WiLab at the
University of Bologna

First NEWCOM++ Summer School

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Introduction and Applications of WSNs

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WiLab at the
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WiLab
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IEIIT CNR (Consiglio Nazionale delle Ricerche)

CNIT, Consorzio Nazionale Interuniversitario per le Telecomunicazioni

Also participated by research staff from University of Ferrara

The results shown were obtained at IEIIT-BO/CNR, Univ. of Bologna, with
D. Dardari, A. Zanella, A. Conti, A. Giorgetti, C. Buratti, F. Fabbri

Context

European Projects on WSNs Participated

NEWCOM & NEWCOM++
(Network of Excellence in Wireless Comms)
CRUISE
(Network of Excellence on WSNs)

Other Contracts / Collaborations on WSNs

Sadel
Thales Italia
Telecom Italia
Massachussets Inst. of Technology
…

Theoretical Activity
- **Math**
- **Simulation**

Experimental Activity

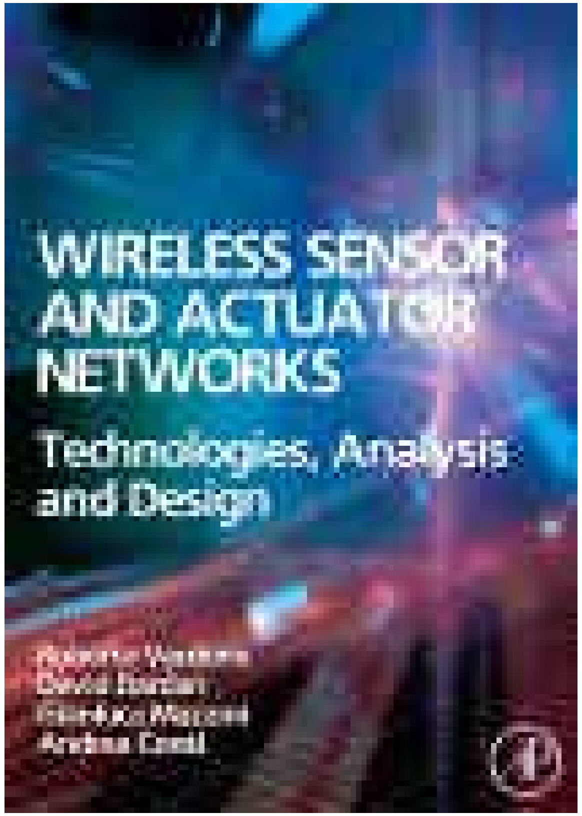
Some Advertisement…

The contents of this talk are part of the book:

Wireless Sensor and Actuator Networks - Technologies, Analysis, and Design

R. Verdone, D. Dardari, G. Mazzini, A. Conti

Publisher: Elsevier
Date of publication: **January 2008**



Some Advertisement…

Some slides are taken from the keynote speeches given at EWSN2008

European Conference on WSNs 2008

Bologna, Italy
January 2008

→ http://www.ewsn.org

Wireless Sensor Networks
R. Verdone (Ed.)
Publisher: Springer

Outline

1. WSNs
2. Applications
3. WSNs vs WAHNs
4. Energy Efficiency
5. Connectivity Layer
6. Network Architectures
7. Network Opportunism in WSNs

Before we Start…

Where are you from? Please introduce yourself:

- Name
- Affiliation
- Country
- PhD student? Post Doc? Researcher? Senior?
- Research Interests: WSNs or other?

Section 1
WSNs

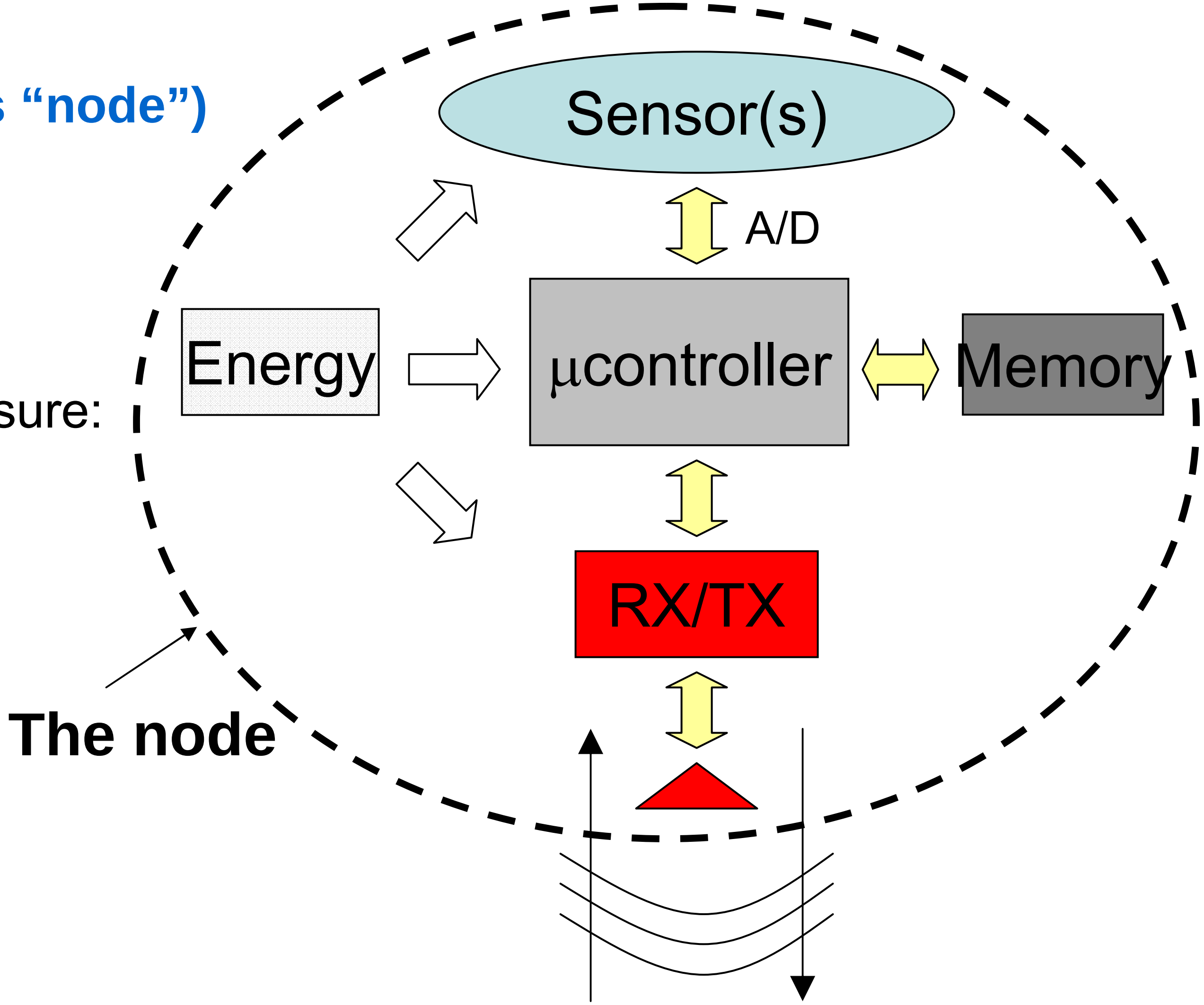
Wireless Sensor Node
WSNs
Main Features
Reference Node Architecture

Basics

Wireless Sensor
(hereafter denoted as “node”)

The sensor might measure:

Temperature,
Light,
Acceleration,
Humidity,
Pollution,
Magnetic fields,
Seismic events,
…



Basics

Wireless Sensor

The sensor might measure:

Temperature,
Light,
Acceleration,
Humidity,
Pollution,
Magnetic fields,
Seismic events,
…

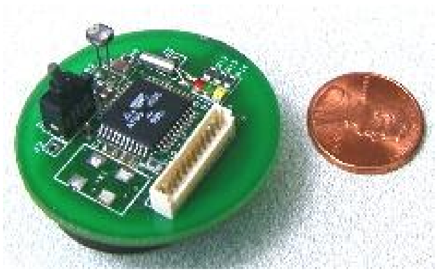
Nodes are

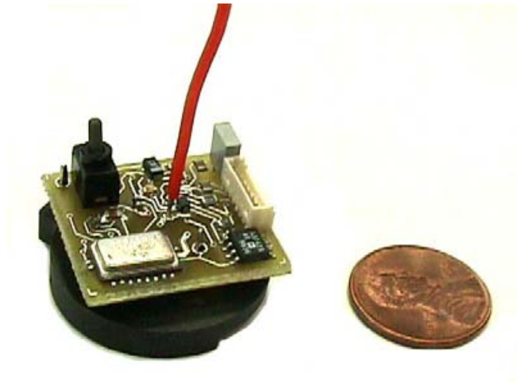
low – cost
low – complexity
low – size
[low – energy]

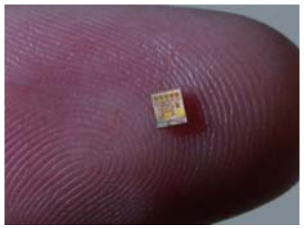
devices

Basics

Wireless Sensor







The sensor might measure:

Temperature,
Light,
Acceleration,
Humidity,
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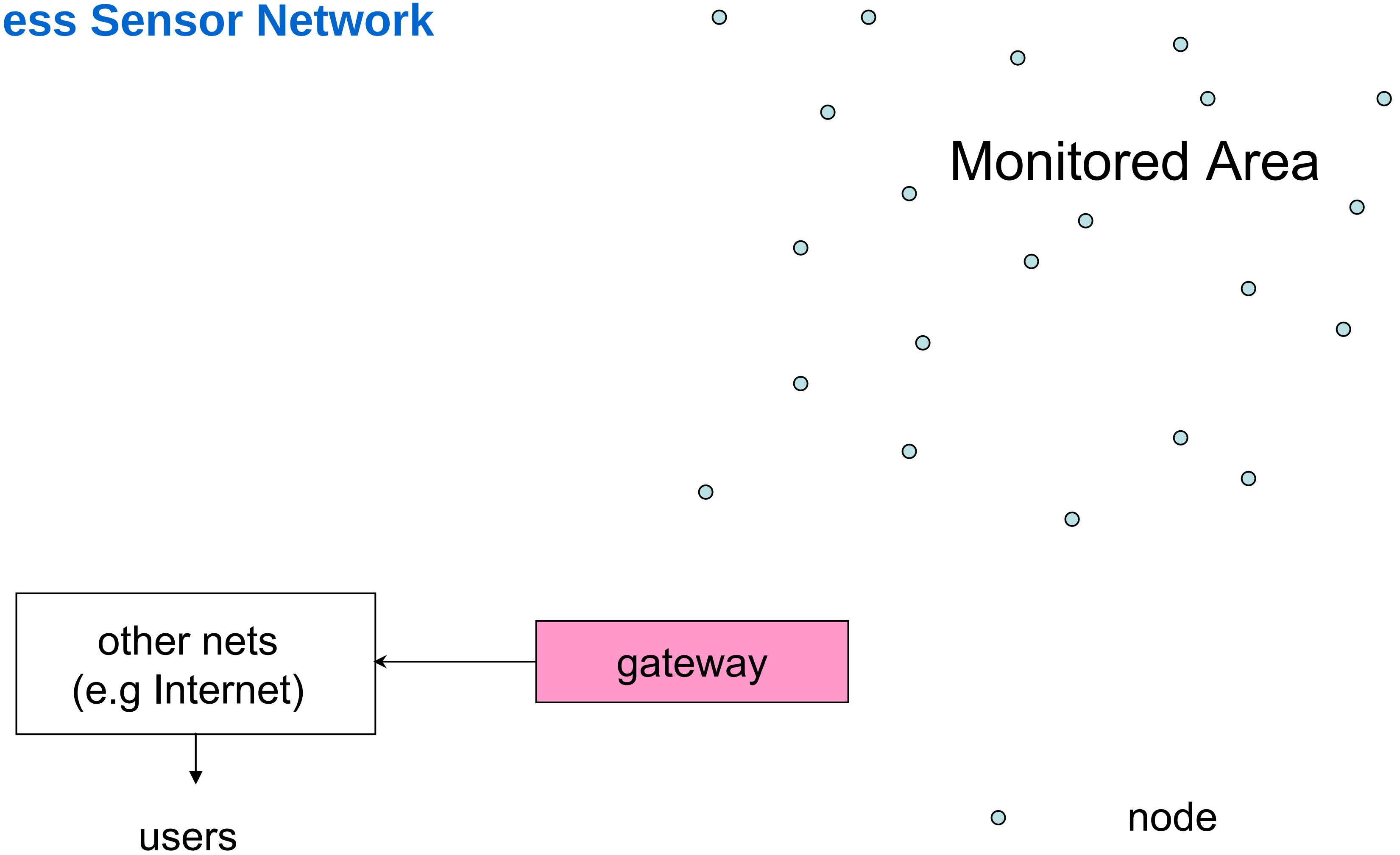
Magnetic fields,
Seismic events,
…

Basics

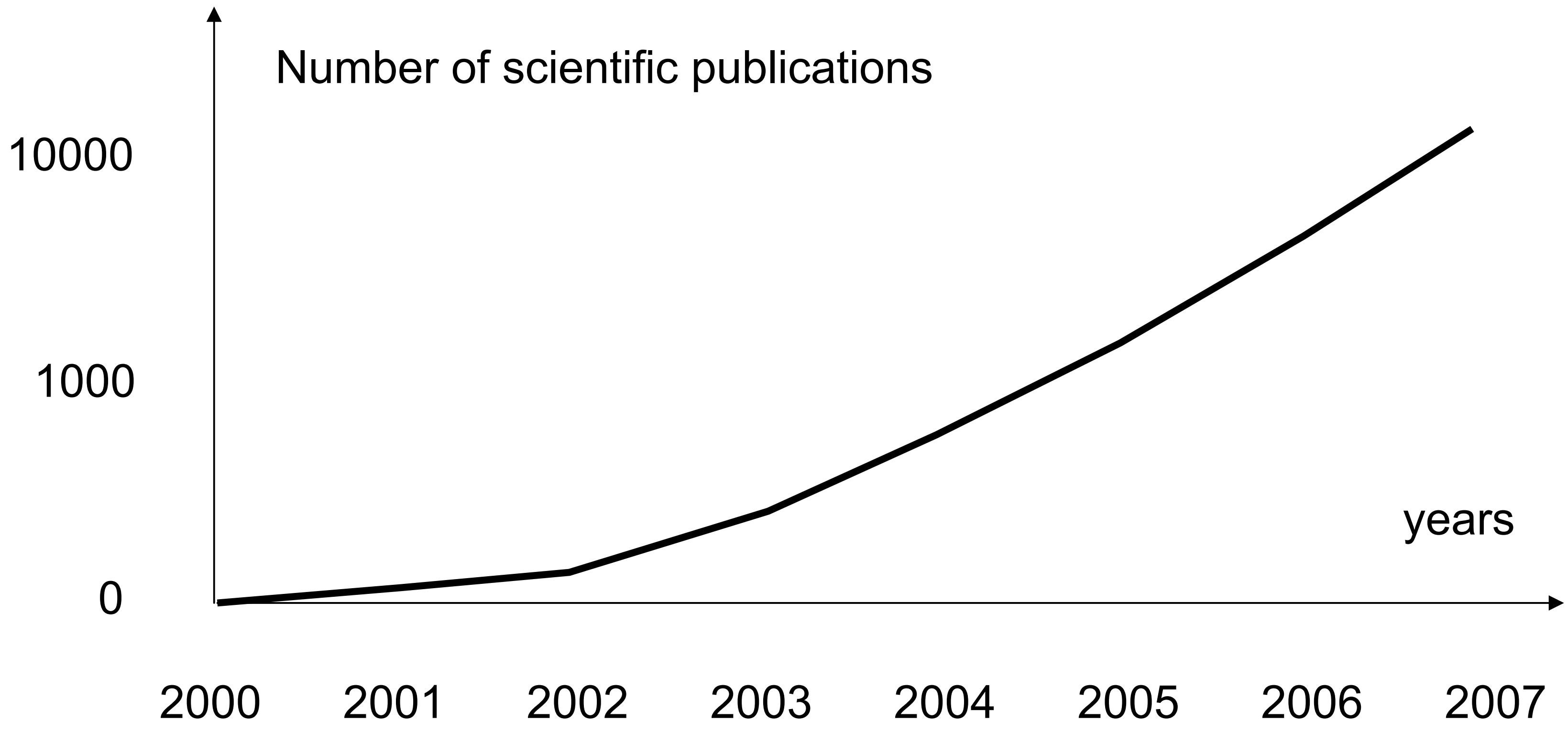
Wireless Sensor Network



Density of Nodes?

