Wireless Sensor Networks: An Overview

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STMicroelectronics

Outline

- Design Perspectives for Pervasive Computing
- WSN Application Areas
- WSN Driver Technologies and Constraints
- WSN Network Design Challenges
- WSN Node Design Challenges

The Pervasive Computing Vision

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it"

Mark Weiser - The Computer for the 21st Century
Scientific American - 1991

"Ambient Intelligence" (The Concept)

Embedded	Many invisible distributed devices throughout the environment
Context Aware	That knows about their situational states (location, environment conditions,....)
Adaptive	That can change in response to you and your environment
Personalized	That can be tailored towards your needs and can recognize you
Anticipatory	That anticipates your desires without conscious mediation


Setting the scene:
What do people really want?
AT HOME:
• Seamlessly connectable applications
– No new wires
• Easy workable operation
– One simple remote control for TV, DVD, lights, phone …
Setting the scene:
What do people really want?
IN THE OFFICE
• Reduce the cost of cabling, and increase flexibility …
laptop users to roam
the building …
Setting the scene:
What do people really want?
IN THE CAR
• Car recognises your phone in your pocket and connects to car …
• Music device that enables you to download tracks at home and bring to the car …
• Road toll and gas pump payment …
• Downloading music and movies at gas stations
Source: Bob Payne, Philips
ie scene:
people really want?
ON THE MOVE
• Wireless headsets
– possibly built into ear-rings, glasses …
• PDA/phone connected to the office on demand …
• Context aware mobile phone which can add 'location' services…
• Long battery life
Source: Bob Payne, Philips

Consider the possibilities – Smart Packaging

Electronic "Bar Code"

Passive RF circuit that talk to the outside world… no need for scanners

Real-time labeling

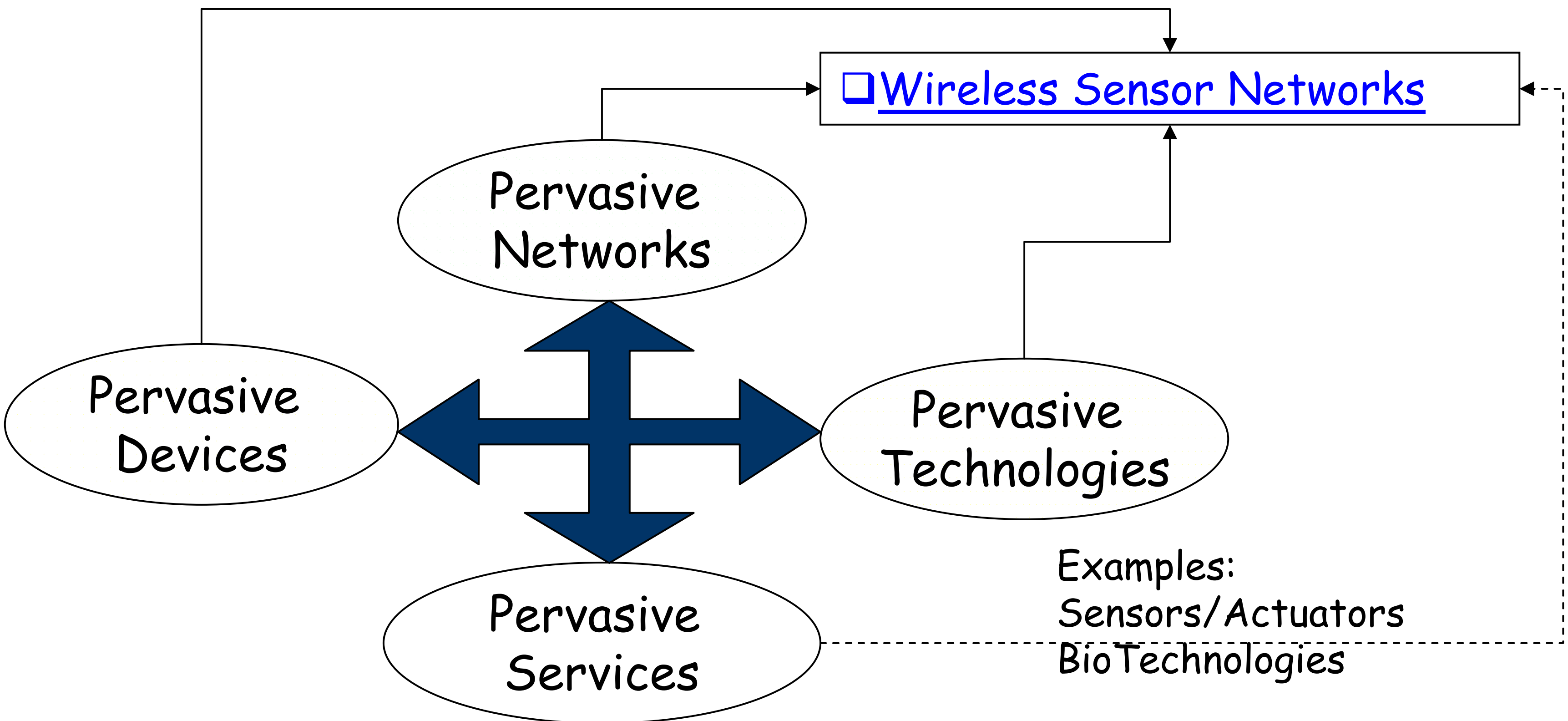
No more incorrect pricing!

Closed Loop Content Monitoring

No more expiration dates… the can knows when it has expired!

Source: V. Subramanian, Berkeley

Pervasive Computing: Perspectives

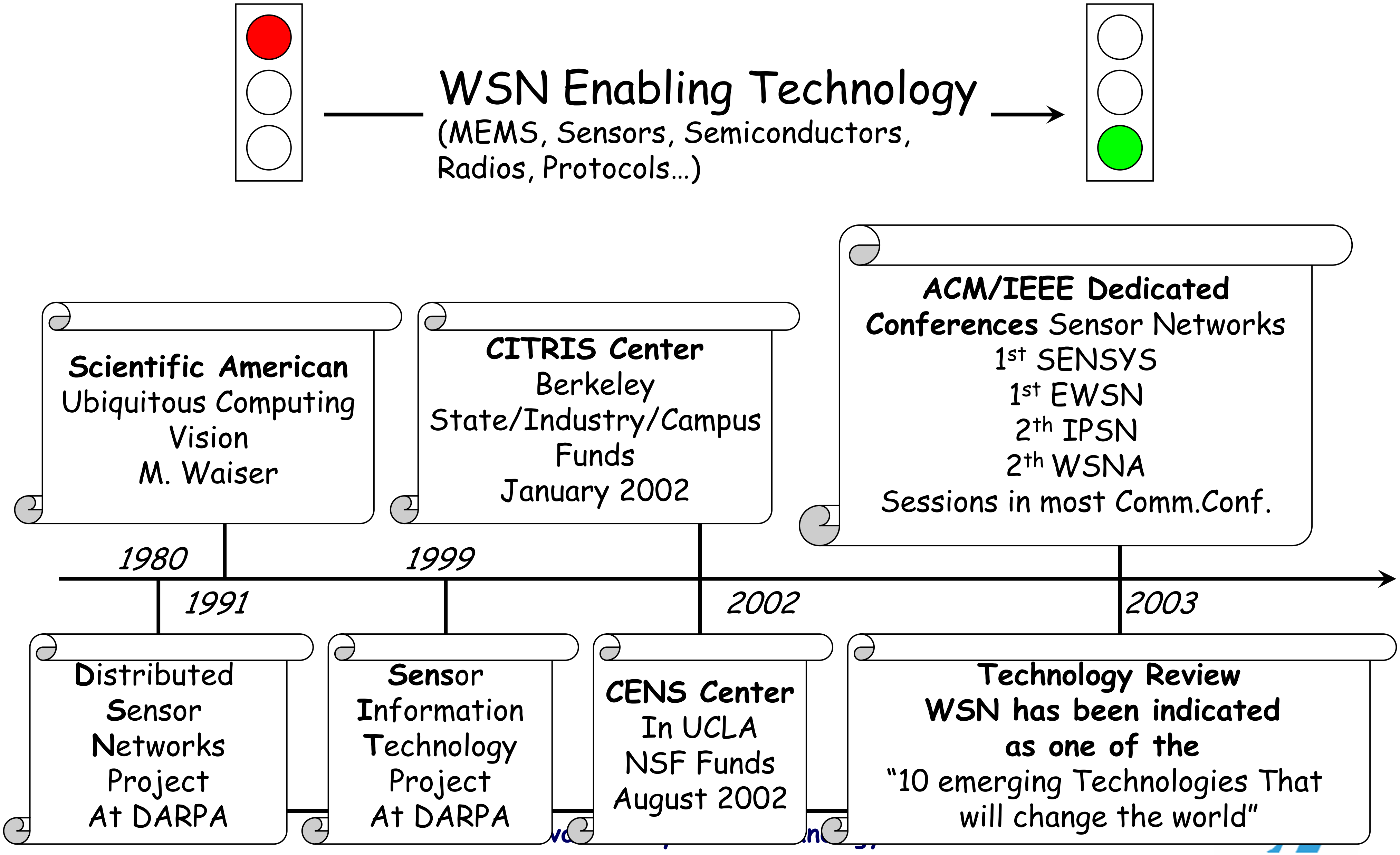


Examples:
RFID
Mobile Phone

Examples:
Sensors/Actuators
BioTechnologies

Examples:
Email - web

WSN Evolution: Some Significant Events



Tackling Societal Scale Problems

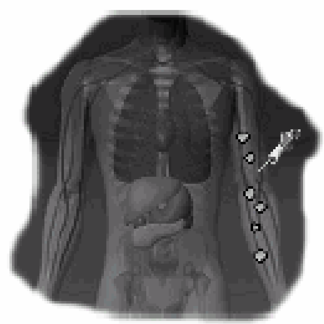
Disaster Mitigation

Smart buildings

Traffic management

Infrastructure maintenance

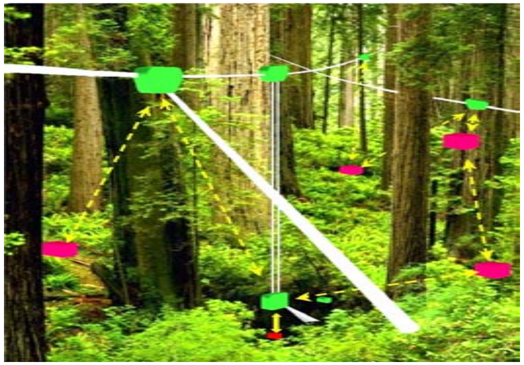
Energy management



Medical

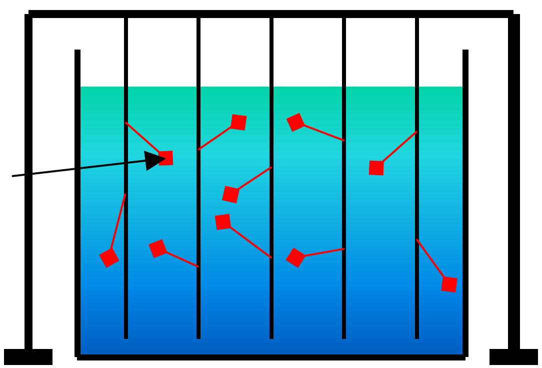
CITRIS
Center for Information Technology Research in the Interest of Society

