Technische Universität Braunschweig

Institut für Betriebssysteme
und Rechnerverbund

Recent Topics in Computer Networking

Wireless Sensor Networks – Introduction and Applications

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Outline

- Motivation
- Terms
- Design considerations
- Challenges
- WSN Applications

WSN Motivation

Various visionary concepts like "Ubiquitous Computing" (also others influenced the field)

Mark Weiser
(1952-1999)

1988: Notion „Ubiquitous Computing“

Introduced and defined by Mark Weiser, XeroxParc

- Ubiquitous „everywhere“
- Ubiquitous: economically, in arbitrary amount available

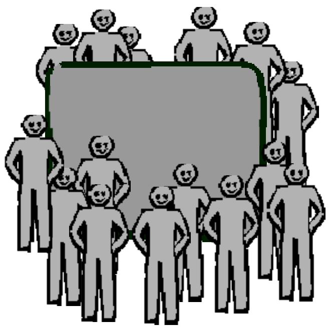
1991 „The Computer for the 21st Century“

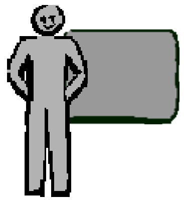
Article in Scientific American

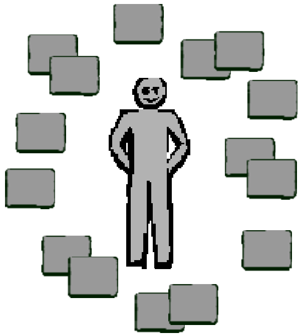
Vision: Computers become so much of our daily live that we do not take notice of them any longer

"Ubiquitous Computing enhances computer use by making computers available throughout the physical environment, while making them effectively invisible to the user"

Vision of M. Weiser, XeroxParc







Mainframe Comp.	Personal Comp.	Ubiquitous Comp.
Humans share a rare resource Usage explicit, use well prepared User: Experts	Personal Direct usage User: Everybody, supported by experts	Ubiquitous Implicit usage User: Everybody

The most profound technologies are those that disappear:

(according to Weiser et al.)

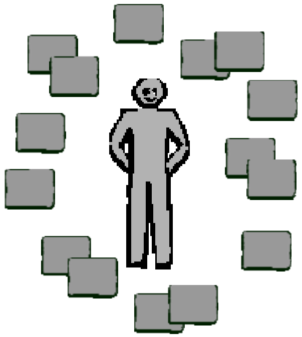
- E.g., Writing: does not require active attention, but the information to be conveyed is ready for use at a glance (Periphery / calm technology)
- We should not be required to live in computer's world (OS, virtual reality), computers should become invisible and ubiquitous (disappear in background) in our physical world
- Already computers in light switches, thermostats, stereos and ovens help to activate the world

Disappearing computing ...

For such, base technologies are crucial, e.g.,

- "Sufficiently" powerful processors & storage
- Wireless communication
- Sensors
- Actuators

Not for all such "applications" & "scenarios", humans must be involved directly



WSN Motivation

For many applications & scenarios where **interaction with environment** is taking place:

- Direct interaction with humans is not necessary or not possible
  - E.g., monitoring industrial processes
- Humans should be involved in specific situations only
  - E.g., in case of an emergency
  - Or if collected measurement data should be studied, interpreted etc.

→potentially autonomous operation unless help by human is needed

WSN Motivation

Needs for applications & scenarios interested in **interaction with environment:**

- Sensing in environment
- Computing in environment to process data
- Communication to transport data
- Networking to build up larger distributed systems
- Actuation to influence environment

→ *Wireless sensor networks* (WSN)

- Or: ***Wireless sensor & actuator networks*** (WSAN)

WSN Motivation

Also a reason:

Technology advances make it possible …

… allow for smaller computerized devices with

- processors, sensors, communication, …

CMOS miniaturization

Micro-sensors (MEMS, materials, circuits)

- acceleration, vibration, gyroscope, tilt, magnetic, heat, motion, pressure, temp, light, moisture, humidity, barometric
- chemical (CO, CO_2, radon), biological, microradar, ...
- actuators too (mirrors, motors, smart surfaces, micro-robots)

Communication

- short range, low bit-rate, CMOS radios

Power

- Batteries, fuel cells
- solar, vibration, flow

Sensor & sensor network

Different terms can be used, also depending on discipline

- Sensor: device which allows "sensing" of the environment (delivers some relatively simple output)
- Sensor system: capable to do some processing
- In WSN field (in computer science & engineering): "sensor / sensor node" typically includes already some processing
  - Often no strict difference between sensor, sensor system, sensor node

Sensor & sensor network

Sensor network consists of some … large number of sensor nodes

- Sources of data
- Potentially hundreds or thousands of nodes
- Sensor nodes cooperate to fullfill their tasks

Sensor nodes are deployed in the “environment” (phenomenon to be observed) or close to it

Sensor nodes are resource constraint

- limited in power, computational capacities, memory, …

Sensor nodes are prone to failures

- e.g., it may not hurt if a node dies if WSN is still operational

Sensor & sensor network: further elements

Actuators

- Control some „in-field device“
- Needed to form control loops and have an impact on the environment