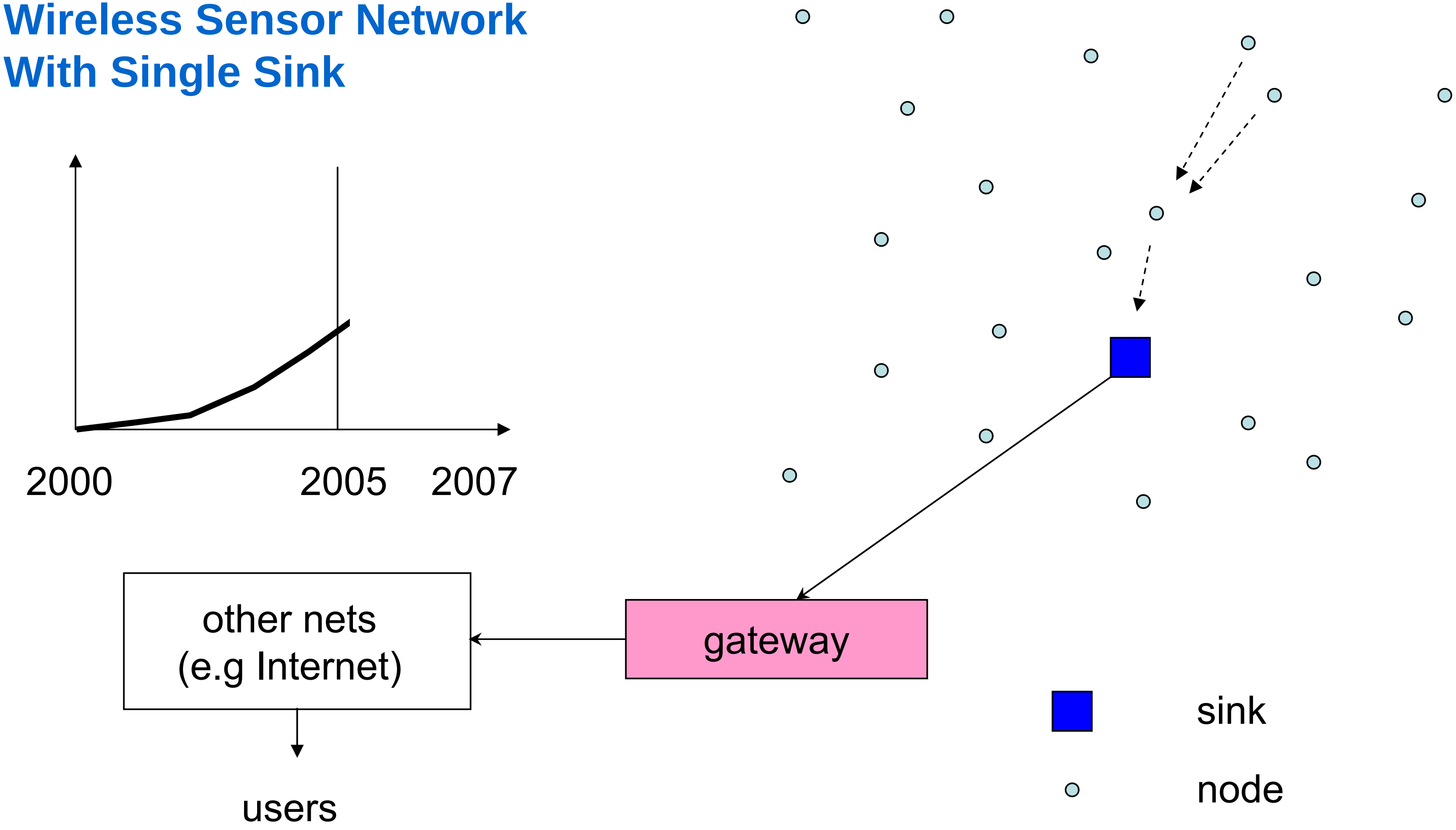
Basics

Wireless Sensor Network



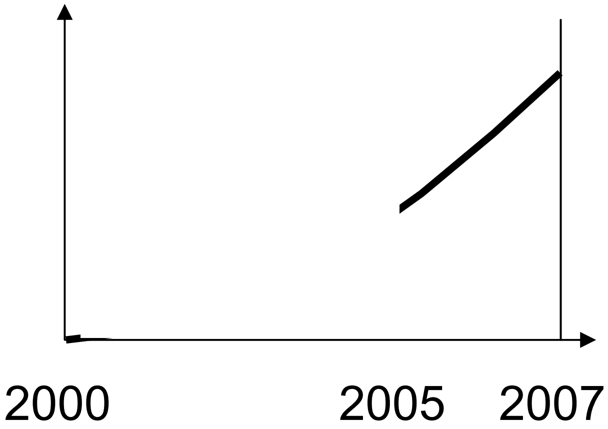
Basics

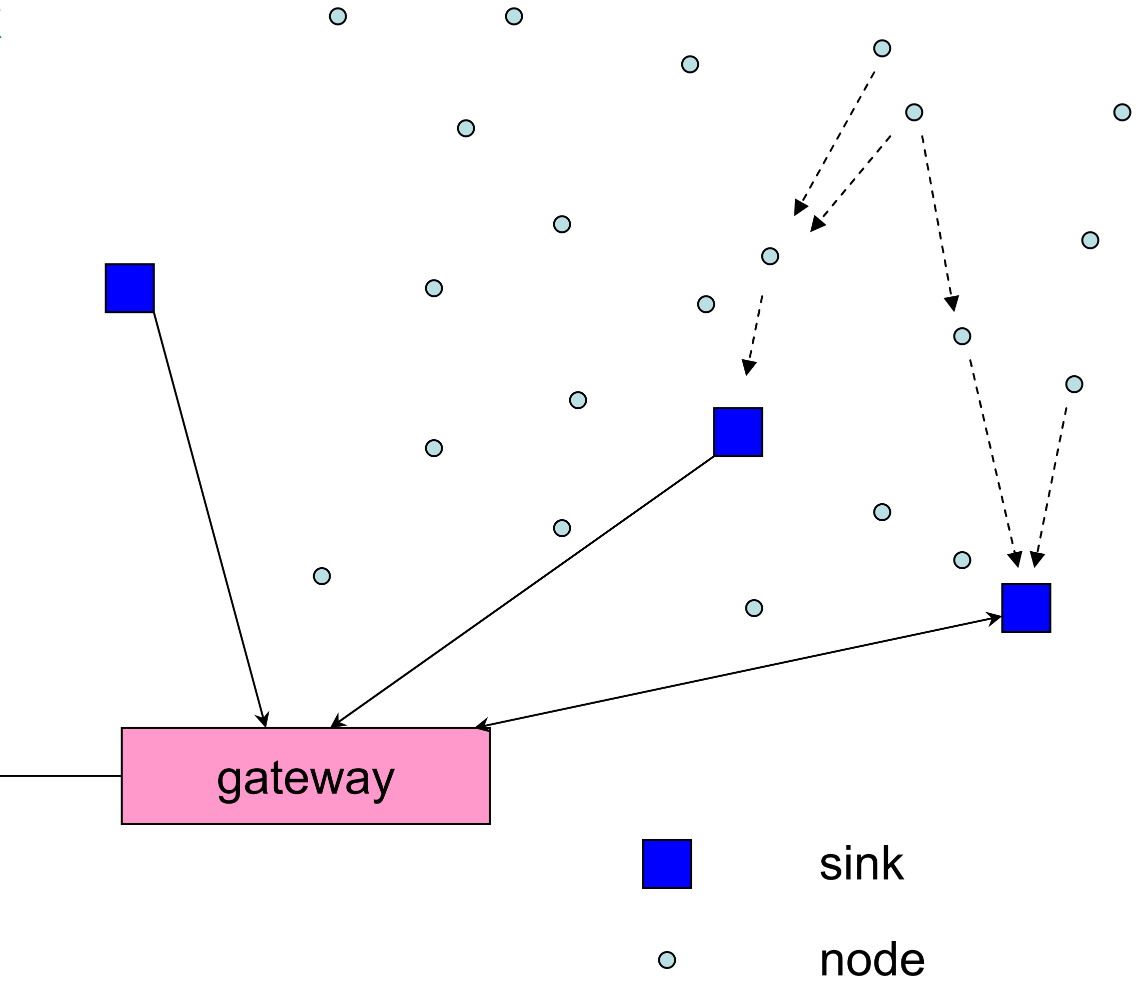
Wireless Sensor Network
With Single Sink



Basics

Wireless Sensor Network
With Multiple Sinks

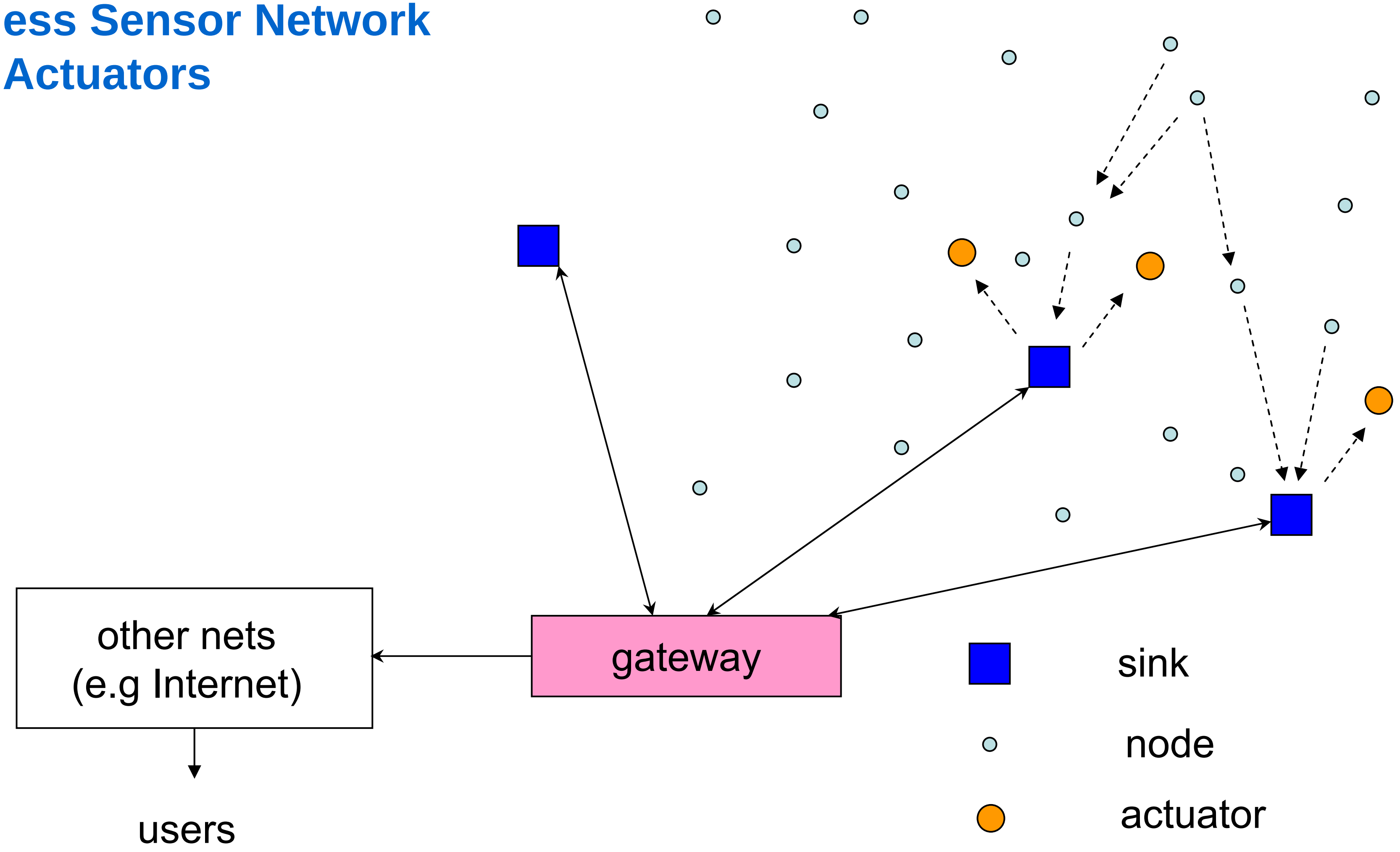




Density of Sinks?

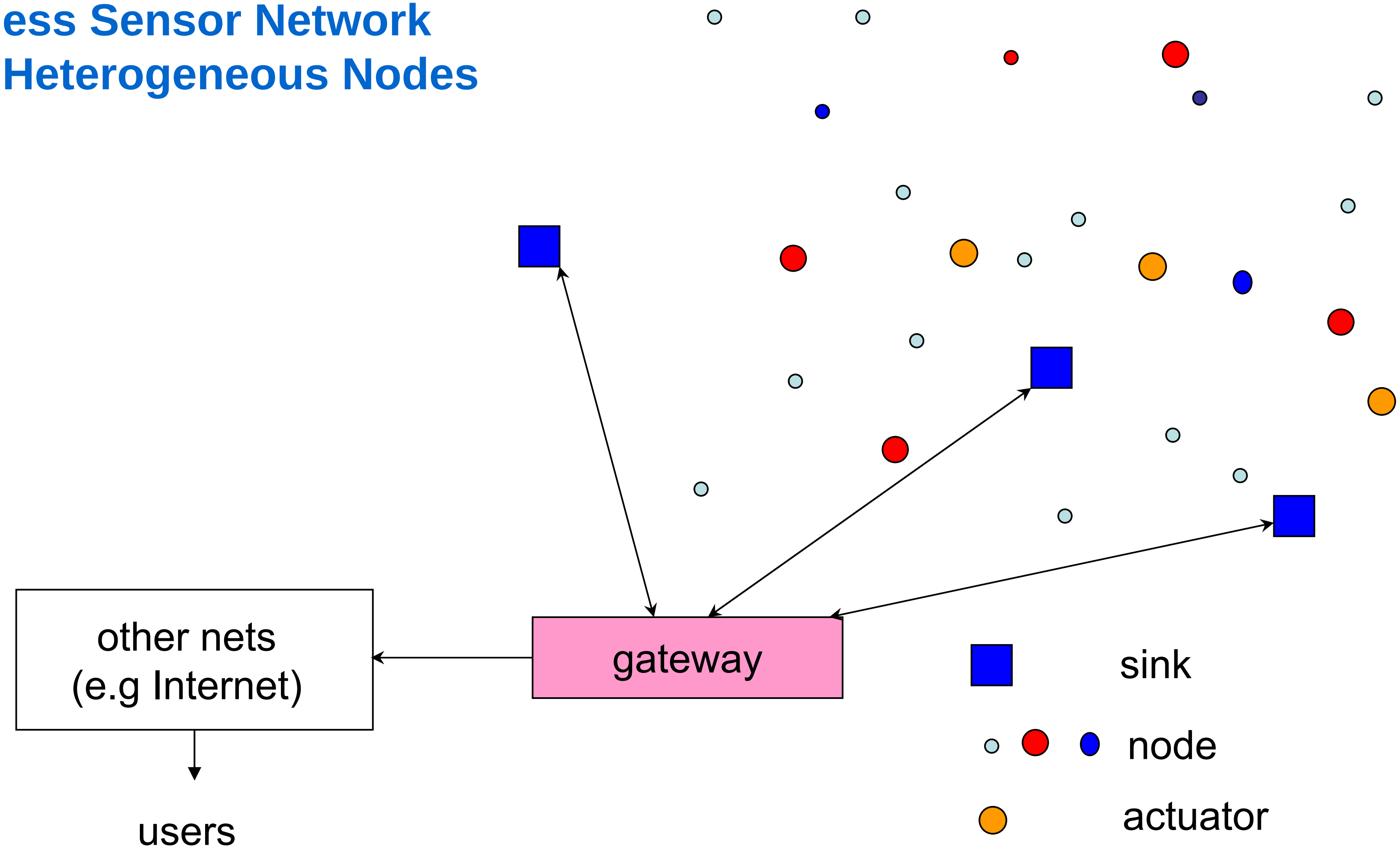
Basics

Wireless Sensor Network
With Actuators



Basics

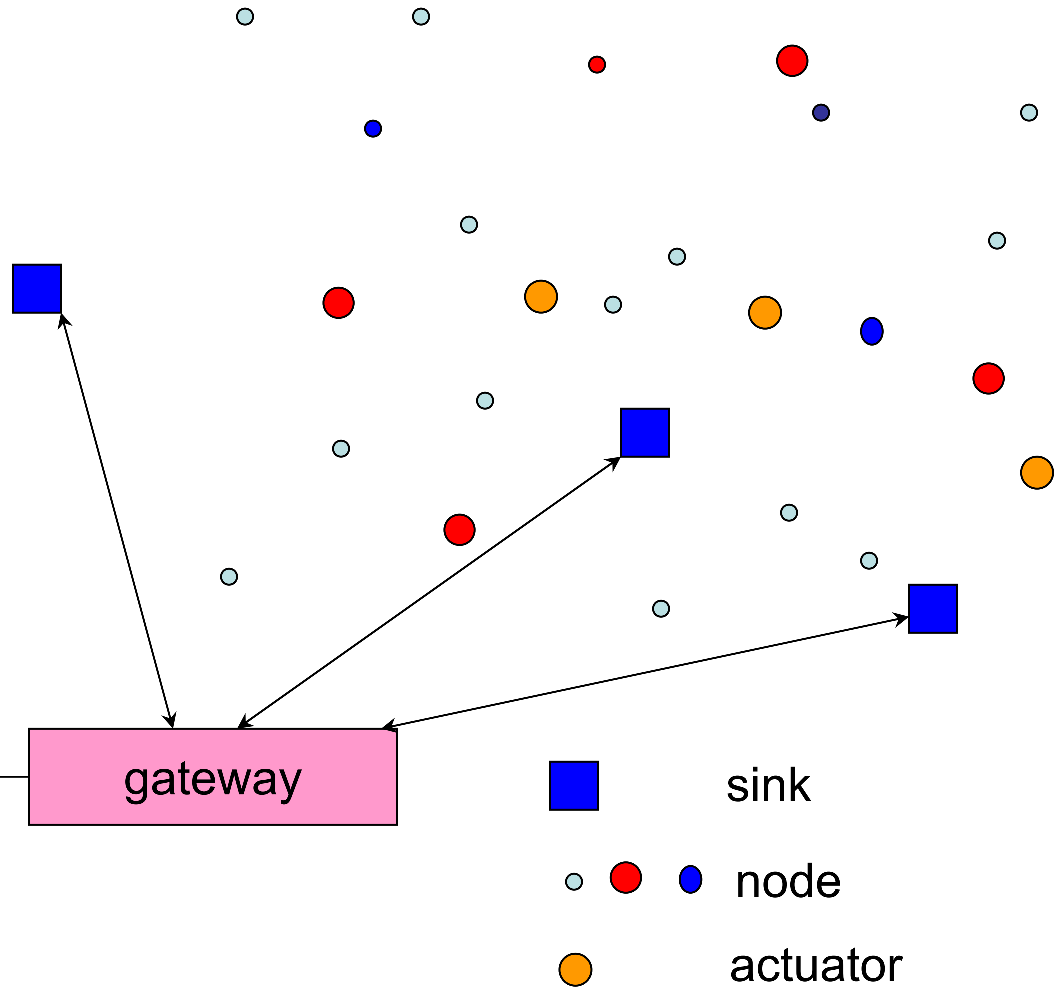
Wireless Sensor Network
With Heterogeneous Nodes

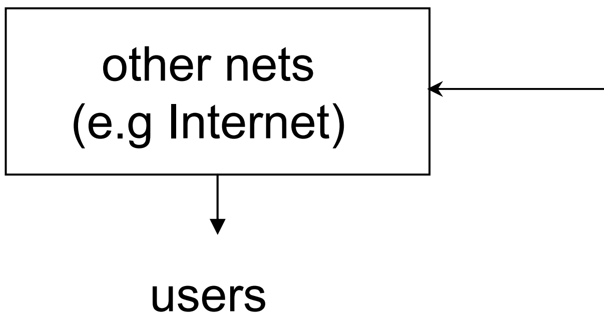


Basics

Wireless Sensor Network With Heterogeneous Nodes

A network of nodes that cooperatively sense the environment and may control it, enabling interaction between People (the users) and the Environment.





Basics

Nodes are
- low – cost
- low – complexity
- low – size
- [low – energy]

Short Transmission Ranges

Multi-Hop Transmission

WSNs are
- (possibly) large
- unplanned
- self-organising

Very Complex Unpredictable Topologies

Basics

What is a Wireless Sensor Network ?

Wireless sensors (hereafter, ***nodes***) are deployed in a given area, or volume (generically denoted as ***monitored space***).

They are connected through a self-organised wireless network.
Nodes can either be aware of their **location** or not.
In most cases, they are **stationary**. Nevertheless, applications with mobile sensors are becoming increasingly interesting.

In many cases each node is equipped with a battery that normally is not replaced during **network lifetime**: **energy efficiency** is a primary issue in these cases.

The network can be **homogeneous** (if all nodes have equal characteristics) or **heterogeneous.**

One or more monitoring stations (denoted as ***sinks***) are located inside or outside the monitored space and collect the information.

All nodes can behave like **receive-and-forward** devices (**multi-hop** routing is used); however, nodes can perform **distributed and/or collaborative signal processing** in order to reduce the amount of information to be transmitted.

Scalability (with respect to network size, or monitored space size) is a fundamental characteristics.

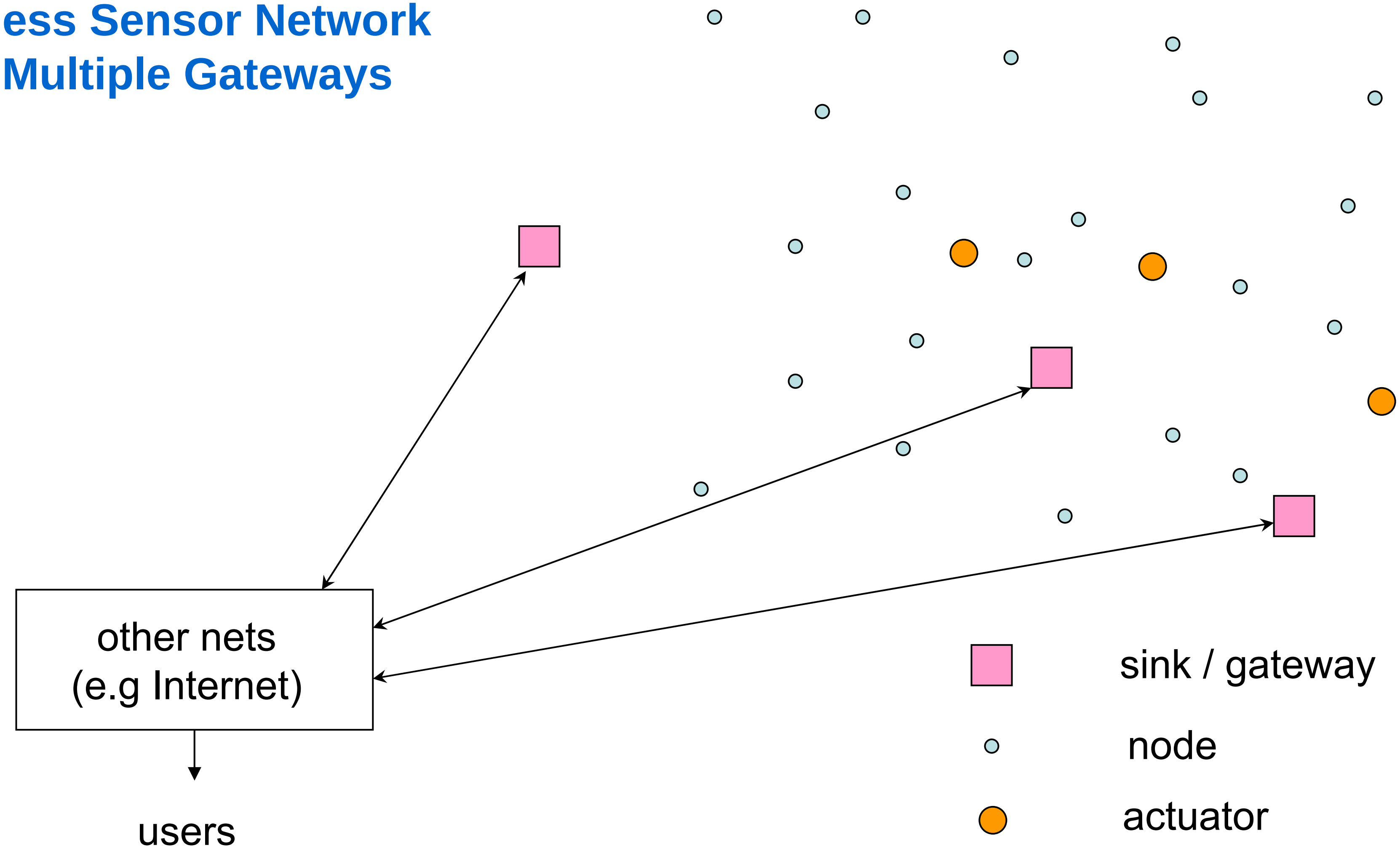
The sinks then transmit the result of their monitoring to external entities by means of a separate network (through a ***gateway***).

Sink(s) can **trigger** nodes. Alternatively,
nodes autonomously transmit the data they sense (i.e. the ***report***) periodically or when an event is detected.
When nodes are triggered, they can be selectively addressed (i.e. the ***sensed space*** is generally a subset of the monitored space).

According to node density and transmission range,
the network can be **fully connected** or not.
Coverage of the sensor network depends on the sensing range of nodes.
Coverage and **connectivity** are closely related features and very relevant aspects.