Embedded Networked Sensing



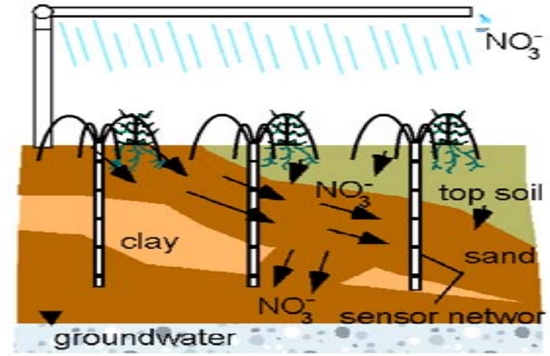
Ecosystems, Biocomplexity

Marine Microorganisms



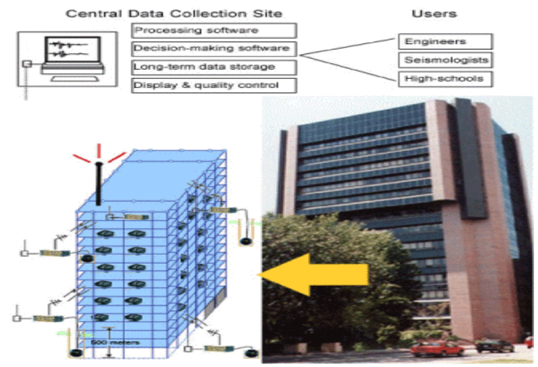
- Micro-sensors, on-board processing, wireless interfaces feasible at very small scale--can monitor phenomena “up close”
- Enables spatially and temporally dense environmental monitoring

Embedded Networked Sensing will reveal previously unobservable phenomena

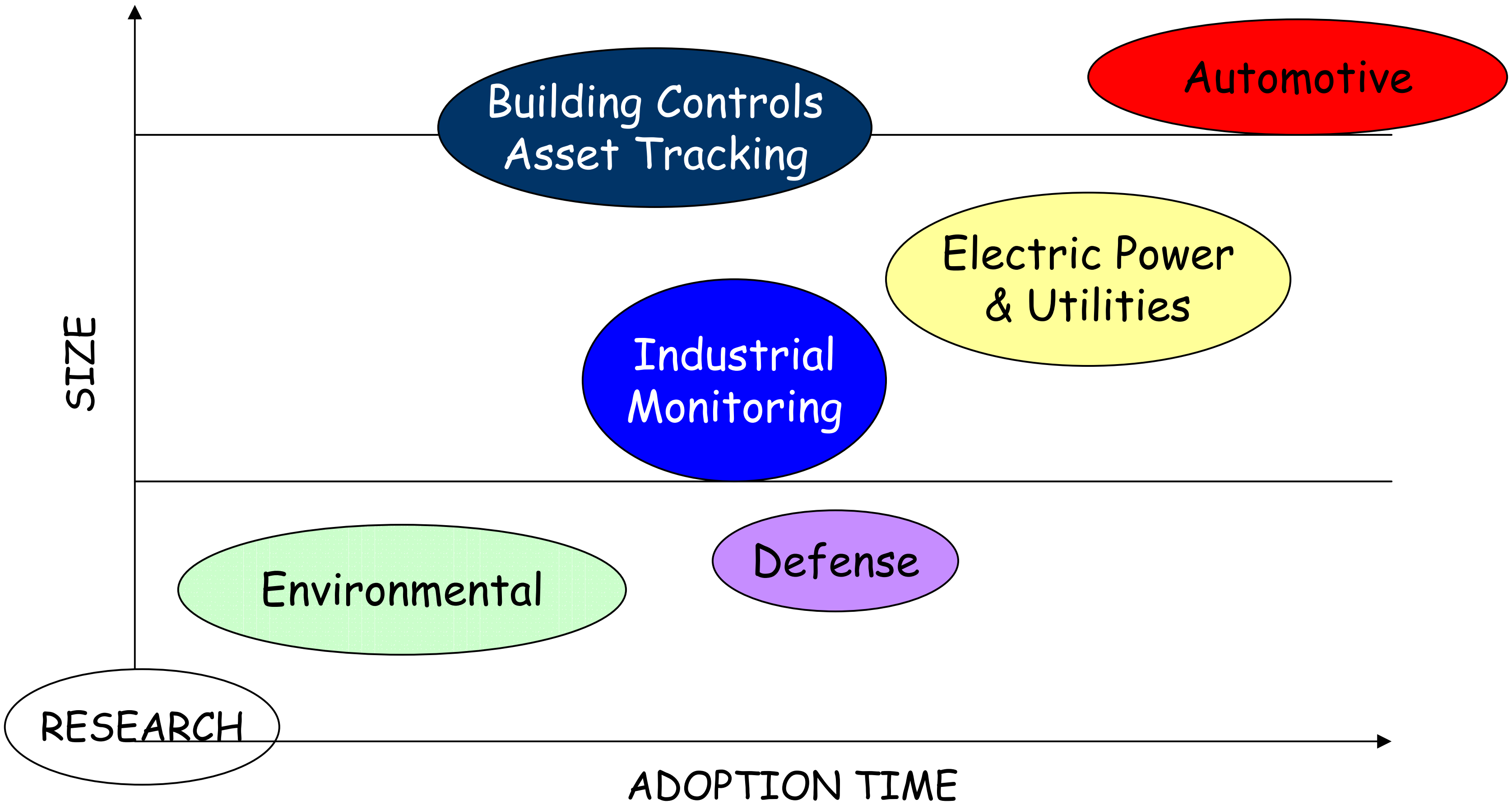


Contaminant Transport

Seismic Structure Response

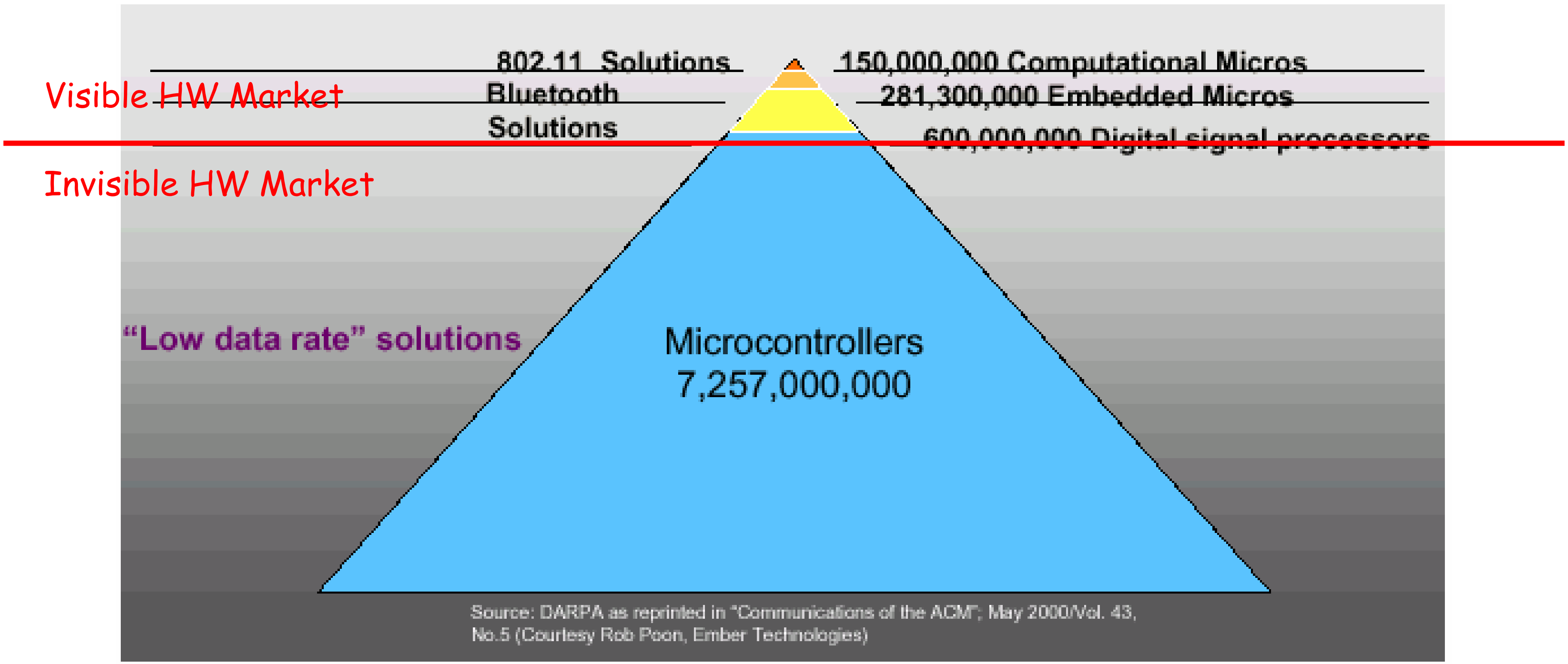


Market Forecast



[Crossbow]

A New Agenda in Wireless



Market Players

More than 40 Companies in USA Have products in the Sensor Area. A few.