Aggregating nodes

- Process and aggregate data received from several nodes

Sink nodes

- Interested in data from sensor nodes
- Connect WSN to backend systems

Sensor & sensor network: further elements

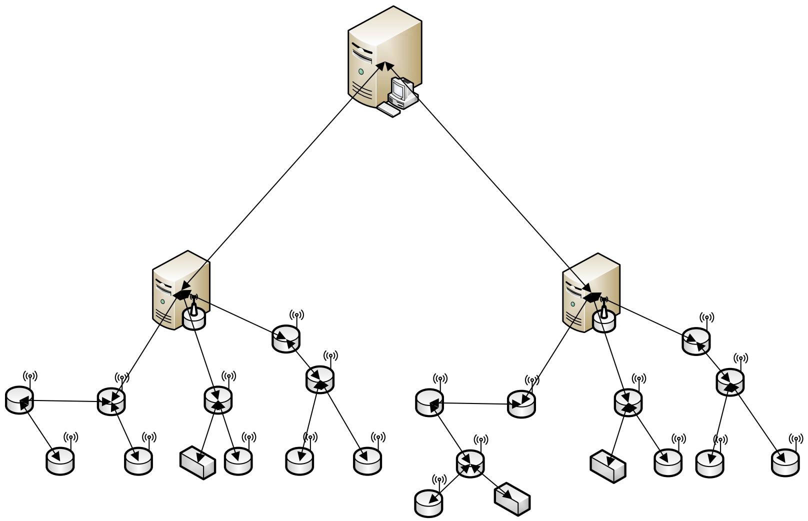
Backend systems

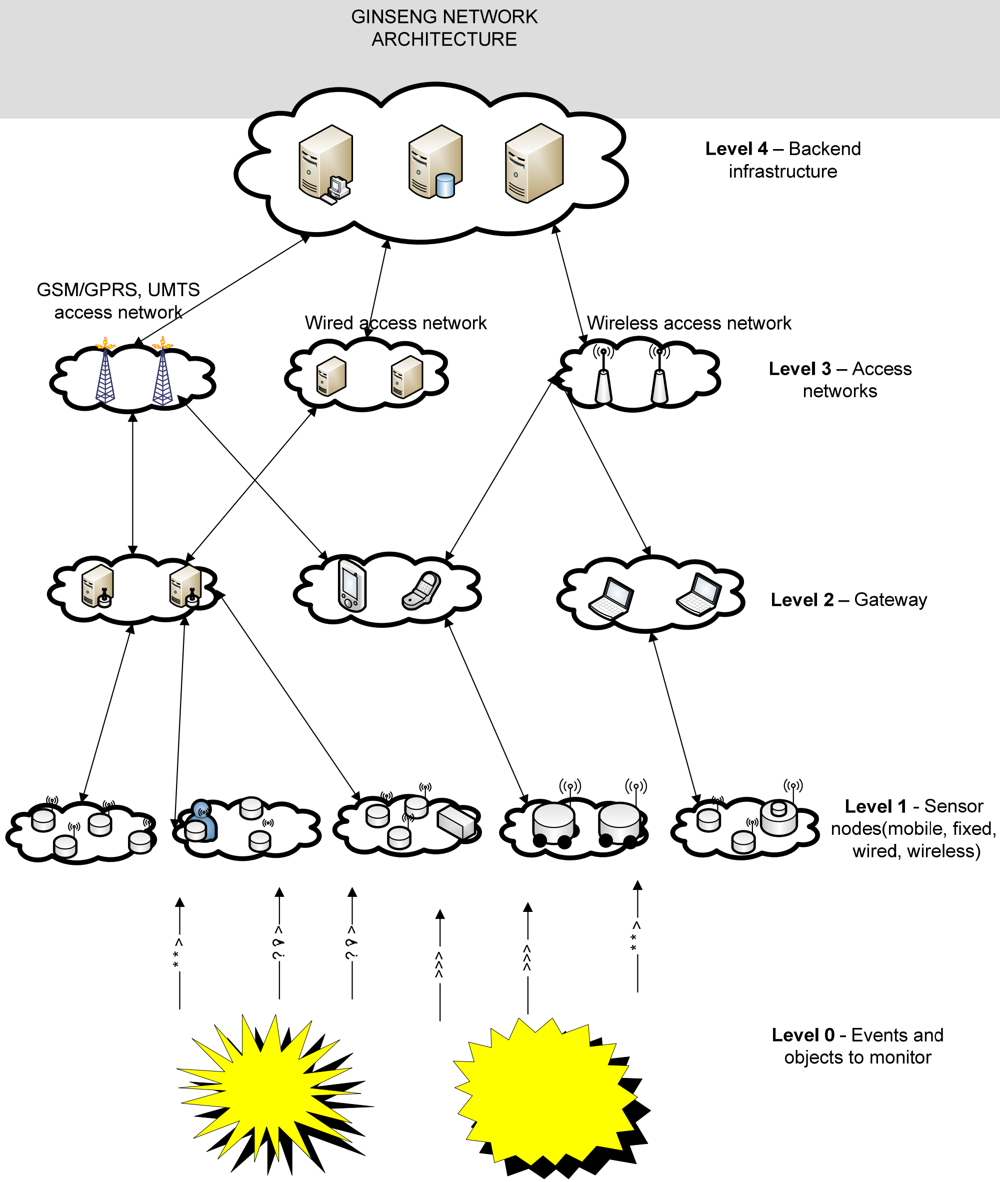
- for further processing, analysis, …
- Also for more complex processing, long-term data storage, …

Networks links between above elements

- Sensor node to sensor node
- Sensor node to sink node
- Sink node to backend
- …
- Typically different technologies

Examples for WSN structures





Promising applications for WSNs

Machine and vehicle monitoring

- Sensor nodes in moveable parts
- Monitoring of hub temperatures, fluid levels …

Health & medicine

- Long-term monitoring of patients with minimal restrictions
- Intensive care with relative great freedom of movement

Intelligent buildings, building monitoring

- Intrusion detection, mechanical stress detection
- Precision HVAC (Heating, Ventilating and Air Conditioning) with individual climate

Environmental monitoring, person tracking

- Monitoring of wildlife and national parks
- Cheap and (almost) invisible person monitoring
- Monitoring waste dumps, demilitarized zones

… and many more: logistics (total asset management, RFID), telematics …

- WSNs are quite often complimentary to fixed networks!

WSN design considerations / design space

Deployment of nodes and WSN in general

- random vs systematic, manual vs. automatic

Mobility of nodes

- static vs mobile; occasional vs continuous; active vs passive

Node's cost, size, resources

- brick vs matchbox vs grain

Heterogeneity within WSN & among nodes

- homogenous vs heterogeneous wrt type, capabilities, ...
  of nodes, tasks, ...

WSN design considerations / design space

Communication approaches

- radio vs light vs …

Infrastructure

- Infrastructure support used vs completely ad hoc

Network topology

- single-hop vs multihop

Coverage

- sparse vs dense

WSN design considerations / design space

Connectivity

- regularly connected vs intermittent vs sporadic

Network size

- 10 vs 100 vs 1000 vs 10000 vs 100000

Lifetime

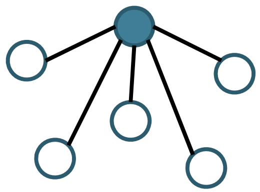
- day vs month vs year vs decade

QOS requirements

- none vs real-time

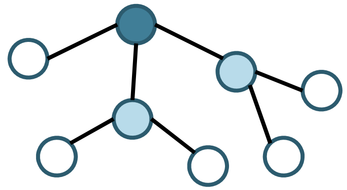
WSN design space: Example network topologies – single- vs. multi-hop

Single-hop (star) topology:



- Direct communication of every sensor node with sink / base station
- Issues:
  - Perhaps large transmission power needed, connectivity, …

Multi-hop topology



- Some sensors serve as relays
- Issues:
  - Potentially lower transmission power, higher coverage, …
  - Needs more complex topology control, routing, …

Challenges in Wireless Sensor Networks

Many challenges in WSN, e.g.,

- Energy constraints
- Unreliable communication
- Unreliable sensors
- Deployment
- Scalability, coverage, density
- Limited computation power
- (Re-) Programmability
- Maintainability
- Distributed execution