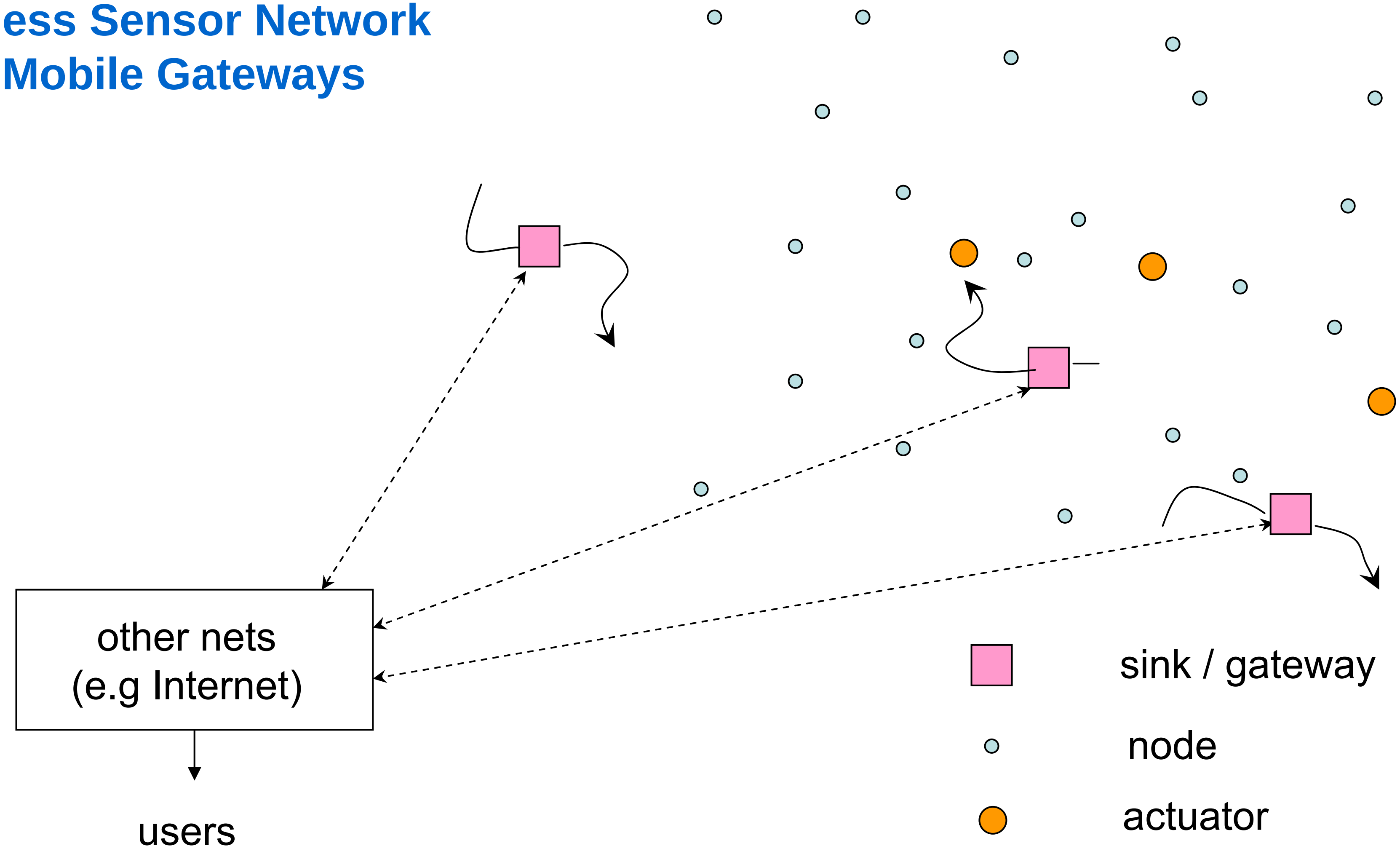
Basics

Wireless Sensor Network
With Multiple Gateways



Basics

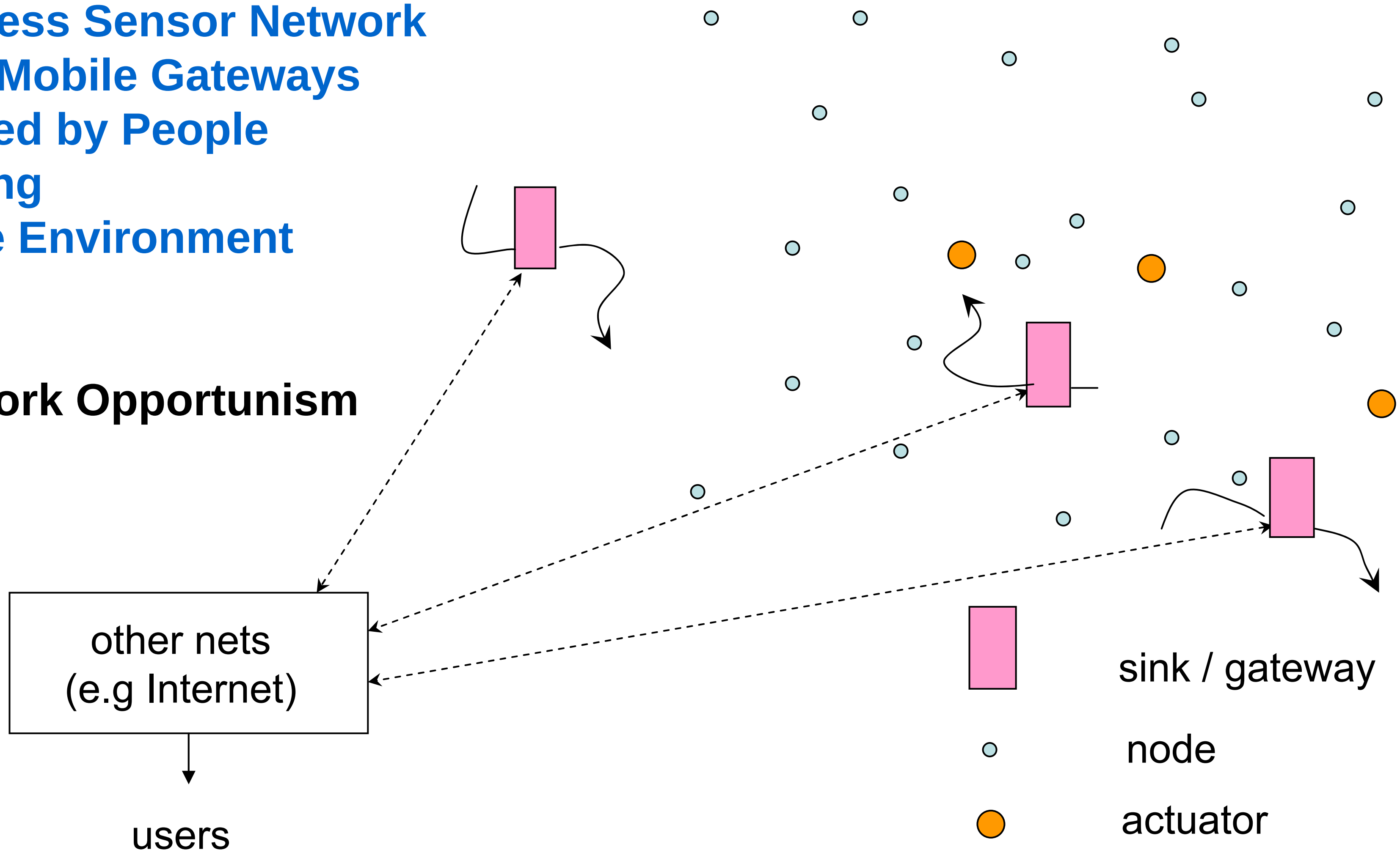
Wireless Sensor Network
With Mobile Gateways



Basics

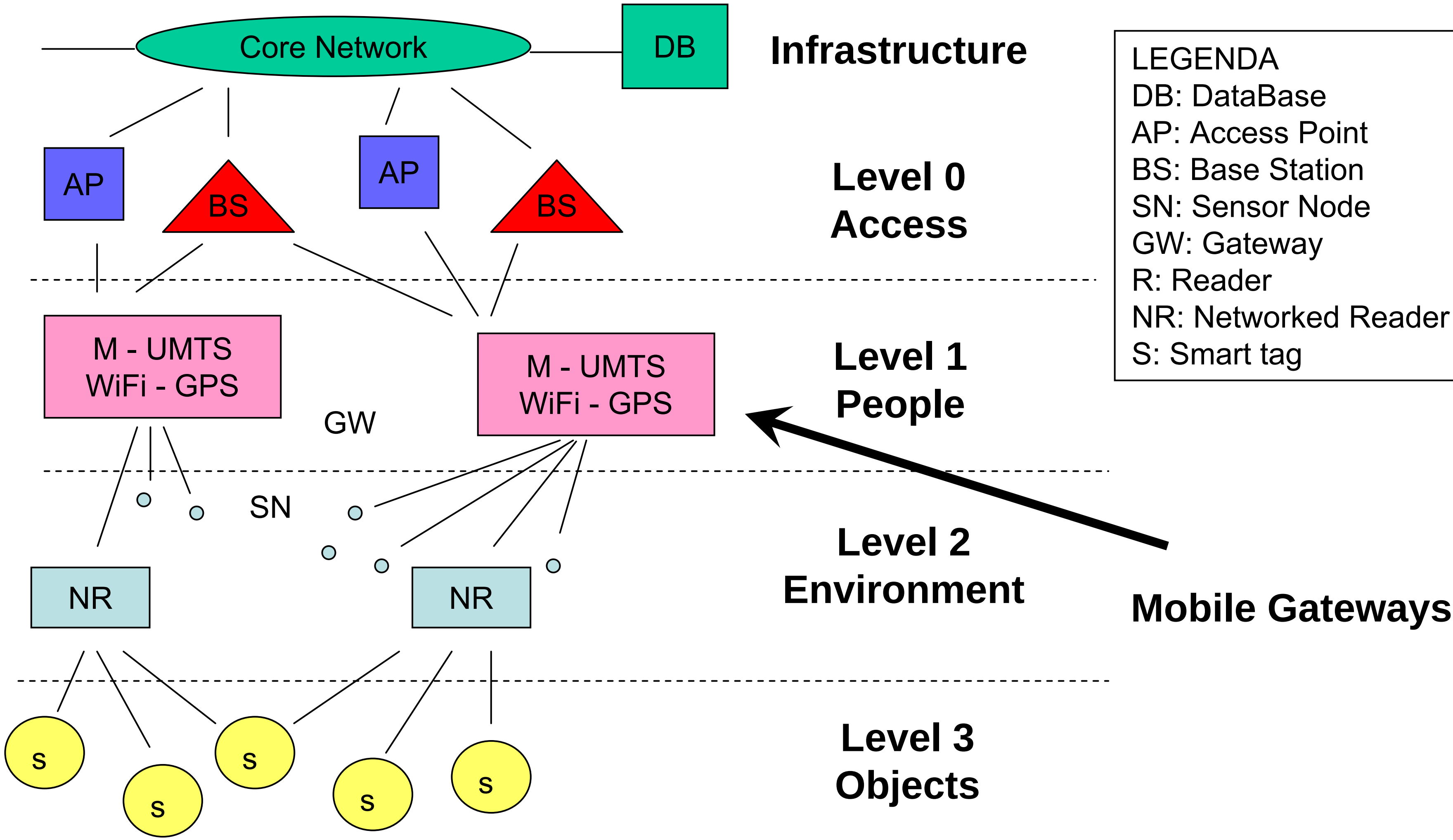
Wireless Sensor Network With Mobile Gateways Carried by People Moving in the Environment

Network Opportunism



Basics

HHA – the Hybrid Hierarchical Architecture (CRUISE, EC FP6)



LEGENDA
DB: DataBase
AP: Access Point
BS: Base Station
SN: Sensor Node
GW: Gateway
R: Reader
NR: Networked Reader
S: Smart tag

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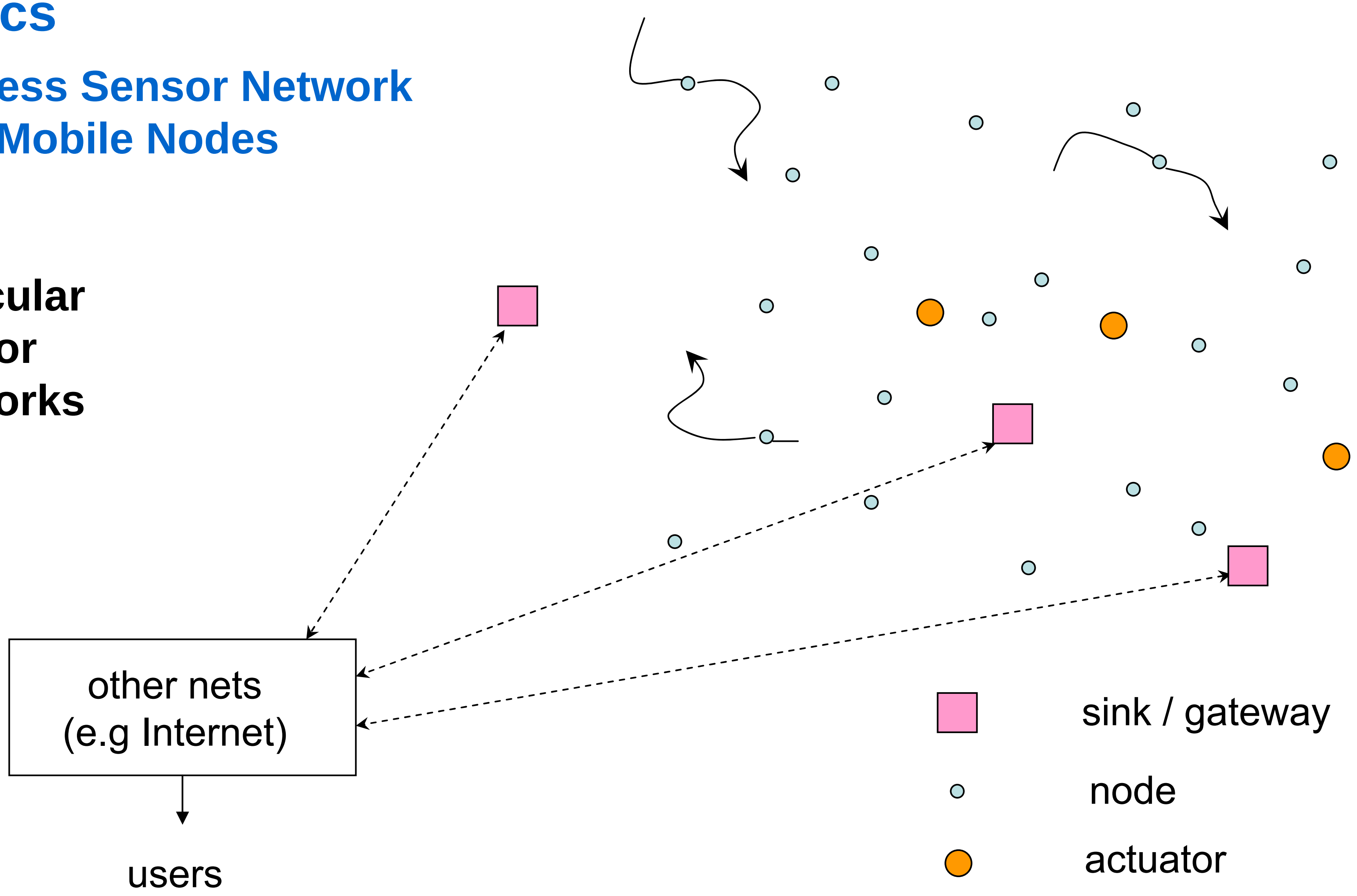
Basics

Wireless Sensor Network
With Mobile Nodes

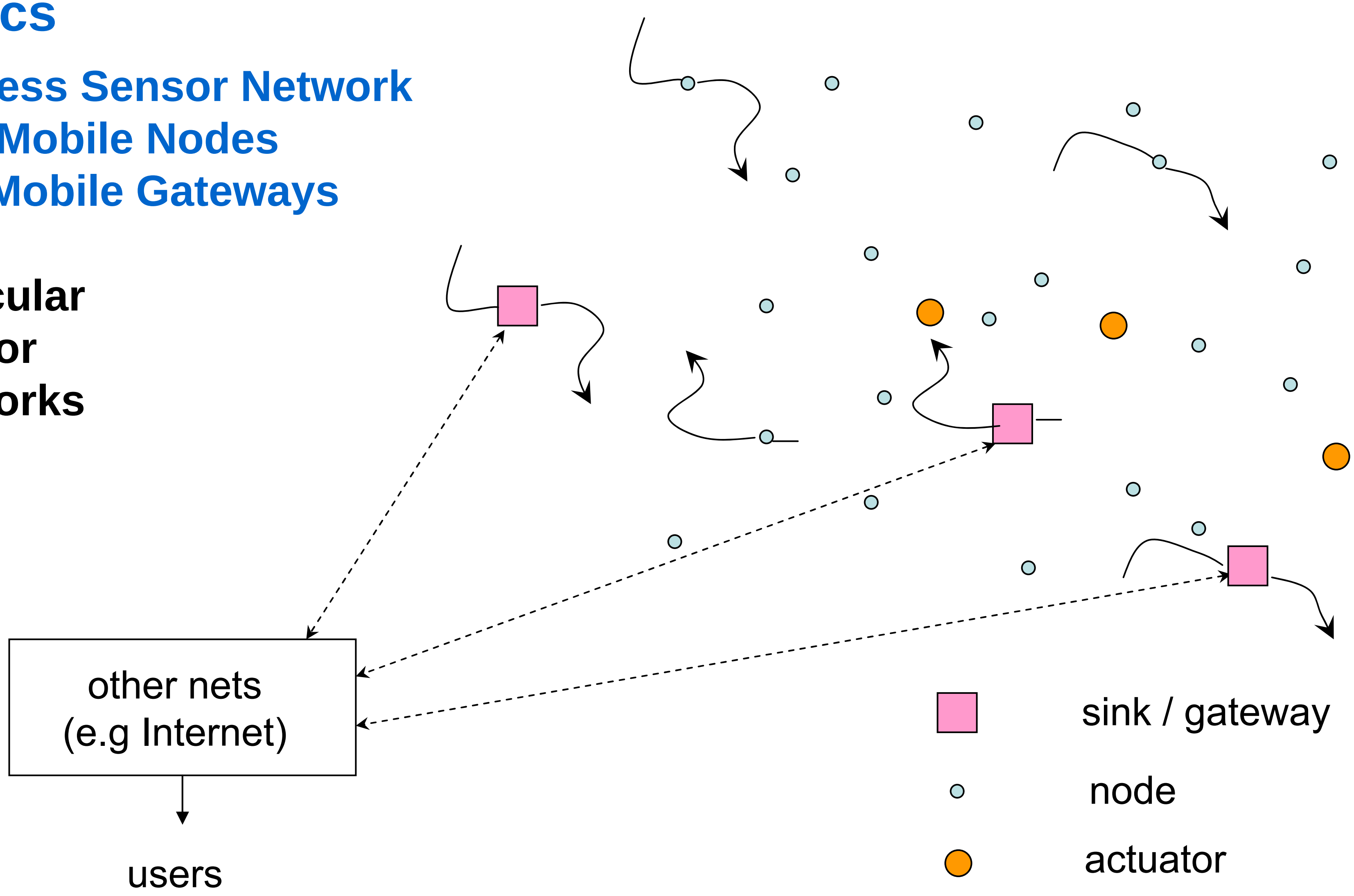
**Vehicular
Sensor
Networks**



Basics

Wireless Sensor Network
With Mobile Nodes
And Mobile Gateways

Vehicular
Sensor
Networks



To Sum Up

Self- Everything (Organisation, Maintenance, Healing, …)

No centralised control
No planning ⇨ Comm. Protocols
No need for human control

Energy Efficiency

Network Lifetime can be the primary performance metric
⇨ Comm. Protocols & HW

Scalability

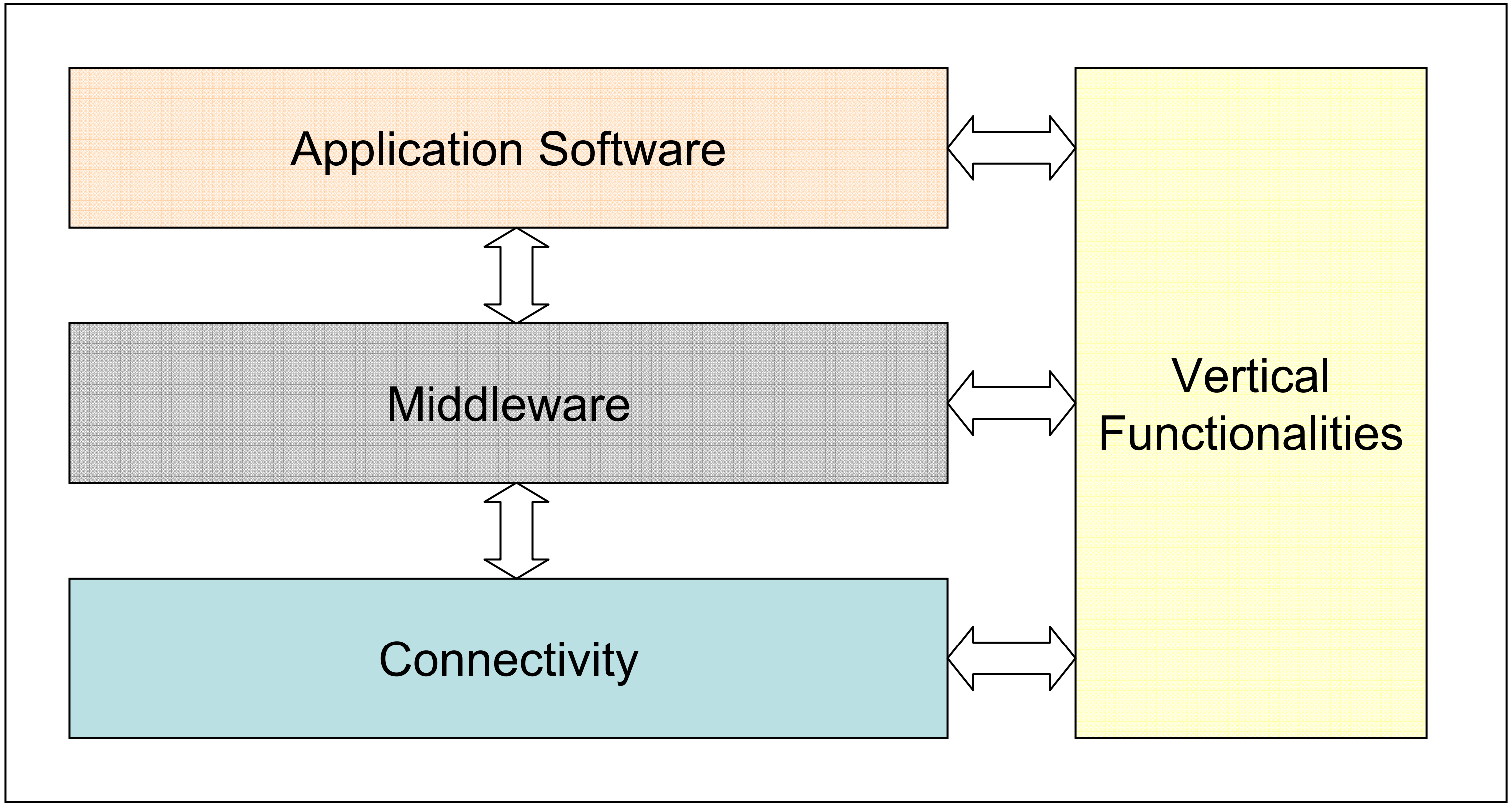
All protocols must work whatever the size of the network
⇨ Data Aggregation