Crossbow Technology
1995, San Jose
Dust
2002, Berkeley

Ember
2001, Boston
Intel Research
2001, Berkeley

Millenial Net
2000, Cambridge
Sensoria
1998, San Diego

- Riding on Moore's law, smart sensors get

More powerful

Sensoria WINSNG 2.0
CPU: 300 MIPS
1.1 GFLOP FPU
32MB Flash
32MB RAM
Sensors: external

Easy to use

HP iPAQ w/802.11
CPU: 240 MIPS
32MB Flash
64MB RAM
Both integrated and off-board sensors

Inexpensive & simple

Crossbow MICA mote
4 MIPS CPU (integer only)
8KB Flash
512B RAM
Sensors: on board stack

Super-cheap & tiny

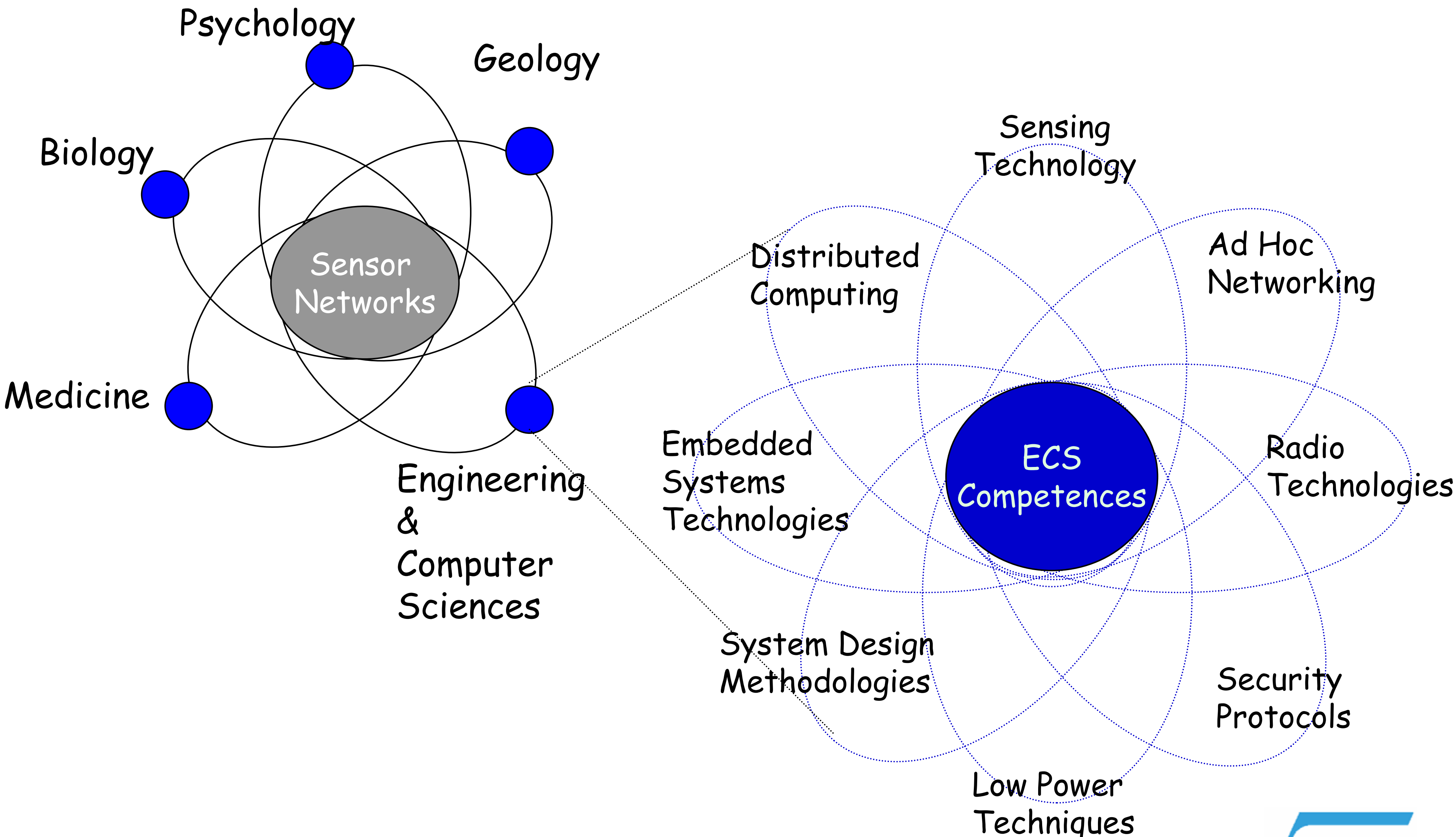
Smart Dust (in progress)
CPU, Memory: TBD (LESS!)
Sensors: integrated

parc Palo Alto Research Center

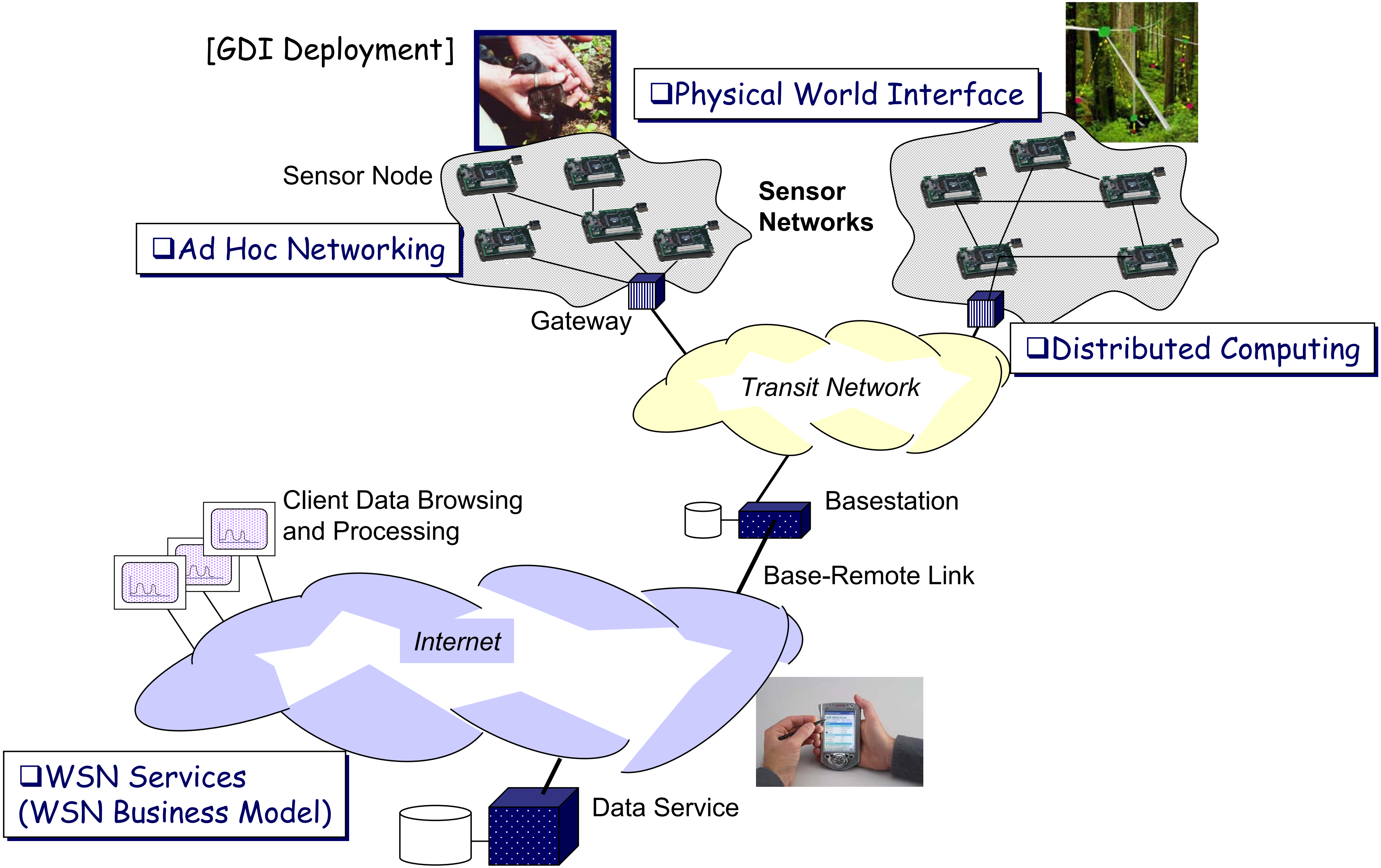
Main Academic References

Project Name (alphabetic Order)	Research AREA	University - Main Researcher
CoSense	Information Processing [DC]	UC Stanford/Parc – Feng Zhao
MICA	Software Platform and Protocols / COTS Architecture [DC, ES]	UC Berkely/Intel Research Berkeley - Pister/Culler
PicoRadio	SoC implementation, Design Methodologies, Low Power Techniques [ES, DM, LP]	BWRC – J.Rabaey/A. Sangiovanni-Vincentelli
SCADDS	Scalable Coordination architecture Monitoring Applications [DC, LP]	UCLA – D. Estrin Center for Embedded Networked Sensing – D. Estrin
SmartDust	Millimeter-scale motes, MEMS [ES]	UCB – J. Pister
Smart-Its	COTS based on Bleutooth [ES]	ETH Zurich – Thiele
uAMPS	Adaptive low power techniques / platform implementation [LP,ES]	MIT – A. Chandrakasan

WSN Interdisciplinarity



Multi-Tiered Network Architecture



WSN Framework Design Platform

- Sensor network prototyping is useful for application incubation but financially expensive ➔ network simulators are a "must" for system design
- Network Simulators Requirements:
  - Ability to simulate ">> 1000 node" scenarios in a wide range of configurations
  - Ability to model the physical environment and its events
  - Coverage of wide range of system level models (algorithmic, protocols, application)

NetworkSimulators

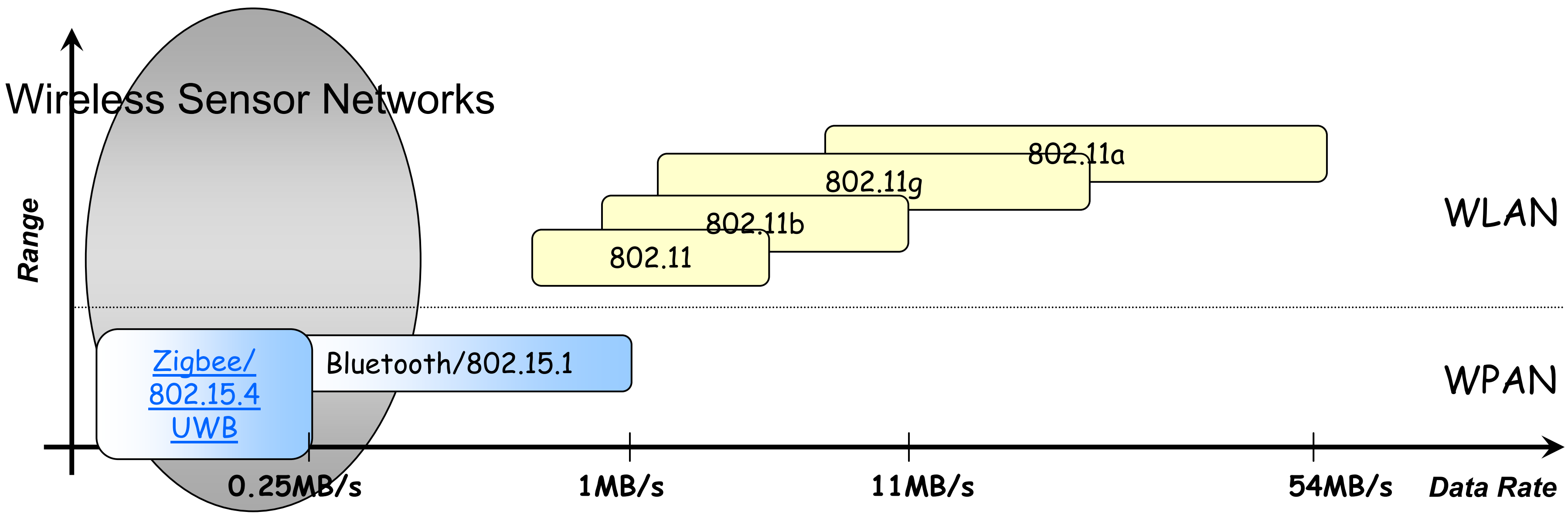
System Design Methodology
To close the gap

