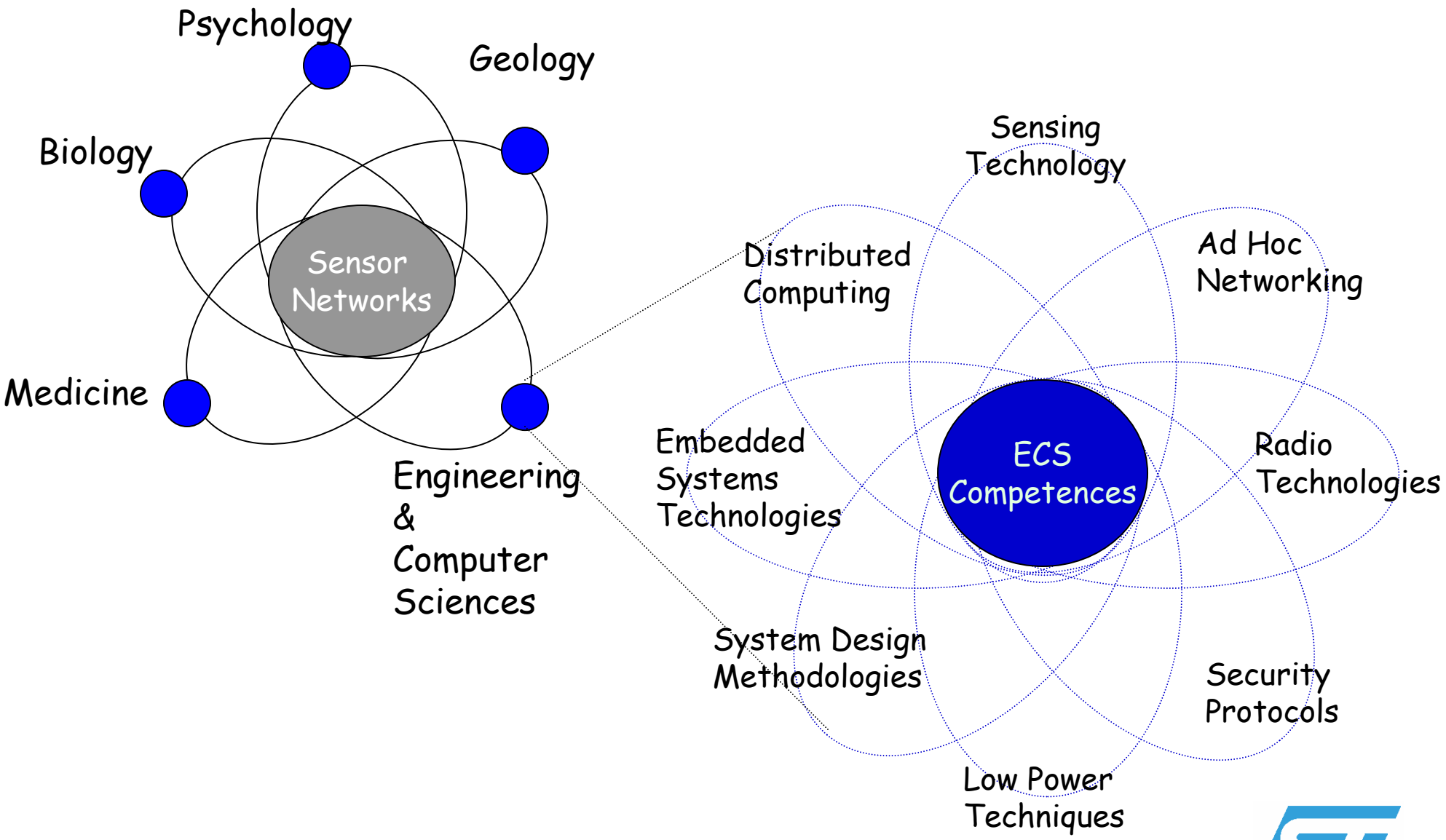
System Domain
- ✓Protocols that minimize the Radio duty cycle
- ✓Energy Aware Algorithms
- ✓System synchronization
- ✓Multihopping
- ✓....

Wired Vs. Wireless

Cablato		Wireless
	costo	
	compattezza	 batterie
	determinismo	
	mobilità	
 cavi	manutenzione	 batterie
 Internet?	sicurezza (security)	
	sicurezza (safety)	 EMI

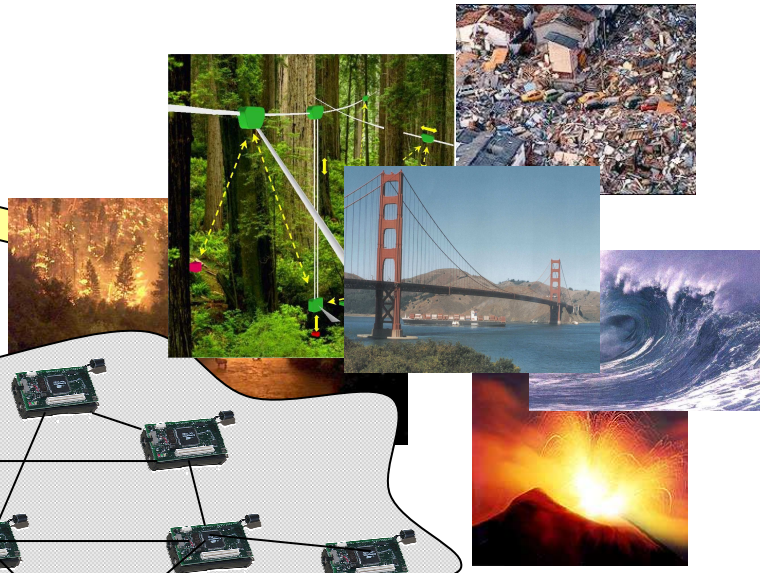
Il costo sarà la chiave di volta se si riesce a risolvere il problema della security

A Problem of Interdisciplinarity

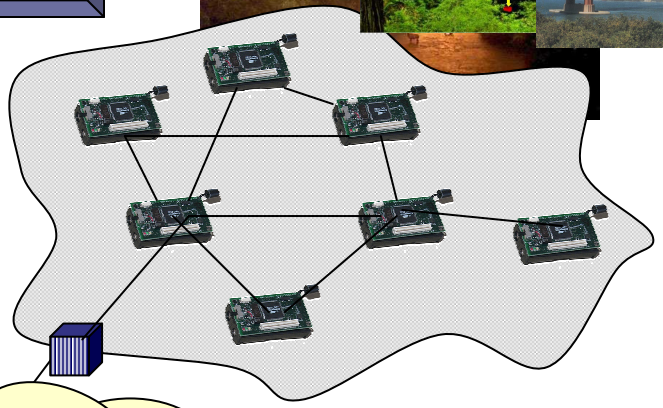


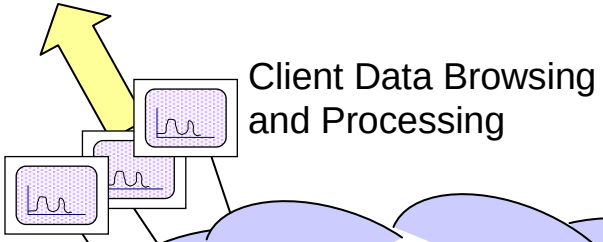
A Problem of Internetworking

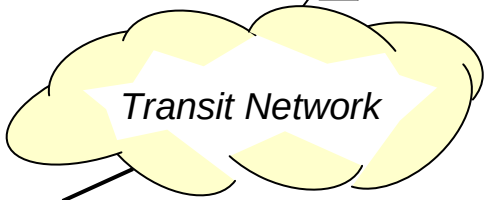
Sensor Networks expand our ability to access data from the physical world

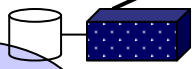


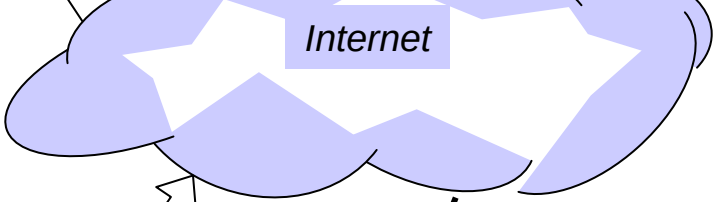
Internet allows us faster easier access to data and information from the digital domain



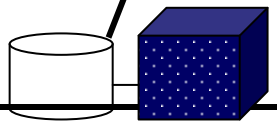








Integration of Sensor and Internet Networks drives the Vision of Ambient Intelligence And Pervasive Computing