Connectivity and Coverage

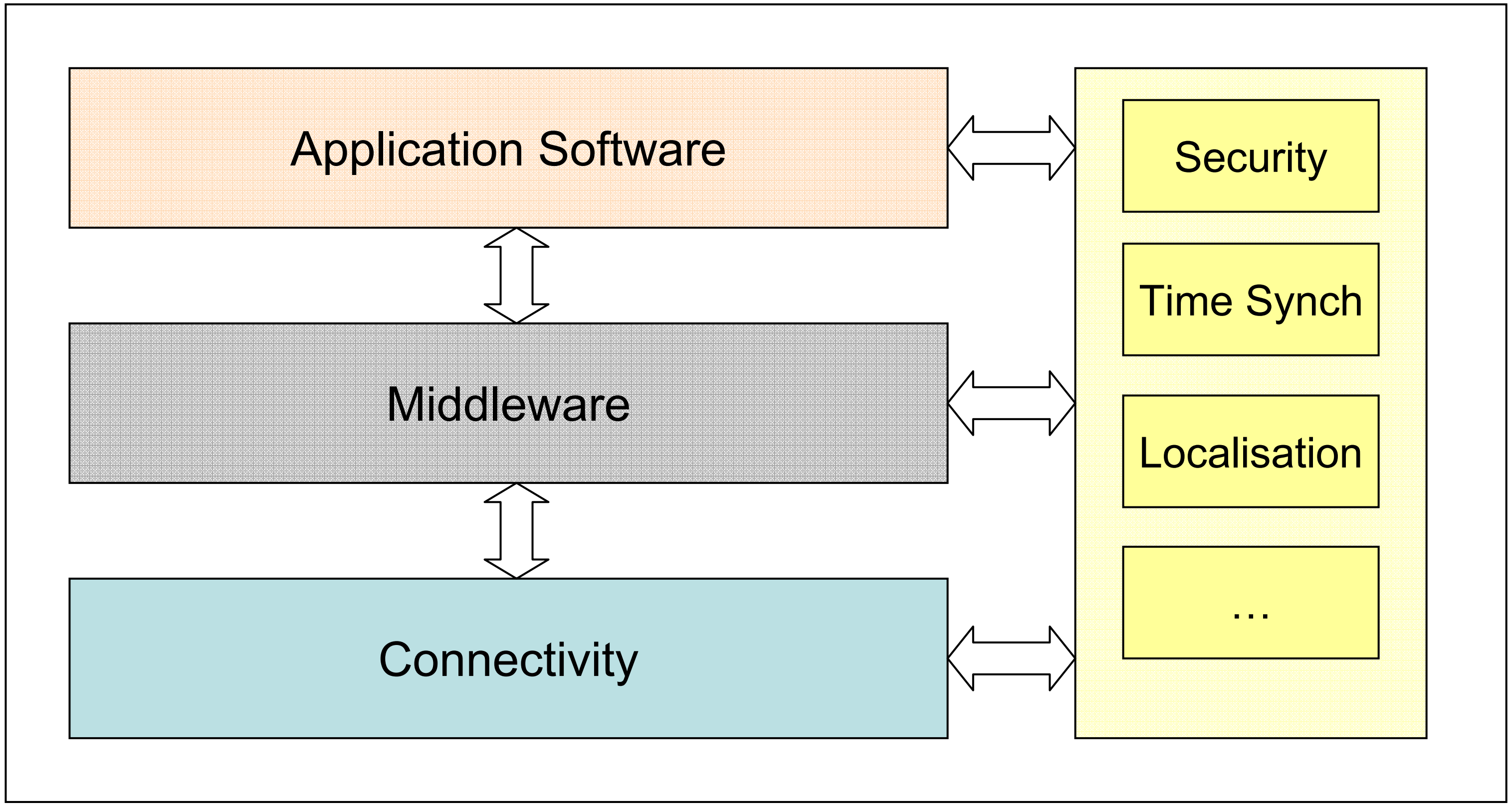
The information must be detected and forwarded to sinks
⇨ Radio Channel Perform.

Other aspects: Security, Reliability, …

A Reference Node Architecture



A Reference Node Architecture



Section 2
Applications

Examples
Taxonomy
Requirement Types

Applications

From “Sensor Networks: A Bridge to the Physical World”
by Jeremy Elson and Deborah Estrin (2003)

THE QUAKE

It was in the early afternoon of an otherwise unremarkable Thursday that the Great Quake of 2053 hit Southern California.

…

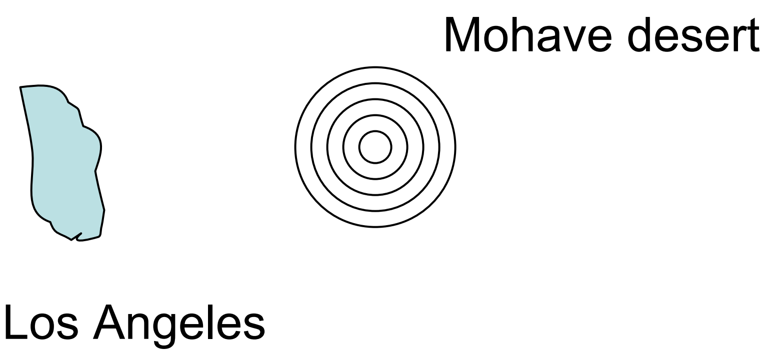
Applications

The earth began to rupture several miles under the surface of an uninhabitated part of the Mohave desert.

Decades of pent-up energy was violently released, sending huge shear waves speeding toward Los Angeles.

The quake was enormous, even by California standards, as its magnitude surpassed 8 on the Richter scale.

…



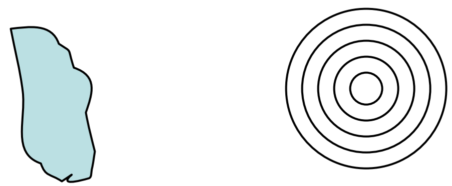
Applications

Residents had long ago understood such an event was possible.
This area had been instrumented by scientists for more than a century.

By the turn of the century, the situation had improved considerably.
Many seismometers were connected to the Internet …

If a sensor was close enough to the epicenter,
and the epicenter was far enough from a population center,
the alarm could be raised 20 or 30 seconds before the city started to shake.
The idea was promising.

…

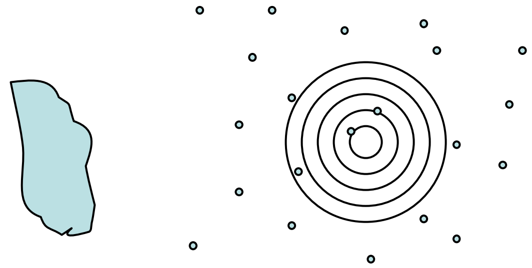


Applications

But, in the half century leading up to the Great Quake of 2053, technological advances changed everything.

By the mid 2040's, the vast, desolate expanse of the desert floor was home to nearly a million tiny, self-contained sensors.

…



Applications

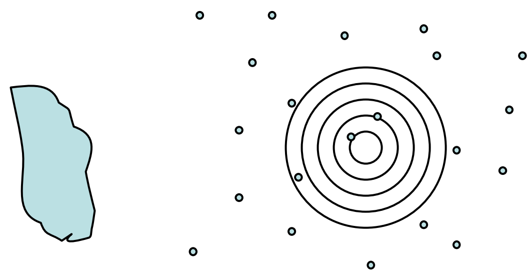
It was just a few dozen of those seismometers – closest to the epicenter – that first sensed unusual acceleration in the ground.

As the number of confirmed observations grew, so did the likelihood that this event was not simply random noise. It was real.

In a few tenths of a second, the earth's movement had the attention of thousands of seismometers within a few miles of the epicenter.

The network soon reached consensus: this was an earthquake.
It was a dangerous one.

…



Applications

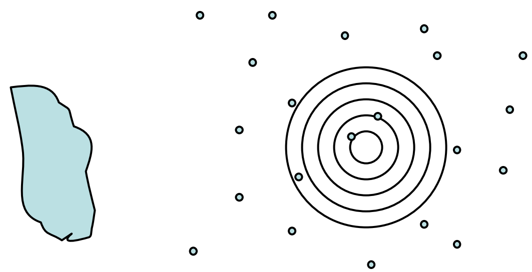
The information hopped from one node to the next.
After 41 miles, it finally reached the first sign of civilization:
a wired communication access point.

Four seconds had passed since the quake began.

Once on the wired grid, the alarm spread almost instantly to every city.

The new generation of smart structures in Los Angeles
learned of the quake nearly thirty seconds before it arrived.

…

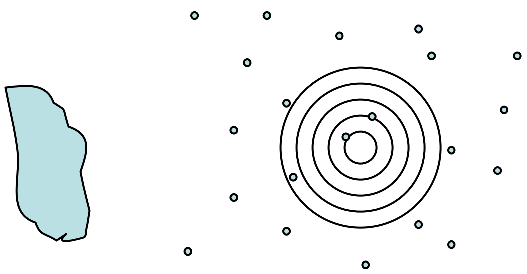


Applications

Tense moments passed.
Sirens blared as every traffic light turned red,
every elevator stopped and opened at the nearest floor …

Finally, the silence was broken, a low rumble, a deafening roar.
The earth rolled and shook violently.

…



Applications

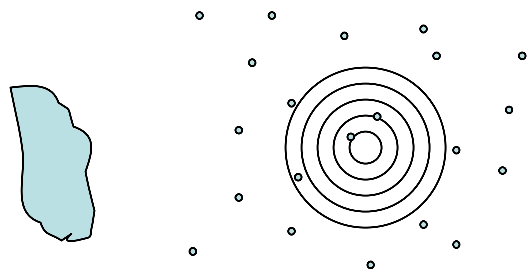
The city could not completely escape damage. Many older homes collapsed.

Rescue crews arrived with Portable Emergency Survivor Locators.
Each was a nylon package the size of a bottle containing thousands of tiny sensors that could disperse themselves as the package was thrown.

Back at the rescue truck, a map of the structure began to appear.
People were visible as heat sources.

Chemical sensors began to detect abnormal traces of natural gas …

…

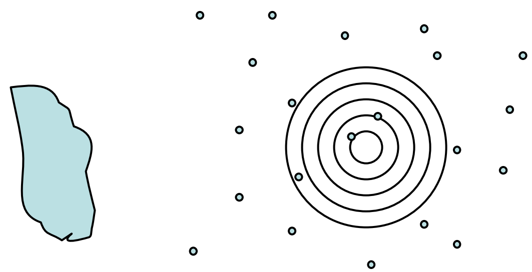


Applications

By Monday, Southern California had returned to normal.
The 2053 quake came and went, thanks largely to the pervasive sensors…

…

IS ALL THIS INVENTION, OR WILL IT BE REALITY?

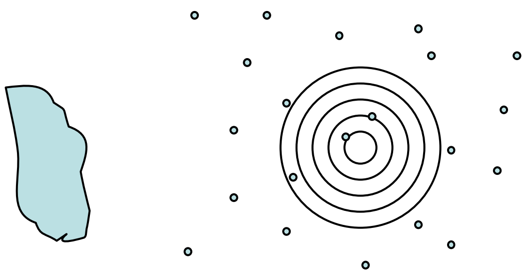


Applications

To many people in 2003, using technology to prevent such a catastrophe must have seemed fanciful and improbable.

It seemed as improbable as 2003's globally interconnected network of nearly a billion computers (the Internet!) must have seemed to those in 1953.

Indeed, perhaps even as improbable as 1953's "electronic brain" must have seemed to those in 1903, who would soon experience their own Great Earthquake in San Francisco.



Applications

Application Examples are

…

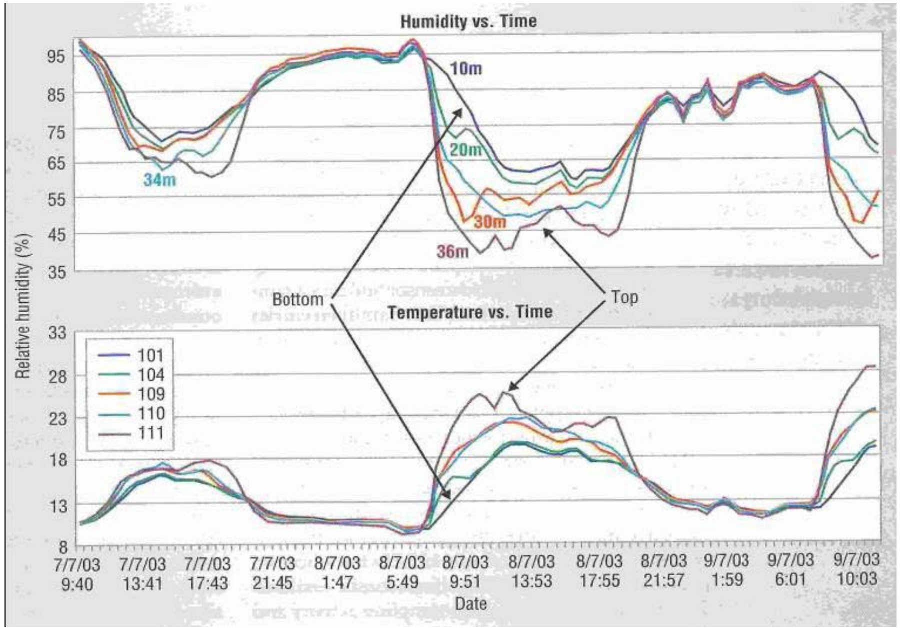
Applications

Application Examples:

WSNs for home/office control
WSNs for industrial automation
WSNs for logistics
WSNs for transportation systems
WSNs for emergency systems
WSNs for healthcare
WSNs for monitoring of constructions
WSNs for urban control (traffic, safety, eco, …)
WSNs for animals tracking
WSNs for smart agriculture
WSNs for environmental monitoring (fire detection,…)
…

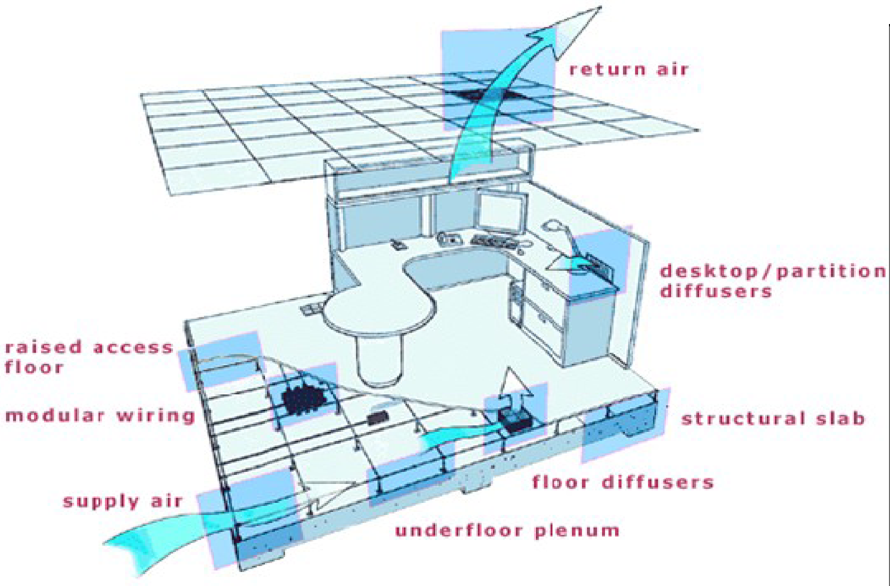
Applications

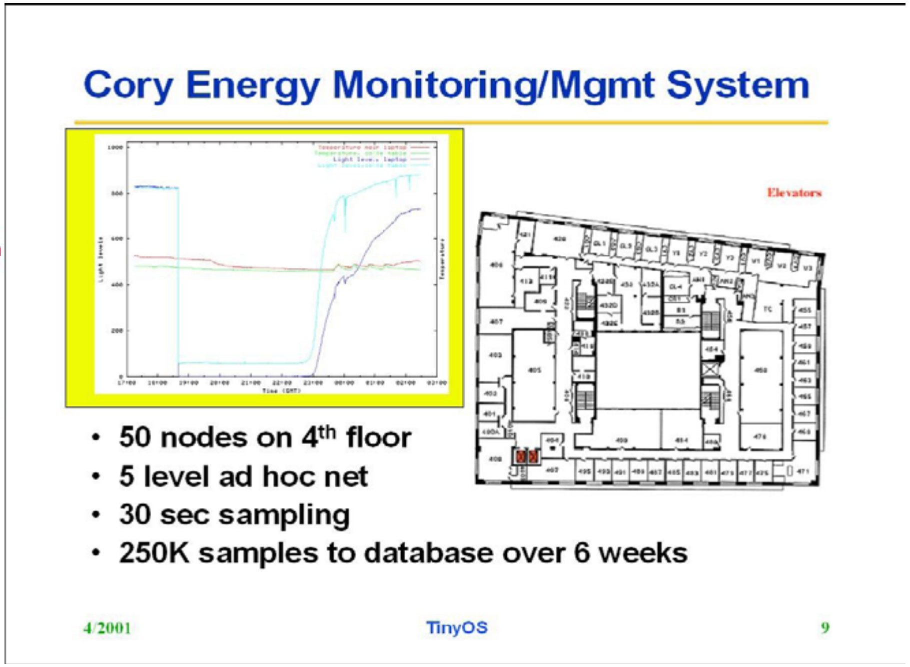
- UC Botanical garden sensor network project:
  - to help understand growth dynamics, water intake, nutrient transport;
  - sensors measure light, humidity, pressure and temperature;
  - data sampled every 5 minutes.



Applications

- Center for Built Environment at UC Berkeley:
  - improve building energy efficiency, improve indoor environmental quality;
  - wiring is most of a sensor network's cost;
  - small enough to embed in furniture or ceiling tiles.