Architecture Simulators

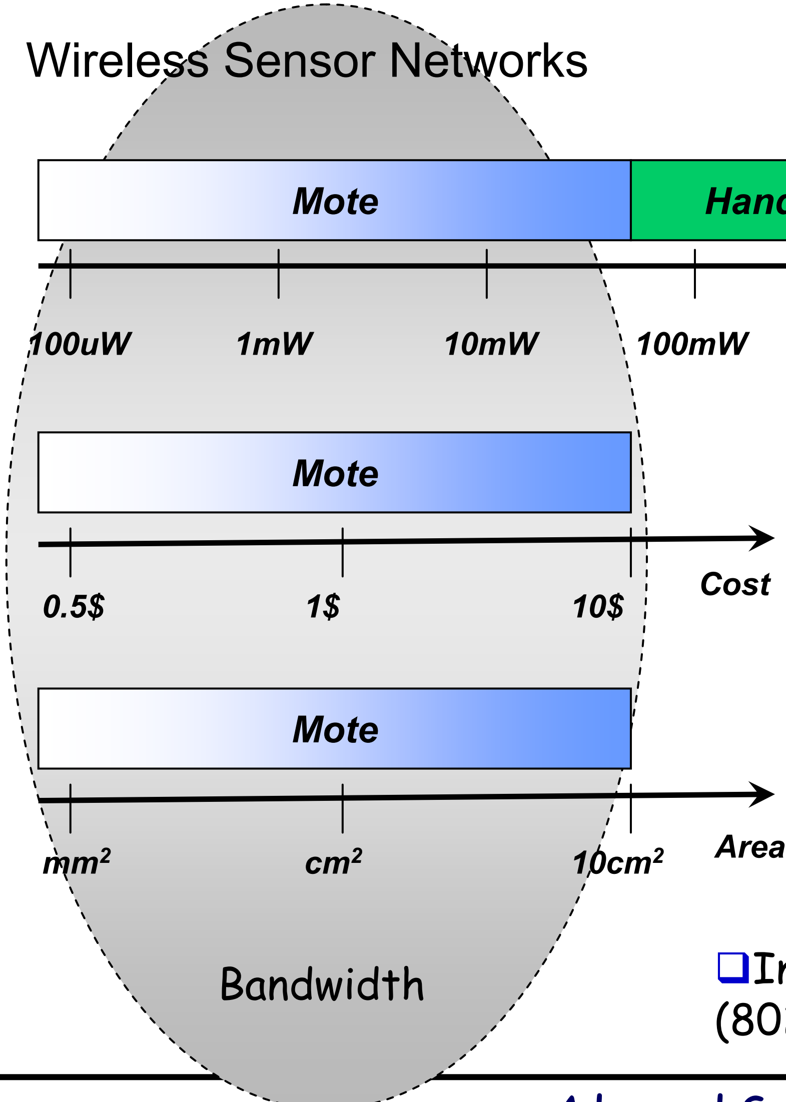
- Architecture Simulators are useful for exploration of design alternatives and trade-offs evaluations
  - Performance evaluation techniques and profiling of energy of SW and HW

WSN Design Factors

- **Application Level**
  - **Adaptable, Scalable and Reliable**
  - **Data Centric**
  - **Event Driven and Real Time**
- **Network Level**
  - **High Density** ranges from few to few hundred sensor nodes in a region which can be less than 10 m in diameter.
  - **Dynamic Topology**
    - Related to the working conditions of a device (dead, off, sleep, on)
    - Environment Conditions
  - **Self Configuring**

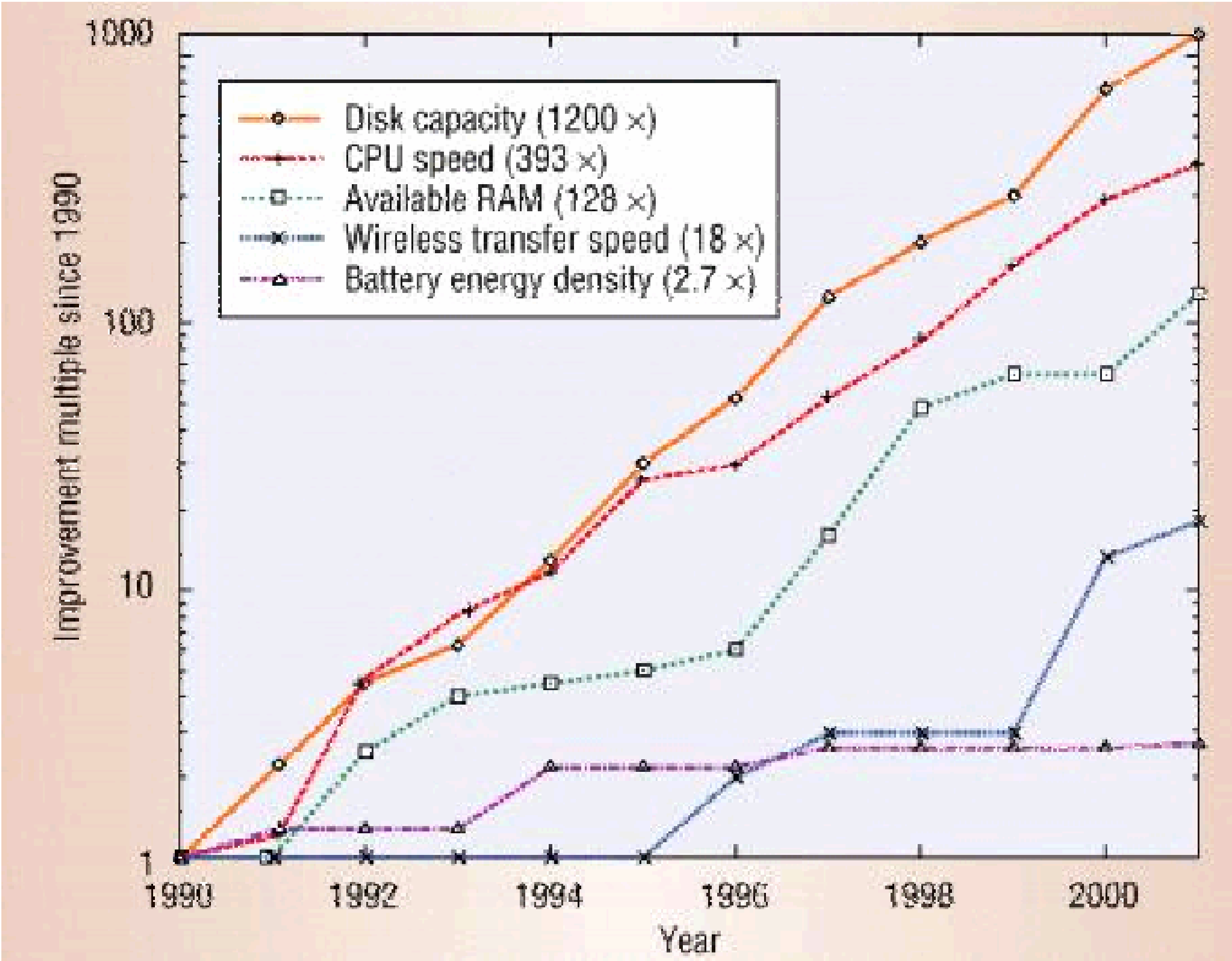


WSN Constraints



- 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
- Interference and spectrum sharing in ISM Bands (802.15.4: 816/916 MHz – 2.4 GHz)

Technology Trends

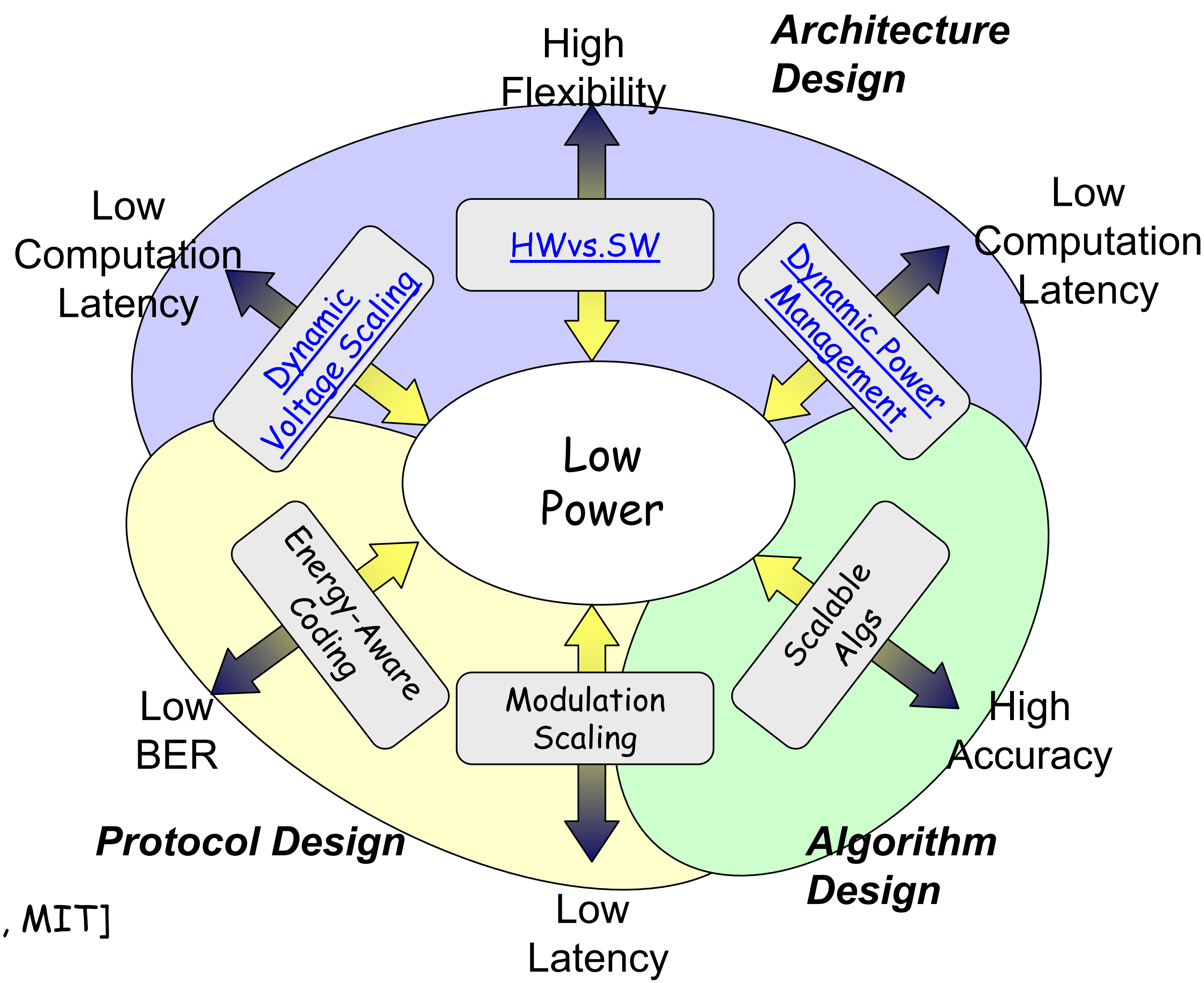


Low Power Design Factors

- **Energy Cost**:
  - The ratio of energy spent in sending one bit (nJ/bit) versus executing one instruction (nJ/op) ranges from 220 to 2900 in different architectures [Srivastava]
    - 100 nJ/bit with Bluetooth
    - 100 pJ/operation with Atmel
  - @10 m : > 1 Million instruction/transmitted bit using dedicated HW [Chandrakasan]
- **Technology**: Energy per operation (nJ/op) will scale with the technology while Communication Cost (nJ/bit) will not scale at the same rate
- **Battery** Technology does not evolve significantly. In many cases batteries are also an inconvenient solution for WSN nodes (replacement, recharging)
- **Energy Scavenging** is still a research field in many cases