Challenges in Wireless Sensor Networks: Often not independent

Processing characteristics

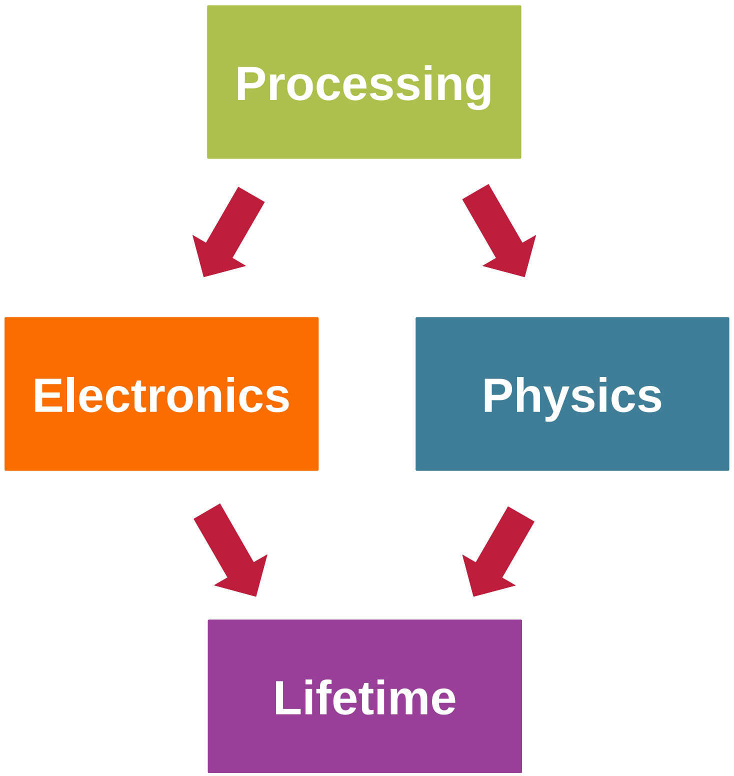
- Computation power
- Throughput

Electrical characteristics

- Energy consumption
- Energy dissipation

Physical characteristics

- Shape, ergonomics, robustness
- Dimensions, weight (also of power source)



Challenges in WSNs: Energy

How can energy be supplied?

- Batteries
  - How to replace batteries?
- Energy harvesting
  - Light (solar), temperature gradients, motion, vibrations, …?
- Accept limited life-time of sensor node
  - Necessary lifetime due to mission?

Challenges in WSNs: Energy

Energy consumption:

- **ALL** parts of **sensor node** and **WSN system** are important
  - Node as well as network design

→ energy efficiency important within all parts of sensor node & network design

- Sensing
- Processing data
- Storage of data
- Transmitting data
- Receiving data

Challenges in WSNs: Energy

To reduce consumption, sensor node

- should only be active if really needed
- sleep otherwise

Typical modes

- controller: Active, idle, sleep
- radio mode: Turn on/off transmitter/receiver, both
- different modes possible, e.g., several sleep modes

Good operational points?

- When to put which part into sleep?
- E.g., from when to when put receiver asleep?

Challenges in WSNs: Deployment & Self-Management

Ways to deploy sensor nodes into their environment:

- Random
  - E.g., dropped from airplanes
- Systematic
  - E.g., installed at specific places to be monitored

- Mobile nodes
  - Active or passive (e.g., wind, water)
  - May compensate for unsettled areas
  - Can move to interesting places

Challenges in WSNs: Deployment & Self-Management

Especially if deployed randomly, sensor node should be able to:

- determine location
- detect neighboring nodes and determine their identity
- configure node parameters
- discover route(s) to base station
- initiate sensing responsibility

Nodes must be prepared for unattended operation

- once deployed, WSN must operate without human intervention
- adapt to changes in topology, density, and traffic load
- adapt in response to failures

(not necessarily also for systematic deployments and more tight controlled scenarios)

Challenges in WSNs: Security

Some WSNs monitor critical infrastructure or carry sensitive infos

→ desirable targets for attacks

Attacks

- from inside / from outside
- target wireless communication / nodes

Difficulties to protect against attacks due to

- remote and unattended operation
- wireless communication
- lack of advanced security features (due to cost, form factor, energy, …)

Challenges in WSNs: Security

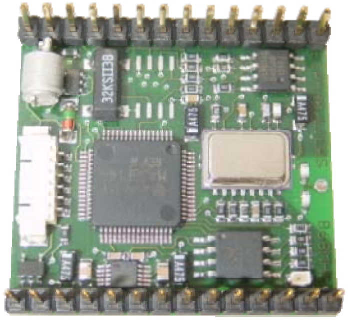
Conventional security techniques

- often not feasible due to their requirements
  - computational, communication, and storage requirements

→new solutions needed for

- intrusion detection
- encryption
- key establishment and distribution
- node authentication
- …

WSN compared to MANETs



Commonalities with MANETs

- (typically) self-organization, multi-hop
- Typically wireless, should be energy efficient

Differences to MANETs

- *Applications:* MANET more powerful, more general ↔ WSN more specific
- *Devices:* MANET more powerful, higher data rates, more resources
  ↔ WSN rather limited, embedded, interacting with environment
- *Scale:* MANET rather small (some dozen devices)
  ↔ WSN can be large (thousands)
- *Basic paradigms:* MANET individual node important, ID centric
  ↔ WSN network important, individual node may be dispensable, data centric
- *Further issues:* Mobility patterns, Quality-of Service, Energy, Cost per node …

Applications for Wireless Sensor Networks

Many different application areas studied in WSN community, e.g. as shown in the following

- Wildlife Monitoring
- Body Area Networks & Ambient Assisted Living
- Firefighters
- Structural Health Monitoring
- Production processes: GINSENG

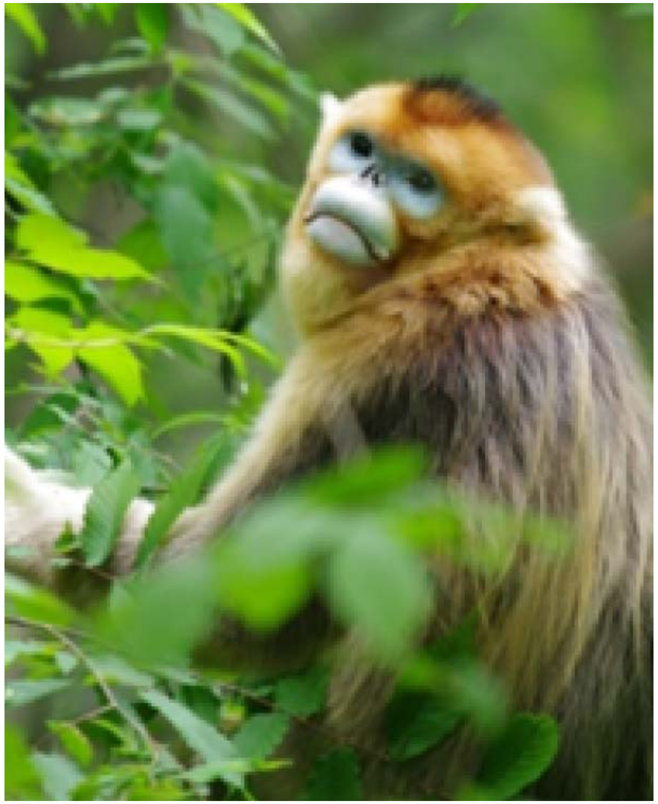
Many others exist (not shown here) like

- Traffic control / Management of parking lots
- Volcanoes / mountains / glaciers monitoring
- Agriculture
- Surveillance (civil & military)