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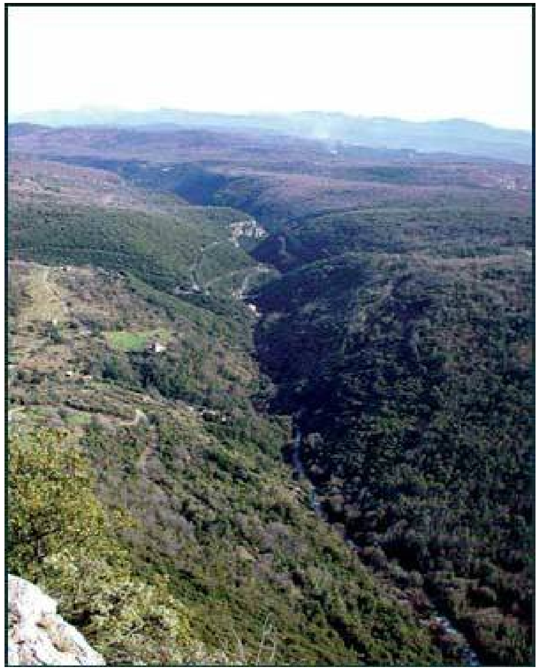
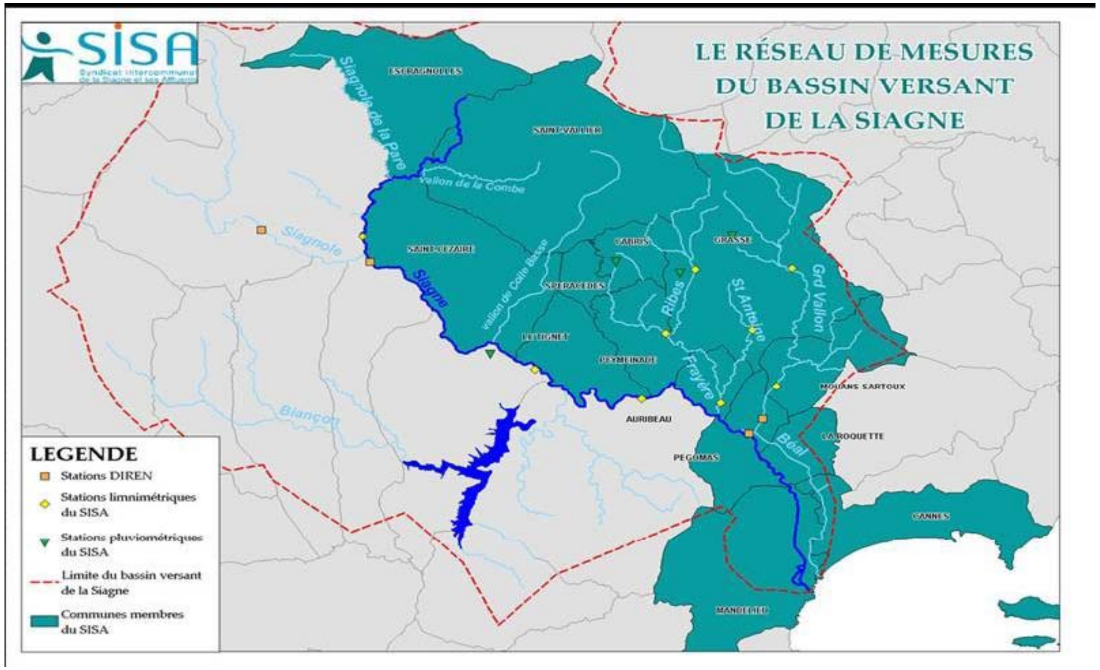
Applications

- River bed monitoring in South of France:
  - floodings of coastal rivers along the Med;
  - experiment on-going which monitor rain fall, water level and raise alert;
  - proprietary meshed network, multi-hop, to GPRS gateways.





Applications: Amount of Data Generated by Nodes

Forest Fire Detection

RF levels in areas covered by cellular systems

Tracking of vehicles in closed areas (airports…)

Videos taken from in-vehicle cameras for security reasons

…

Nodes can send few Bytes per hour, or

many KBytes per second…

Applications: Type of Reporting

Event Detection → **Event – Triggered Reporting**

or

Estimation of Spatial (and Temporal) Random Processes → **Loose Periodic Reporting**

or

Monitoring / Tracking → **Frequent Periodic Reporting**

Applications: Type of Requirements

Event Detection → **Req.s on delay**

or

Estimation of Spatial (and Temporal) Random Processes → **Req.s on data losses**

or

Monitoring / Tracking → **Req.s on network throughput**

Event Detection

The density of nodes must ensure:
- The event is detected with given probability;
  → **coverage**, related to sensing range of nodes and event type
  → **distributed localisation** algorithms
- The report can be received by the sink(s) with given probability;
  → **connectivity**, related to transmission range of nodes
  → **communication** protocols

The sampling frequency must ensure:
- The event is detected with given probability;
  → **responsiveness**, related to event type
- The report timely reaches the sink(s)
  → **communication** protocols

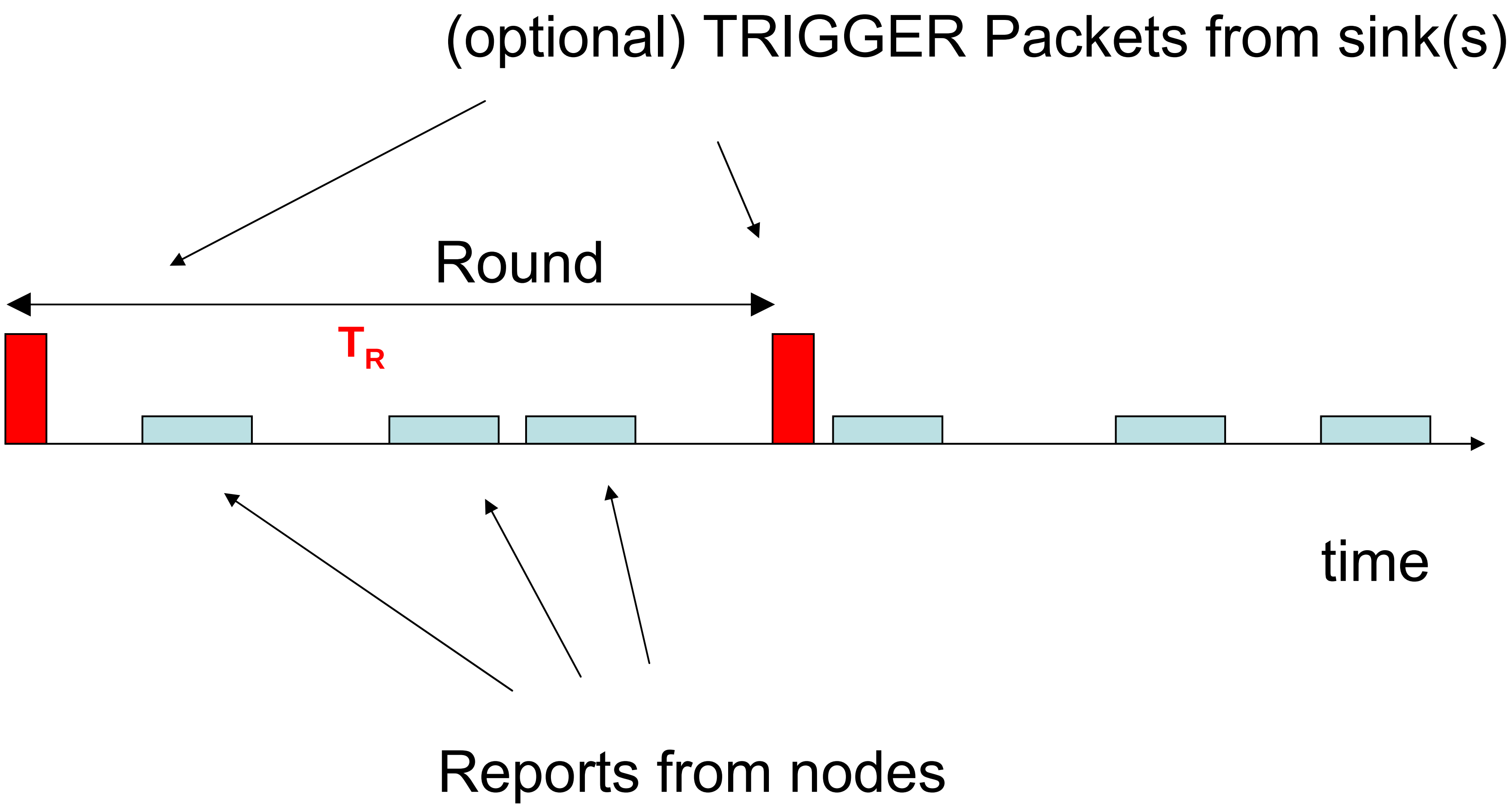
Both the density of nodes and sampling frequency are application-dependent.

Event Detection → Tracking

Tracking is a special case of event detection applications,
where the event (the target) moves and its position needs to be tracked.

→ **localisation** is an important feature
→ **time synchronisation** is also very relevant

Estimation of Random Processes



Estimation of Random Processes

The density of nodes must ensure:
- The process is accurately estimated;
  → **signal processing**, related to process type
- The samples can be received by the sink(s) with given probability;
  → **connectivity**, related to transmission range of nodes
  → **communication** protocols

The sampling frequency must ensure:
- The process evolution is tracked;
  → **responsiveness**, related to process type

Both the density of nodes and sampling frequency are application-dependent.

Requirement Types

Event Detection

Probability of false alarm	< 0.1 – 0.001
Probability of missed detection	< 0.1 – 0.001
Localisation precision	< 100 – 1 m
Latency	< 0.1 – 10 s
Network lifetime	> months - years

Estimation of Random Processes

Sampling frequency	see later
Estimation error	see later
Network lifetime	> months - years

The different types of requirements make protocols very application-dependent.

Estimation of (Temporal) Random Processes – Examples

Requirements for sampling frequency (→ round interval)

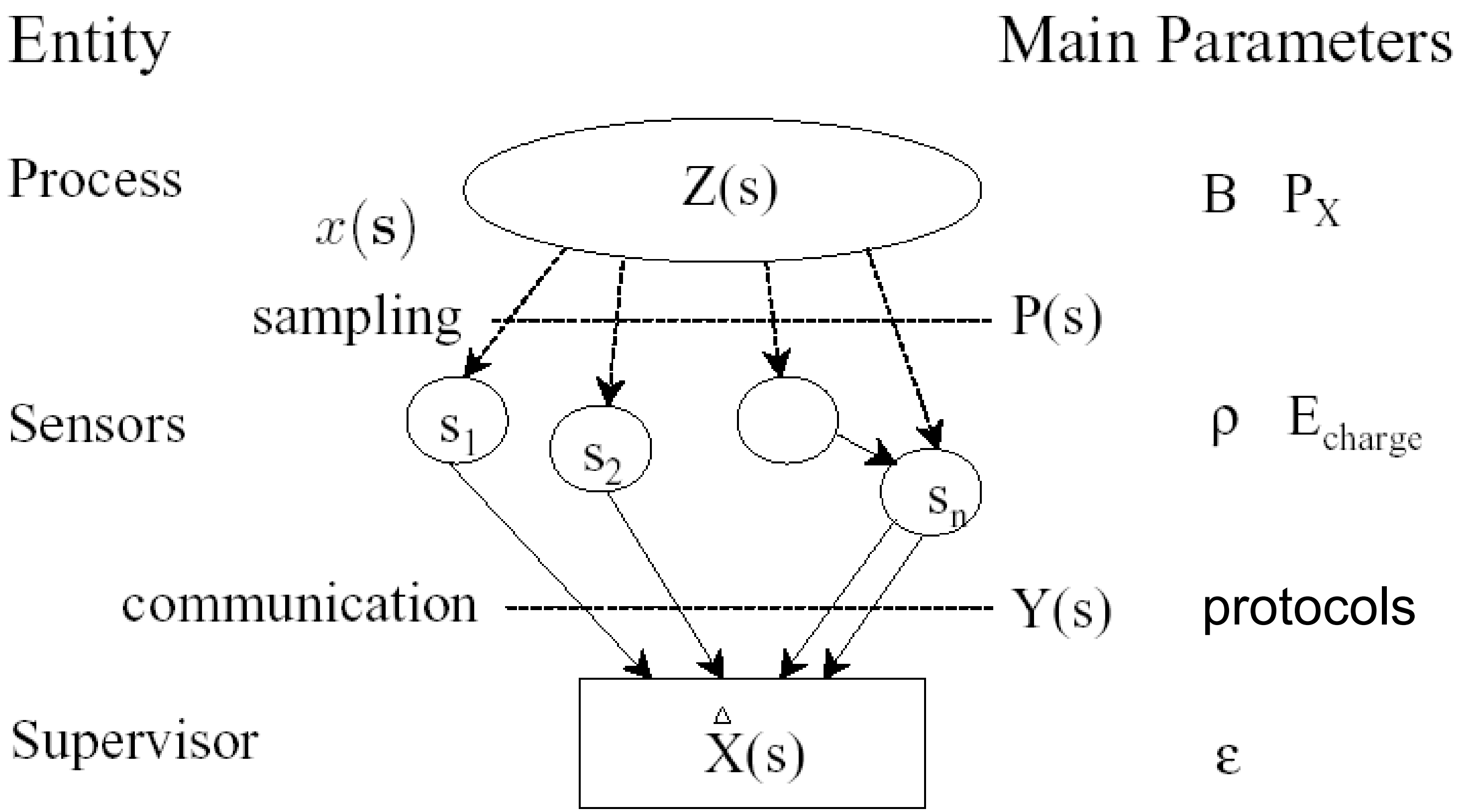
Acoustic sensors – 2 KHz bandwidth
Magnetometers – 10 Hz bandwidth
Accelerometers – samples at 48 KHz

Some applications (e.g pollution control) require few samples per day …

→ T_R might range from 10^{-5} to 10^{+5} seconds.

Very different values of the round interval, depending on specific application.

Estimation of Spatial Random Processes – A Model*



* Verdone, Conti, Sangiorgi, Dardari, "Process Estimation through …" IEEE GLOBECOM 2004

Estimation of Spatial Random Processes – A Model

$$\varepsilon = \frac{1}{E_0}\mathbb{E}\left\{\int_{\Re^l}\left(\hat{X}(\mathbf{s}) - x(\mathbf{s})\right)^2 d\mathbf{s}\right\}$$

$$\varepsilon = p^2 + (1-p)\beta\zeta/\rho \qquad \beta = (2B)^l$$

ς=1

p probability of missing reception from a generic node

ρ density of nodes

Estimation of Spatial Random Processes – A Model

$$\varepsilon = p^2 + (1-p)\beta\zeta/\rho$$

$p = 0$ error proportional to β
error inversely proportional to ρ

$p > 0$ error increases

Example: $B = 10^{-3}$ m^{-1} i.e. $\beta = 4 \times 10^{-6}$
$\rho = 10^{-2}$ [nodes/m^2]
$p = 0$ → $\varepsilon = 4 \times 10^{-4}$
$p = 0.1$ → $\varepsilon = 10^{-2}$

MAC/Routing protocols, affecting missed packet reception probability, have a direct and significant impact on estimation quality.

Estimation of Spatial Random Processes – Example

$$\varepsilon = p^2 + (1-p)\beta\zeta/\rho$$

Example: $B = 10^{-3}\ \mathrm{m}^{-1}$ i.e. $\beta = 4 \times 10^{-6}$
$p = 0$
$\varepsilon = 4 \times 10^{-2}$ → $\rho = 10^{-4}$ [nodes/m^2]

Example: $B = 10^{-1}\ \mathrm{m}^{-1}$ i.e. $\beta = 4 \times 10^{-2}$
$p = 0$
$\varepsilon = 4 \times 10^{-2}$ → $\rho = 1$ [nodes/m^2]

→ Node density might range from 10^{-4} to 1 [nodes/m^2].

Very different values of the node density, depending on specific application.

To Sum Up

**Very wide ranges of
node densities, sampling frequencies,
QoS requirements,
make the design of wireless sensor networks
extremely application-dependent.**

**As a consequence, all protocols
must be very flexible
and adaptive to the different user requirements.**

ARTEMISIA

ARTEMISIA Association is the association for R&D actors in the field of ARTEMIS:
Advanced **R**esearch & **T**echnology for **EM**bedded **I**ntelligence and **S**ystems.

The first call of ARTEMIS Joint Undertaking (JU) is open for proposals.
Deadline: 3 September 2008 at 17:00:00 Brussels local time.

100 MEuros

https://www.artemisia-association.org/

ARTEMISIA Strategic Agenda includes
networked embedded systems as key elements

→ WSNs

ARTEMISIA

SP1. Methods and processes for **safety-relevant** embedded systems

SP2. Person-centric **health** management

SP3. Smart environments and scalable digital **services**

SP4. Efficient manufacturing and **logistics**

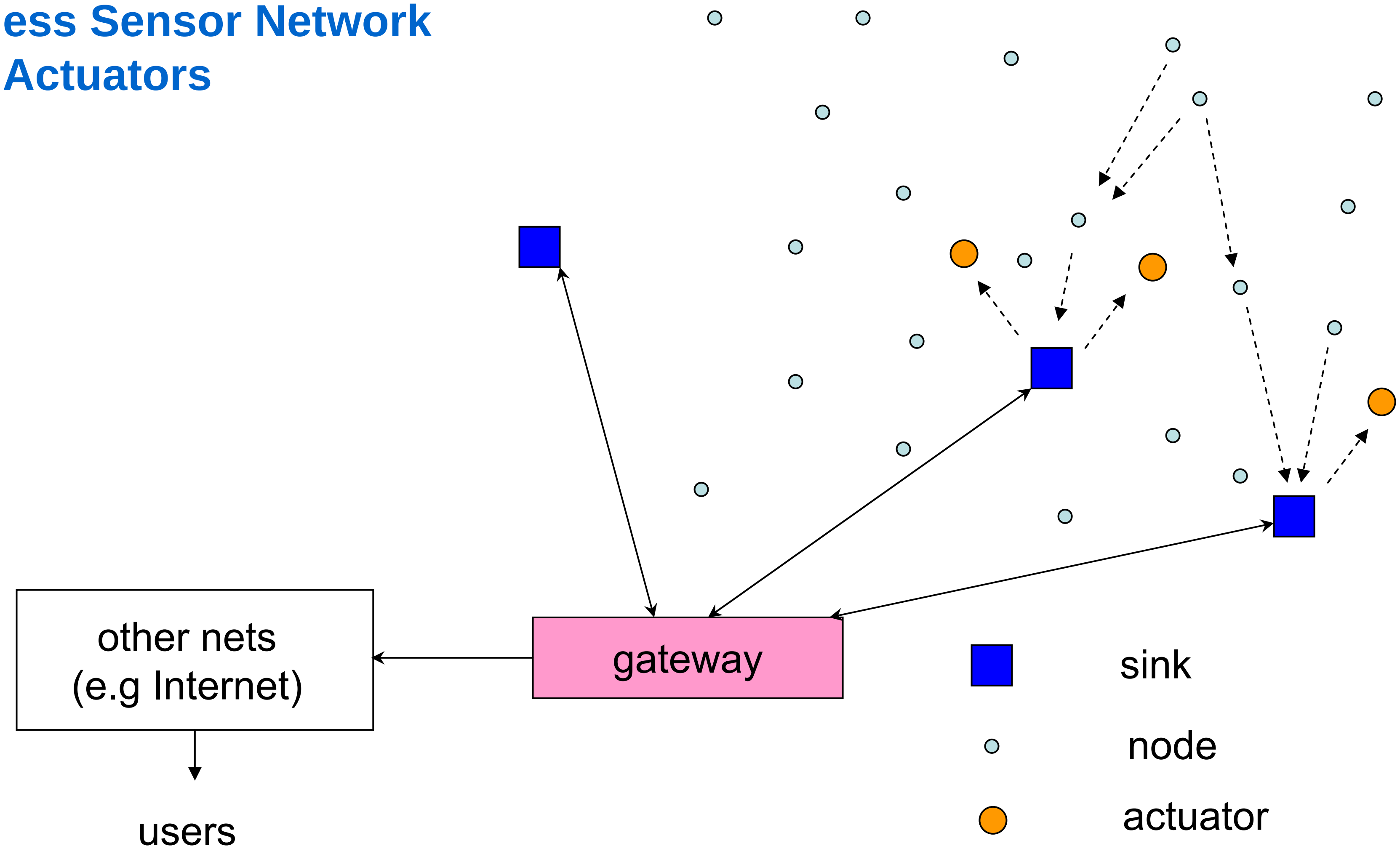
SP5. **Computing environments** for embedded systems

SP6. **Security, privacy** and dependability in Embedded Systems for applications, networks and services