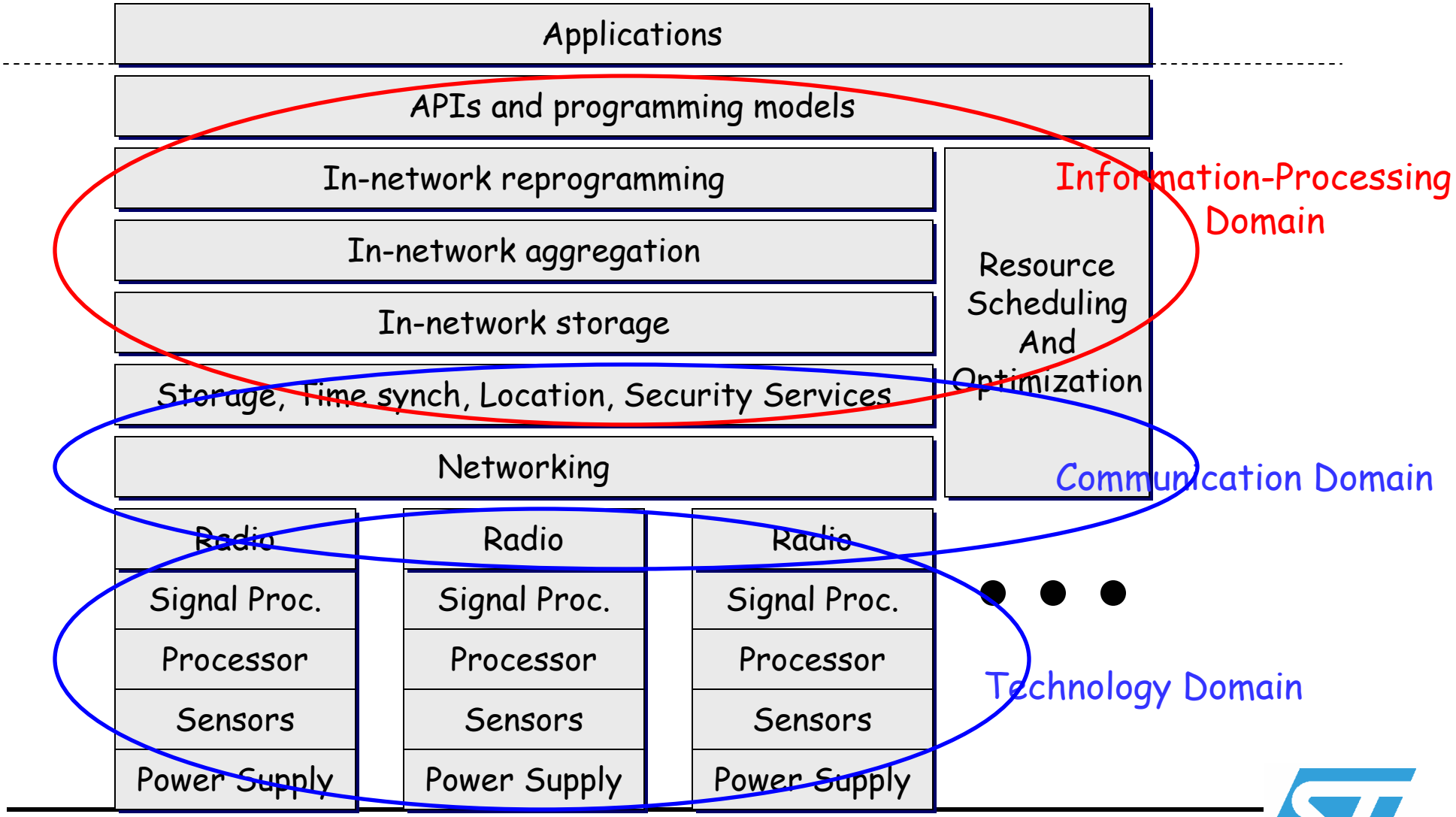
A Problem of Distributed Computing

- Heterogeneity
  - Heterogeneity applies to Protocols, Hardware, Operating Systems, programming languages, implementation by different developers
  - Middleware Layer and Platform Virtualization
- Openness
  - It's a characteristic that determines whether the system can be extended and re-implemented in various ways
  - High level interfaces must be standardized or at least published
- Security
  - Confidentiality, integrity, denial of services, security of mobile code
- Scalability
  - A system is defined scalable if it will remain effective when there is a significant increase in the number of resources and the number of users
- Failure Handling
  - In WSN redundancy is possible and mandatory
- Concurrency
  - Several application client could attempt to access a WSN node at the same time
- Transparency
  - The system must be perceived as a whole rather than as a collection of independent components

WSN Nodes classification

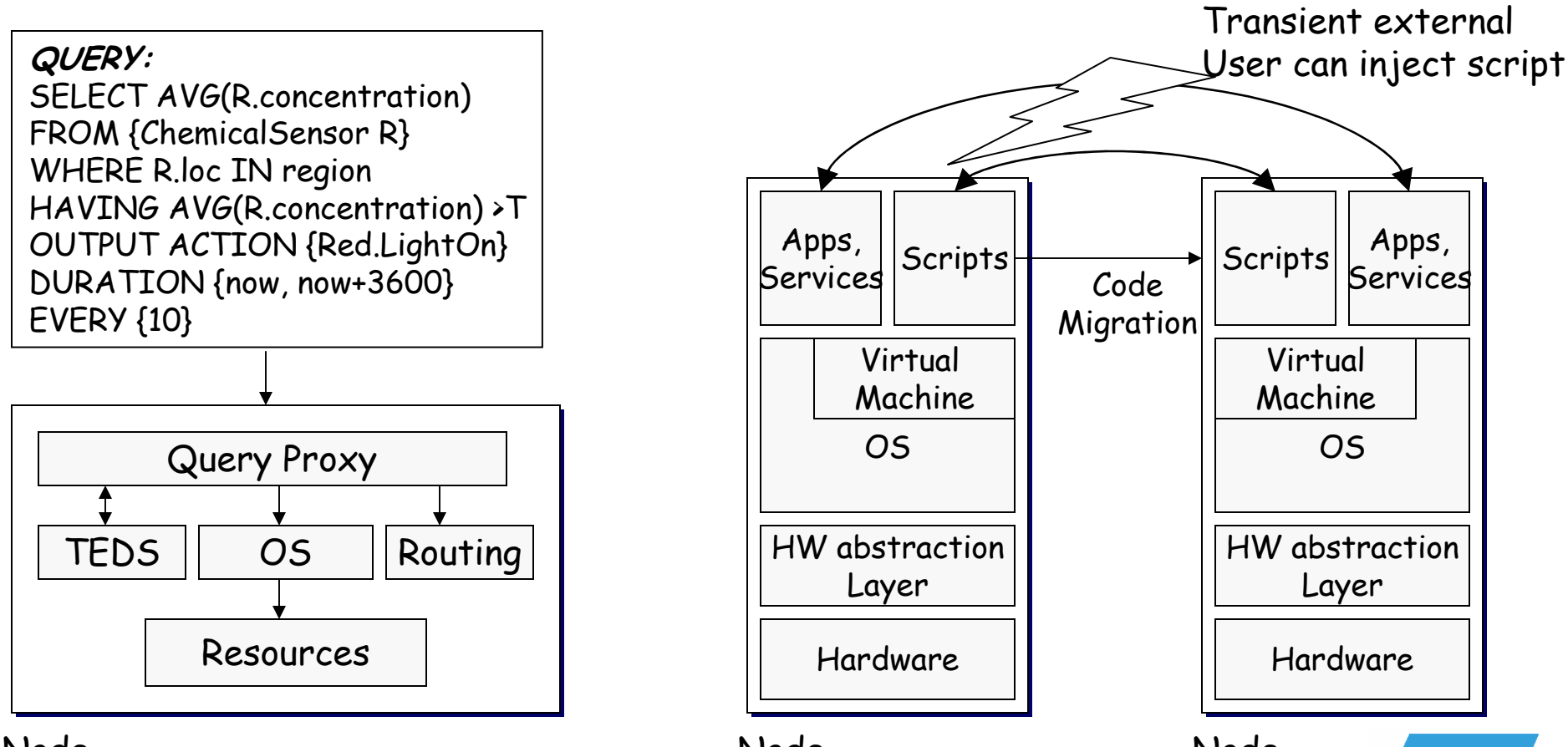
Node Type (Sample Name)	Size	Application Sensors	Radio Bandwidth	MIPS	FLASH	RAM	Typ. Active Energy (mW)	Typ. Sleep Energy (uW)	Typ. Duty Cycle (%)
Specialized sensing Platforms (Spec)	mm^3	Specialized low-bandwidth sensors or advanced RF tag	<50Kbps	<5	<0.1 Mb	<4kb	1.8V 10-15 mA	1.8V 1 uA	0.1 – 0.5
Generic Sensing Platform (Mote)	1-10 cm^3	General-purpose sensing and communications relay	~100 Kbps	<10	<0.5 Mb	10 Kb	3.0V 10-15 mA	3.0V – 10 uA	1-2
High Bandwidth Sensing (Imote)	1-10 cm^3	High-bandwidth sensing (video, acoustic)	~500 kbps	<50	<10 Mb	<128 Kb	3.0V 60 mA	3.0V – 100 uA	5 - 10
Gateway (Stargate)	>10 cm^3	High-bandwidth sensing (Gateway node)	>500kbps – 10Mbps				3.0V 200 mA	3.0V – 10 mA	> 50

An overall view of the Stack

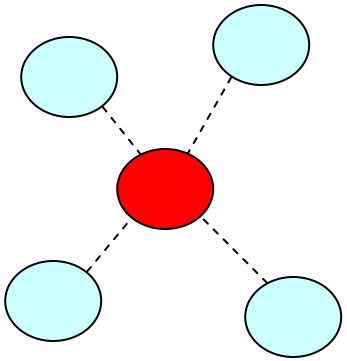


Queries vs Mobile Code

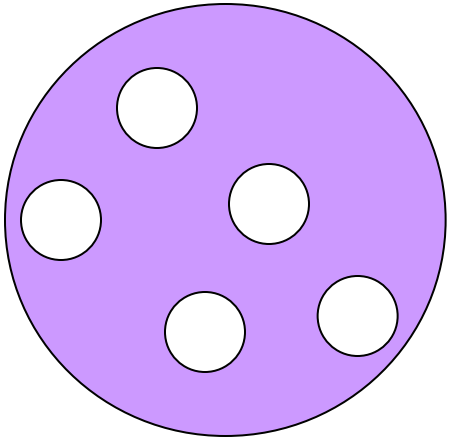
- Declarative Long-Running Periodic and event-oriented Queries [Cougar, TinyDB, SCADDS] vs Mobile Code [SensorWare, Mate]