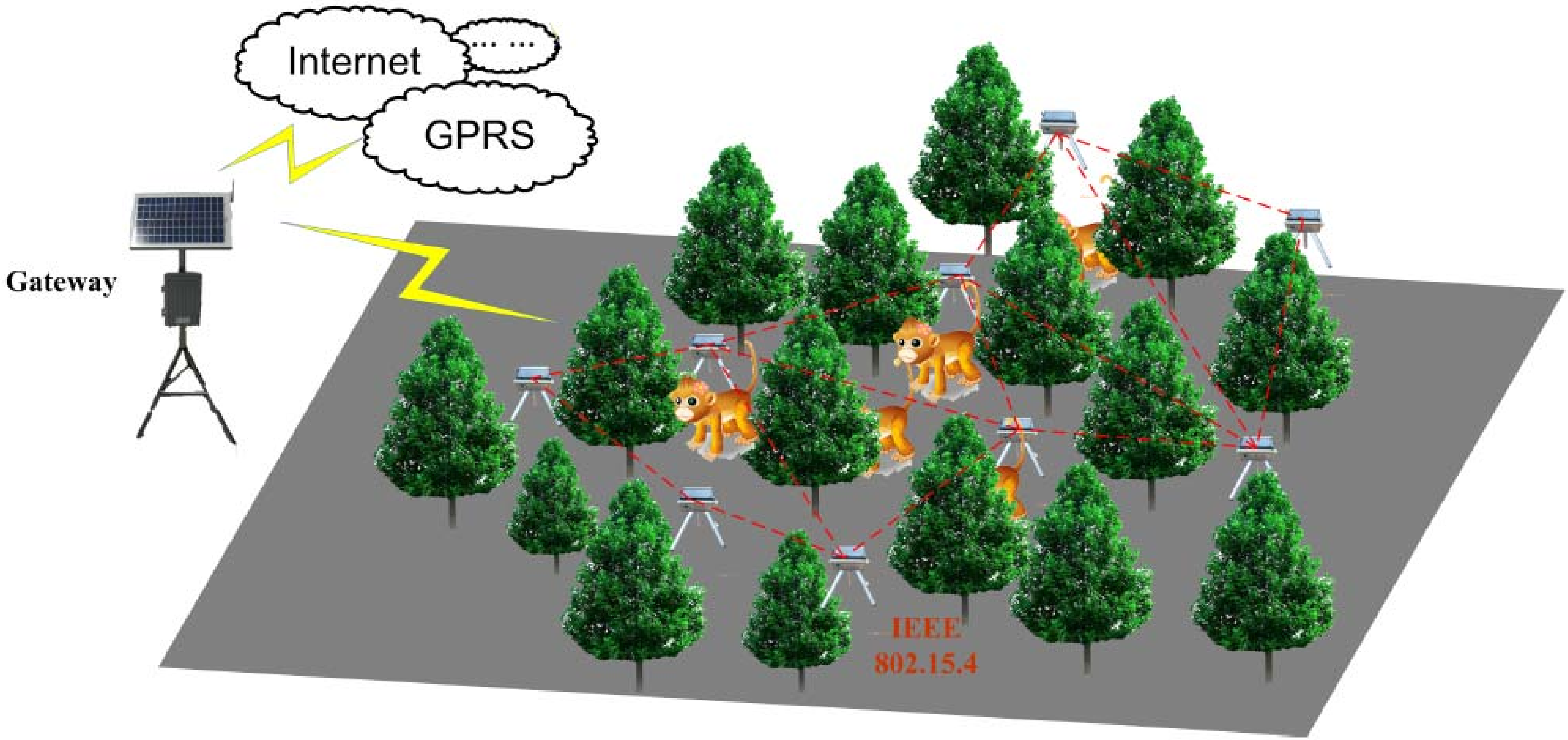
Wildlife Monitoring: Rhinopithecus roxellana Monitoring

Real WSN deployment to monitor and track monkeys

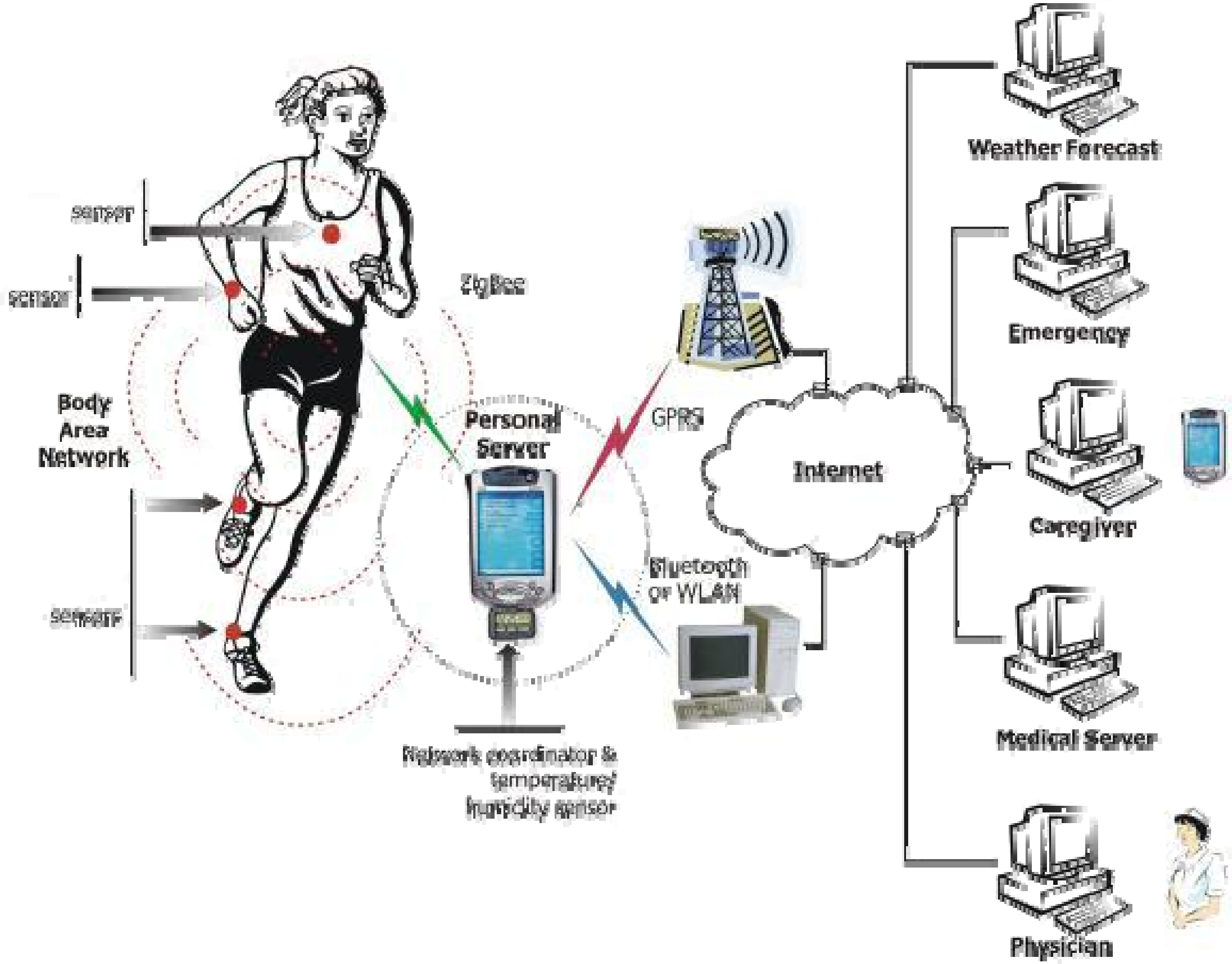
- Protected animals
  - No invasive (e.g. RFID) method possible
- Identification by sound
  - Pattern matching to identify individual animals
- Tracking by camera sensors
  - Wake-up camera by change in RSSI