SP7. Embedded technology for sustainable **urban life**

SP8. **Human-centric** design of embedded systems

Wireless Sensor Network With Actuators



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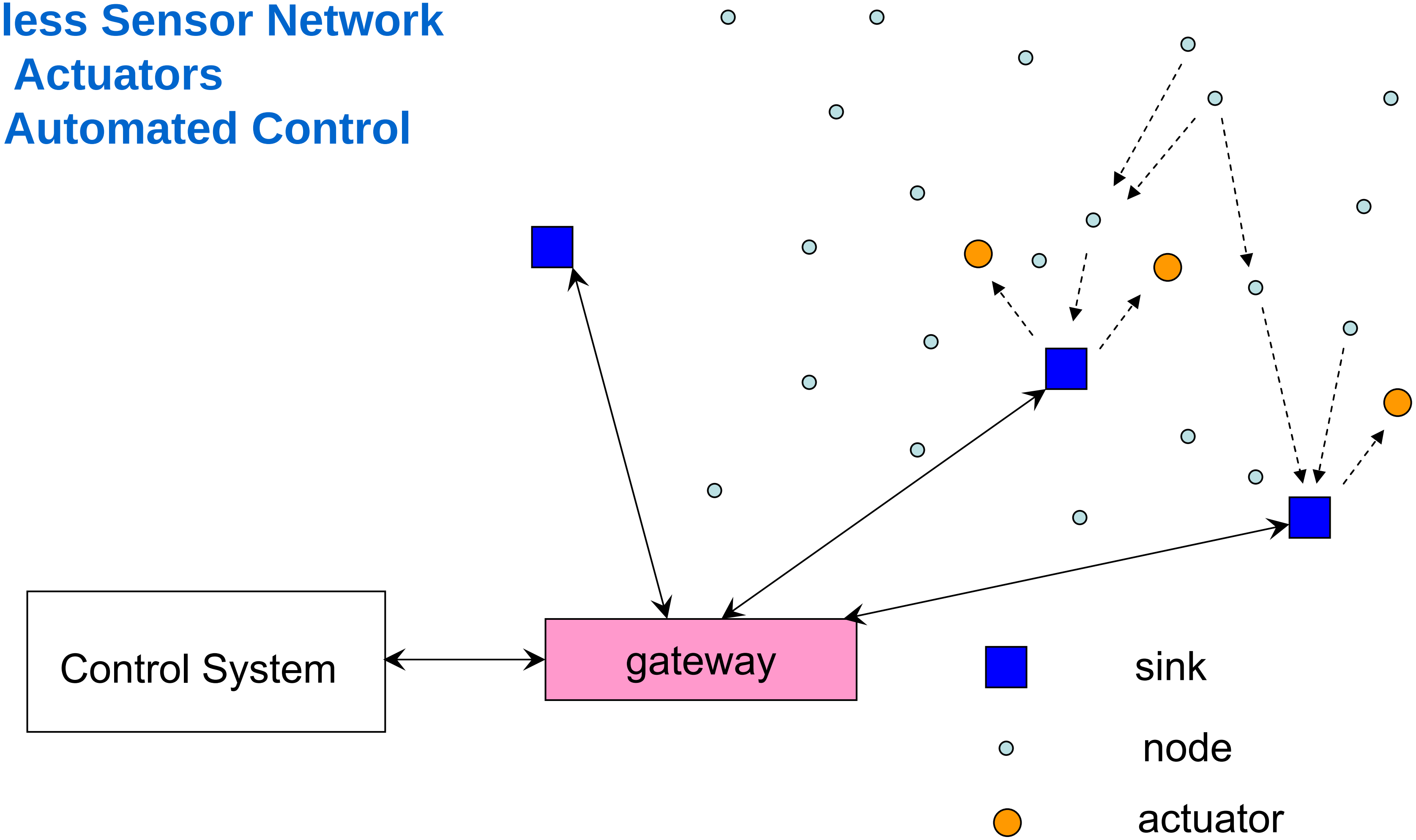
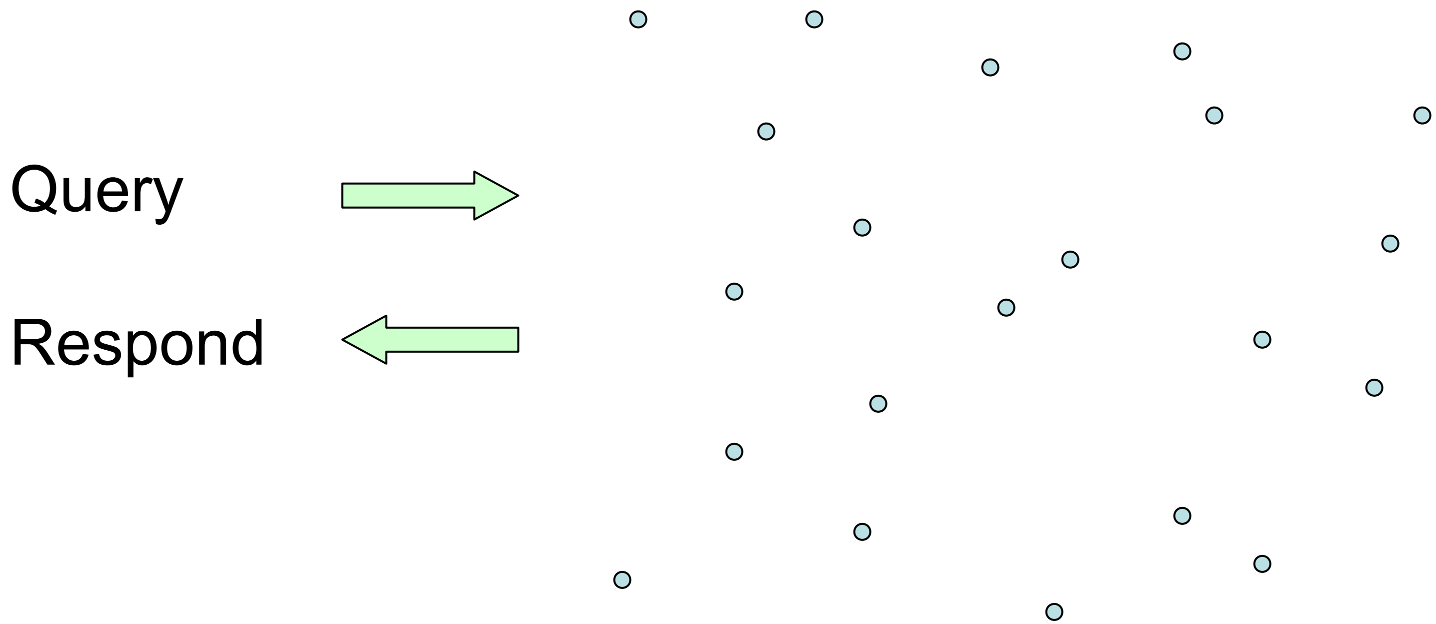
Wireless Sensor Network
With Actuators
And Automated Control

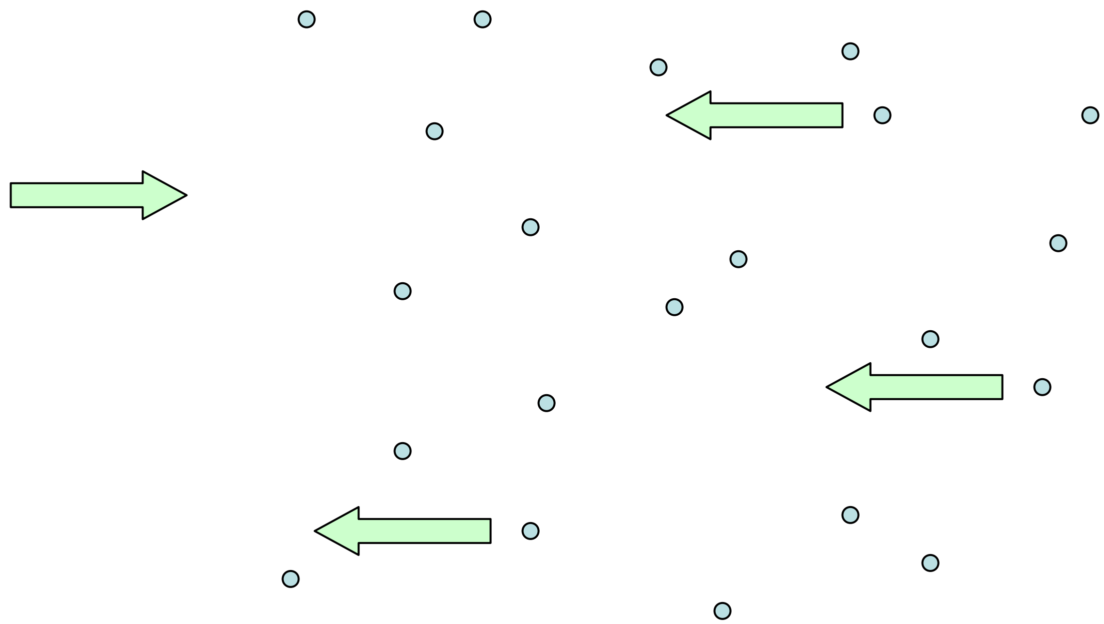


Query/Respond Paradigm



Publish/Subscribe Paradigm

Subscription



Publications

Section 3
WSNs vs WAHNs

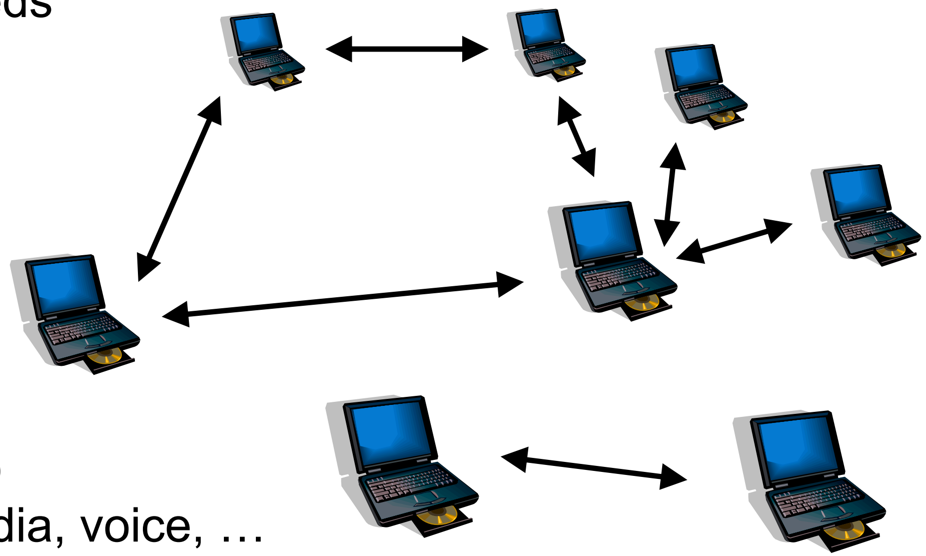
Wireless Ad Hoc Networks

WAHNs (Wireless Ad Hoc Networks) are formed dynamically
by an autonomous system of nodes connected via wireless links without using
an existing network infrastructure or centralised administration.

Nodes are connected through “ad hoc” topologies,
set up and cleared according to user needs
and temporary conditions.

Main Features

Fixed infrastructure is not needed
Unplanned and highly dynamical

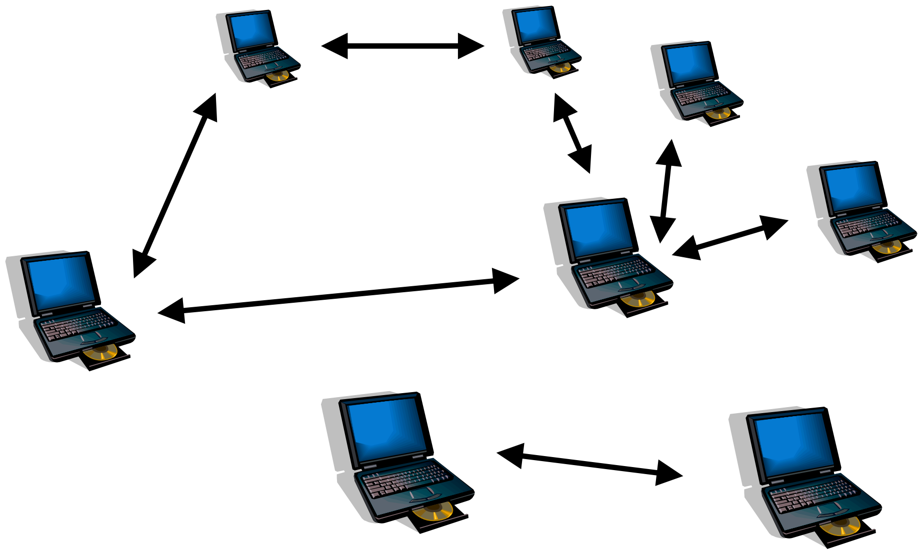


Nodes are “smart” terminals (laptops, …)
Real-time or non real-time data, multimedia, voice, …
Every node can be either source or destination of information
Every node can be a router toward other nodes
Energy is not the most relevant matter
Capacity is the most relevant matter

Wireless Ad Hoc Networks

Application Examples:

- Tactical Networks (military application) – nodes are mobile over battle field
- Emergency Services – nodes are mobile over large areas
- Home and Enterprise Networks – nodes are nomadic, palmtops or laptops
- …



WSNs vs Wireless Ad Hoc Networks (WAHNs)

WAHNs:

Fixed infrastructure is not needed
Unplanned

Nodes are “smart” terminals (laptops, …) no
Real-time or non real-time data, multimedia, voice, … no
Every node can be either source or destination of information no
Every node can be a router toward other nodes no
Energy is not the most relevant matter no
Capacity is the most relevant matter no

To Sum Up

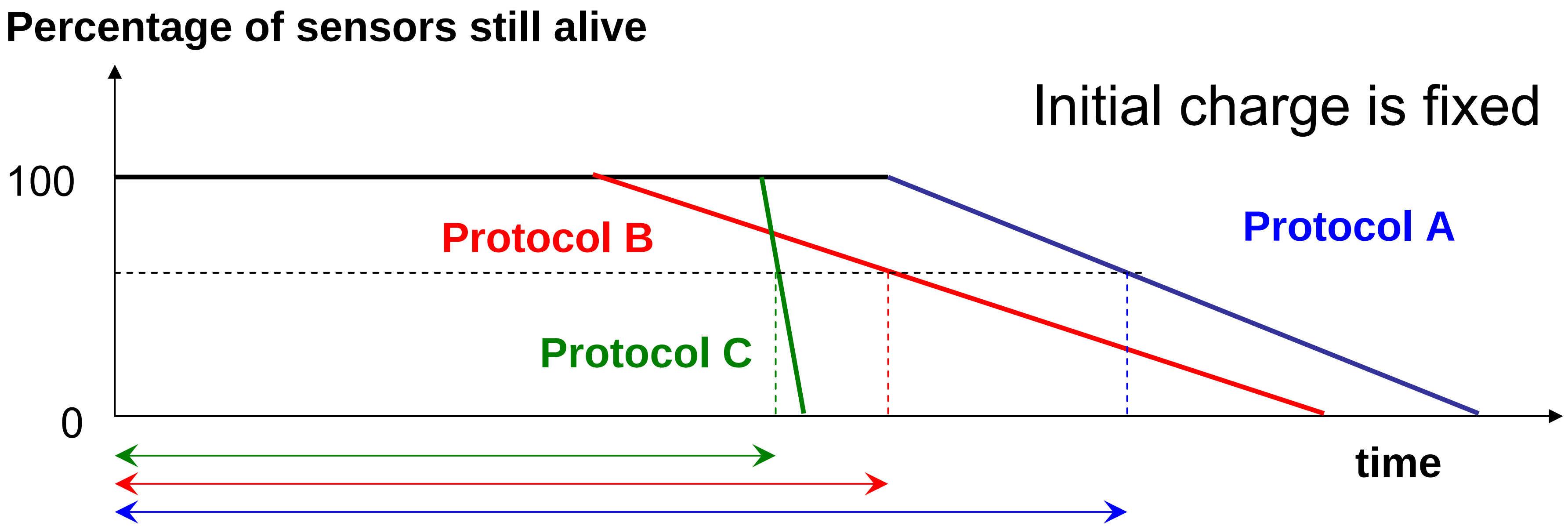
**WSNs are NOT a special case
of Ad Hoc Networks:**

**Communication Strategies
and Protocols
should be very different
(do not re-use IEEE 802.11 as it is!).**

Section 4
Energy Efficiency

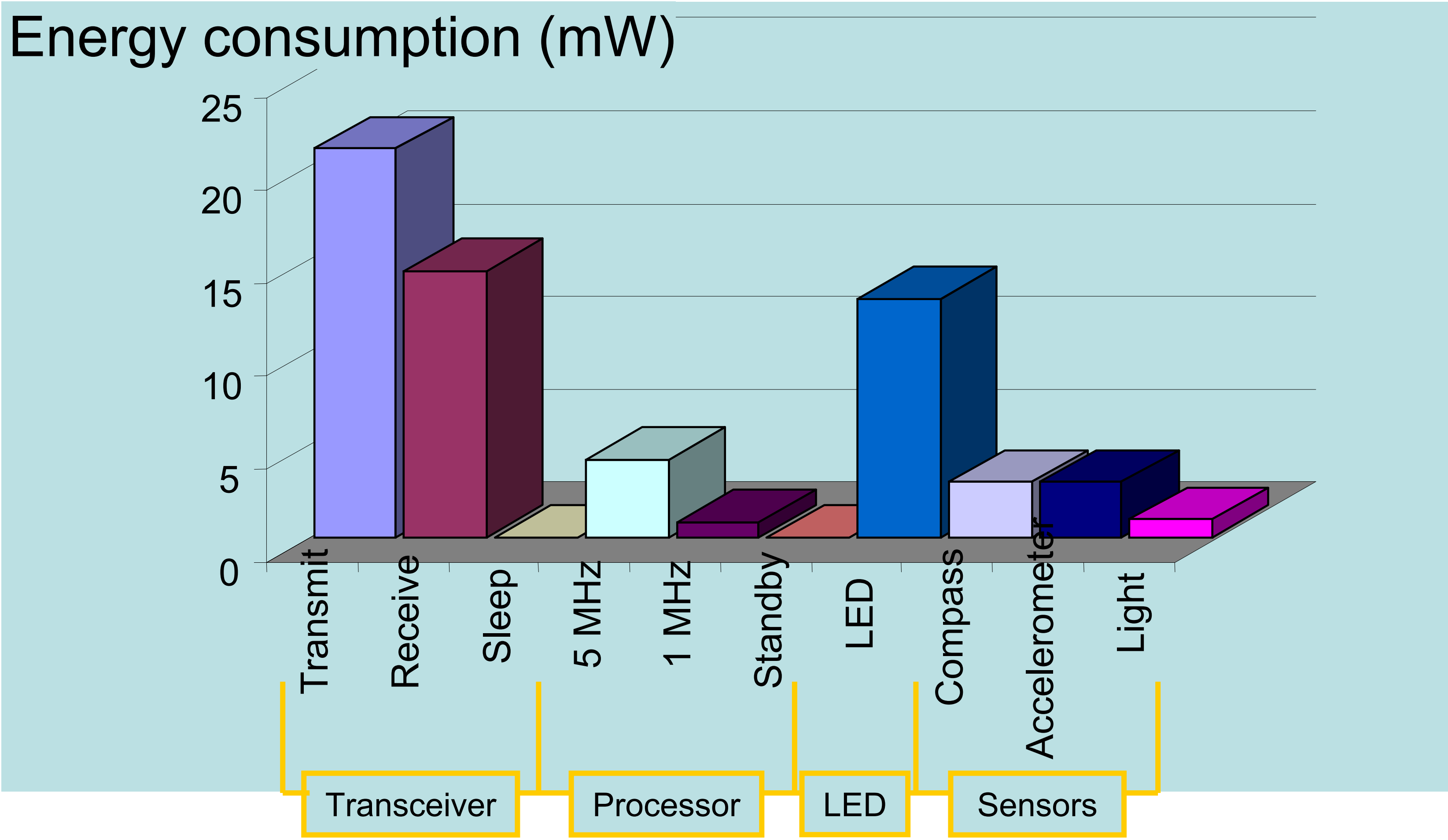
Energy Efficiency

Network lifetime is defined as the interval of time (possibly measured in *rounds*), started with the first transmission in the wireless network, ending when the percentage of nodes that have not terminated their residual energy falls below a specific threshold, which is set according to the type of application (it can be either 100% or less).



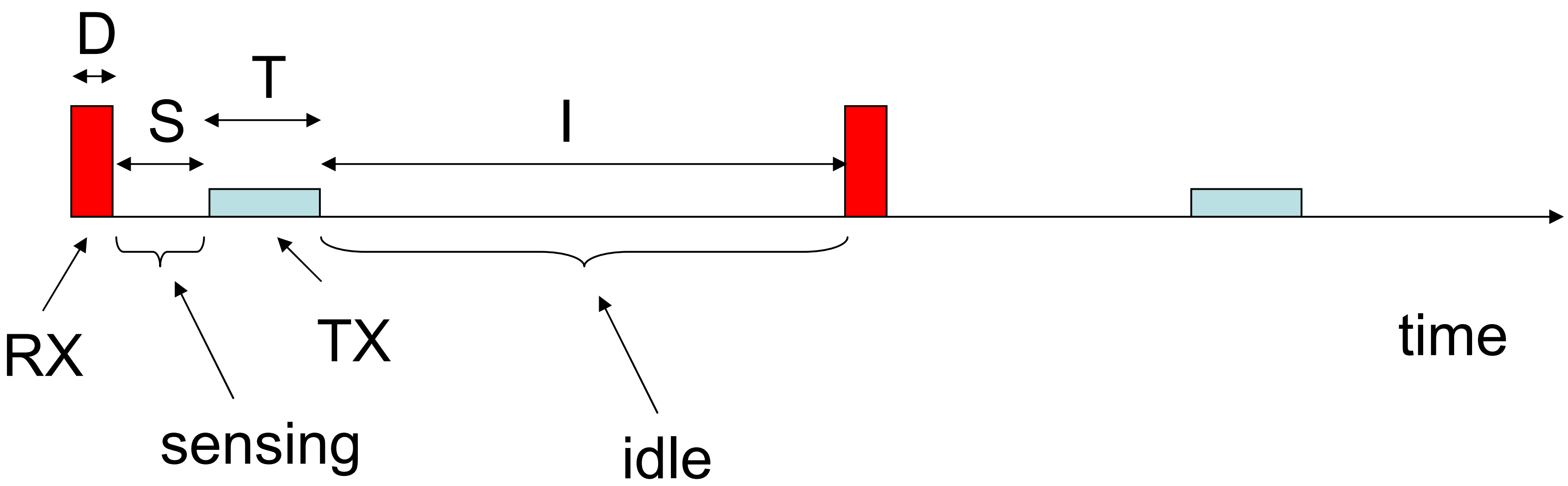
Energy Efficiency

Where is energy consumed?



Energy Efficiency

When is energy consumed?



$$E = e_{rec}\,D + e_{rec}\,S + e_{trasm}\,T \qquad \text{Joule/round}$$

This model is not complete! Dynamic effects are neglected:

- relaxation effect
- energy dissipation during transients

Energy Efficiency

When is energy consumed?