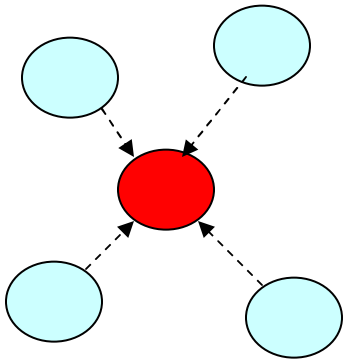
Collaborative Groups



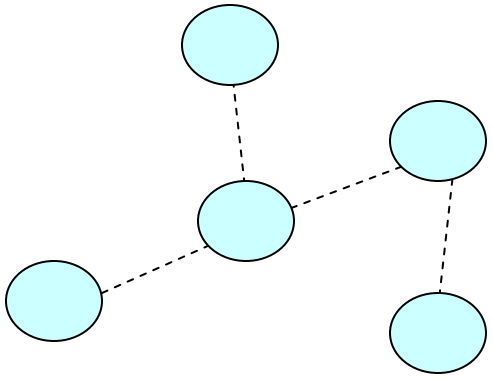
N-hop neighbor groups



Geographically Constrained Group
Defined by geographic extent



Publish-Subscribe Groups
Defined by Producers and Consumers of shared interests



Acquaintance Group
Roaming Members keep Persistent Connectivity

- Raise the level of abstractions to enable programming over collectives
- Allow in-network processing in order to reduce the data communication over the network
- Allow an efficient network resources management at the protocol (Routing-MAC) level in absence of infrastructure

Home Automation
- HVAC, Lighting
- Remote door openers
- Security and Smoke Detectors
- Smart Appliances

Automotive
- Tire Pressure monitoring
- Remote Keyless Entry
- Hands-free command units
- Engine Control
- Traffic Management

People Tracking/Monitoring
- Patients in Hospitals (possibly with sensing capabilities)
- Children in schools and public areas
- Soldiers, Firefighters emergency Rescuers
- Animals

A Whole New World of Applications

Health Monitoring
- Home Automation and Networking
- Wearable Sensors

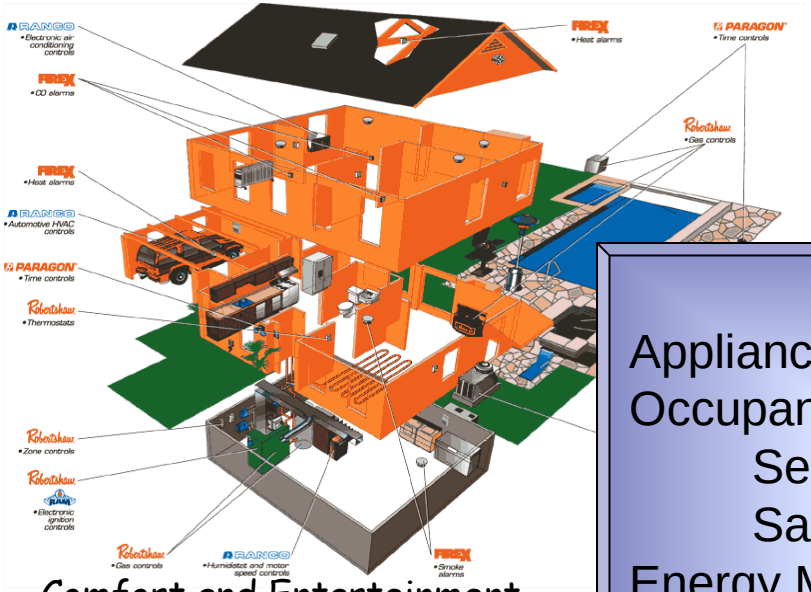
Consumer Electronics
- Universal Remote Control
- Cable Replacement
- Toys
- Tourism and Shopping

Environment Sensing
- Precision Agriculture
- Habitat Monitoring
- Monitoring for Environment Risk Management and Security

Asset Tracking and Supply Chain Management
- Hospital Equipment
- Containers
- Vehicles in factory yards
- Warehousing, Department Stores stock Management

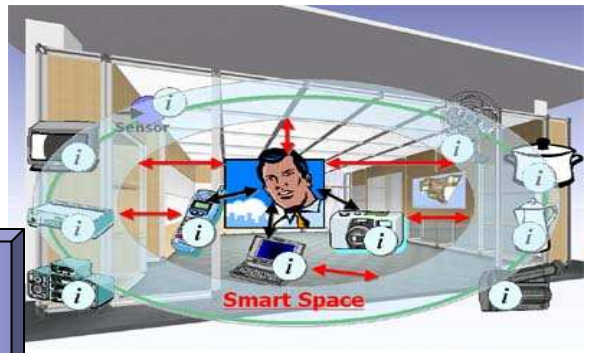
Industrial and Commercial Building Monitoring
- Security and Surveillance
- Smart Energy
- Process Control
- Structural Health Monitoring

The “Smart Home”



Comfort and Entarteinment

Appliances Control (Domotic)
Occupancy Detection
Security
Safety
Energy Management and Saving
Elderly Assistance
……



Communication

Energy Management

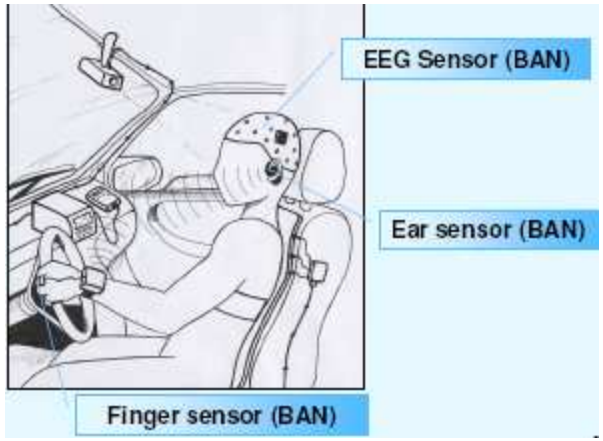
Security

The “Super Car”

Telematic

Wireless Car

Smart Roads



Driver Monitoring

Source: CRF

The “Secure Environment”

Ecosystem and Biocomplexity

Embedded Sensor Networks
Will reveal previously
Unobservable phenomena

Microsensors, on board
Processing wireless interfaces
Feaseable at very small size
Can monitor phenomena “up close”

Disaster Prevention

Infrastructure Health Monitoring

Enables spatially and temporally
Dense environmental
monitoring

Agriculture

WSN Driver Motivations

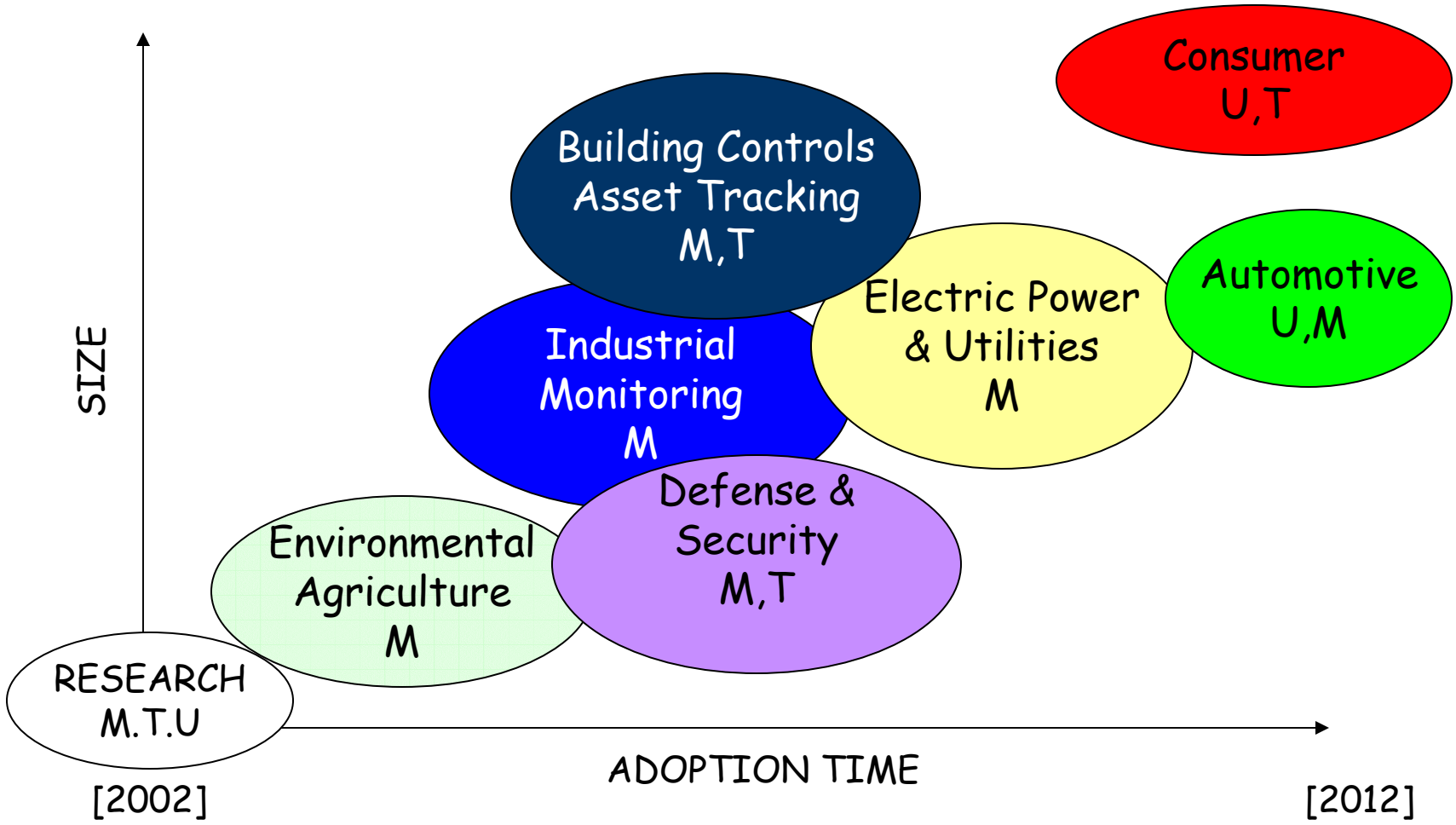
- No or little IT infrastructure
- Cabling Cost and Time
- No or little real-time data on assets, environment, or activity
- Mobility control is required or advantageous
- Productivity can be increased
- Data driven, remote feedback control
- Government priorities or industry mandates
- Personal Computing Themes

