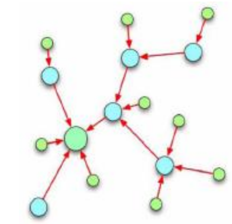
WSN Lab at the
University of Bologna



Wireless Sensor and Actuator Networks:
Technologies, Analysis and Design

Introduction to WSANs and Their Applications

Roberto Verdone

roberto.verdone@unibo.it
http://www.robertoverdone.org

Outline

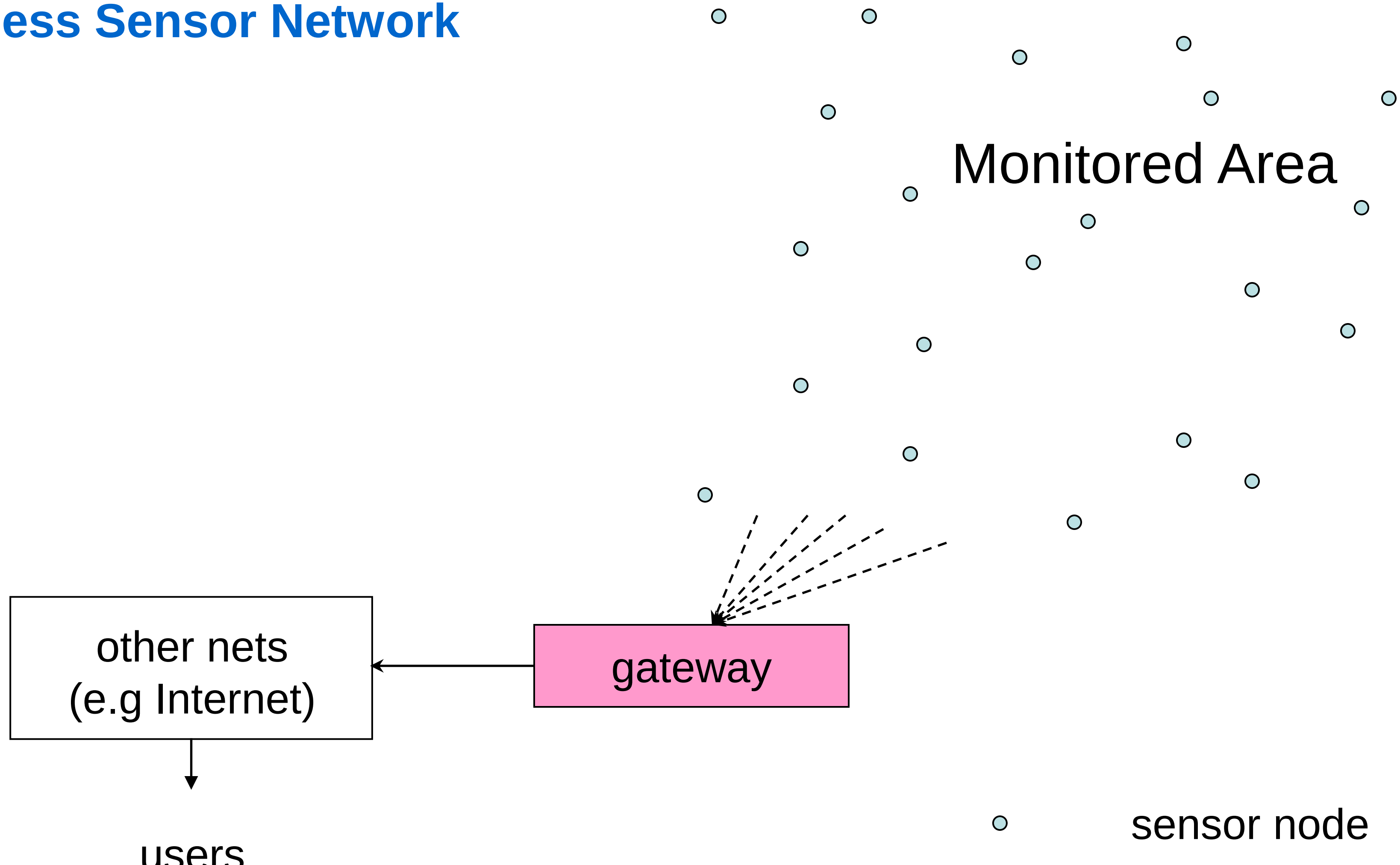
1. WS(A)Ns
2. Applications
3. Energy Efficiency

Section 1
WS(A)Ns

Basics

Basics

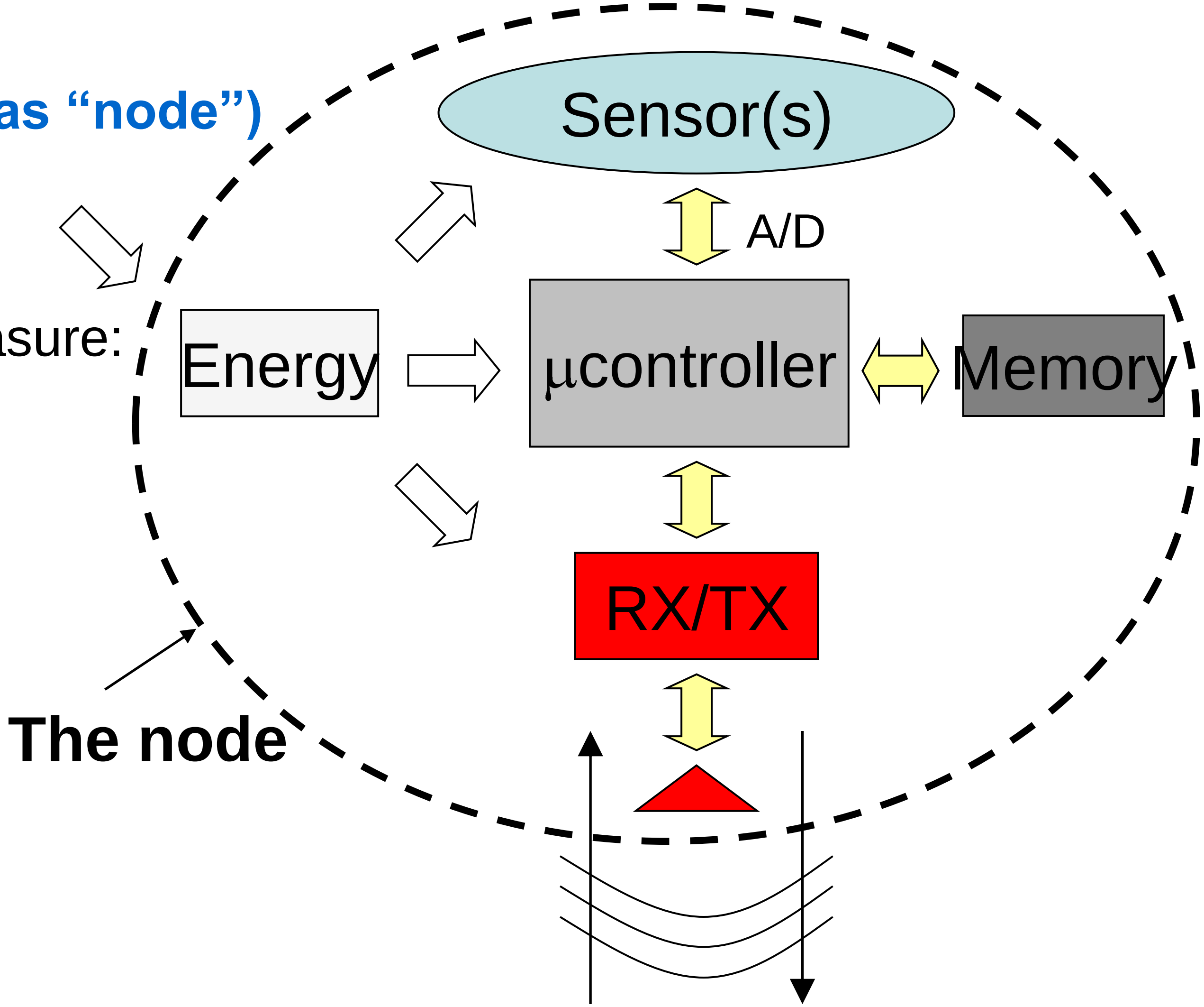
Wireless Sensor Network



Density / Number of Nodes?

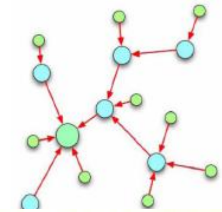
Basics

Wireless Sensor
(hereafter denoted as “node”)



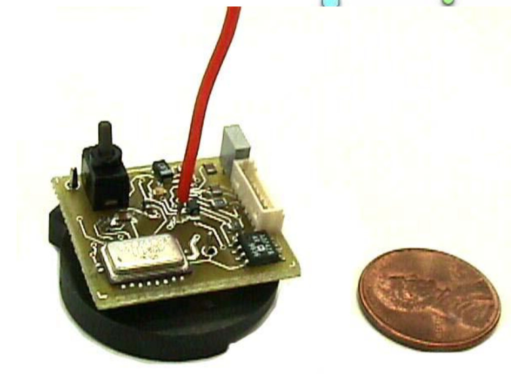
The sensor may measure:

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



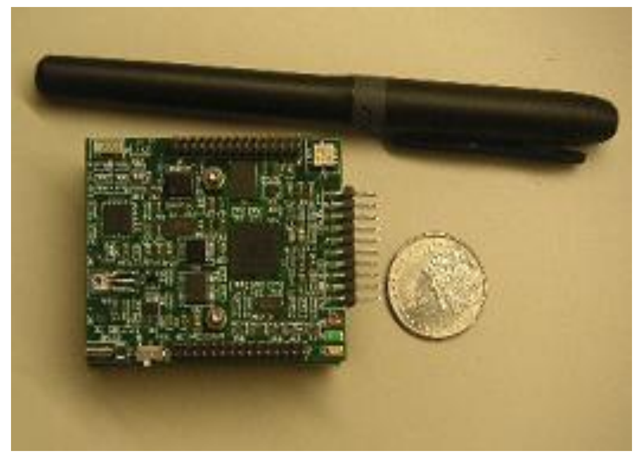
Basics

Wireless Sensor

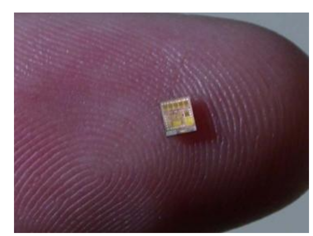


Nodes are

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



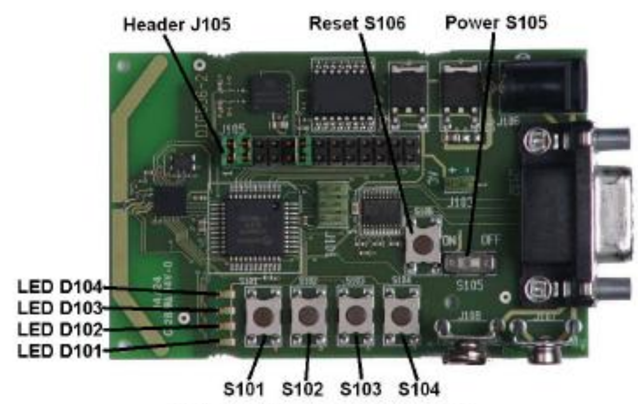
devices



Basics

Wireless Sensor
Commercially Available Products (Sample

www.freescale.com



Compliant 802.15.4	Clock	Flash	RAM	Receive Sensitivity	RF Power Min	RF Power Max	Cost	Country
YES	40 MHz	60K	4K	-92 dBm	-16.6 dBm	+3.6 dBm	$ 199	USA

transmit power

Basics

Wireless Sensor
Commercially Available Products (Samples)

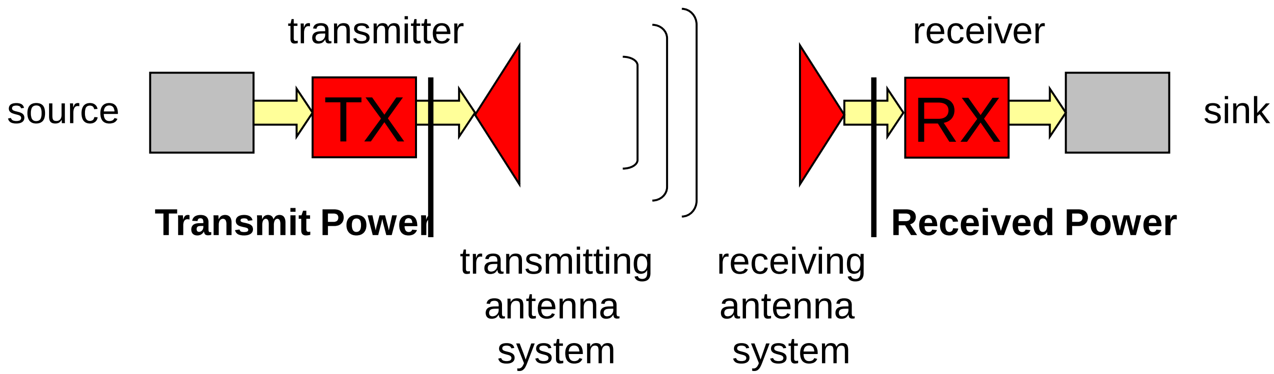
Crossbow TECHNOLOGY INC.

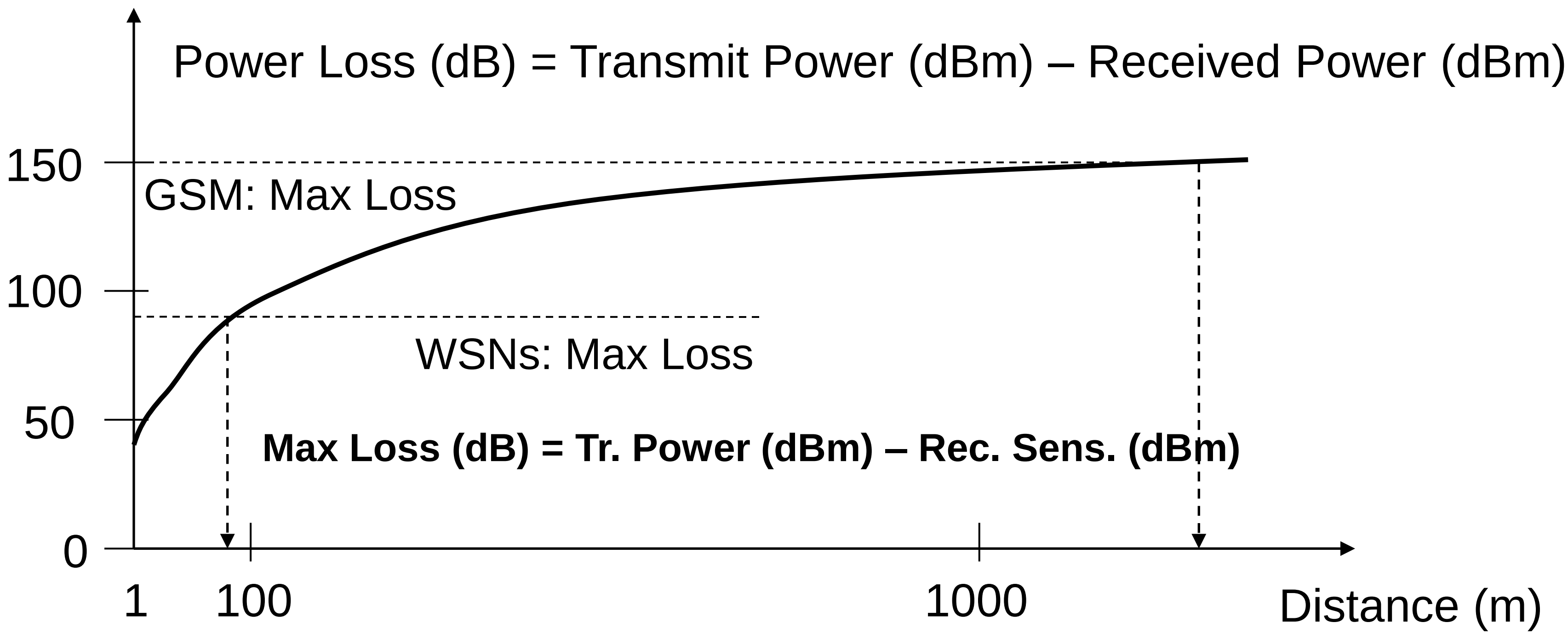
www.xbow.com

Compliant 802.15.4	Clock	Flash	RAM	Receive Sensitivity	RF Power Min	RF Power Max	Cost	Country
YES	8 MHz	48K	10K	-94 dBm	-24 dBm	0 dBm	$ 134	USA

transmit power (RF Power Min – RF Power Max)

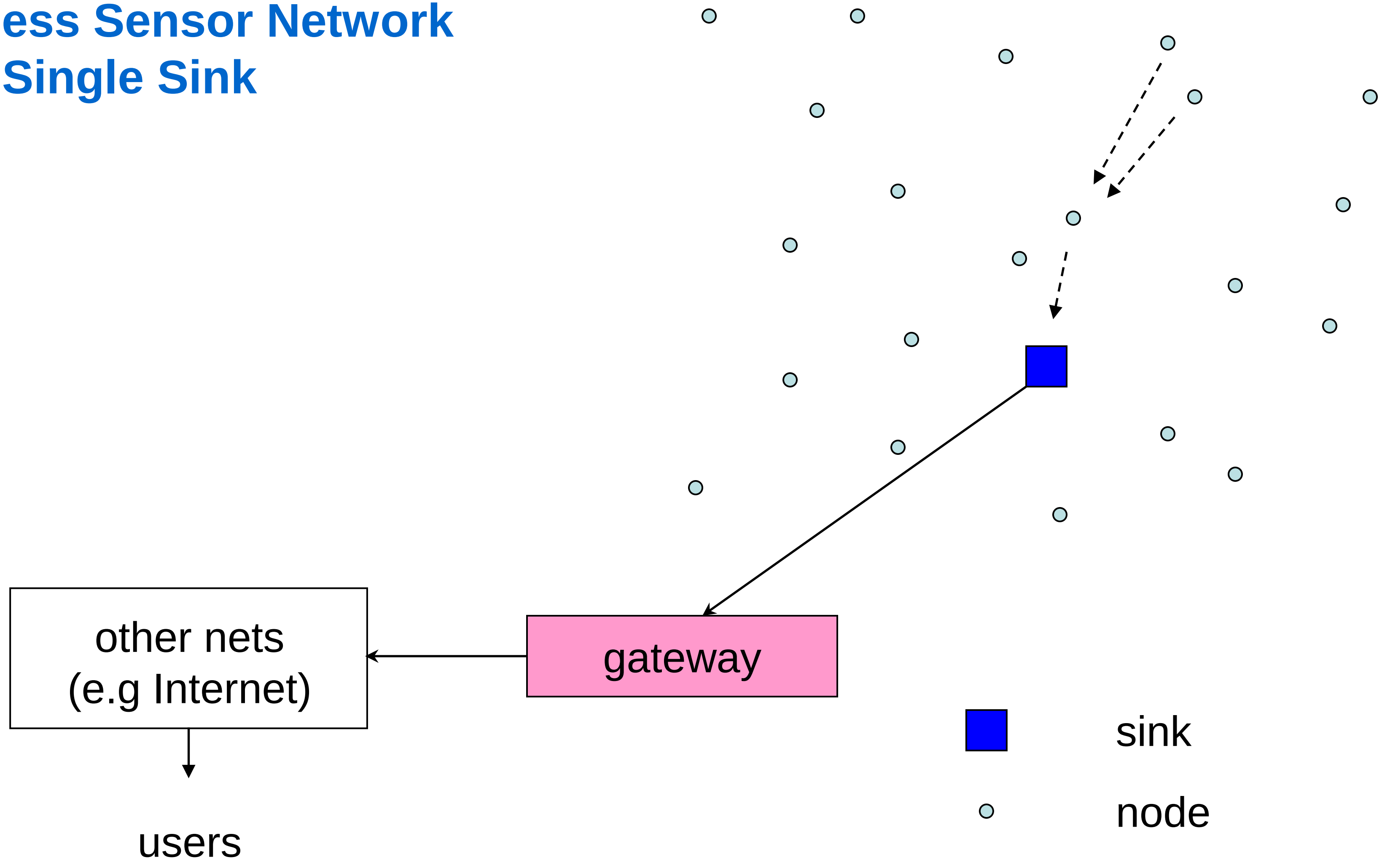
Basics


transmitter
receiver
source
TX
RX
sink
Transmit Power
Received Power
transmitting antenna system
receiving antenna system