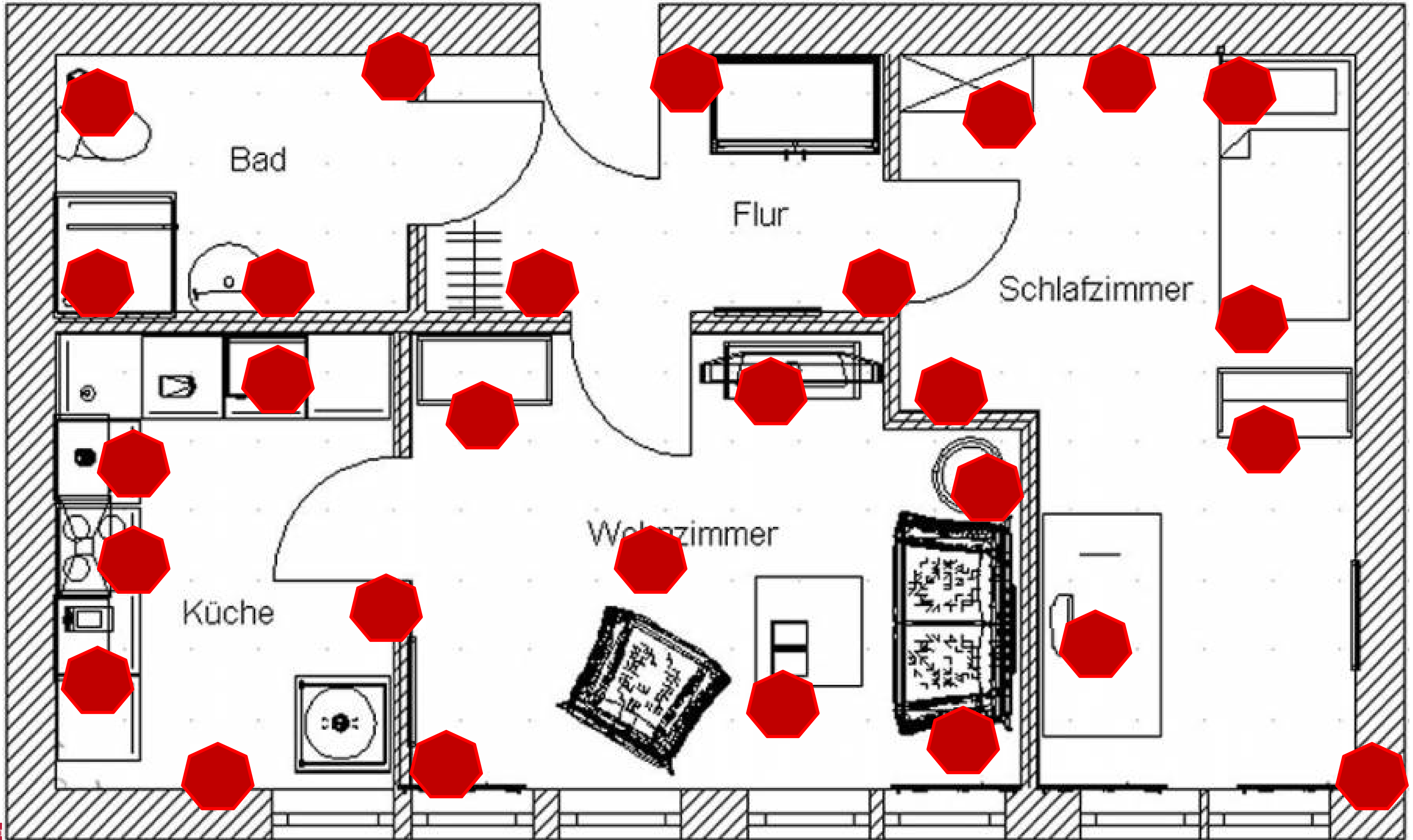
Rhinopithecus roxellana Monitoring – System Architecture



BAN: Body Area Networks



Habitat Monitoring



Fire detection with WSNs - Motivation

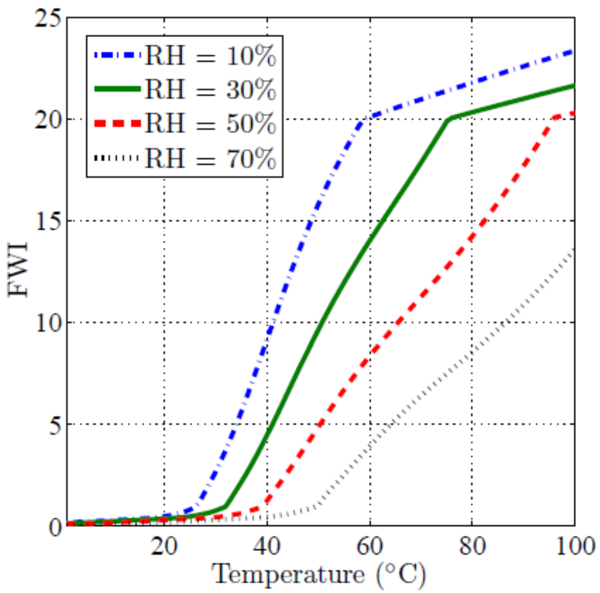
Moderate surface fire (FWI = 14)