Application Categories

- Monitoring Things & Spaces (M)
  - Precision Agriculture, habitat studies, HVAC, structural response, security, safety, …
  - Periodic transmission of data measures, Aggregate data, Fixed and regular Topology, Long-term operation, energy scavenging,…
- Tagging and Tracking (T)
  - Asset Tracking, Smart Tags, Supply chain Monitoring, Food Chain, Indoor Location Services,…
  - High Mobility, Data provided upon Request, Accuracy, Locationing, RFID exploitation, …
- Ubiquitous Computing (U)
  - Context aware computing, non-verbal computing. Assisted living facilities, Smart furniture
  - Advanced HMI, Deep Embedded Computing, Activity Inferencing, Ambient Displays, Integration with Personal Mobile Terminals, vital signs sensors, imaging,…

SN Highlights: Market Forecast

M = Monitoring
T = Tagging,Tracking
U= Ubiquitous



[Source: Crossbow]

WSN Highlights: market penetration

Stage 1 …… 2003

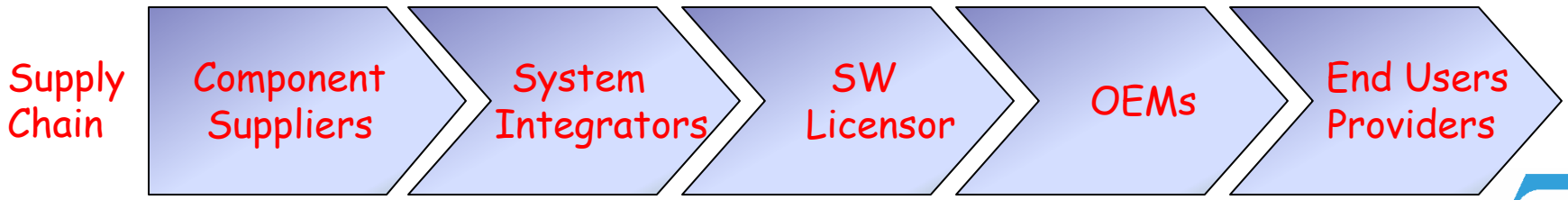
- Proprietary radios
- 802.15.4 emerges
- Market Fragmentation
- Focused on systems integrators & a few leading edge OEMs
- Unit costs: $100 – 1000
- Pilots:
  - Bldg Automation
  - Equipment Monitoring
  - Wireless AMR/LM
  - Home Automation

Stage 2 2004 2005 2006

- Market traction
- Zigbee emerges
- Semiconductor Focus
- Early adopter OEMs
- Unit costs: $10 - 100
- Ramp up:
  - Defense
  - Bldg Automation
  - Equipment monitoring
  - Wireless AMR/LM
  - Home automation

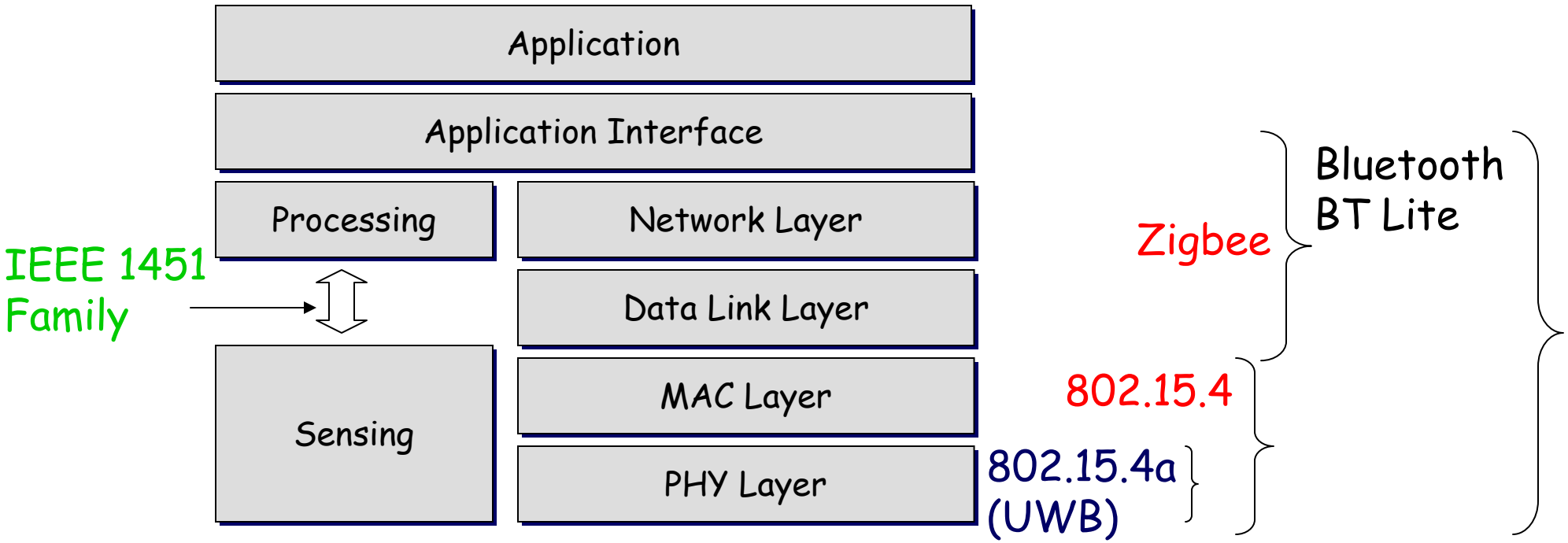
Stage 3 2007 2008 2009+

- Wireless Ubiquity
- Standards dominate
- IEEE 1451.5 emerges
- OEM Focus
- Unit costs: $1 – 10
- New apps emerge:
  - Medical/health
  - Personal Convenience
  - Automotive
  - Transportation
  - Asset tracking, etc.