Power Loss (dB) = Transmit Power (dBm) – Received Power (dBm)
150
100
50
0
GSM: Max Loss
WSNs: Max Loss
Max Loss (dB) = Tr. Power (dBm) – Rec. Sens. (dBm)
1
100
1000
Distance (m)

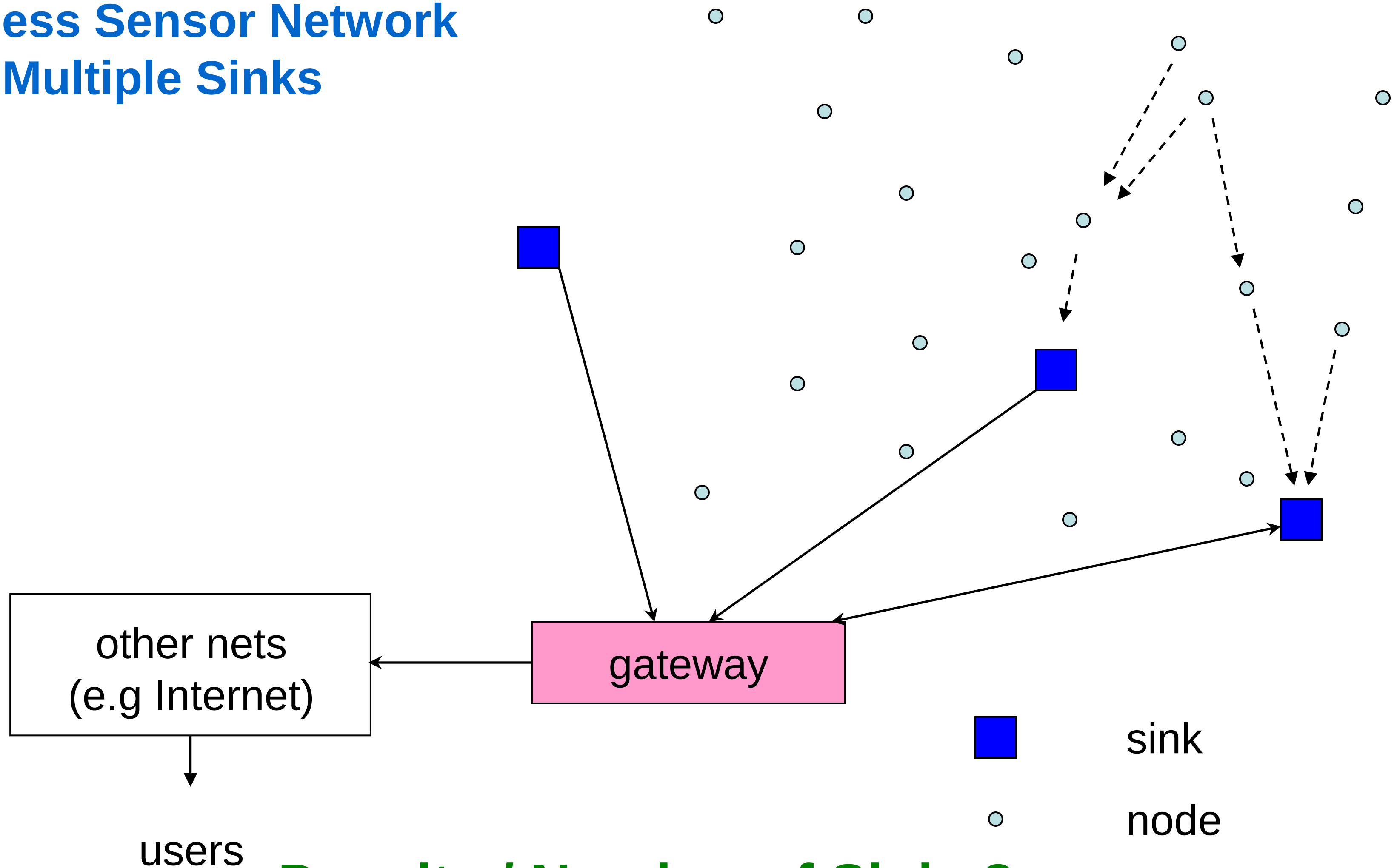
Basics

Wireless Sensor Network
With Single Sink



Basics

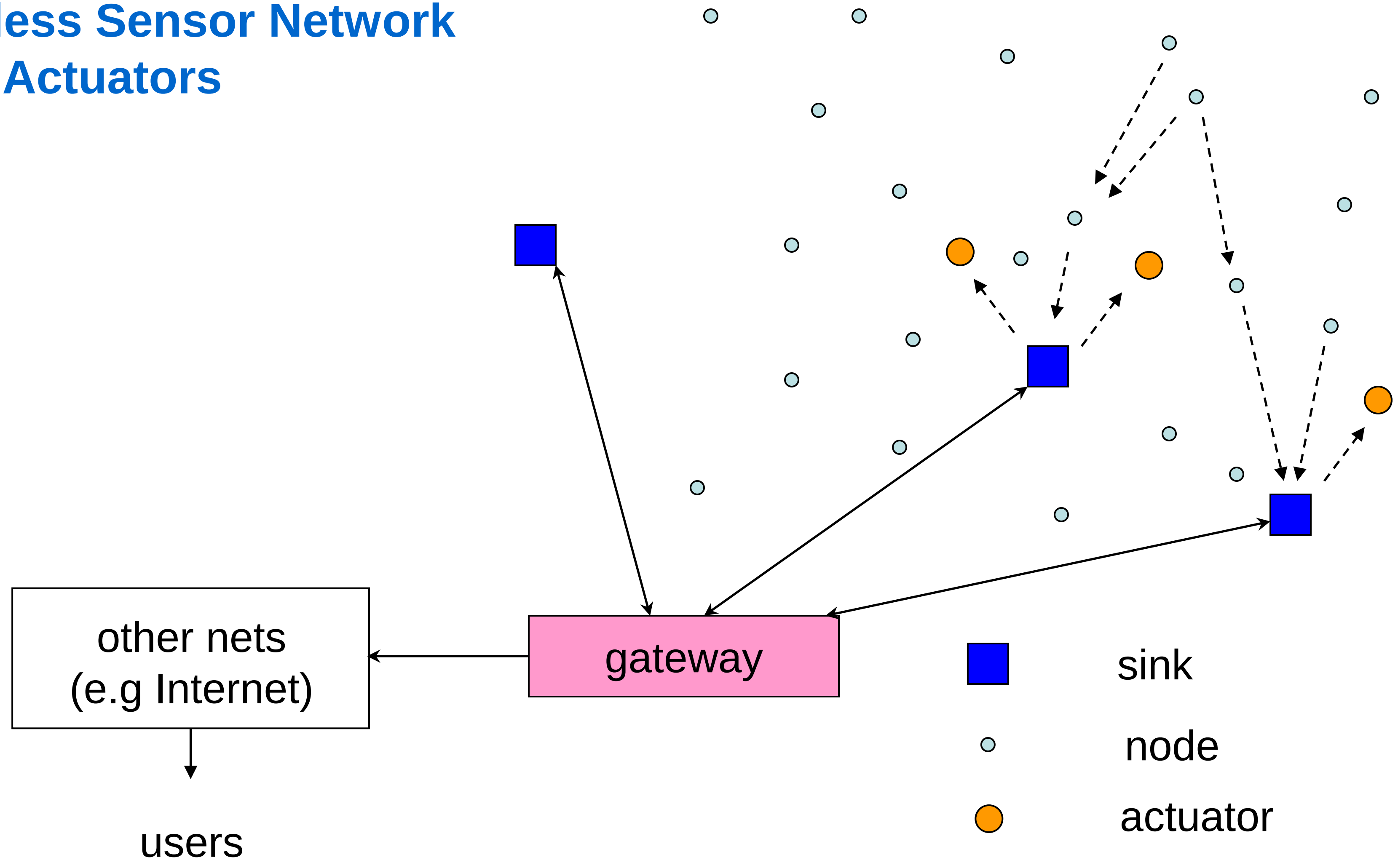
Wireless Sensor Network
With Multiple Sinks



Density / Number of Sinks?