Very intense surface fire (FWI = 24)

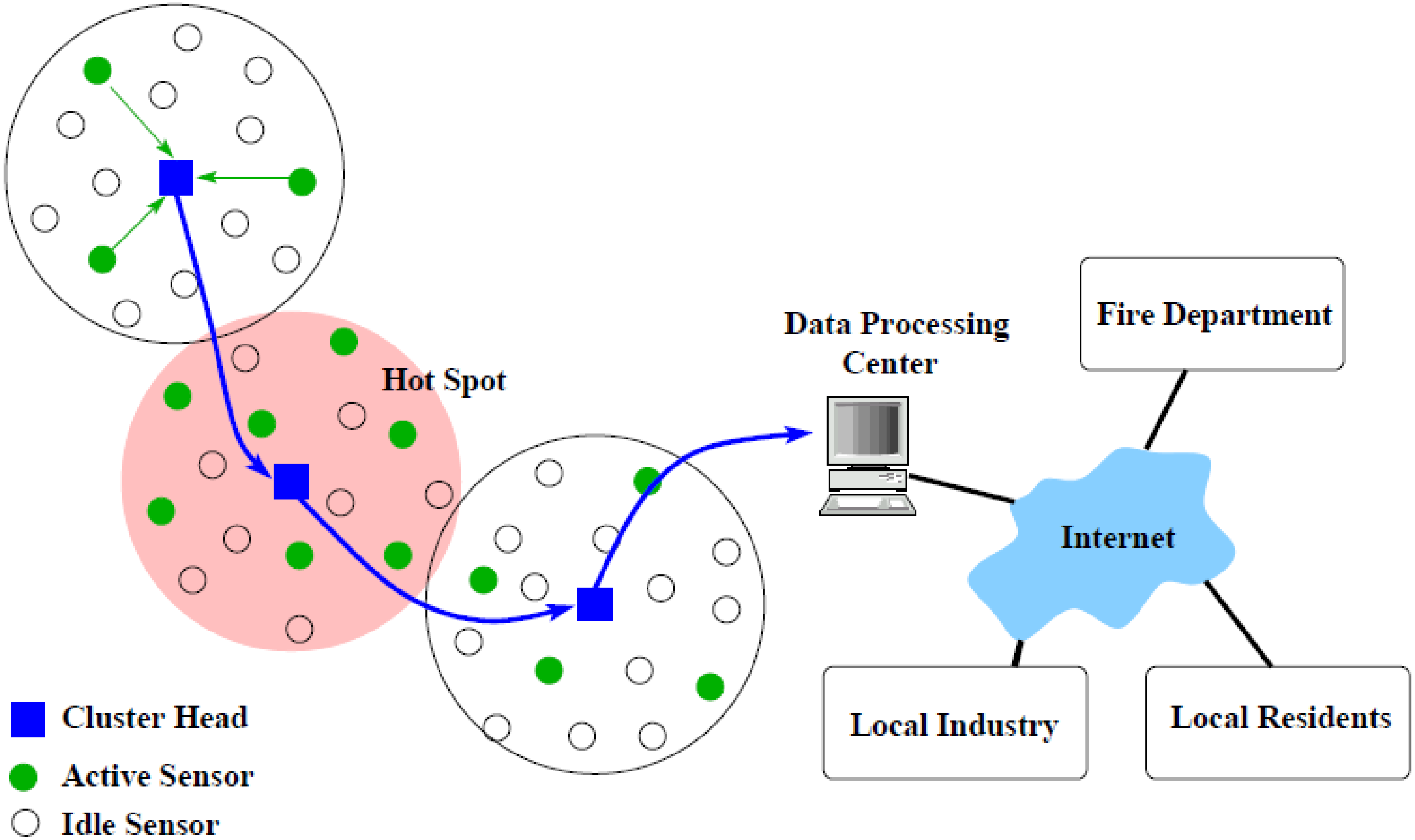
Developing active fire (FWI = 34)

FWI – Fire Weather Index

- Depends on temperature & relative humidity
- Measurable with simple and cheap sensors (at least temperature)