- **MultiHopping**: Multi-hop Networks allows to reduce the power consumption by a very relevant factor [Rabaey]:
  - $Et \sim d^g$ - g is the path-loss exponent; $1<g<4$ indoor
- **In-Network Processing** in order to reduce the communication charge on each node [UCB, UCLA, Cornell]

Low Power Design Techniques



[Chandrakasan, MIT]
[Rabaey, UCB]
[Srivastava, UCLA]

Information Processing

Vertical Markets
(Scenarios):
Technologies Deployment

Horizontal Apps
Collaborative Processing
Technology

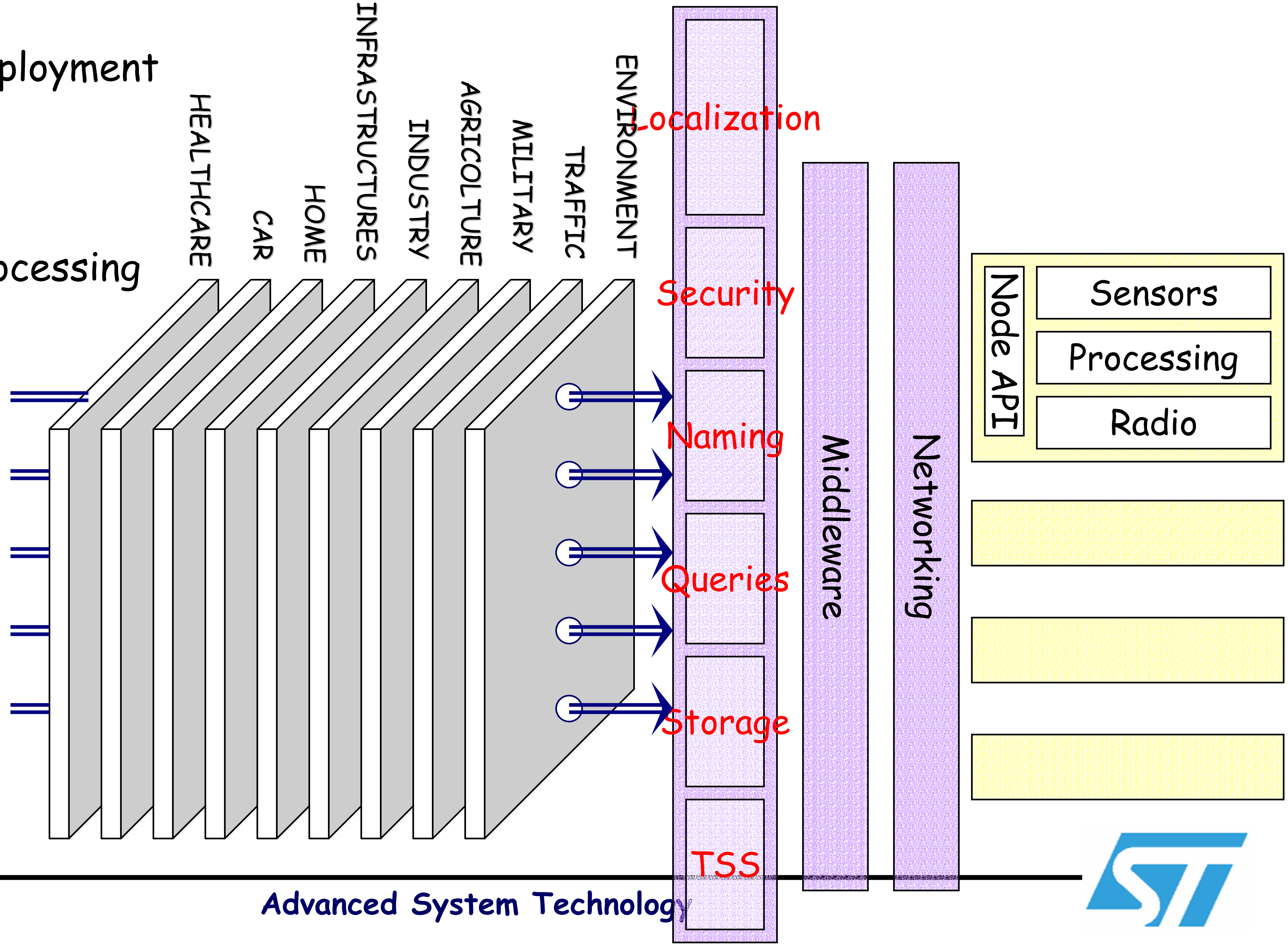
OBJECT TRACKING

OBJECT CLASSIFICATION

OBJECT IDENTIFICATION

EVENT IDENTIFICATION

LOCALIZED MONITORING & CONTROL



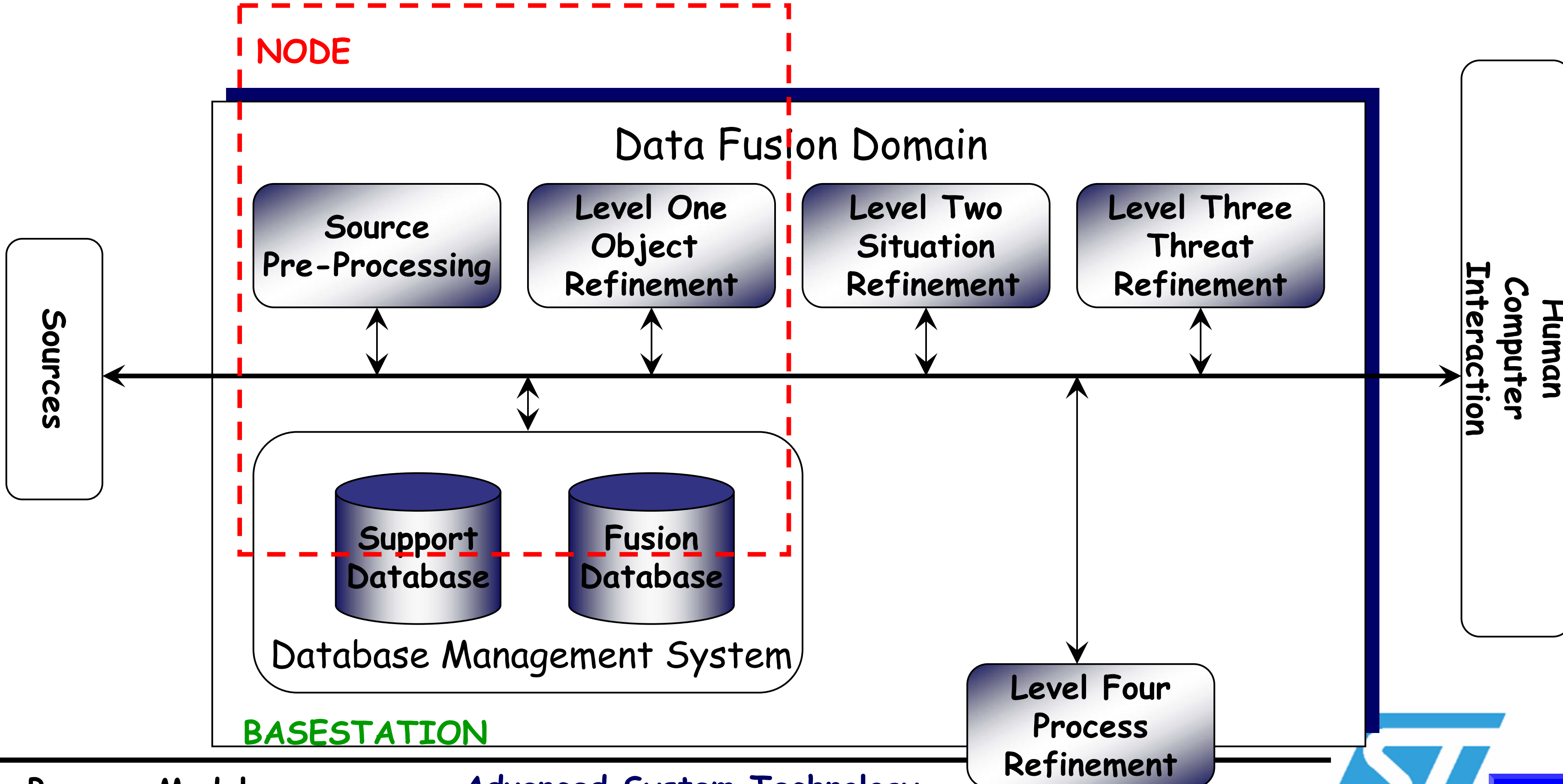
Sensor Data Fusion

High Level Functions :