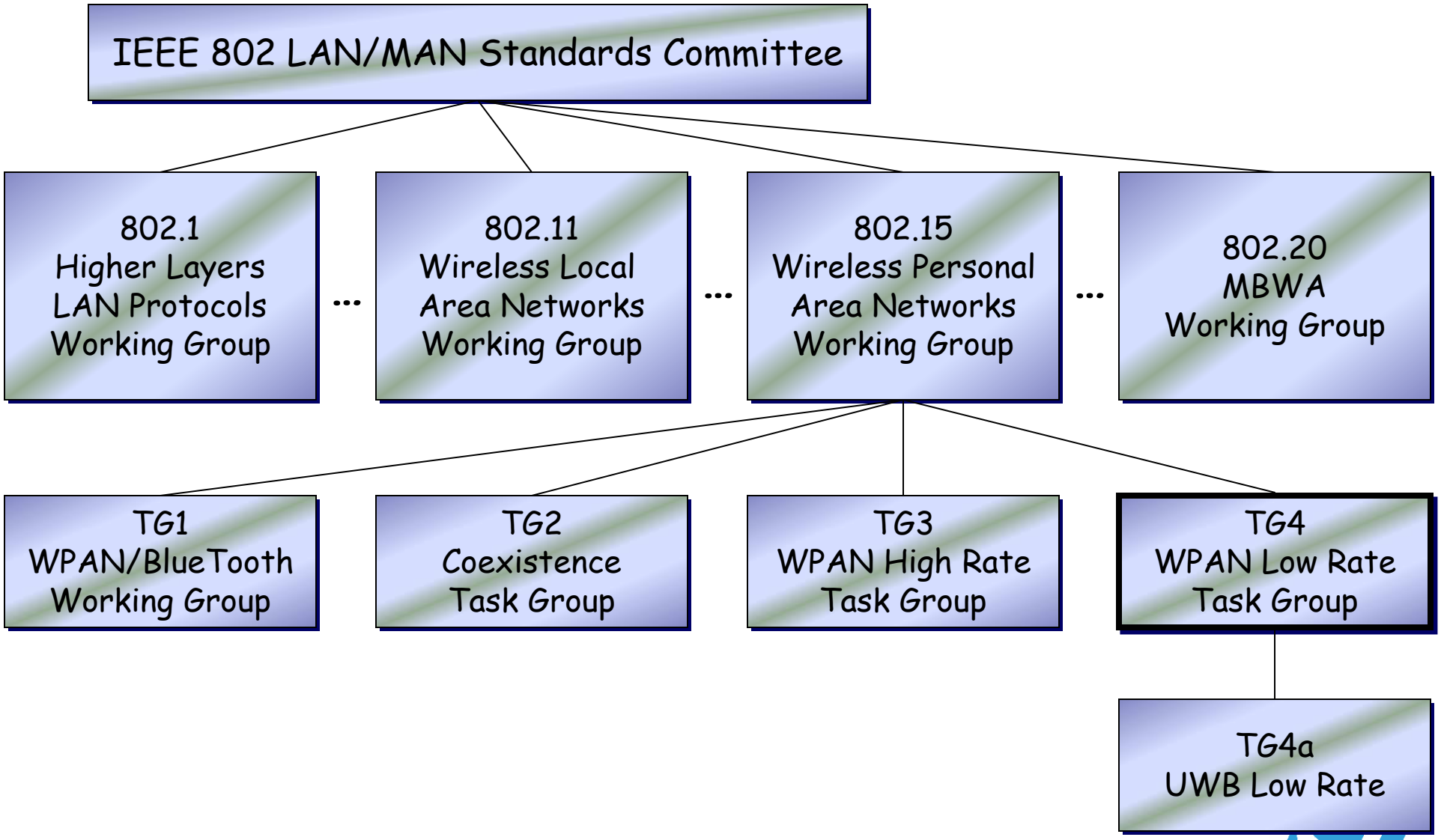


[Source: OnWorld]

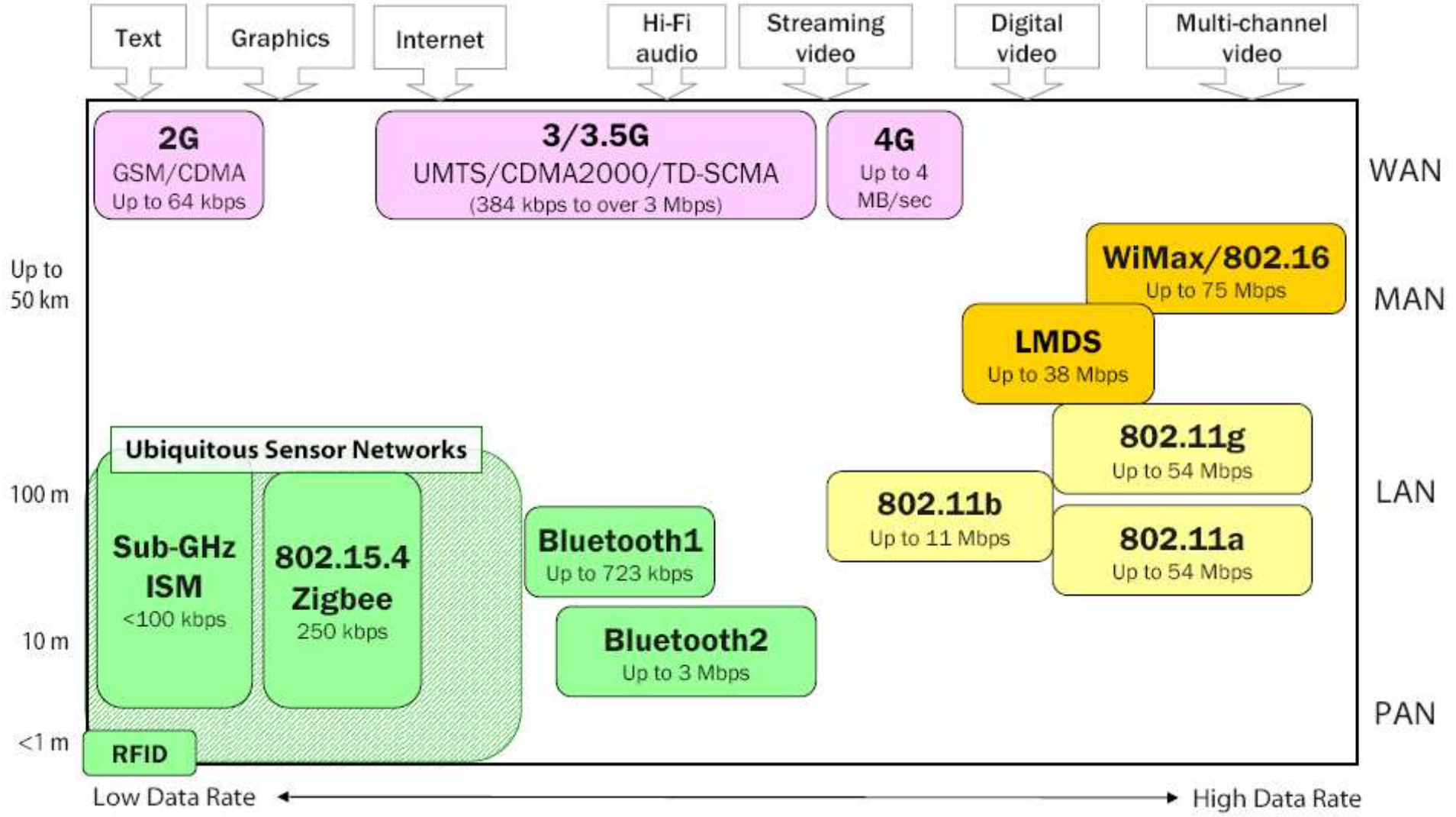
How Getting Device Interoperability: Standards



IEEE ….what?


IEEE 802 LAN/MAN Standards Committee
802.1
Higher Layers
LAN Protocols
Working Group
802.11
Wireless Local
Area Networks
Working Group
802.15
Wireless Personal
Area Networks
Working Group
802.20
MBWA
Working Group
TG1
WPAN/BlueTooth
Working Group
TG2
Coexistence
Task Group
TG3
WPAN High Rate
Task Group
TG4
WPAN Low Rate
Task Group
TG4a
UWB Low Rate

Wireless Technologies



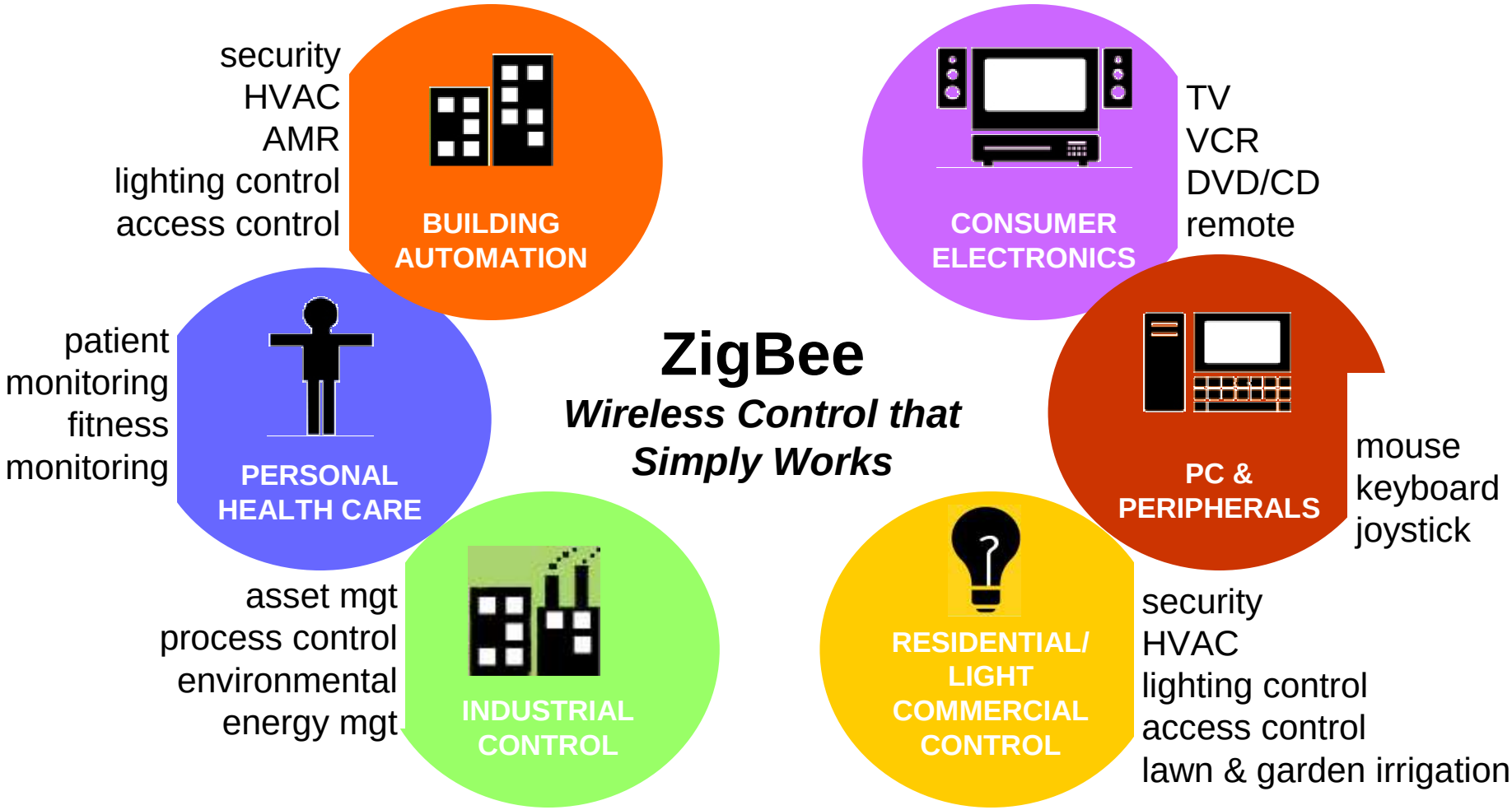
From *Wireless Sensor Networks* by Feng Zhao and Leo Gubias, 2004.