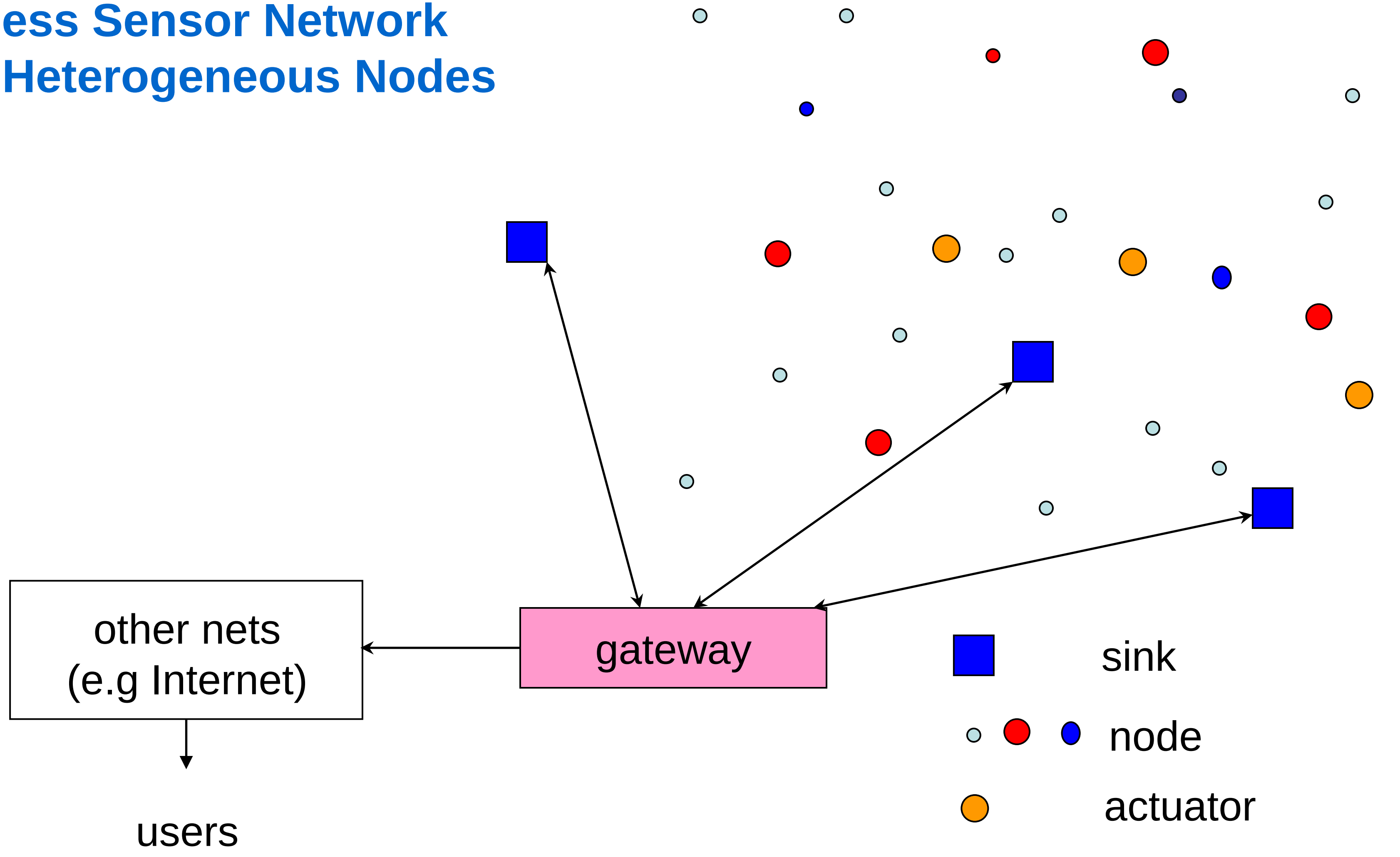
Basics

Wireless Sensor Network With Actuators



Basics

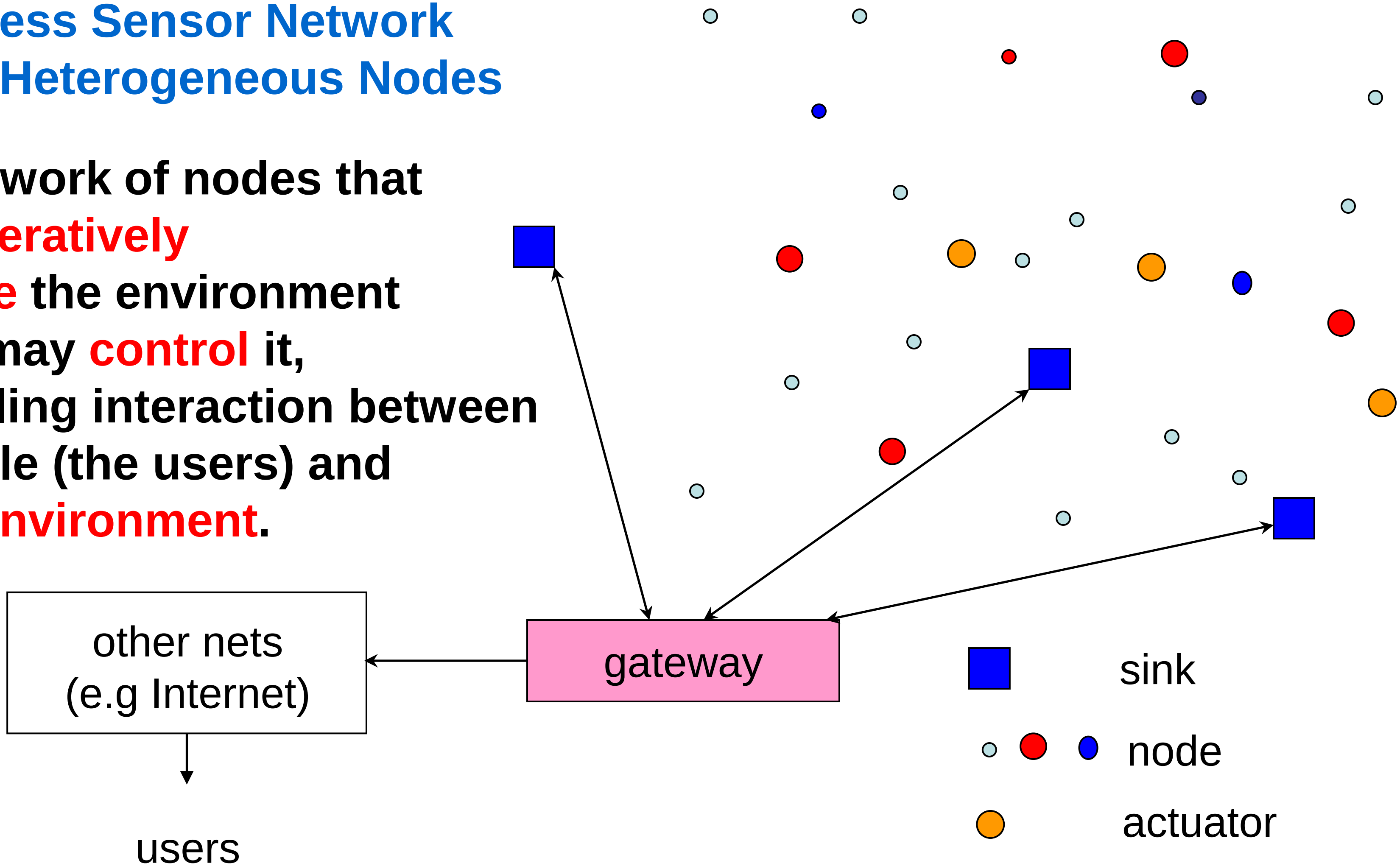
Wireless Sensor Network
With Heterogeneous Nodes

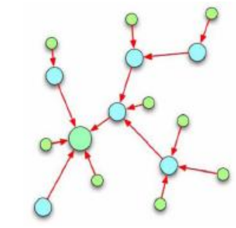


Basics

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 determines the **network lifetime**: **energy efficiency** is a primary issue in these cases.

The network can be **homogeneous** 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;
however, nodes can perform **distributed and/or collaborative processing** in order to reduce the amount of information to be transmitted.

Scalability (with respect to network size) is a fundamental characteristics.

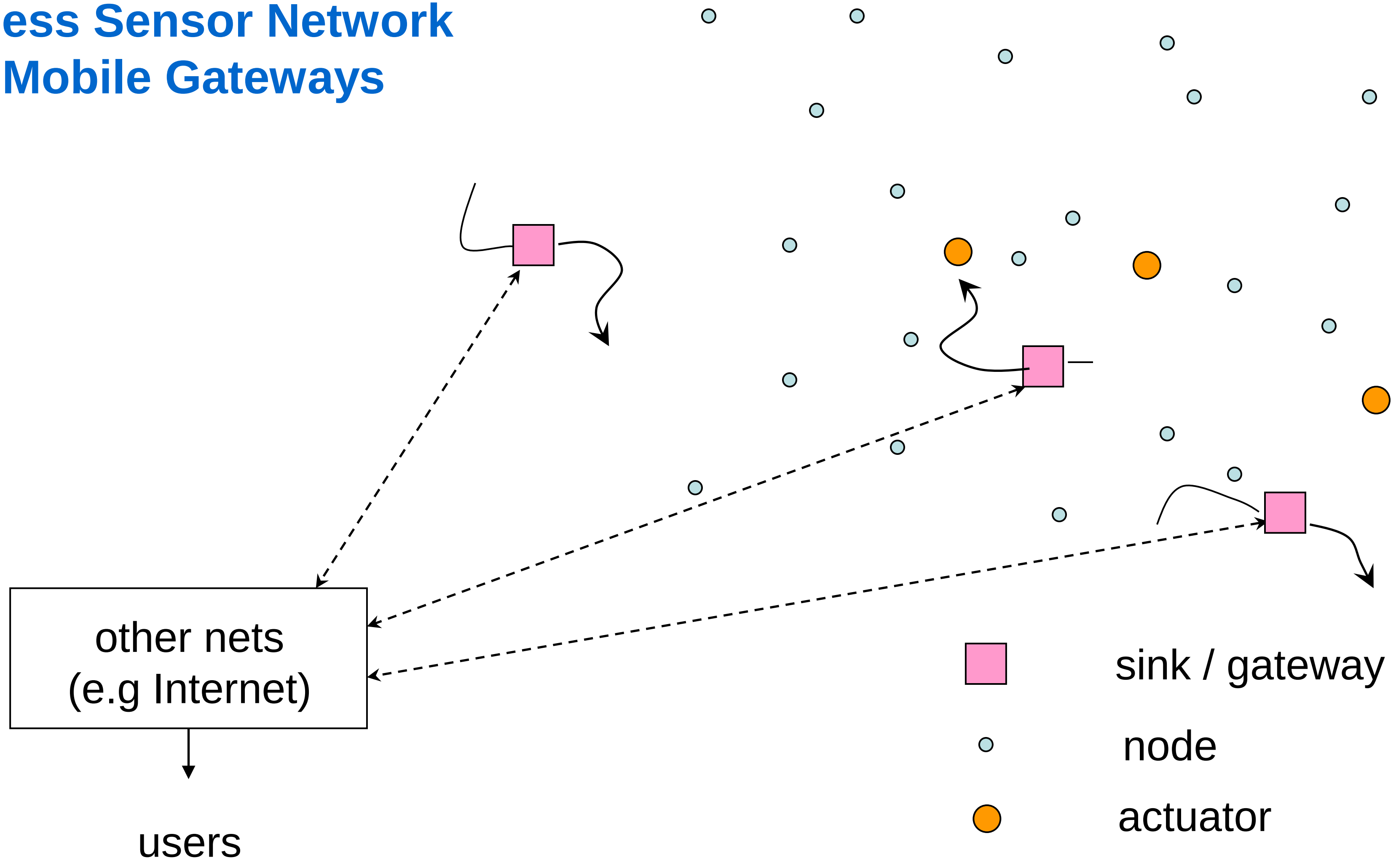
The sinks then transmit the result of their monitoring to external entities by means of a separate network (through a ***gateway***).

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.