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

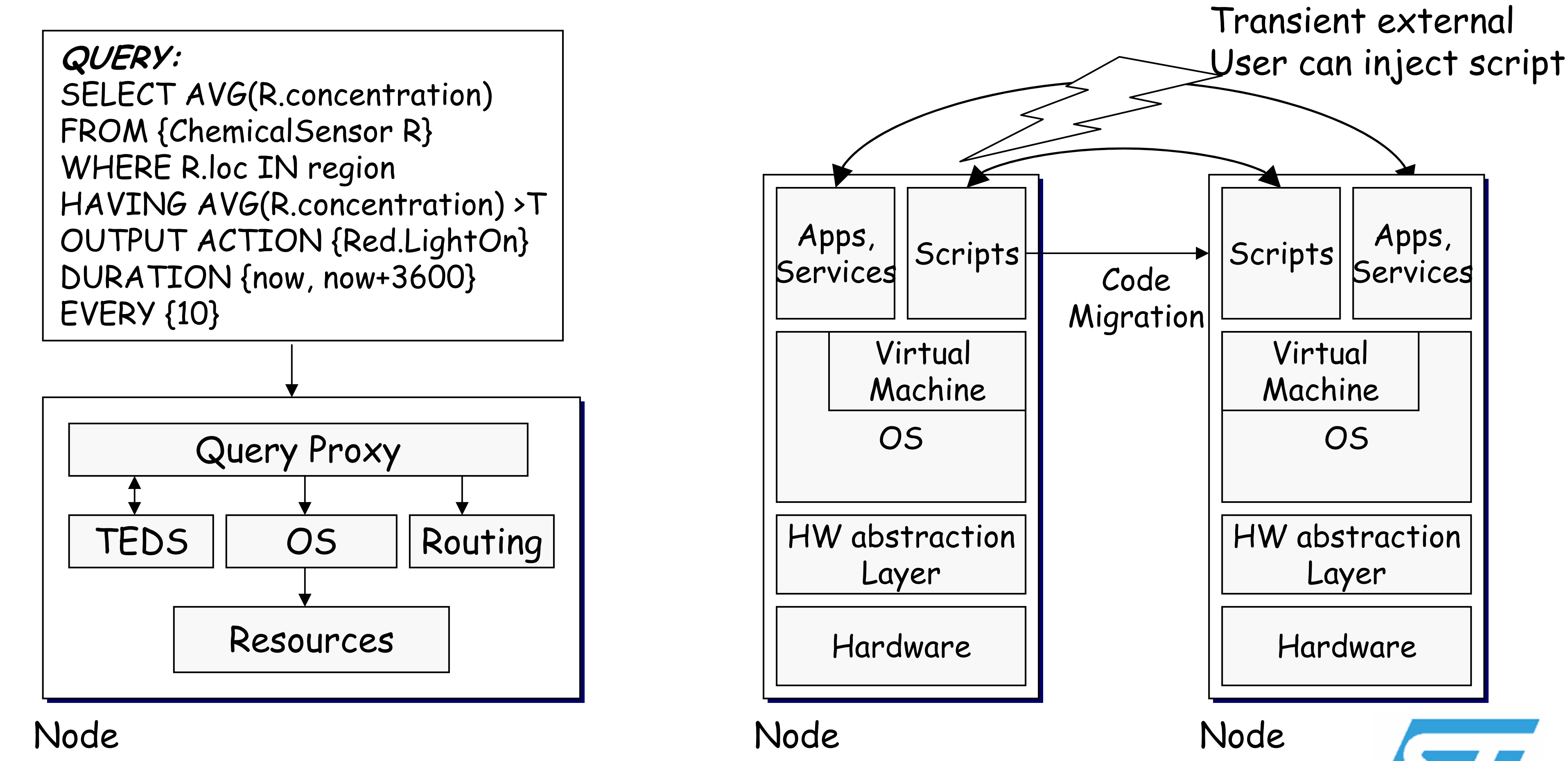
Techniques:

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



Queries vs Commands

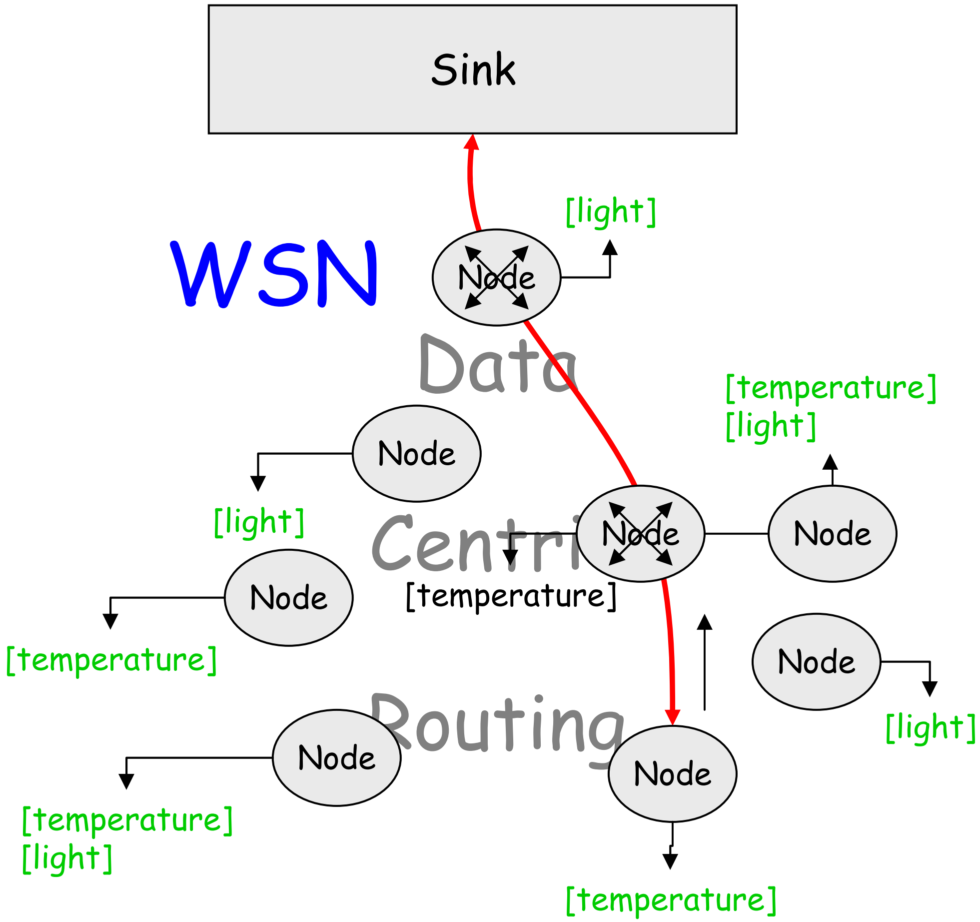
- Declarative Long-Running Periodic and event-oriented Queries [Cougar, TinyDB, SCADDS] vs Mobile Code [SensorWare, Mate]



Naming

- In WSN low-level communication relies on names that are relevant to the application
  - Sensors types
  - Geographic location
- Attribute-Based Naming Systems for WSN can be built data-centric routing communication paradigms
  - Directed Diffusion Routing [Estrin, UCLA]
  - Tree-Based Routing [Culler, UCB]
  - Flooding Routing [Rabaey, UCB]
  - Declarative Routing [MIT]
- Self-identifying data enable in-network processing
  - Data Compression [LEACH]
  - Aggregation [TinyDb, Cougar]
- Limited node resources are the fundamental constraint that characterize implementation of Naming System in WSN

Data-Centric Communication Paradigm



Attribute-Based Query/Command
"Evaluate The T Average at the South-East"

↓

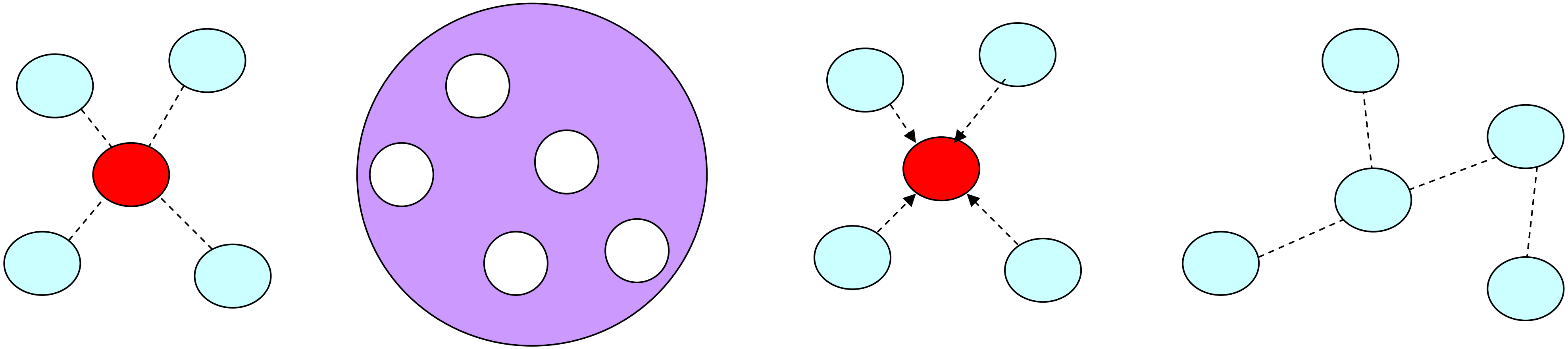
A **Publish-Subscribe** Mechanism Based on Query Attributes and node Parameters creates a "Gradient Vector" For Data Flow

↓

The Data Requested Are **Aggregated /Fused** On the Way-Back

Information Processing is coupled with Middleware and Networking in order to improve Resource Management and Network Scalability

Collaborative Groups



N-hop neighbor groups

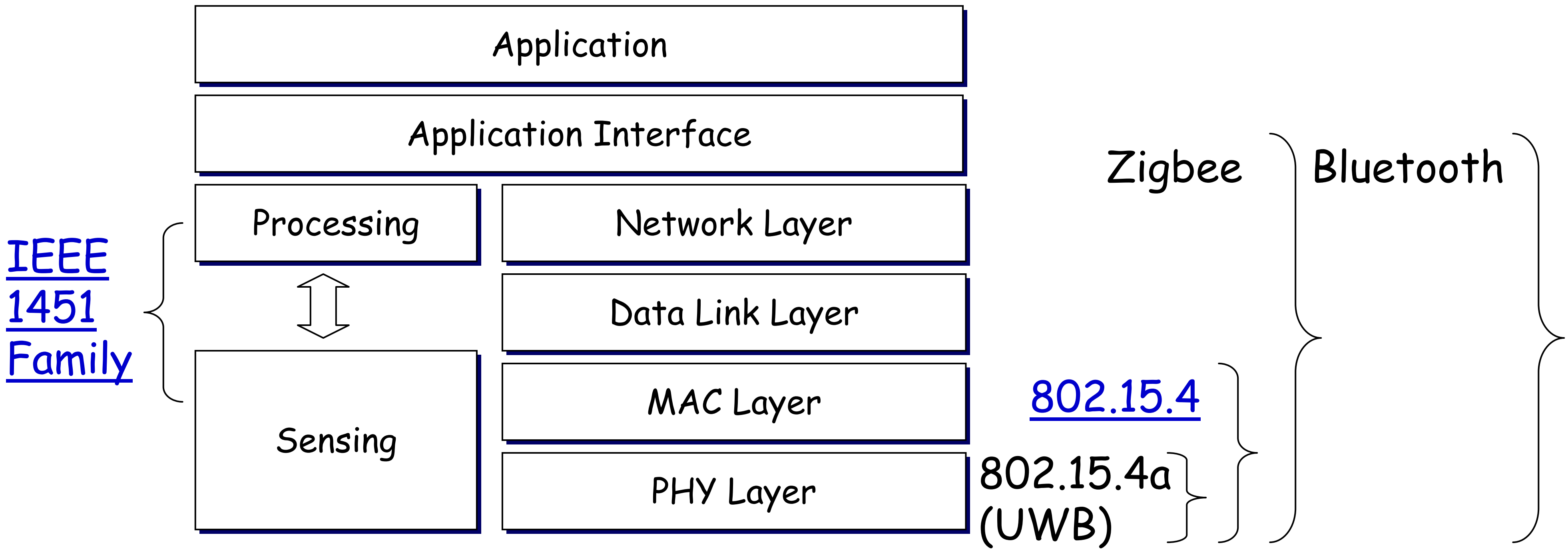
Geographically Constrained Group
Defined by geographic extent