Wireless Standard Comparisons

	802.15.4	Bluetooth 802.15.1	Wi-Fi 802.11b	GPRS/GSM 1XRTT/CDMA
Application Focus	Monitoring & Control	Cable Replacement	Web, Video, Email	WAN, Voice/Data
System Resource (Protocol Stack Size)	4KB – 32KB	250KB+	1MB+	16MB+
Battery Life (days)	100-1000+	1-7	1-5	1-7
Nodes per Networks	255-65K+	7	30	1
Bandwidth(kbps)	20-250	720	11,000+	64-128+
Range (meters)	1-75+	1-10+	1-100	1,000+
Key Market Attributes	Low Data rate Low Power, Low Cost,	Cost, Convenience	Speed, Flexibility	Reach, Quality

[Source: Zigbee Alliance]

Zigbee Applications

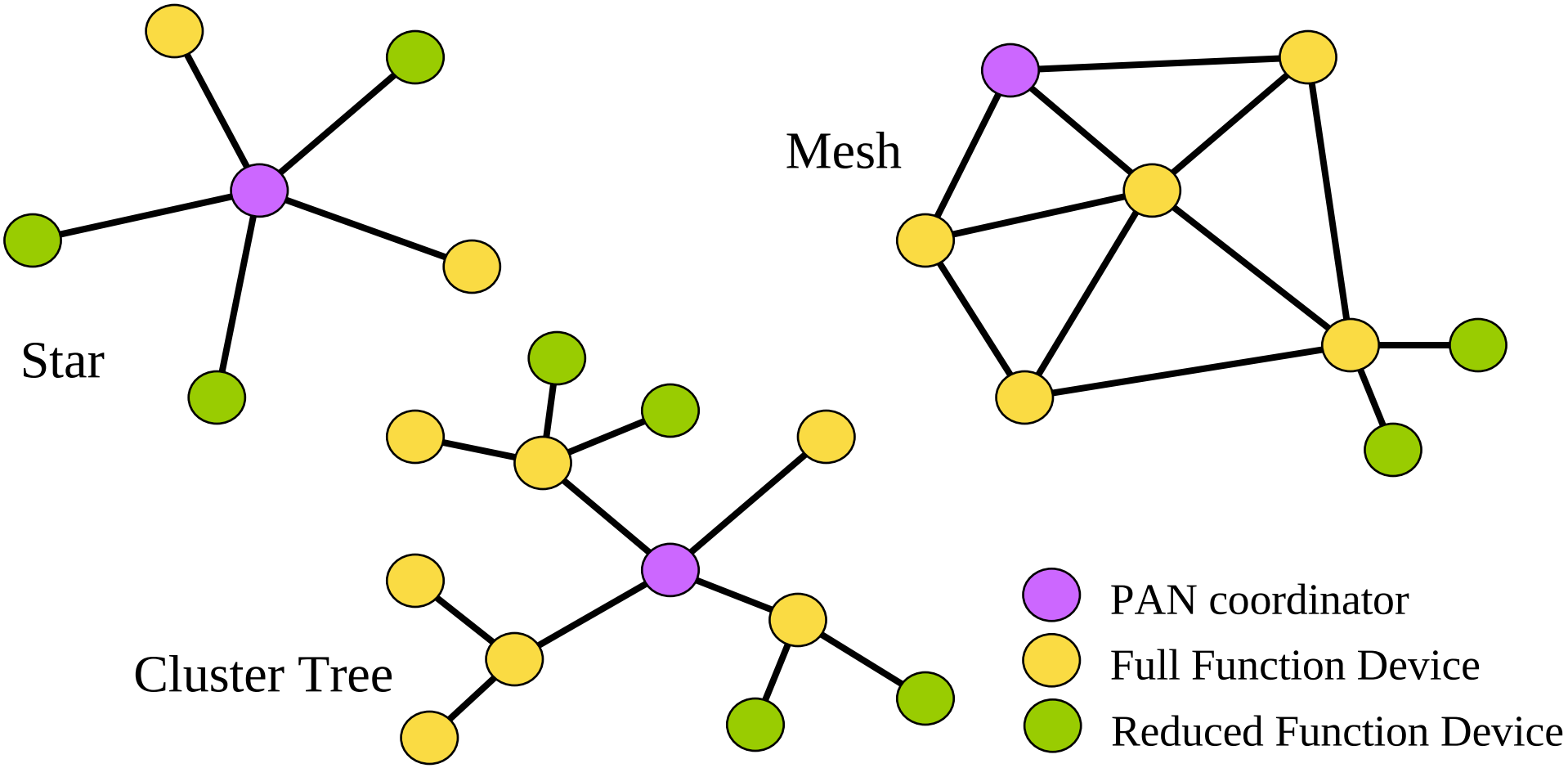


Source: Zigbee

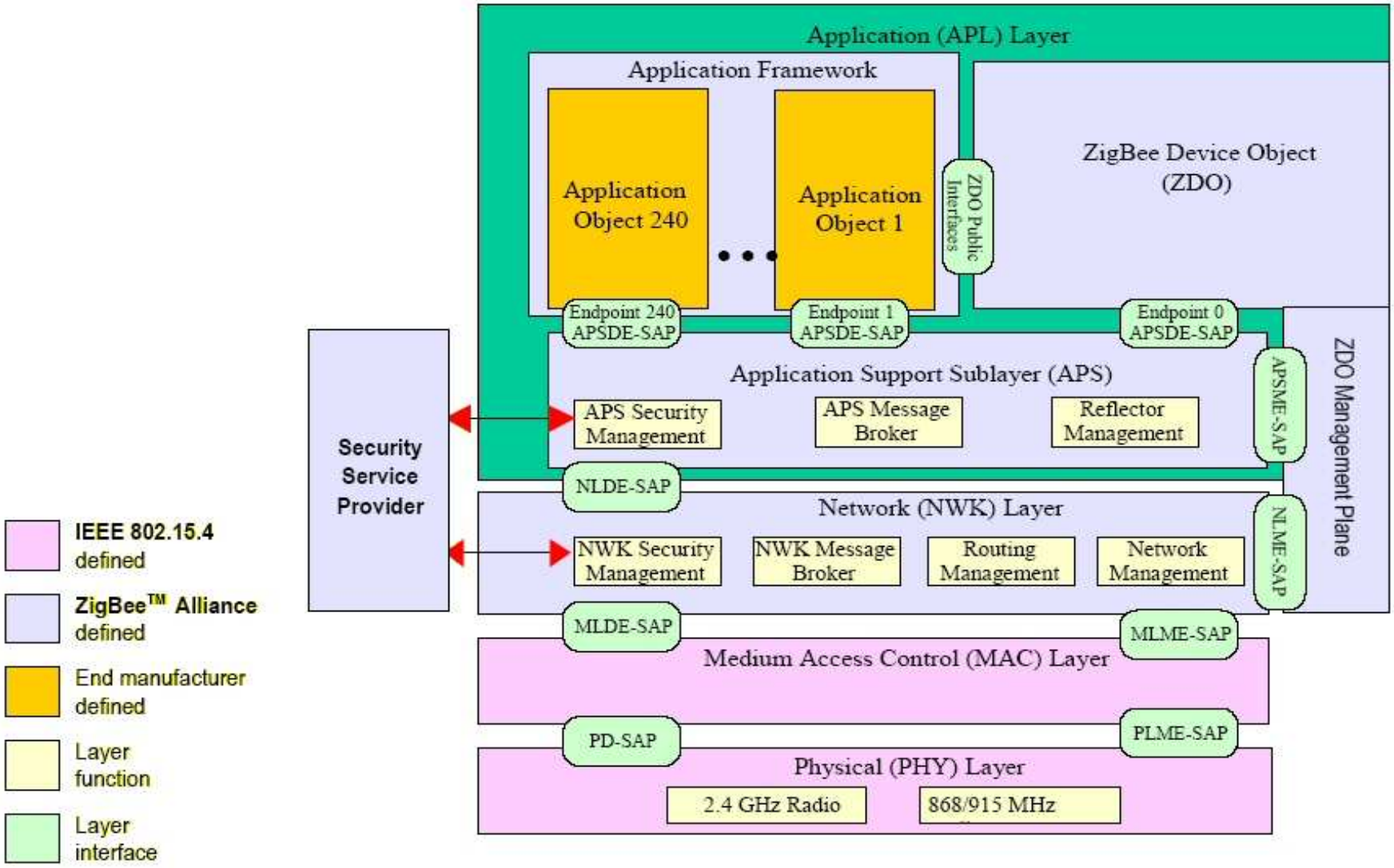
Zigbee Highlights

- It's NOT a IEEE standard but a consortium of industries promoting low data rate communication markets
- 8 promoter companies (Philips, Ember, Freescale, Honeywell, Invensys, Mitsubishi, Motorola, Samsung)
- Long list of participants (today > 120)
  - Industry leader worldwide committed to provide Zigbee compliant products and solutions
  - Include semiconductor manufacturers (STM too), SW licensor, wireless providers, system integrators and end users
- Version 1.0 of the specification has been delivered in december 2004