Fire detection with WSNs – System Architecture

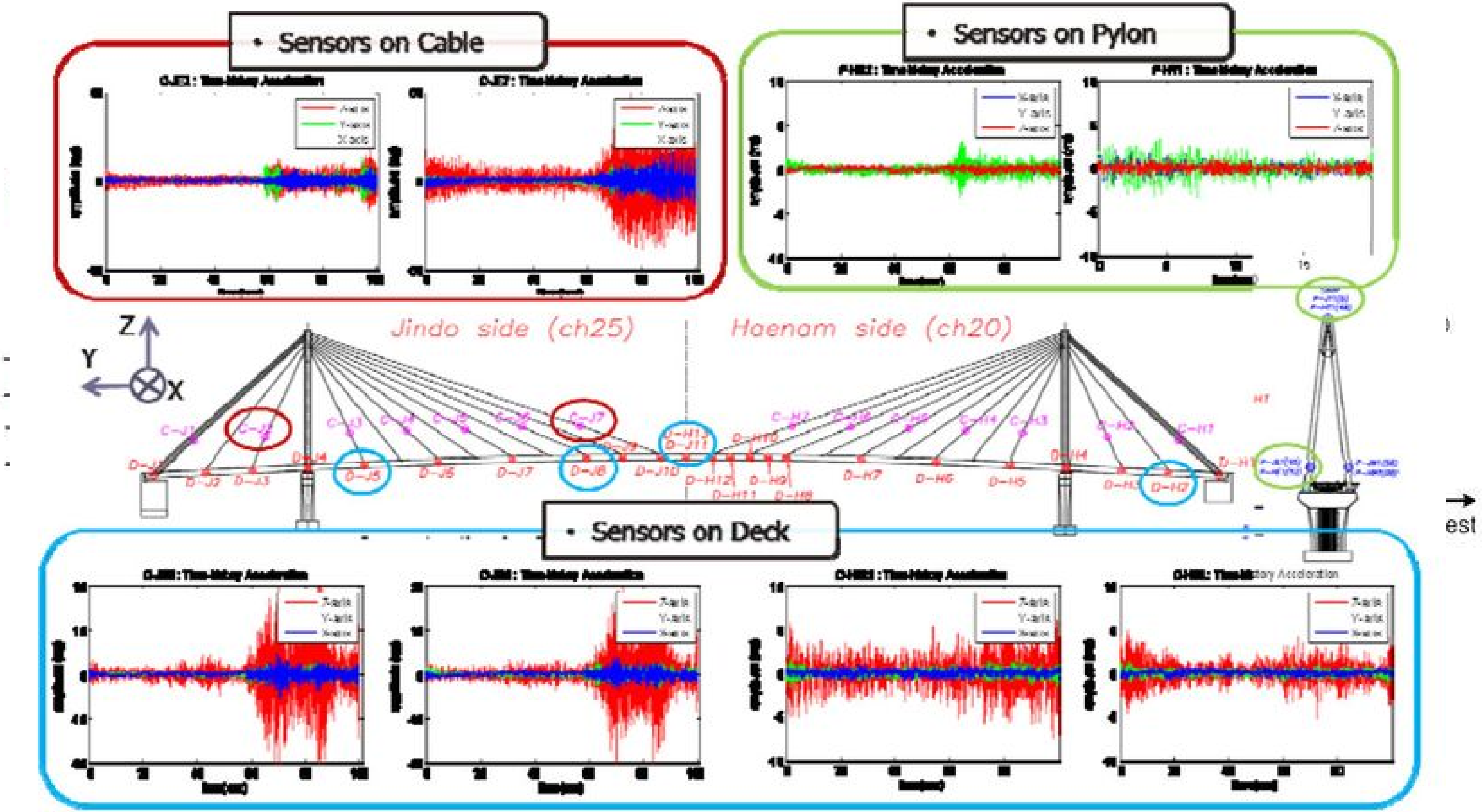


Illinois Structural Health Monitoring Project (ISHMP)

Jindo-gun, South-Korea

2009, Photography by MEMSIC, from http://blog.memsic.com/2009/11/structural-health-monitoring-part-2-software.html

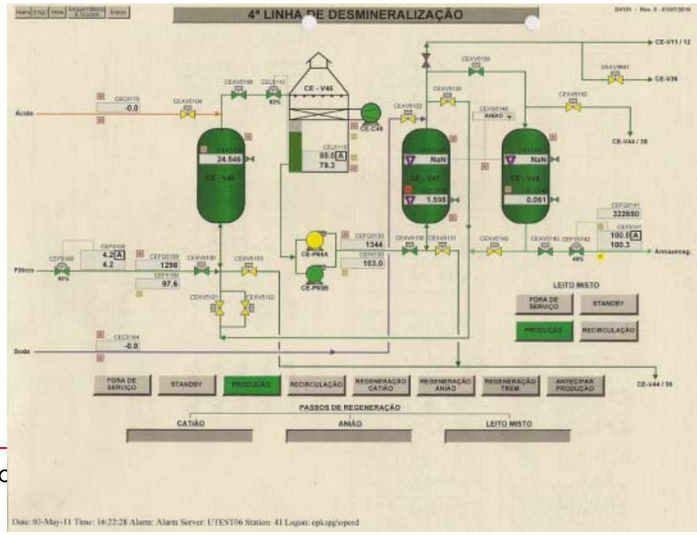
Structural Health Monitoring



GINSENG

Control of production processes in refinery

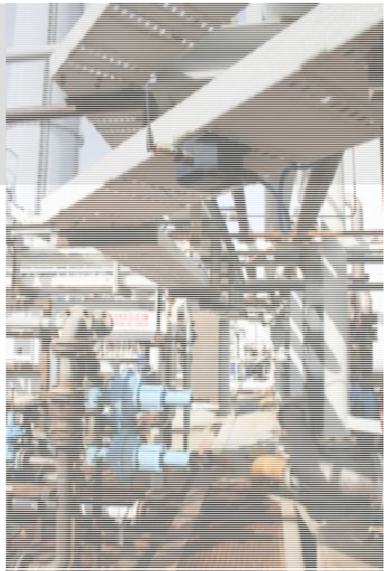
- E.g., constant monitoring of pipes
- Close valves before critical condition is reached
- Reduces maintenance effort & production cost
- Improve safety and reduce environment hazards

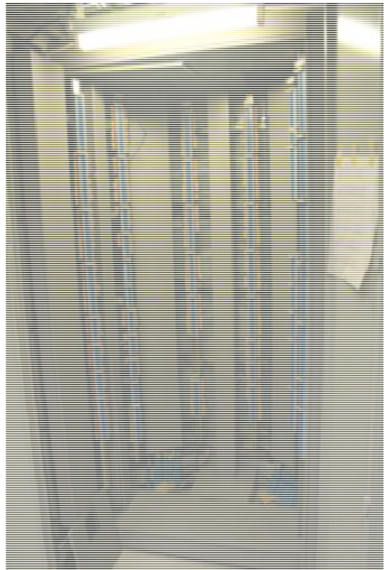


GINSENG

In GALP refinery in Portugal:

- currently approx. 35000 sensors and actuators to perform
  - monitoring of industrial operations such as leakage detection,
  - measurement of pressure in the pipes, fluid levels
  - ...