During transmission [Joule/bit]	**1 (normalised)**
Typical values:	10^{-7} - 10^{-5} Joule/bit
During reception	**1 – 0.1**
When sensing the channel	**1 – 0.01**
When idle	**0.01 – 0.0001**
When sleeping	**0.0001 – 0**

Energy Efficiency (e.g. CHIPCON CC2420)

Radio supply voltage = 2.5V
Power = I*V

PA_LEVEL	TXCTRL register	Output Power [dBm]	Current Consumption [mA]
31	0xA0FF	0 = *1 mW*	17.4 = *43.5 mW*
27	0xA0FB	-1	16.5
23	0xA0F7	-3	15.2
19	0xA0F3	-5	13.9
15	0xA0EF	-7	12.5
11	0xA0EB	-10	11.2
7	0xA0E7	-15	9.9
3	0xA0E3	-25 = *0.003 mW*	8.5 = *21.25 mW*

- 25 dB ➡ **- 3 dB**

Energy Efficiency

All phases of the communication protocol
must be designed to minimise energy consumption

Radio Resource and Energy Resource Management
are closely related issues.

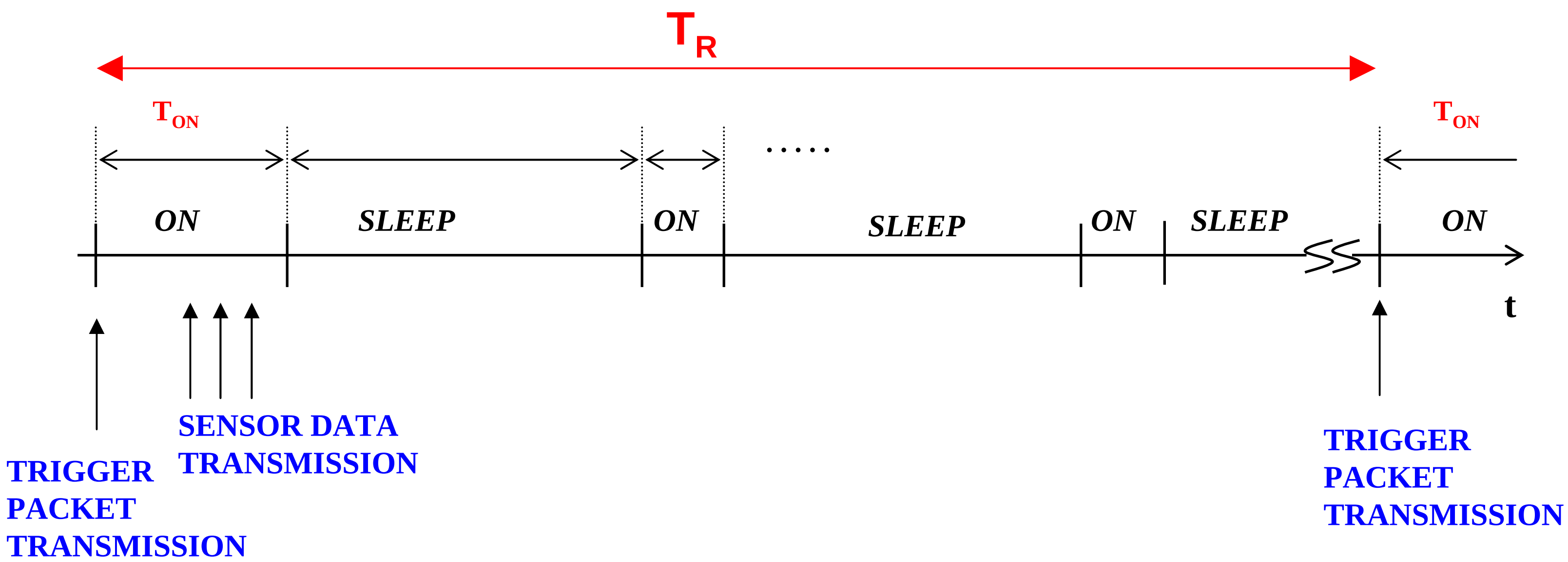
Circuitry must be designed to minimise energy consumption

Nodes must turn off during inactive periods of time

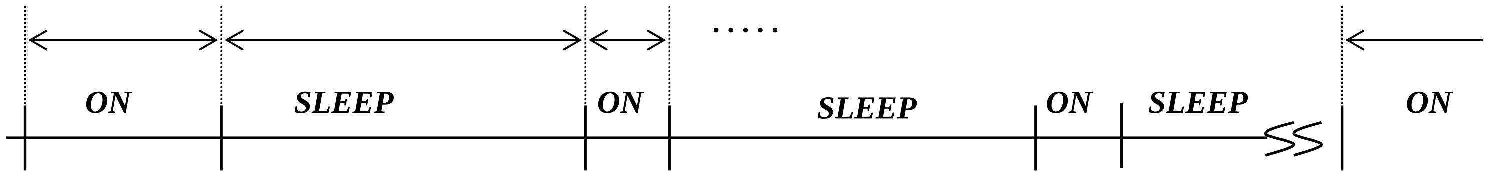
Energy Efficiency

round

1) The sink sends the QUERY packet
2) Sensors send the data measured
3) All sensors move to sleep state after Tout seconds
4) Sensors periodically wake up to sense the channel till a new QUERY packet is sent by the sink



Energy Efficiency: Estimation of Activity Factor



$$AF_{on} = T_{on} / (T_{on}+T_{sleep})$$

$$E_{charge} = 5000 \text{ J}$$
$$= P_{sleep}\ T_{sleep} + P_{on}\ T_{on} = P_{on}\ T_{on}$$
$$= 50\ 10^{-3}\ T_{on}$$

$$\rightarrow \quad T_{on} = 10^5 \text{ s} = \text{approximately one day !}$$

If requested node lifetime is one year, AF_{on} must be 1/365 < 1 %

To Sum Up

Reception is as energy consuming as transmission is (avoid overhearing!).

Sensing can be also very energy consuming (be careful with CSMA!).

To Sum Up

**Power consumption
scarcely depends on transmit power !**

**Power control is not effective
in maximising energy efficiency.**

**Very low duty cycles
(making topology control an issue)**

Section 5
Connectivity Layer

Connectivity Layer: Trends

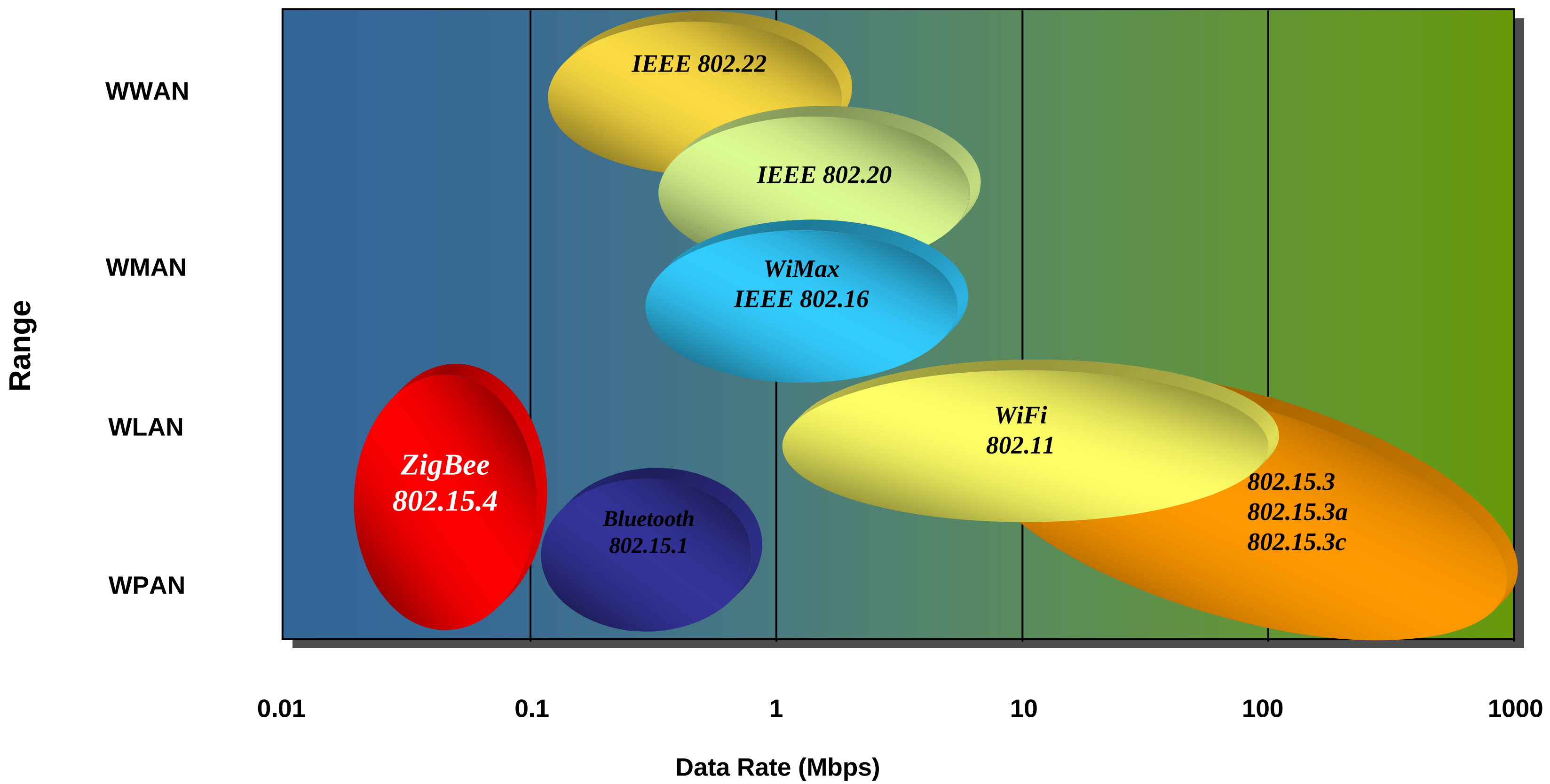
- Proprietary choices (ASK, 1-10 kbit/s, UHF ISM bands)
- Bluetooth, IEEE802.11
- Currently, two main trends
(both systems standardised by IEEE 802.15 groups):

1) IEEE802.15.4
(bit rates below 250 Kbit/s, ISM bands, 2.4 GHz)

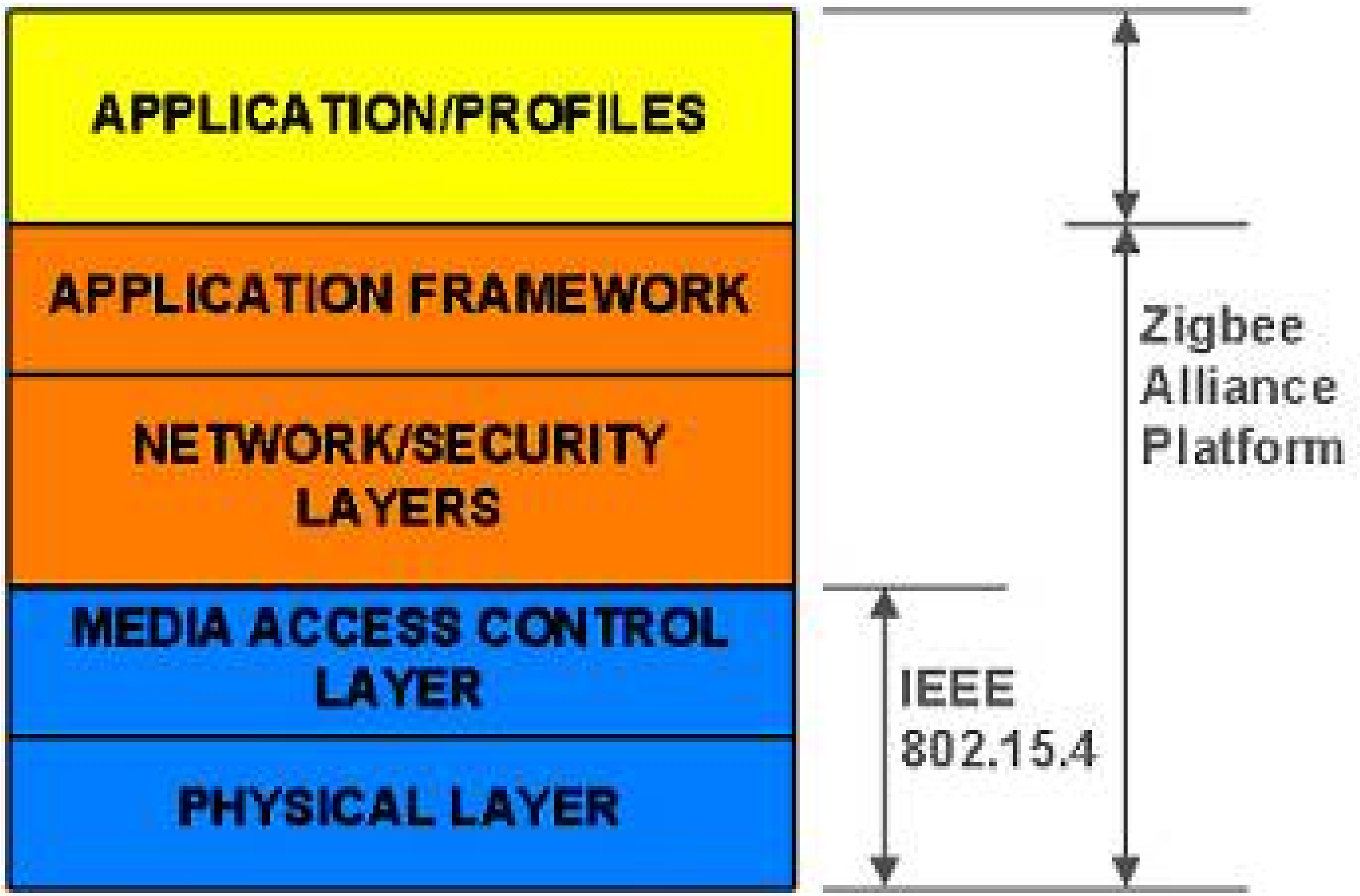
2) IEEE802.15.4a (UWB)

IEEE 802.15.4 is currently a de facto standard for WSNs, except for applications with high bandwidth requirements.

IEEE 802.15.4 / Zigbee



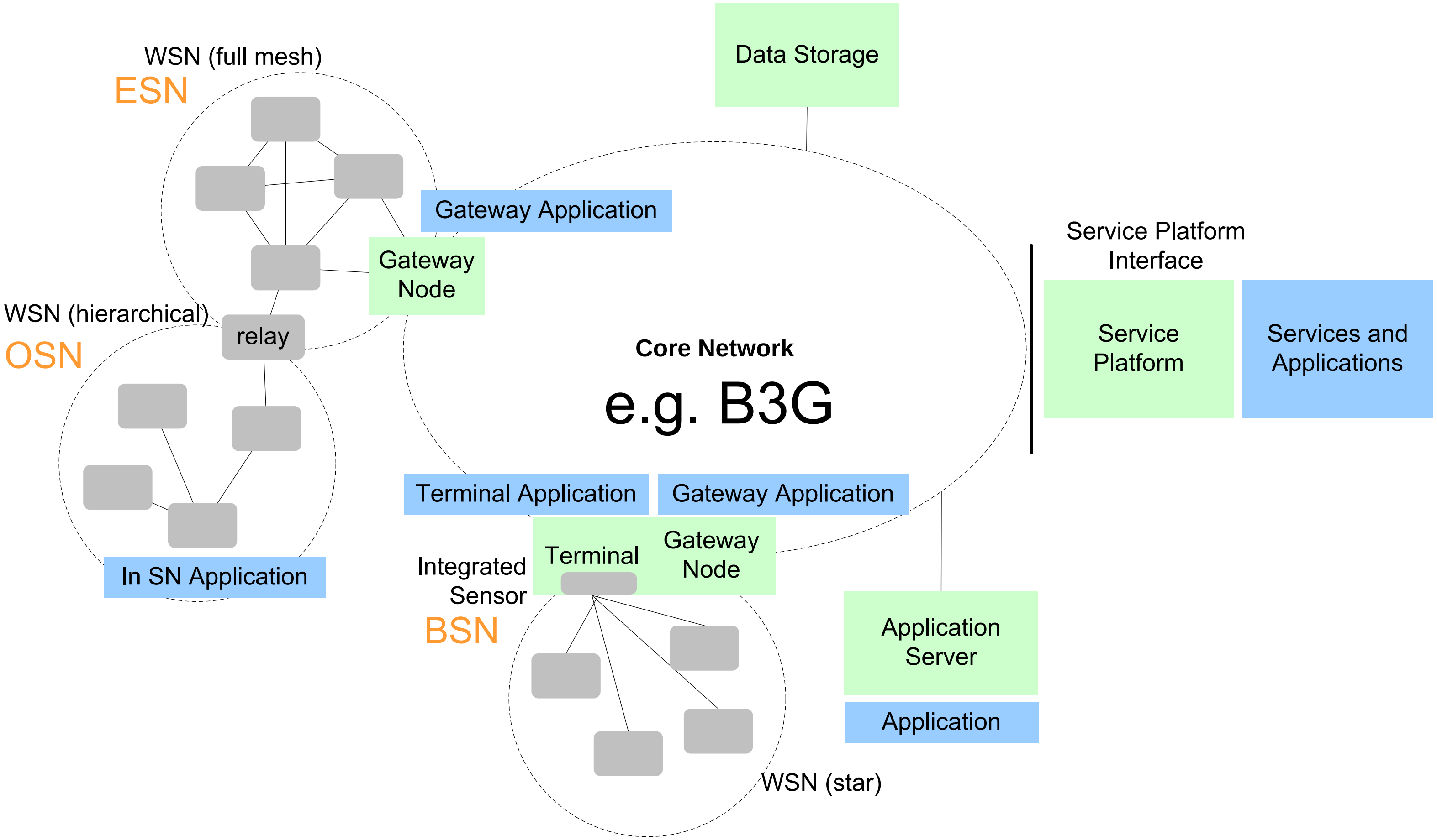
IEEE 802.15.4 / Zigbee



Section 6
Network Architectures

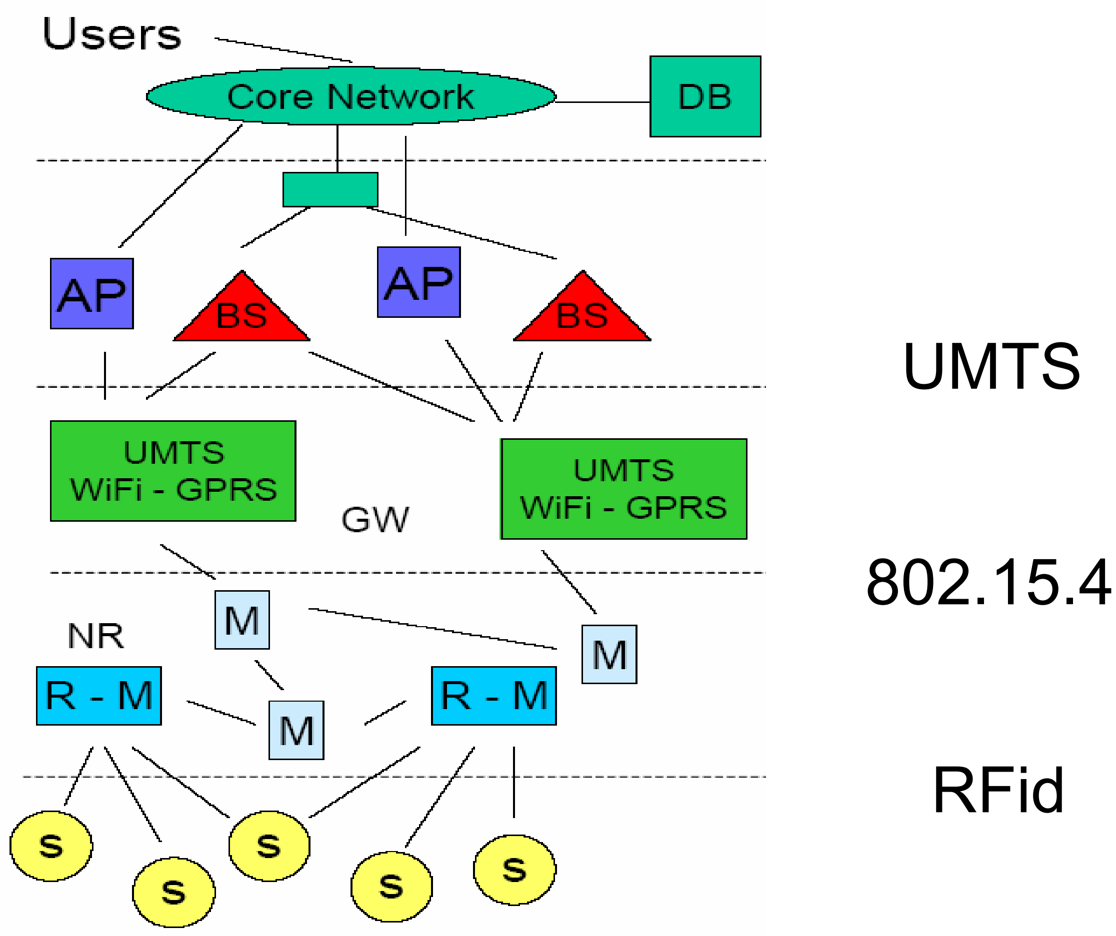
Network Architectures

The reference network architecture for E-SENSE, EC FP6



Network Architectures

The HHA – Hybrid Hierarchical Architecture (reference network architecture for CRUISE, EC FP6)