Basics

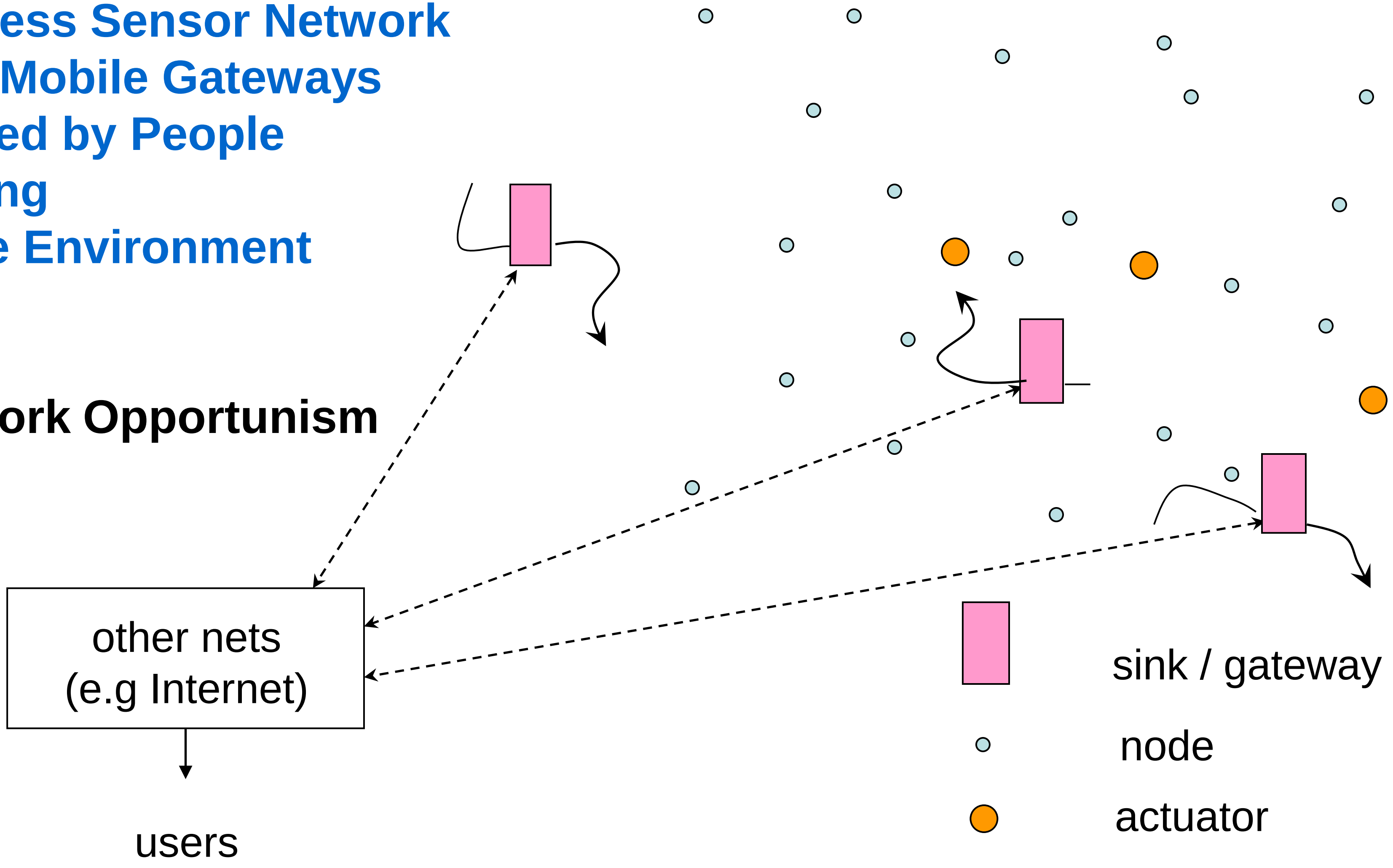
Wireless Sensor Network
With Mobile Gateways



Basics

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

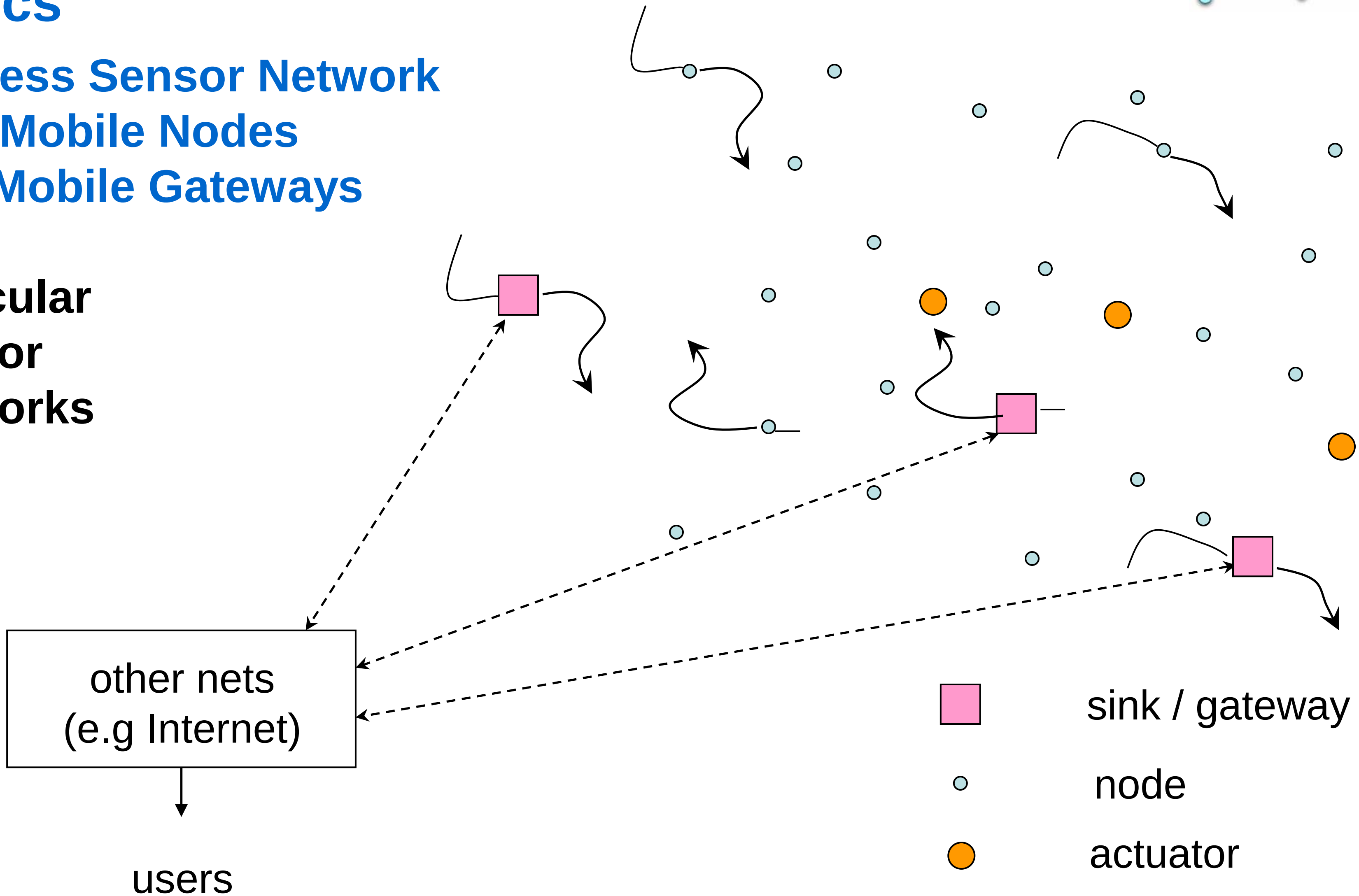
Network Opportunism



Basics

Wireless Sensor Network With Mobile Nodes And Mobile Gateways

Vehicular Sensor Networks



Summing-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

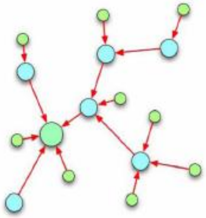
⇒ **Data Aggregation**

Connectivity and Coverage

The information must be detected and forwarded to sinks

⇒ **Network Topology**.