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

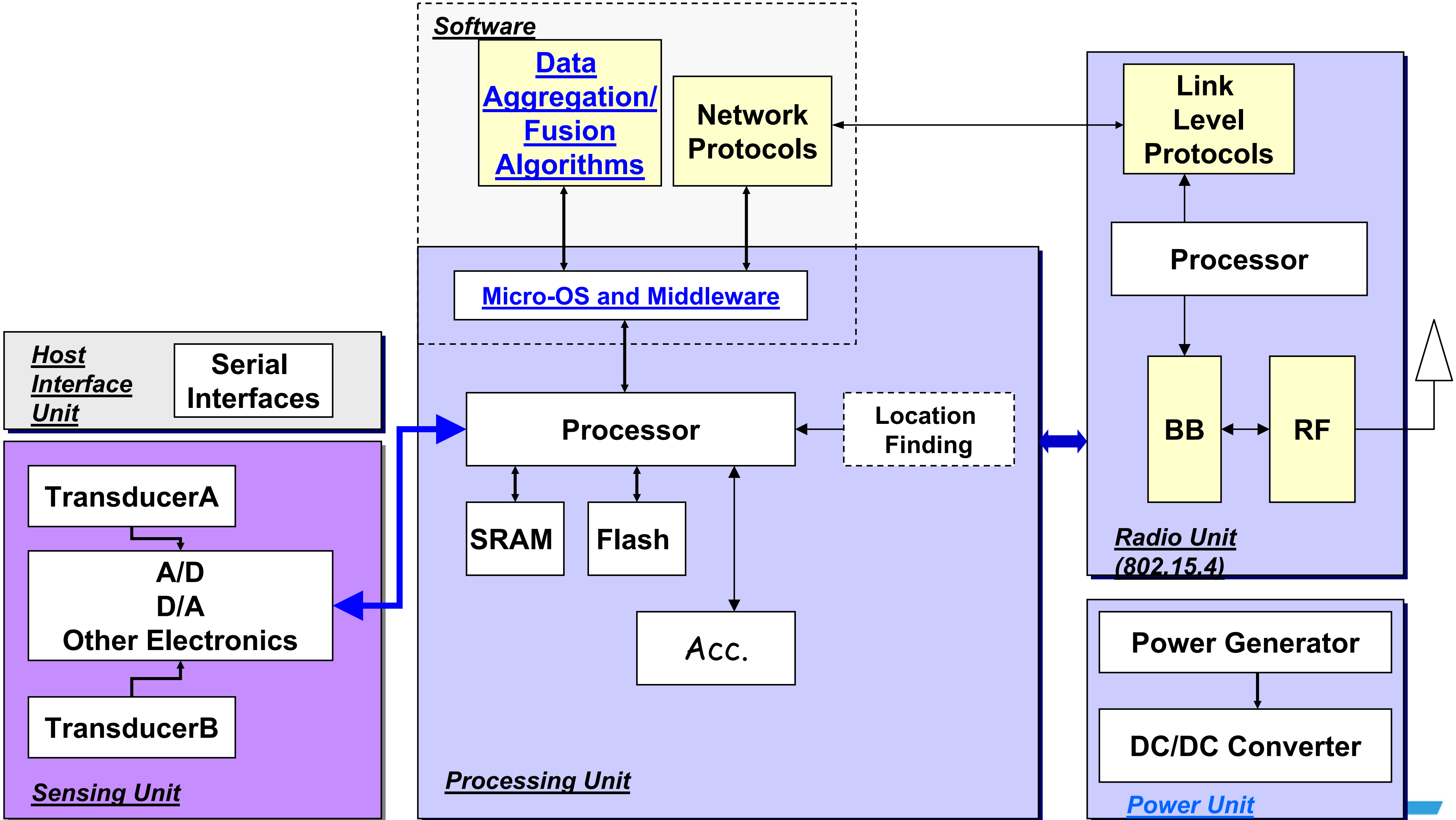
Acquaintance Group
Roaming Members keep Persistent Connectivity

- 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

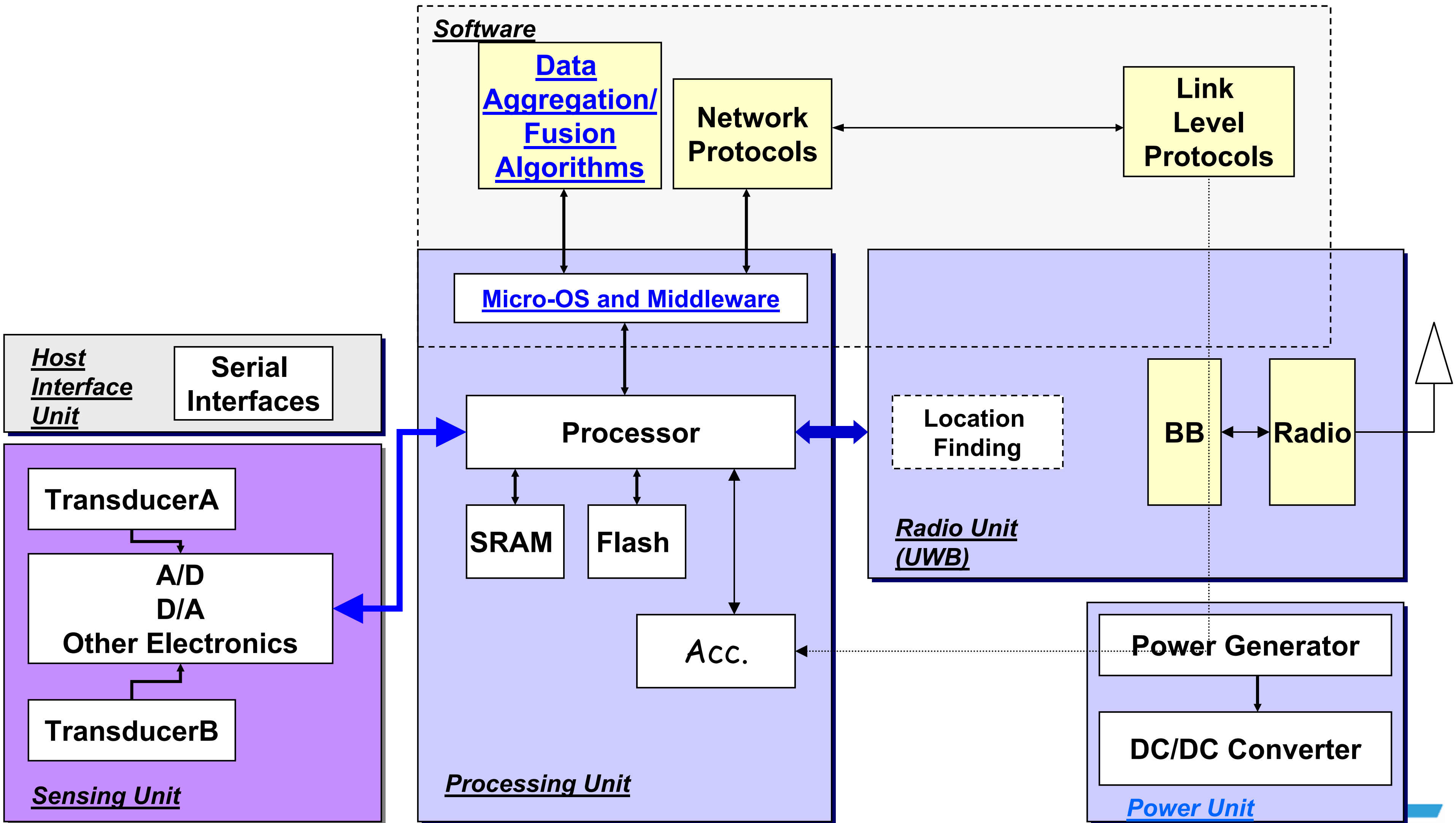
Standards Players



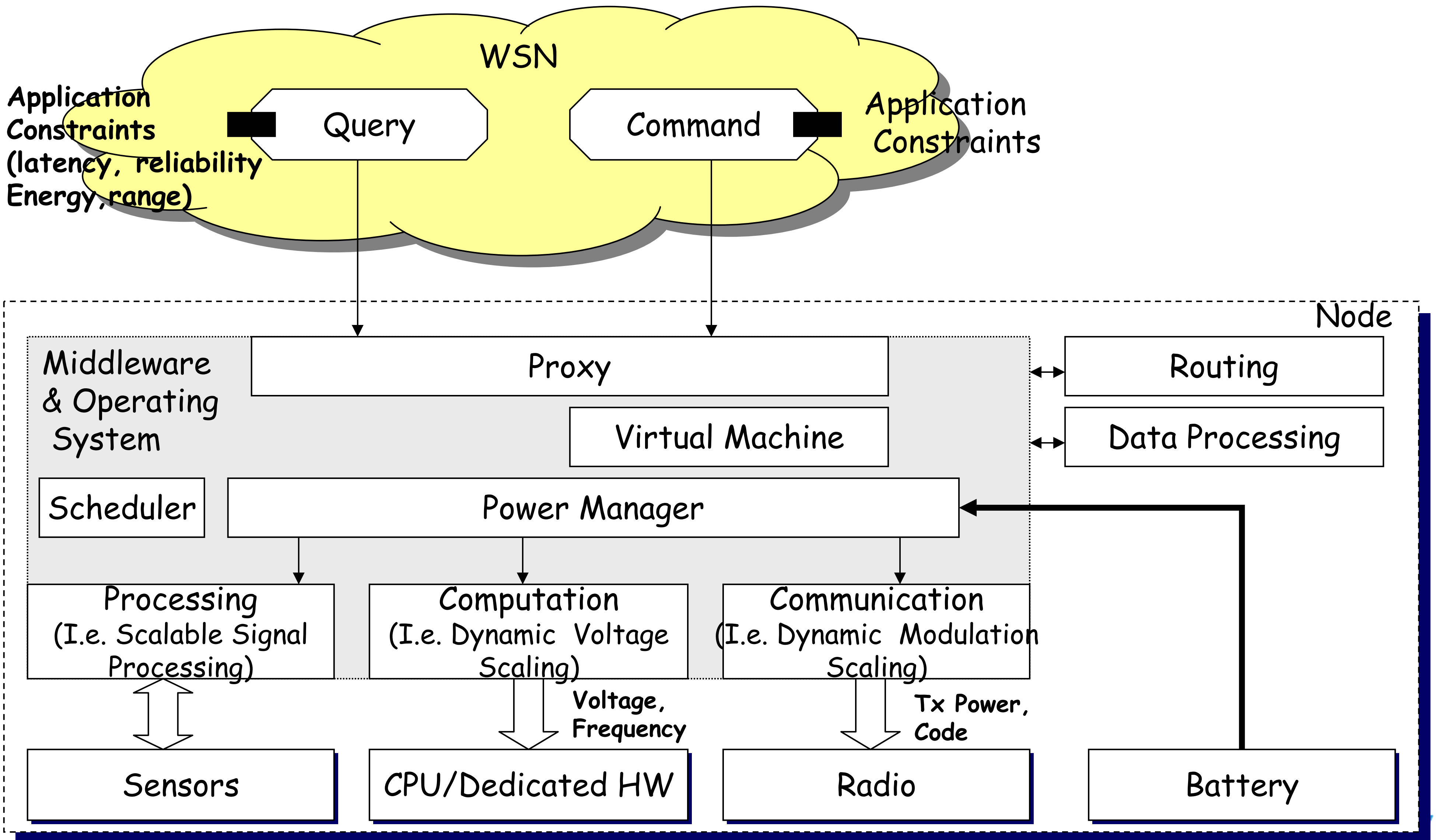
Node Functional Block (1)