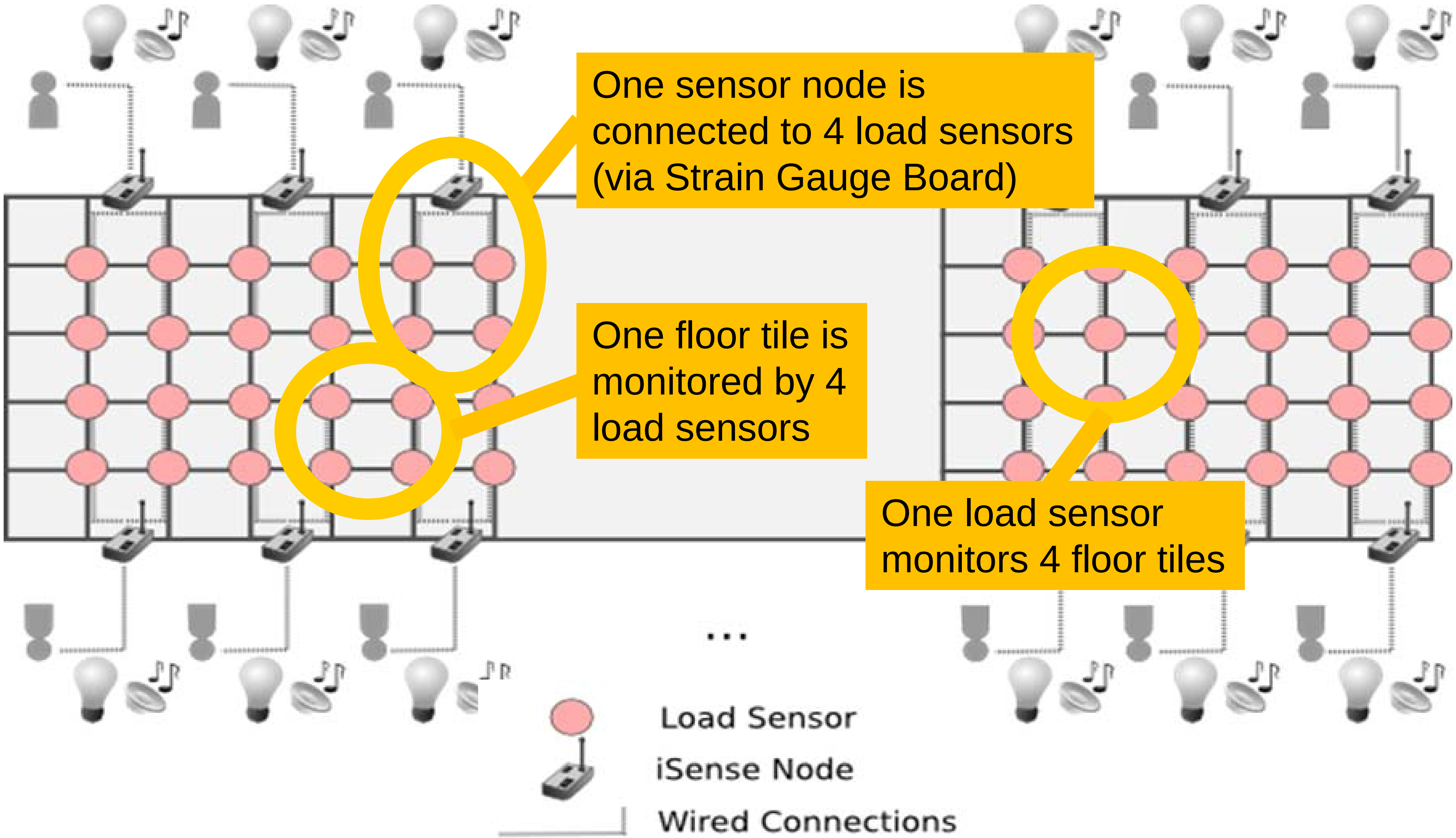




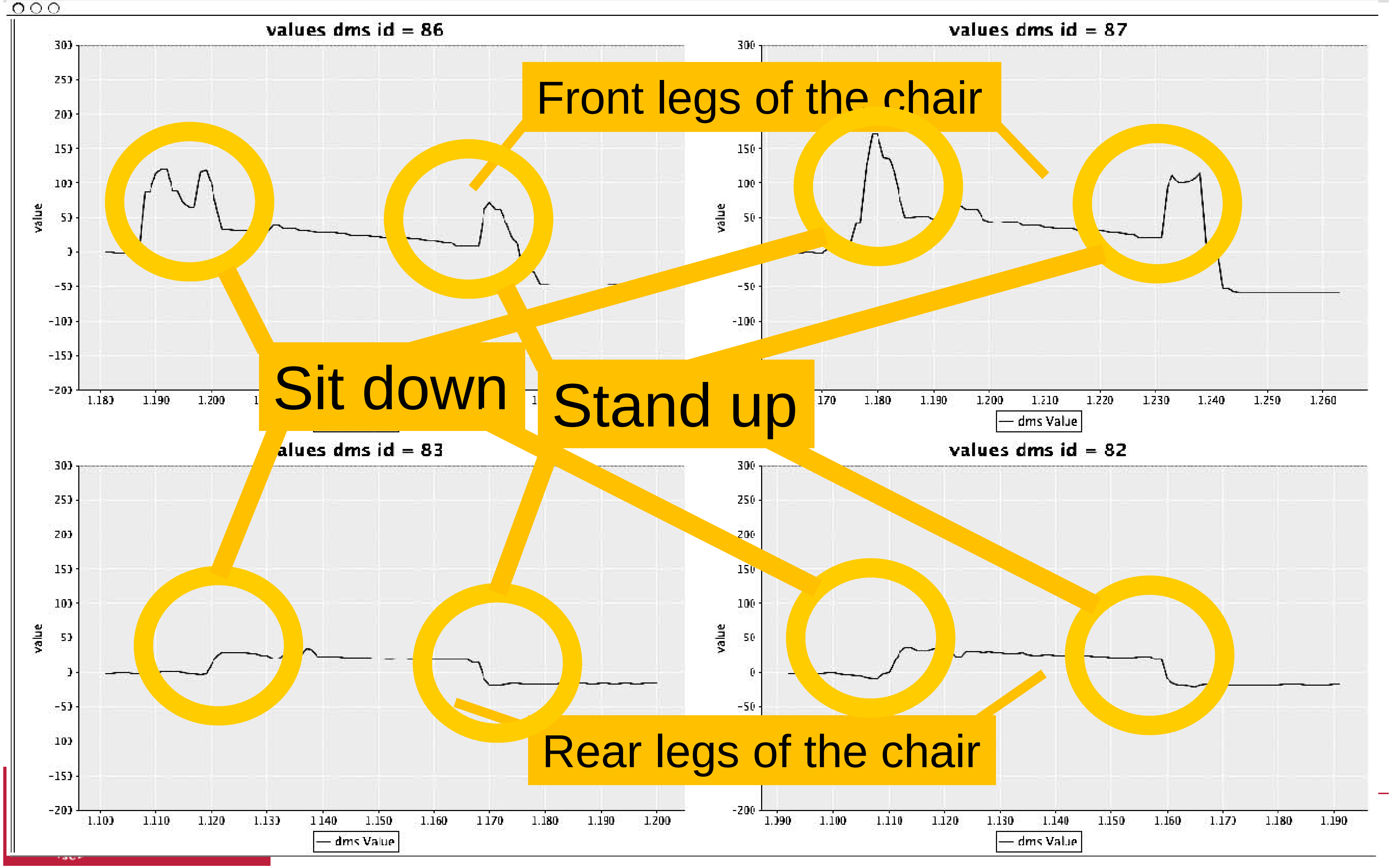
→Reduce cost of cabled sensors, but
  - guarantee reaction in certain time
  - ensure stable operation
  - ...

IBR Sensor Floor

IBR Sensor Floor - Architecture



IBR Sensor Floor - Applications



WSN-Applications: some student projects of past & current WSN-lab

- INGA-Sports (Wii-Mote like game controller)
- Sensorfloor-Tennis
- Juggling pins
- Weather stations with data mules
- Monkey Lights Lite
- EASI – Home automation
- ingaRider – bike computer
- Regatta tracing
- Blinkenlights
- Lift monitoring

WSN Applications: Summary

- Different use cases
  - Specific sensor nodes
  - Specific sensors
- Different challenges
  - Energy
  - Size
  - Robustness
  - Network scale
  - Communication ranges
  - …

➔ Specialized hardware…