Other aspects: Security, Reliability …



Section 2
Applications

Examples
Taxonomy
Requirement Types

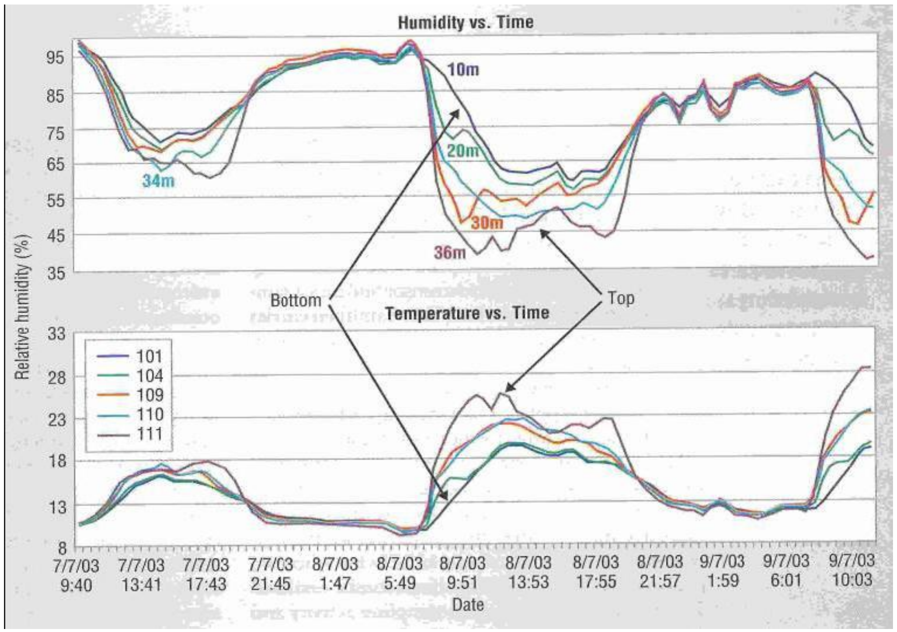
Applications

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,…)
- …

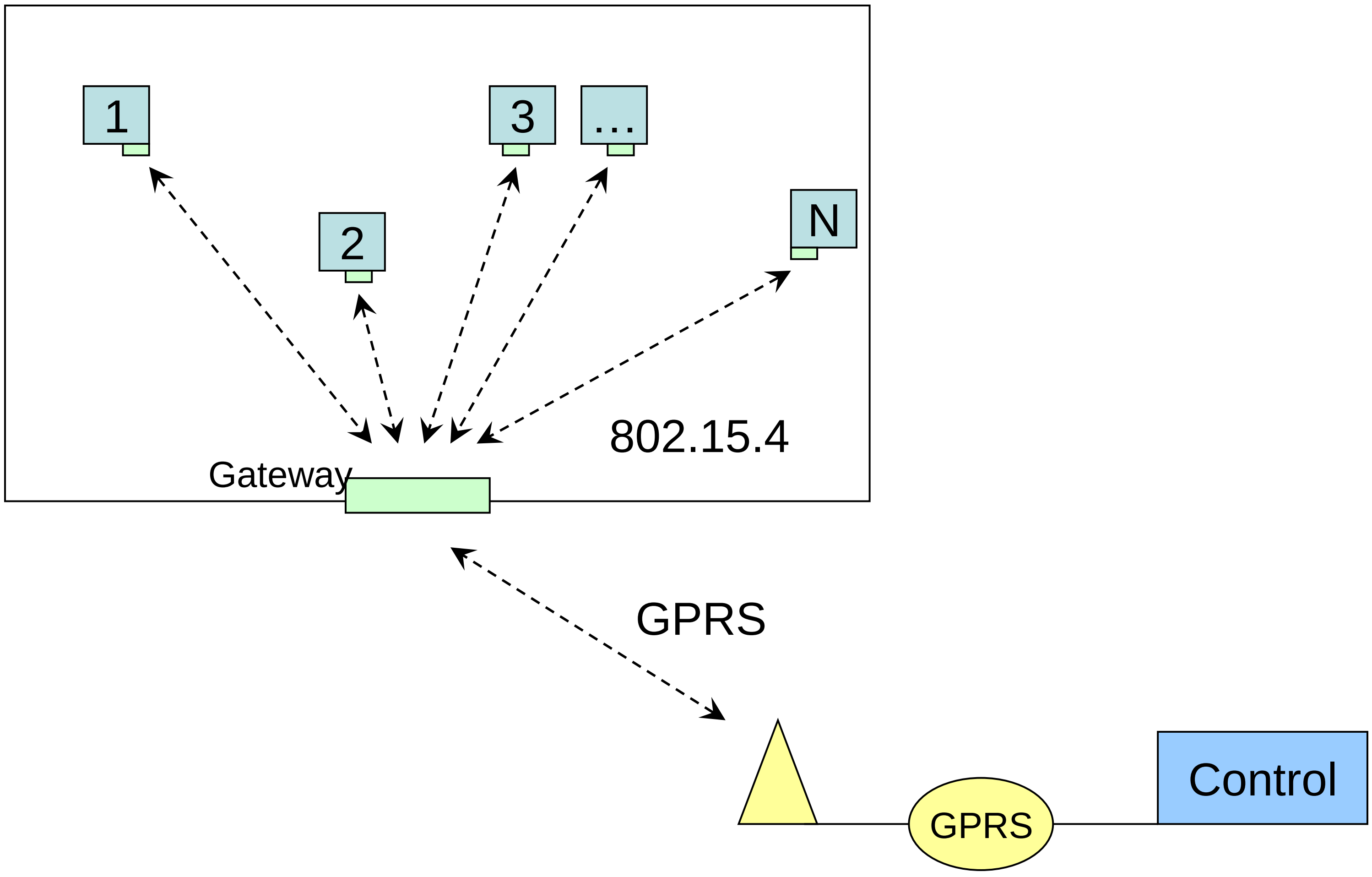
Applications

- 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

- Machine control at customer premises:



Applications

Environmental monitoring

Healthcare

Mood based services

Positioning and tracking

Entertainment

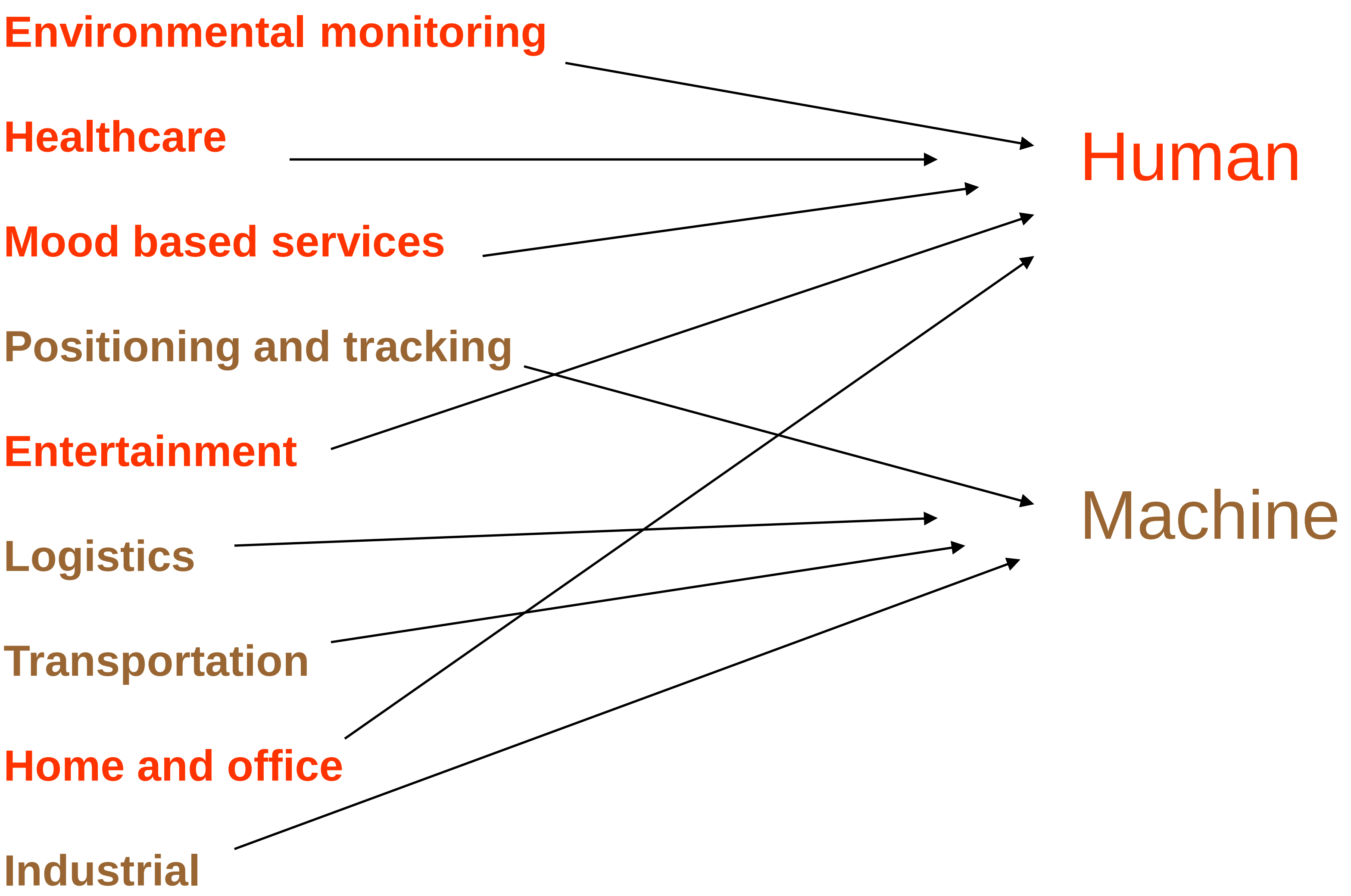
Logistics

Transportation

Home and office

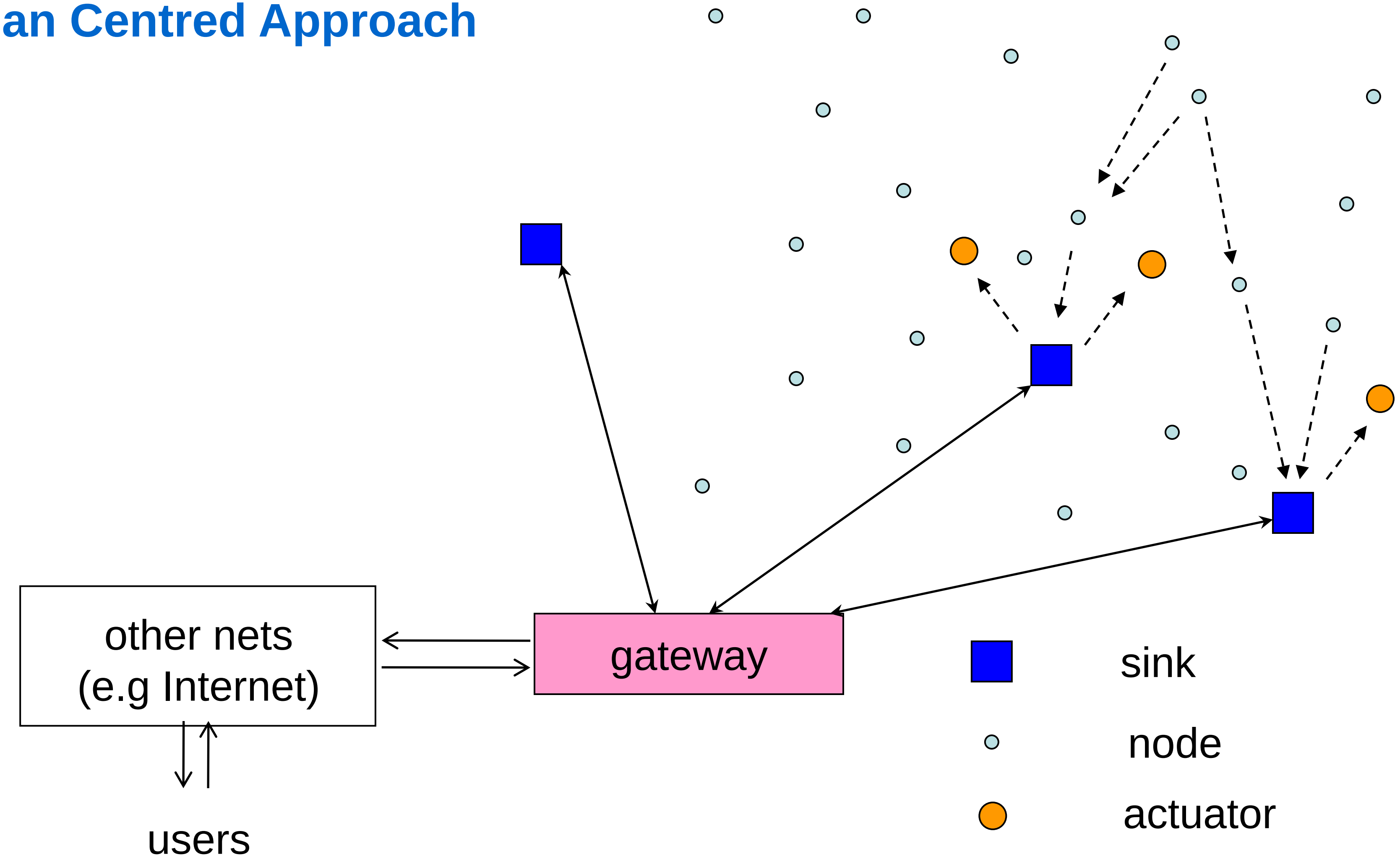
Industrial

Applications



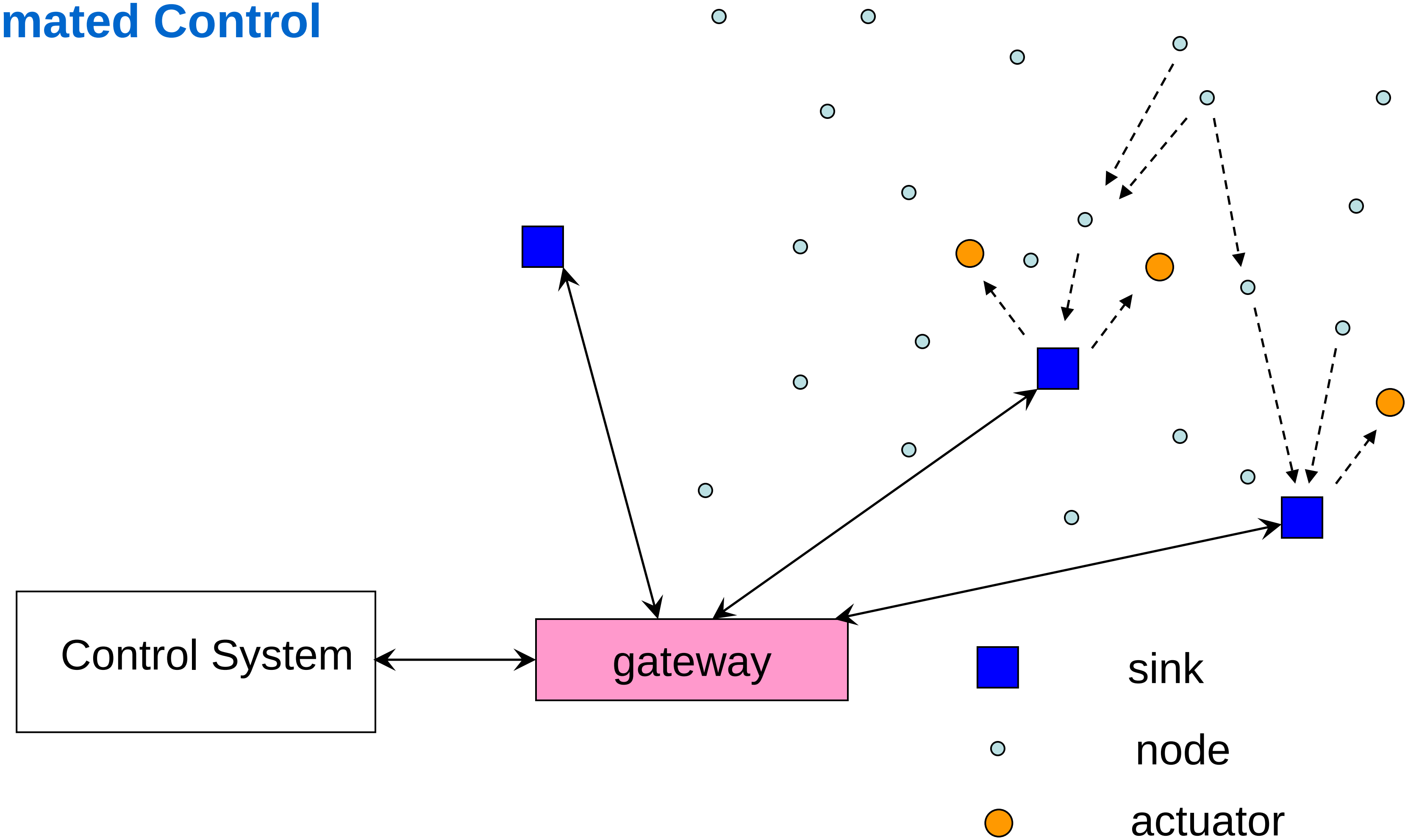
Applications

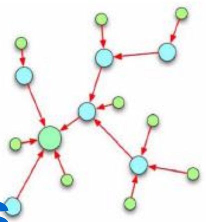
Human Centred Approach



Applications

Automated Control





Applications: Amount of Data Generated by Nodes

Forest Fire Detection

Body Networks for healthcare applications

Tracking of vehicles in closed areas (airports…)

Videos taken from in-vehicle cameras for security

…

Nodes can send few Bytes per day, or

many KBytes per second…

Taxonomy: 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**

Taxonomy

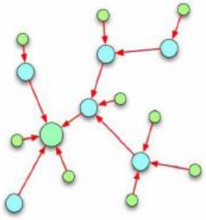
Event Detection → **Req.s on delay**

or

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

or

Monitoring / Tracking → **Req.s on 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

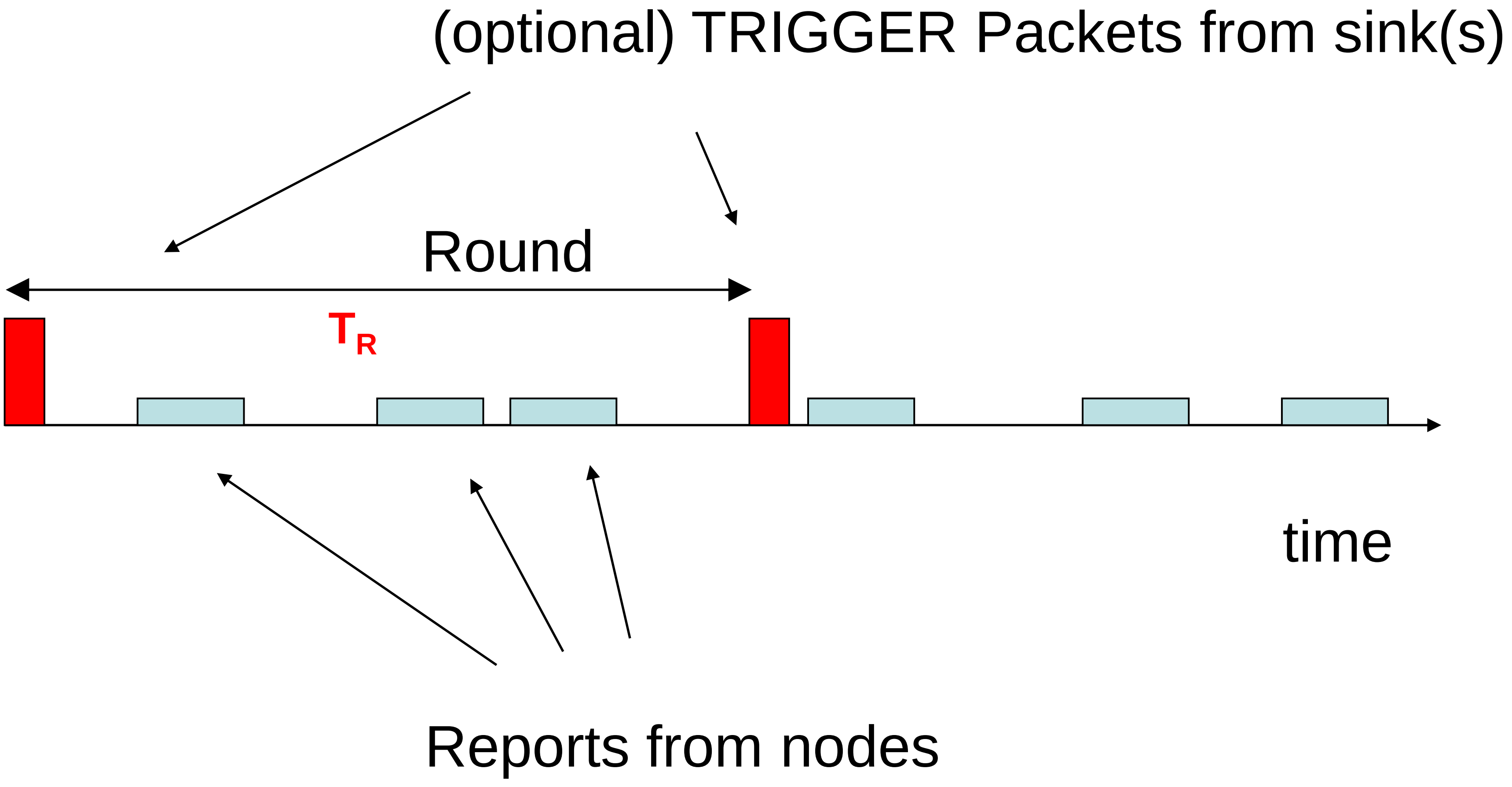
Both the density of nodes and sampling frequency are application-dependent.

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;
  - → **data 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.