Supported Topologies in Zigbee



The ZigBee Stack Architecture



Source: Zigbee

802.15.4 Highlights

- Data Rates of 250 kb/sec (2.4 GHz) and 20-40 kb/sec (868/915 MHz)
- 16 channels in the 2.4 GHz ISM Band, 10 channels in the 915 MHz ISM band and one channel in the European 868 MHz band
- CSMA-CA channel access slotted and unslotted
- Full handshaked protocol for transfer reliability
- Extremely low duty cycle capability
- Designed for controllers, sensors, remote monitoring and portable electronics with selectable latency
- Support for low latency devices (Guaranteed Time Slots in Star Networks)
- Multi-level security

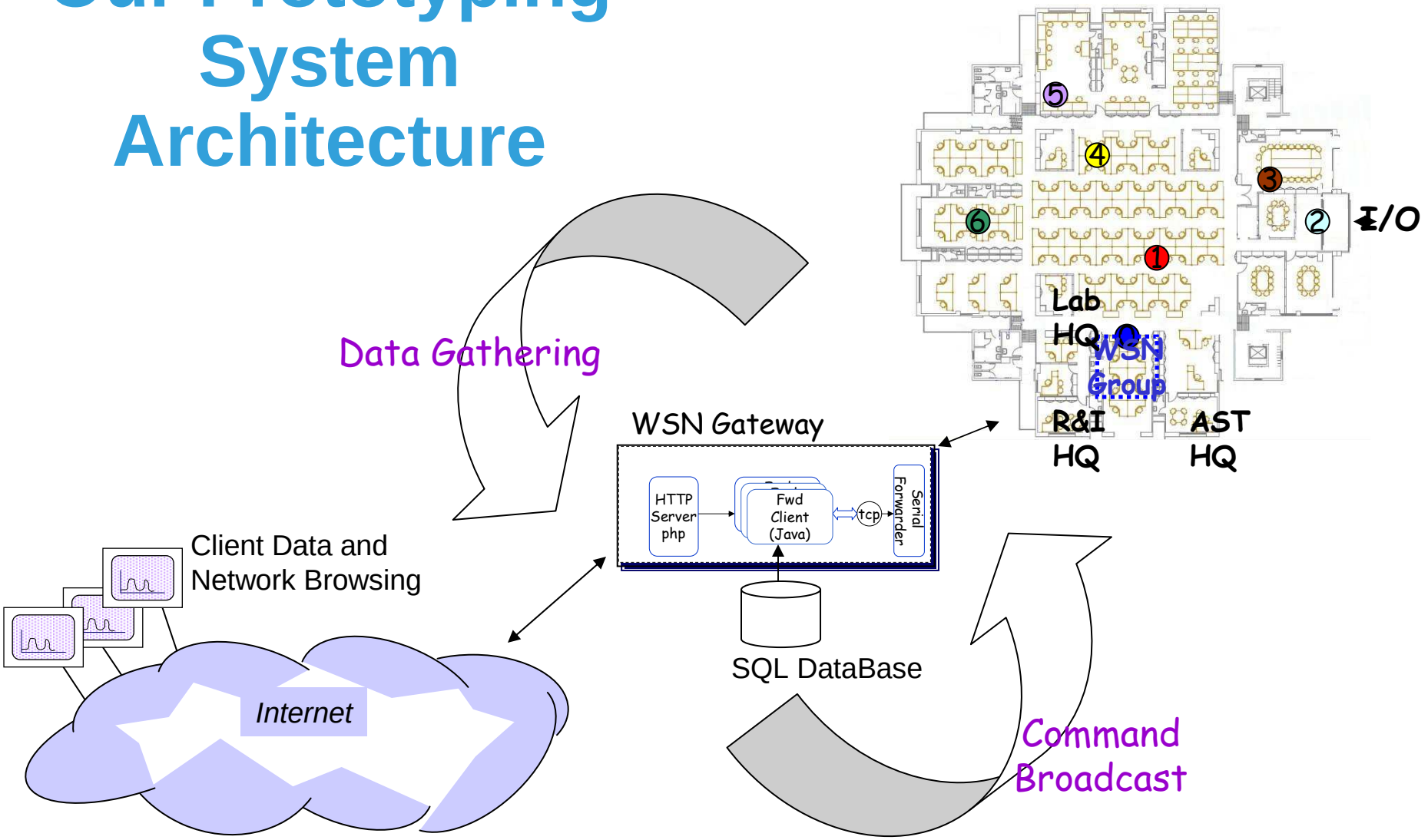
Network Layer Fundamentals

- Contains functionalities for
  - Starting a network
  - Joining or leaving a network
  - Addressing
    - Ability of the Zigbee coordinator to assign short (16 bit) address to nodes
  - Data Routing to destination
    - Cluster tree routing
    - After route discovery and maintenance (cost metric based on link quality and hop counts)
  - Security

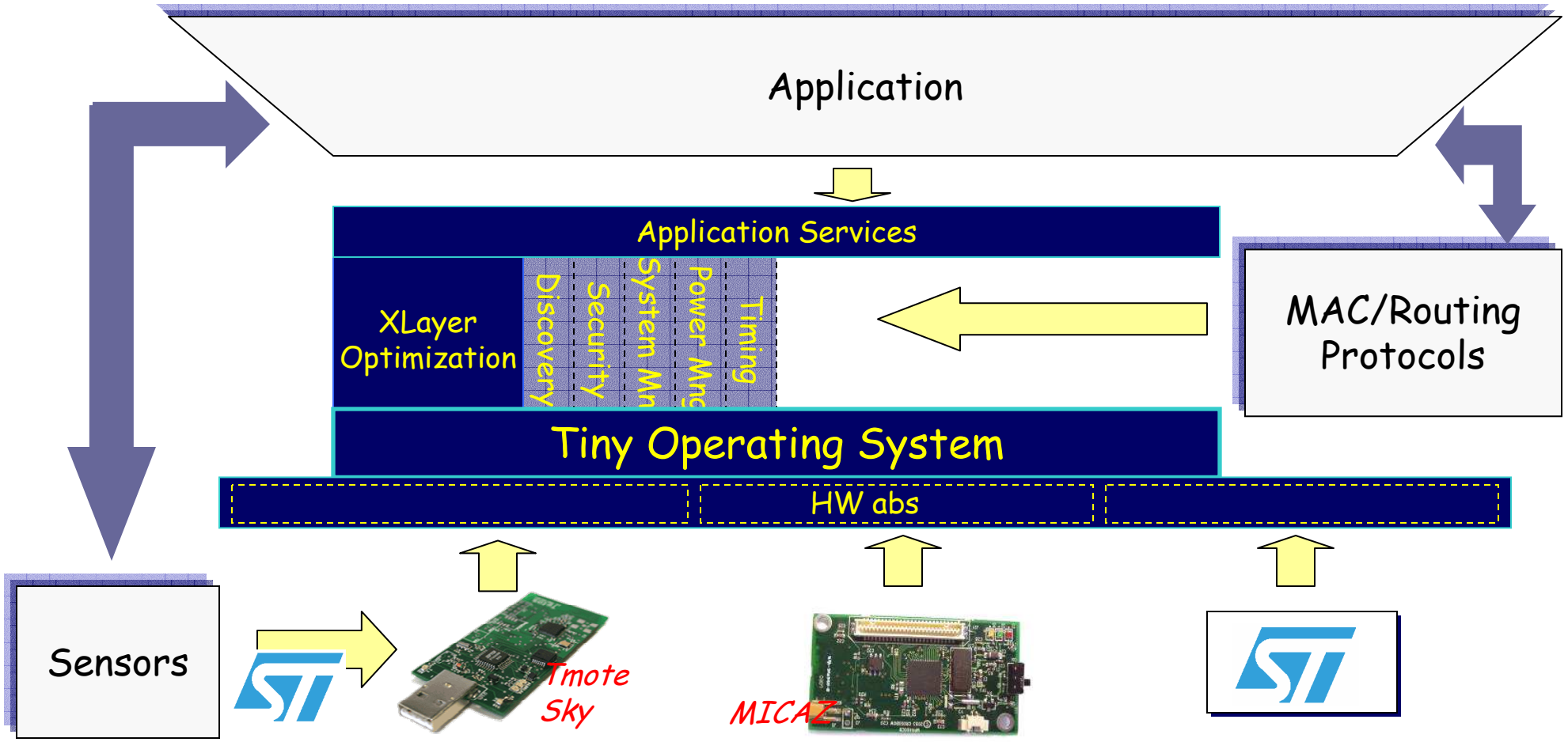
Application Layer Fundamentals

- Consists of
  - Application Framework (AF)
    - Hosting the manufacturer-defined application objects
    - Providing two data services (Key Value Pair or Messages)
  - Application Support Sub-layer (APS)
    - Maintaining table for binding (the ability to match two devices together based on their services and their needs)
    - Forwarding messages between endpoints of bound devices (remote for coordinator)
    - Its services are used by the ZDO and by the application framework objects
  - Zigbee Device Object (ZDO)
    - Defining the role of the devices (coordinator, router, end devices)
    - Initiating and or responding to binding requests
    - Establishing a secure relationship between devices
    - Discovering devices and determining which application services they provide
    - Its services are used by the application objects

Our Prototyping System Architecture



Our Mote Platform



State-of-the-art platforms for WSN prototyping (ca. 90$ each)