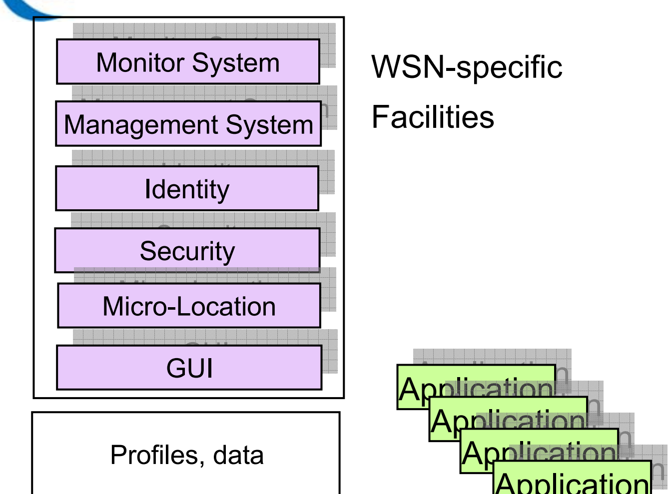


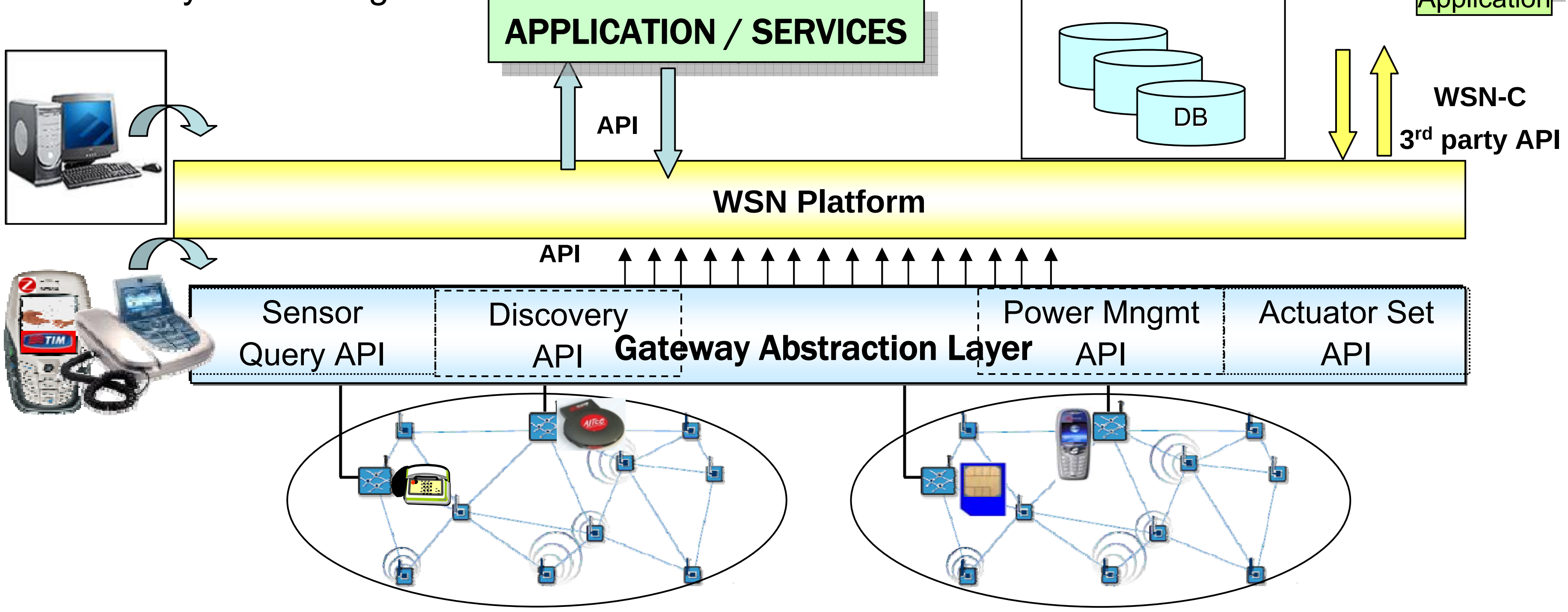
Network Architectures

Network Operator Reference Architecture

Not just the nodes to build the WSN real applications!

- Wireless Sensor Networks nodes
- Gateway
- WSN Platform (configuration, mgmt, data collection)
- Privacy & Trust mgmt





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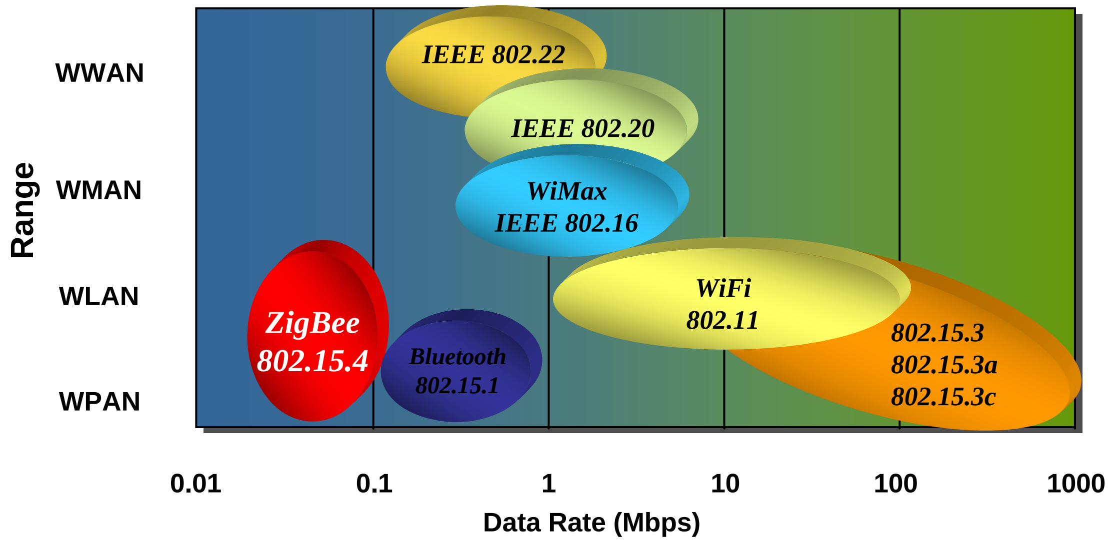
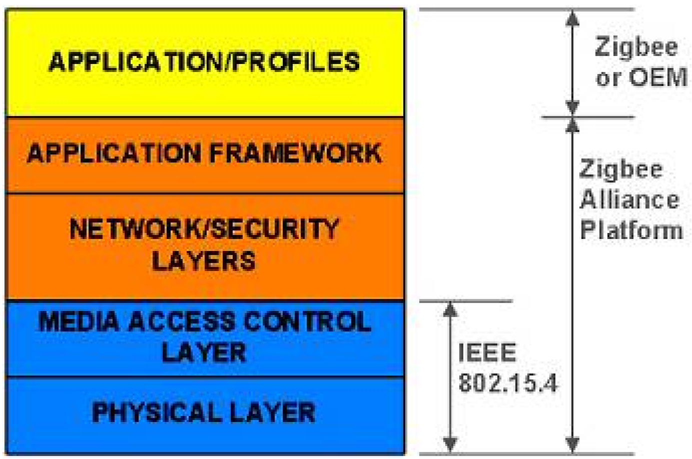
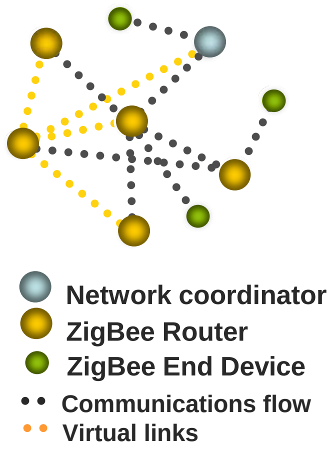
Network Architectures – Why Zigbee

- Open Standard
- Radio + Protocol
- Mesh Networking





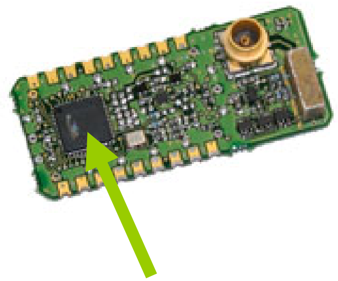
- Up to 65,536 network nodes
- Full Mesh Networking Support
- Multiple channels in the global 2.4 GHz band and regional sub 1GHz bands
- 250Kbps data rate



Network Architectures – Why 6lowpan

6LoWPAN - IP for Low-power Devices

- IETF Standard for IPv6 over IEEE 802.15.4
- 80% compression of headers
- Rich and flexible features
  - Auto-configuration
  - IPv6 fragmentation
  - UDP + ICMP
  - Mesh forwarding
- Common Socket API
- Super compact implementation
- Direct end-to-end Internet integration
- Extremely scalable



Sockets

UDP + ICMP

IPv6 + LoWPAN

802.15.4 MAC

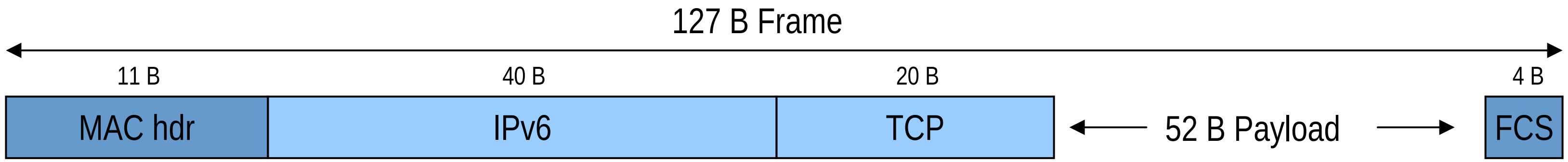
2.4 GHz | UWB

Network Architectures – Why 6lowpan

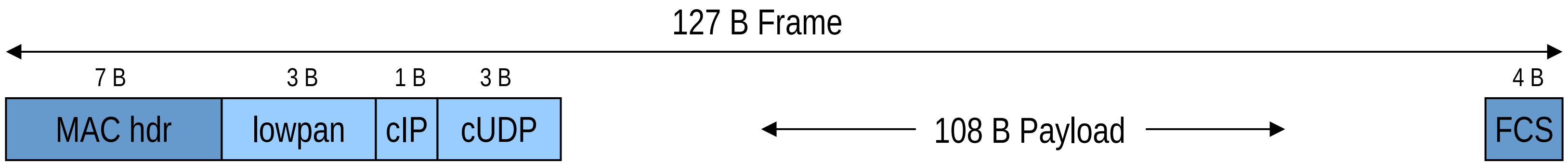
6LoWPAN Headers

- Orthogonal header format for efficiency
- Stateless header compression

Impossible case: Full TCP/IPv6



Best case: 6LoWPAN UDP/IPv6



To Sum Up

Very different network paradigms
(operator-centric, independent, …)

Very different types of applications
(home control, industrial process control, people control, emergency, eco-sustainability, info-mobility, …)

Very different types of environments
(BANs, Office, Home, Urban, Rural, …)

Heterogeneity

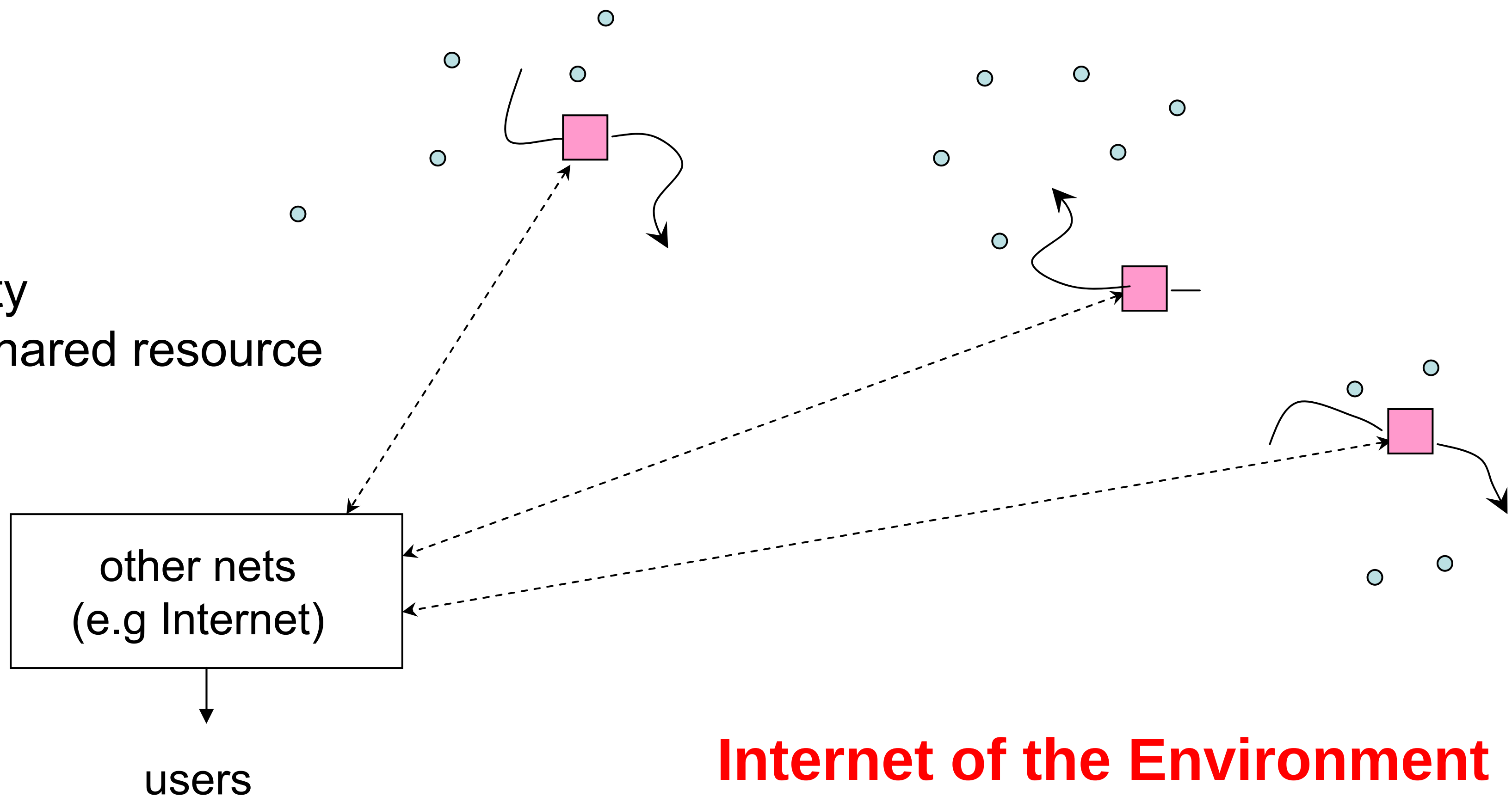
Section 7
Opportunism in WSNs

Delay Tolerant Networks
Resource Exploitation

Delay Tolerant Networks

Mobility of nodes is opportunistically exploited to forward information from one part of a network to an other part, even if separated.

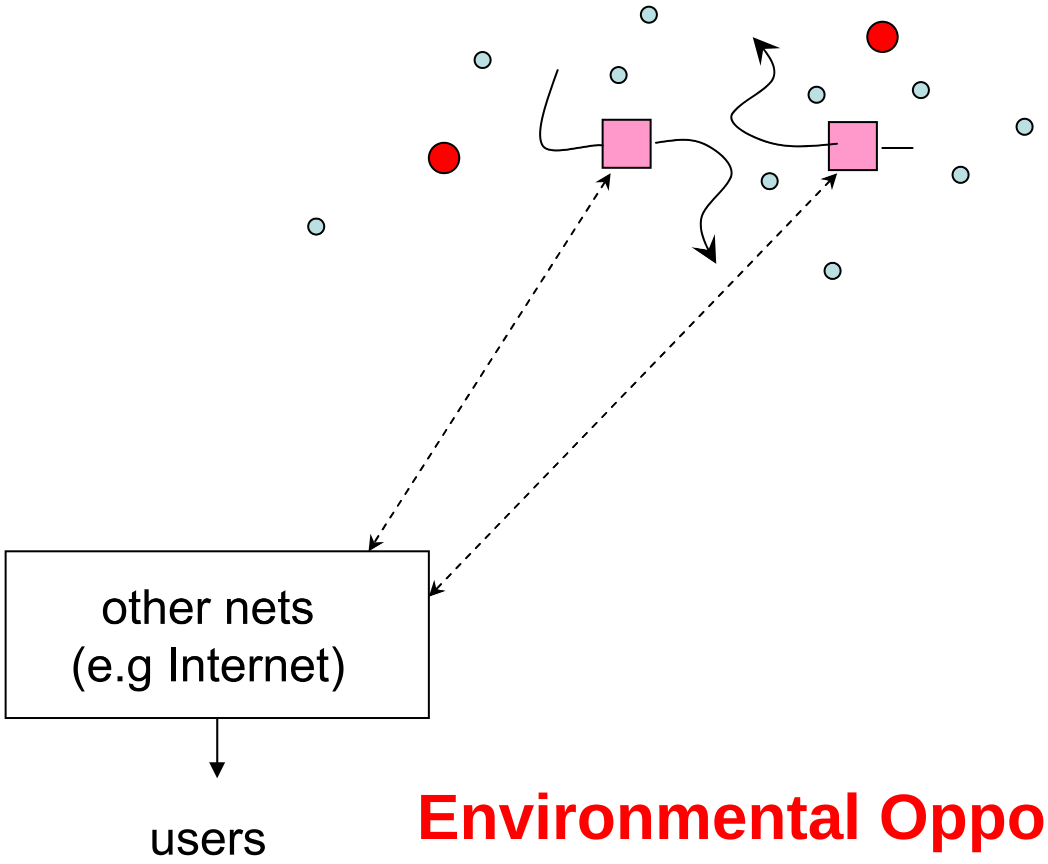
Mobility
as a shared resource



Internet of the Environment

Resource Exploitation

A network of nodes entering an environment where a WSN is deployed can discover it, and for a specific task exploit its resources.



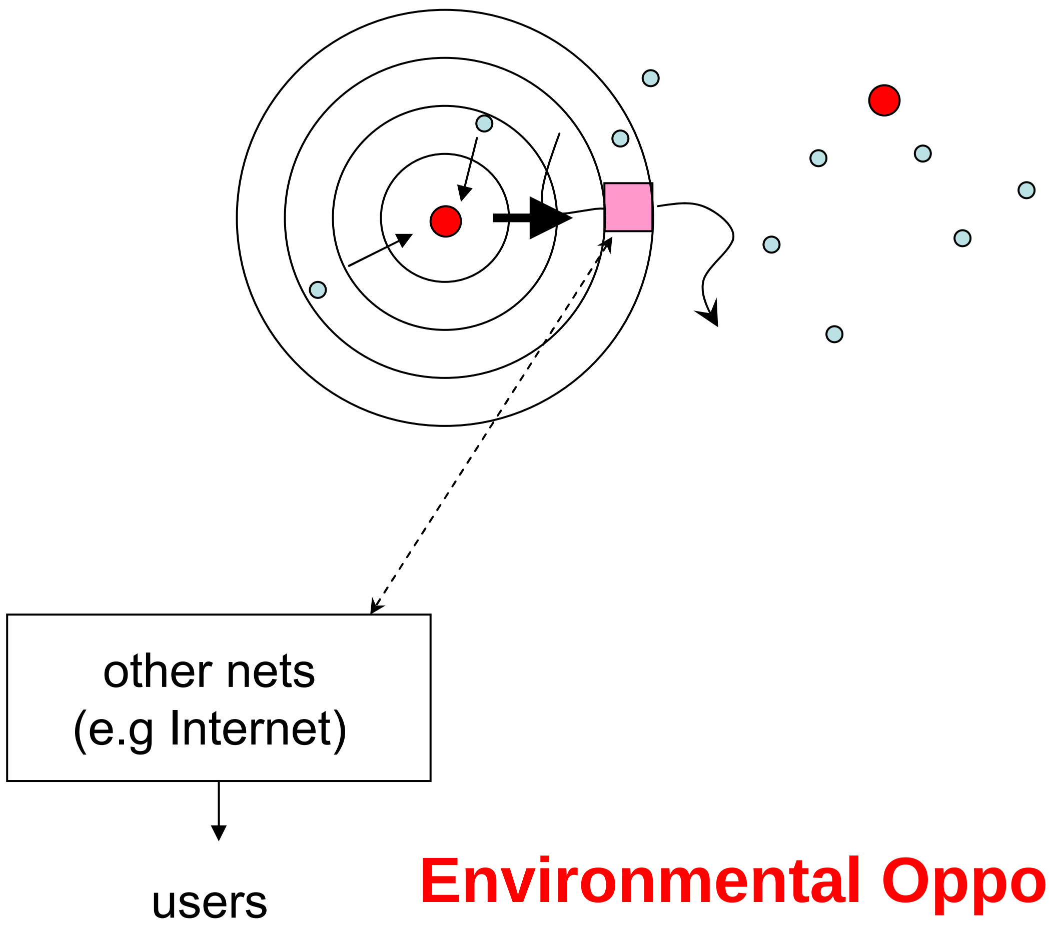
Resources:

- Computing
- Storage
- Sensing
- Actuation

…

Environmental Opportunistic Networks

Resource Exploitation



Every node should be able to broadcast information on its resources
AND
the resources made available by the surrounding nodes

Every node provides a different view of available resources

Environmental Opportunistic Networks

Introduction and Applications of WSNs

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Thank You