Summing-Up

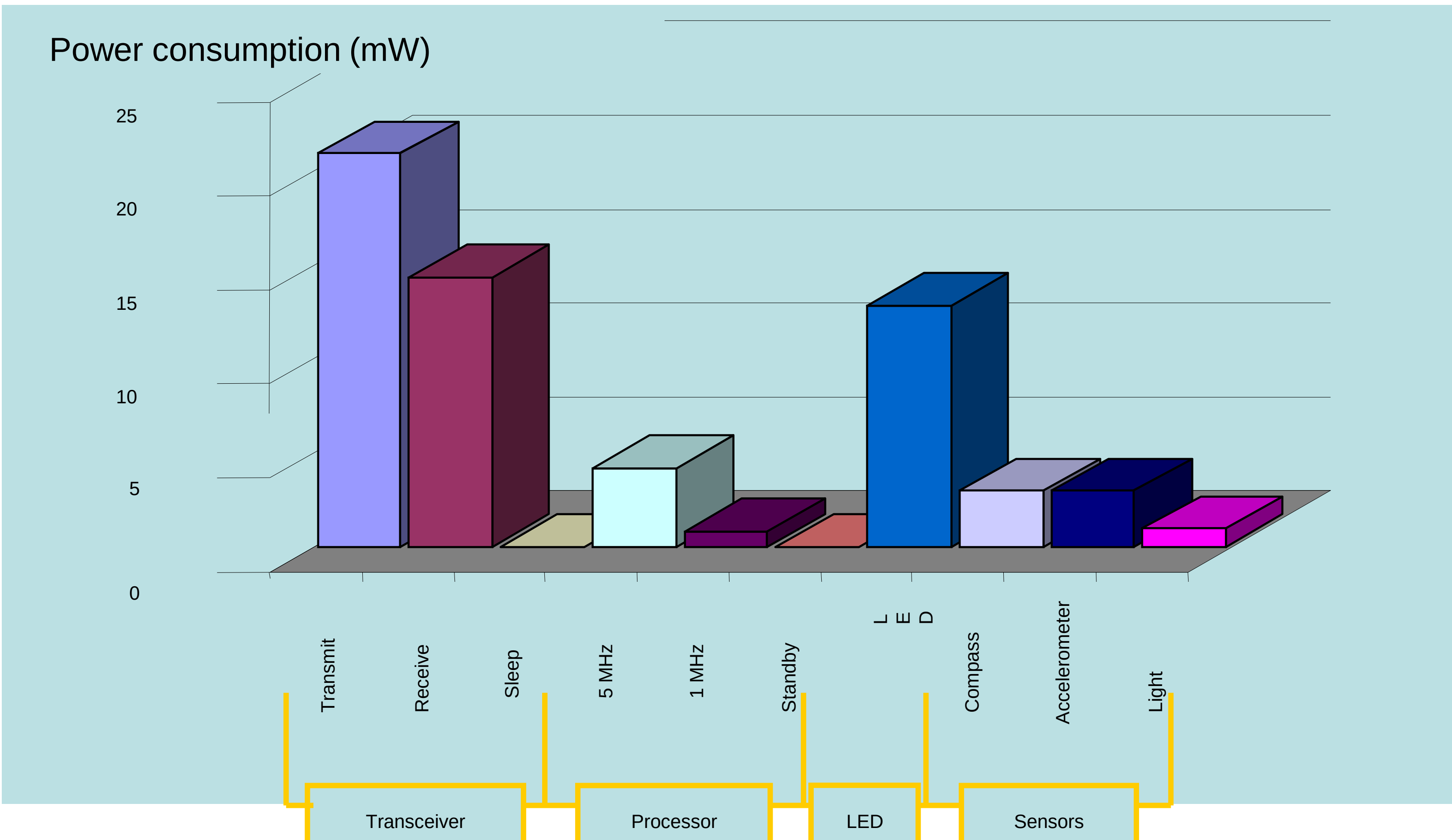
**Very wide ranges of
node densities, sampling frequencies,
QoS requirements,
make the design of wireless sensor networks
extremely application-dependent.**

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

Section 3
Energy Efficiency

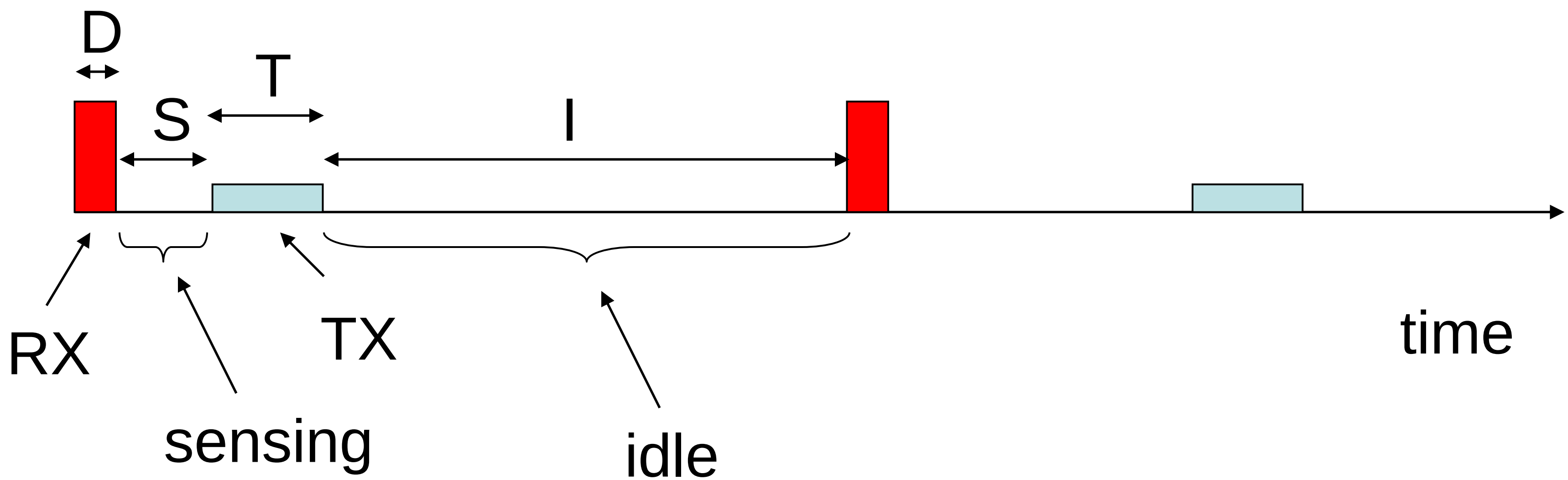
Energy Efficiency

Where is energy consumed?



Energy Efficiency

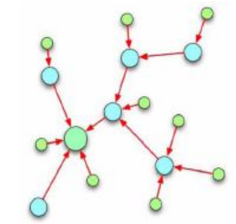
When is energy consumed?



$E = p_{rec}\, D + p_{sens}\, S + p_{trasm}\, T$ 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	**2 – 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

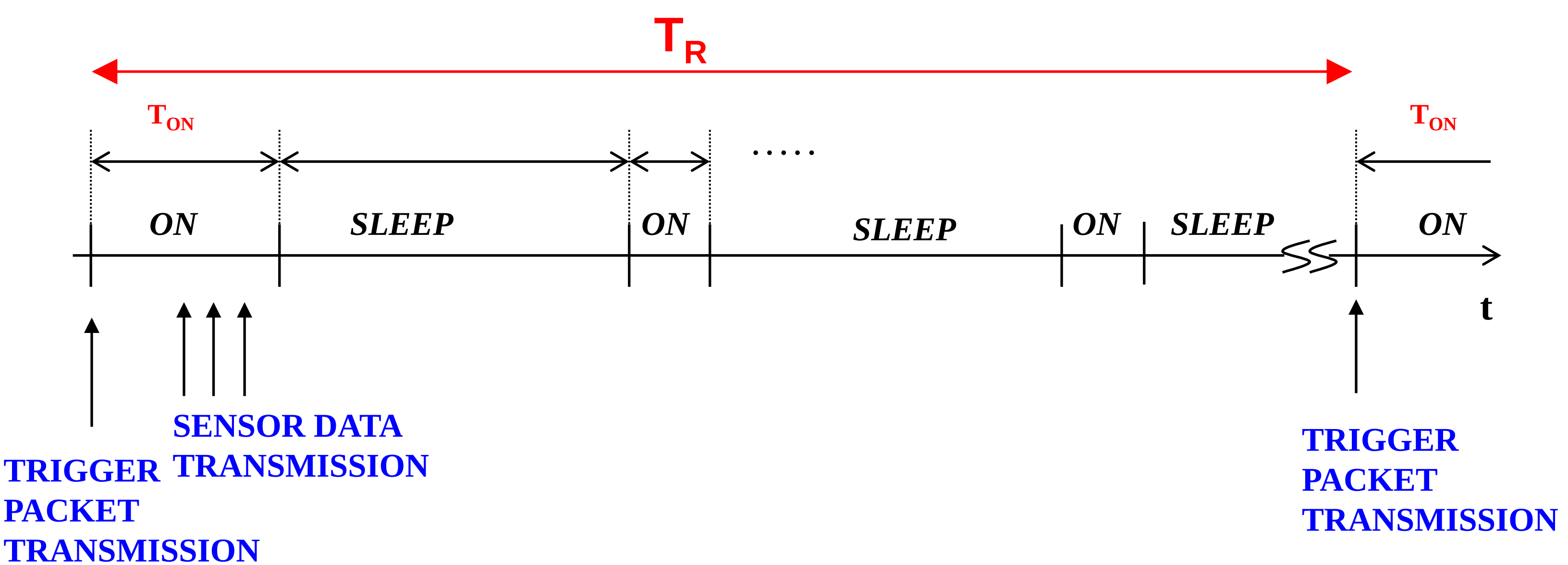
Circuitry must be designed to minimise energy consumption

Nodes must turn off during inactive periods of time

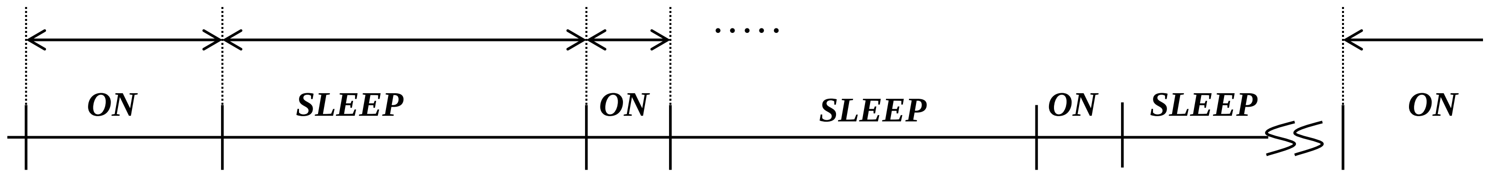
Energy Efficiency

round:

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



Energy Efficiency: Estimation of Activity Factor



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

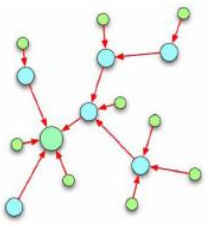
E_{charge} = *5000* J

$= P_{sleep}\ T_{sleep} + P_{on}\ T_{on} = P_{on}\ T_{on}$

$= 50\ 10^{-3}\ T_{on}$

→ $T_{on} = 10^5$ s = approximately one day !

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



Summing-Up

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

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