- **Mica2 (AVR)**
  - 0.2 ms wakeup
  - 30 µW sleep
  - 33 mW active
  - 21 mW radio
  - 19 kbps
  - 2.5V min
- **MicaZ (AVR)**
  - 0.2 ms wakeup
  - 30 µW sleep
  - 33 mW active
  - 45 mW radio
  - 250 kbps
  - 2.5V min
- **Telos (TI MSP)**
  - 0.006 ms wakeup
  - 2 µW sleep
  - 3 mW active
  - 45 mW radio
  - 250 kbps
  - 1.8V min

Supporting mesh networking with a pair of AA batteries reporting data once every 3 minutes using synchronization (<1% duty cycle)

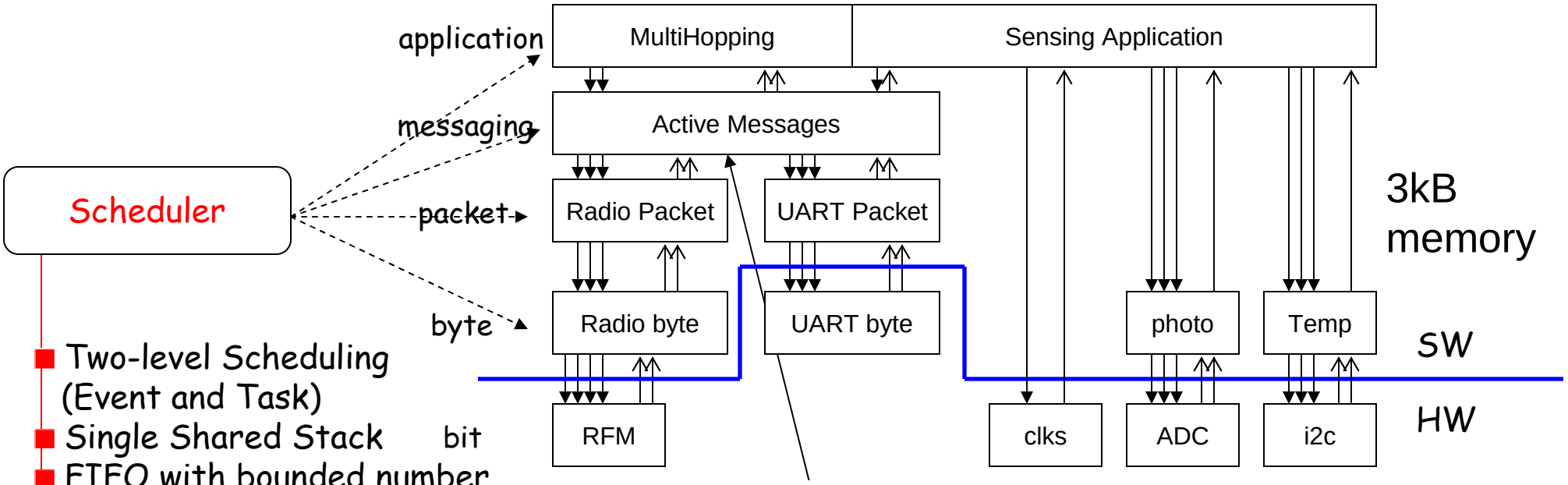
453 days 328 days 945 days

TinyOS Highlights

- Originally developed at UC Berkeley (David Culler, Kris Pister)
- Explicitely designed for wireless sensor networks
- > 500 Groups Actively Use TinyOS in both academies and industries
- Open source tools and libraries
- User group for support on the web
- It has been ported on many HW platforms (MICA, Eyes, Telos, Imote…) and processors (Atmega128, MSP430, Pic, ARM …)

TinyOS Application

The component model allows the definition of an application specific configuration FILE where independent components are "wired" together by means of their interfaces



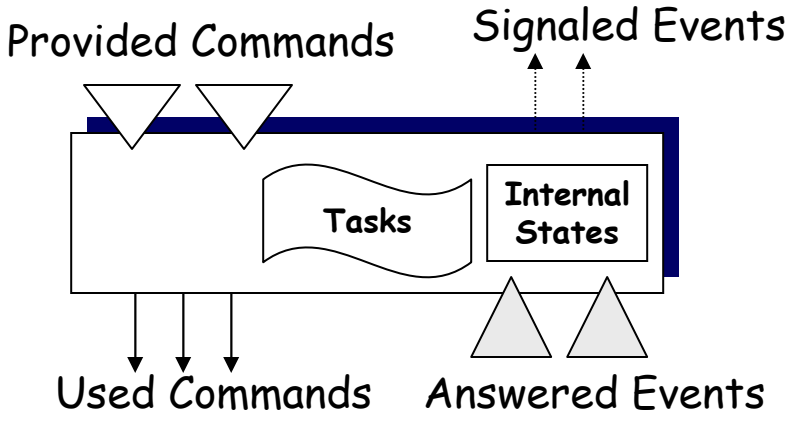
- Two-level Scheduling (Event and Task)
- Single Shared Stack bit
- FIFO with bounded number of pending Task
- Task can NOT preempt each other
- Event has high priority than Task
- Event can preempt task and each other
- When idle, scheduler shut down node except for clock

- The communication model supported by TinyOS uses the Active Message paradigm
  - Each Active Message contains the name of the application-level handler to be invoked on a target node upon arrival and a data payload to pass in as arguments

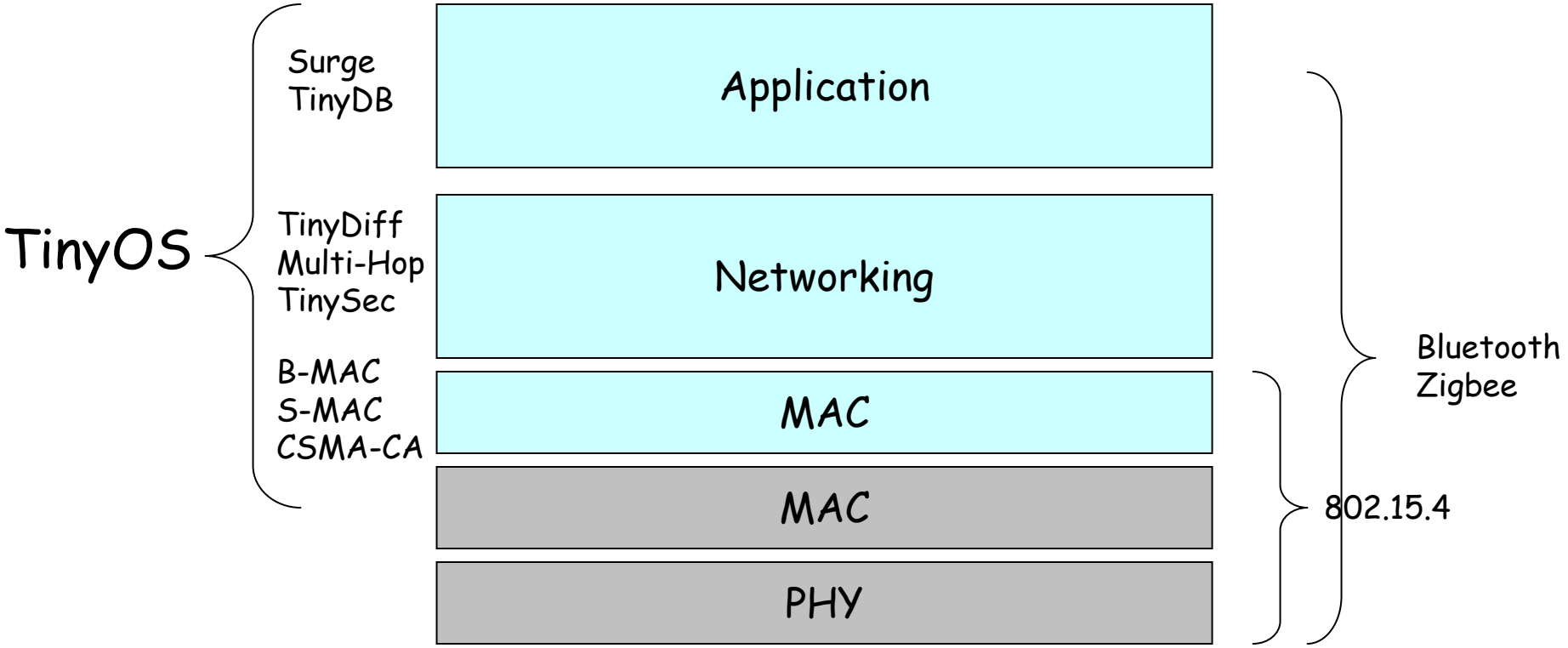
TinyOS Components

- Component is written in NesC
  - A Pre-Processor
    - nesC is a C program file that is compiled and linked using gnu gcc tools
- Component has:
  - Frame: static storage model –compile time memory allocation
  - Tasks: is an execution context that runs-to-completion in the background. All the tasks run on the same stack. They run asynchronously in respect to the event ➔ concurrency model
  - Interface:
    - Command deposit request parameters into its local frame and conditionally post a task for later execution
    - Events correspond to HW interrupts or other kind of priority signals

Typical TinyOS Component



TinyOS is a library and a development environment



Some TinyOS Developments

- TinyDB
  - Implement a query processing system for extracting information from a network of TinyOS sensors
  - Provides simple, SQL-like interface to specify the data you want to extract
- Deluge application to remote reprogramming a mote
- Mat'e implements a Virtual Machine
  - Allows lightweight In-Network re-programming
- TOSSIM Simulator for Network Simulations
  - Same TinyOS components used in real motes

Areas of further investigation