Node Functional Block (2)



Energy-Aware Node Design



Academic COTS Implementations

Project Name (alphabetic Order)	Node Platform	University - Main Researcher
Mote	**MICA2** Atmel 128L – TinyOS/TinyDB – CSMA + ChipCon (433/916 MHz)	UCB/IRB – Culler
PicoRadio	**PicoNode** StrongARM+ Dedicated HW + FPGA - Custom/TinyOS –Bluetooth RF + Sensor Board	BWRC – J.Rabaey/A. Sangiovanni-Vincentelli
SmartDust	**SmartDust** Dedicated HW – Optical Radio – MEMS Sensor in Package + Solar Cell + thick-film batteries	UCB – J. Pister
Smart-Its	**BTNode** ATMEL 128L – Custom OS – BlueTooth + Sensor Board	ETH Zurich – O. Kasten
uAMPS	**uAMPS** StrongARM – eCOS – 2.4 GHz DS Radio + Sensor board	MIT – A. Chandrakasan

MICA2 Motes

- Size: 1.5x2.5 inches
- Cost: 72$
- CPU: Atmel 8MHz 8 bits
- Memory: 128kB + 512kB
- ChipCon Radio 433/916

Power Breakdown

Operation	Active (mA)	Idle (mA)	Sleep(uA)
MCU core	5	2	5
Led	4.6 each	-	-
Photocell	.3	-	-
Radio (TX)	12	-	5
Radio (RX)	4.5	-	5
Temp	1	0.6	1.5

[GDI]

AA Batteries: 2000mAh @3V
Life Period: 6 months
Duty cycle (active-sleep modes) :2%

TinyOS Framework and Developments

- TinyOS is a Light-Weight OS and a Component-Based library
  - Adopted in many academic and industrial research teams in US and Europe for application prototyping
  - “Continuos” updates with new modules and HW drivers
    - Micro-diffusion, S-MAC and TS from UCLA
    - TinyBT from U. Copenaghen
  - Supported by UCBerkeley
- Many active developments on the top of TinyOS:
  - 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
  - TASK (Tiny Application Sensor kit)
    - Targetted towards actual users of sensor networks
  - Mat’e implements a Virtual Machine
    - Allows lightweight In-Network re-programming
  - TOSSIM Simulator for Network Simulations
  - Tython Script/Probes Manager

Small Technology, Broad Agenda, Unique Confluence

- Social Factor
  - Security, privacy, information sharing
- Applications
  - Long lived, self-maintaining, dense instrumentation of previously unobservable phenomena
  - Interacting with a computing environment
- Programming the ensemble
  - Describe global behavior, synthesis local rules that have correct, predictable global behaviour
- Distributed Services
  - Localization, time synchronization, aggregation and fusion
- Networking
  - Self-organizing multihop, resilient energy efficient routing
  - Despite limited storage and tremendous noise
- Operating System
  - Extensive resource-constrained concurrency, modularity
  - Dynamic Power Management
- Architecture
  - Rich interfaces and simple primitives allowing cross-layer optimization
  - Low-power processor, ADC, radio, communication, encryption

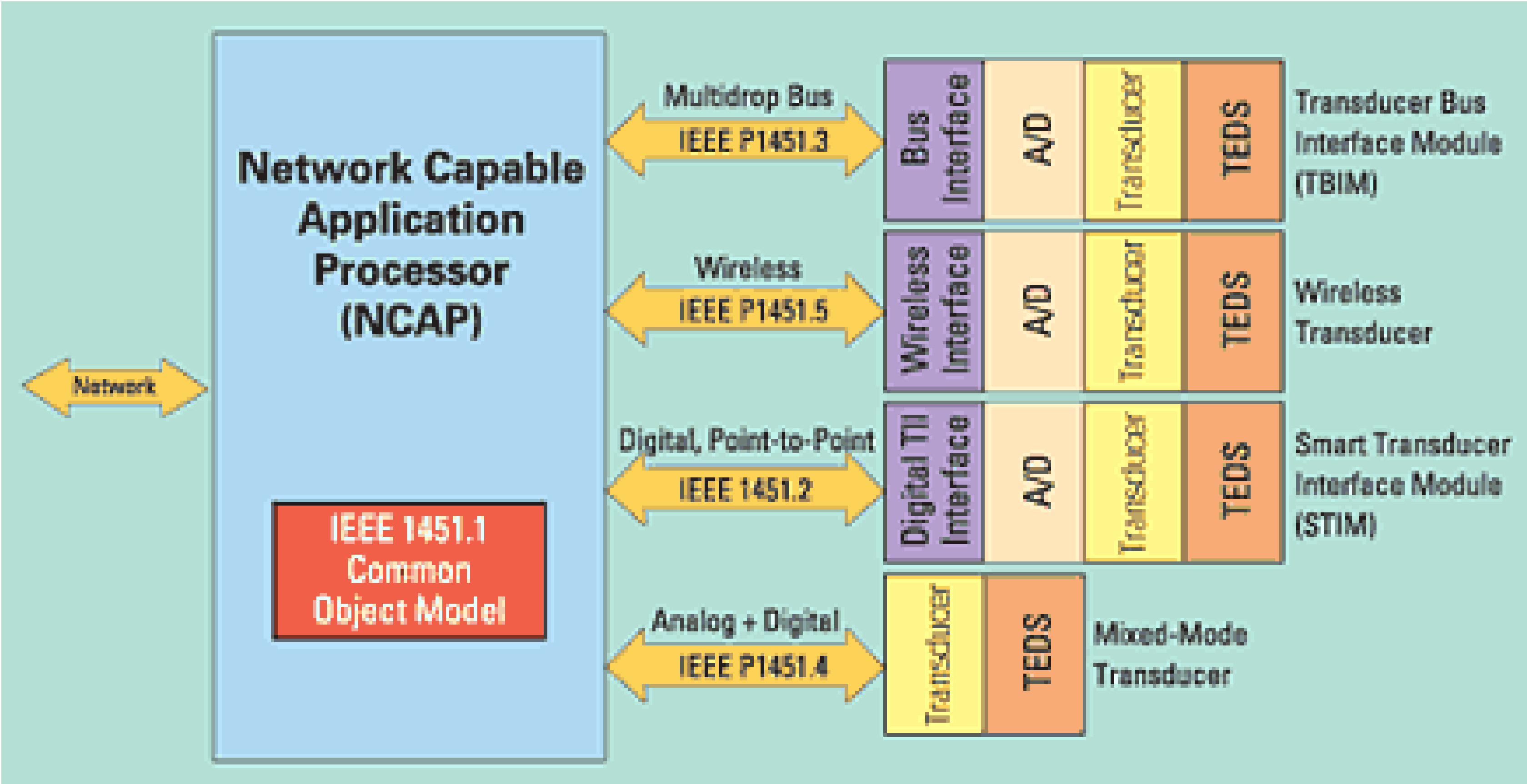
Thanks. Questions?

Power Sources for WSN

Power Source	P/cm^3 (uW/cm^3)	E/cm^3 (J/cm^3)	$P/cm^3/yr$ ($uW/cm^3/Yr$)	Secondary Storage	Voltage Regulation	Comm. Available
Primary Battery (Lithium)	-	2880	90	No	No	Yes
Secondary Battery	-	1080	34	-	No	Yes
Micro-Fuel Cell	-	3500	110	Maybe	Maybe	No
Heat engine	-	3346	106	Yes	Yes	No
Radioactive (^{63}Ni)	0.52	1640	0.52	Yes	Yes	No
Solar (outdoor)	15000*	-	-	Usually	Maybe	Yes
Solar (indoor)	10*	-	-	Usually	Maybe	Yes
Temperature	40* (5 °C)	-	-	Usually	Maybe	Soon
Human Power	330* (walking)	-	-	Yes	Yes	No
Air Flow	380 (5m/s) 5% efficiency	-	-	Yes	Yes	No
Vibrations	200 2.25 m/s^2 120 hz	-	-	Yes	Yes	No

[Source: Roundy]

IEEE 1451



Network Capable Application Processor (NCAP)
IEEE 1451.1 Common Object Model
Network
Multidrop Bus
IEEE P1451.3
Wireless
IEEE P1451.5
Digital, Point-to-Point
IEEE 1451.2
Analog + Digital
IEEE P1451.4
Bus Interface
A/D
Transducer
TEDS
Transducer Bus Interface Module (TBIM)
Wireless Interface
A/D
Transducer
TEDS
Wireless Transducer
Digital TII Interface
A/D
Transducer
TEDS
Smart Transducer Interface Module (STIM)
Transducer
TEDS
Mixed-Mode Transducer

802.15.4 General Technical Characteristics

- Data rates of 250 kb/s (2.4 GHz) and 20/40 kb/s (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
- Fully handshaked protocol for transfer reliability
- Extremely low duty-cycle capability
- Beaconless operation available
- Support for low latency devices (Guaranteed Time Slots in star networks)
- Star or Peer-to-Peer network topologies supported