Wireless Sensor Networks
A Decade of Wireless Sensing Applications

MO809 - Tópicos em Computação Distribuída

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Agenda

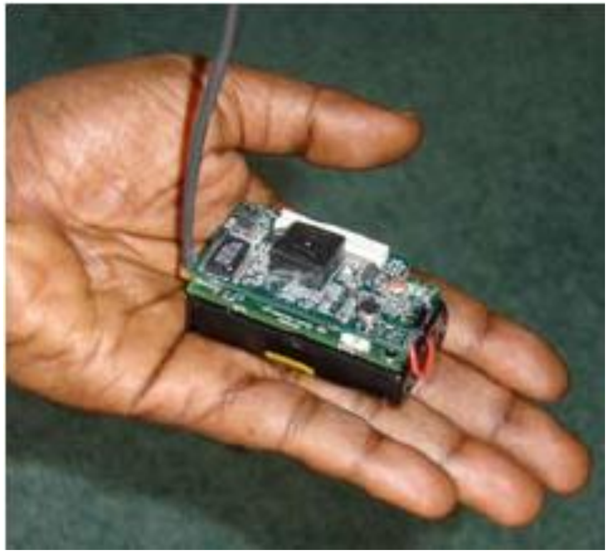
- Introduction
- Applications

1. Low-Rate Data Collection
2. High-Rate Data Collection
3. On-Demand Data Collection
4. Event detection and classification
5. Localization and Tracking
6. Actuation

A Decade of WSN

- The first prototypes of WSNs actually consisted of a small number of matchbox-sized devices, often called “motes.”
  - Small size allows a careful placement close to the phenomenon of interest
  - Low costs
  - Minimal need of human intervention
- Most WSN deployments have a strong scientific background.
  - Main purpose: demonstration of new technologies
  - Exploration of remaining limitations
  - The requirements of the actual application at hand are often secondary

- First application areas
  - Military surveillance: sensors are seen as a tool to enable reliable detection and tracking of enemy forces
  - Environment Monitoring: Great Duck Island in the year 2002 (first significant application deployment of a WSN)
- Around the year 2004: the number of reported WSN deployments increased significantly.
  - Commercialization of the first WSN platforms: Mica2, Mica2Dot, MICAz, TelosB.
  - Maturing software infrastructures (TinyOS, TinyDB)
  - Increasing robustness of networking protocols
  - In recent years: overlap of neighboring research areas (home automation, Internet of Things)



"Most deployments remain prototypical in character and are conducted by researchers working on sensor network technologies. Commercial applications tend to be conceptually simple and not to exploit the full potential of scientific innovations. For example, advanced **multi-hop routing protocols are rarely used**"

Applications Classification

1. *Low-Rate Data*
   Periodic collection using low data-rate sensors
2. *High-Rate Data*
   Periodic collection with high generated data-rate
3. *On-Demand Data Collection*
   Data collection on-demand
4. *Event Detection and Classification*
   Sensor network performs on-node processing (event detection or classification)
5. *Localization and Tracking*
   In-network event detection to localize or even track their position
6. *Actuation*
   Actively manipulate the monitored environment

1 Low-Rate Data Collection

- First application scenario for WSNs
- Still represents the majority of existing deployments
- Periodic monitoring with low-data rate sensors
  - Temperature
  - infrared sensors that usually produce a single scalar value per measurement

- Support an extensive lifetime of the network up to several years
- It is feasible to communicate the collected raw data without filtering, compression, or aggregation

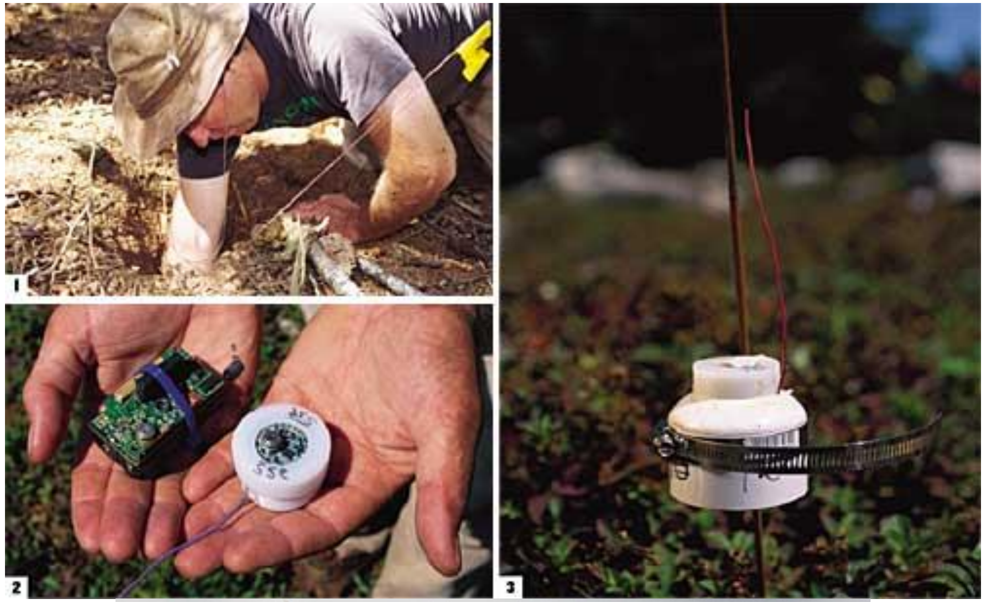
Habitat monitoring: Great Duck Island

2002-2004 - [102, 62, 72]

Mobility: static. Connectivity: connected.

Storage: persistent (server). 32 - 190 sensors.

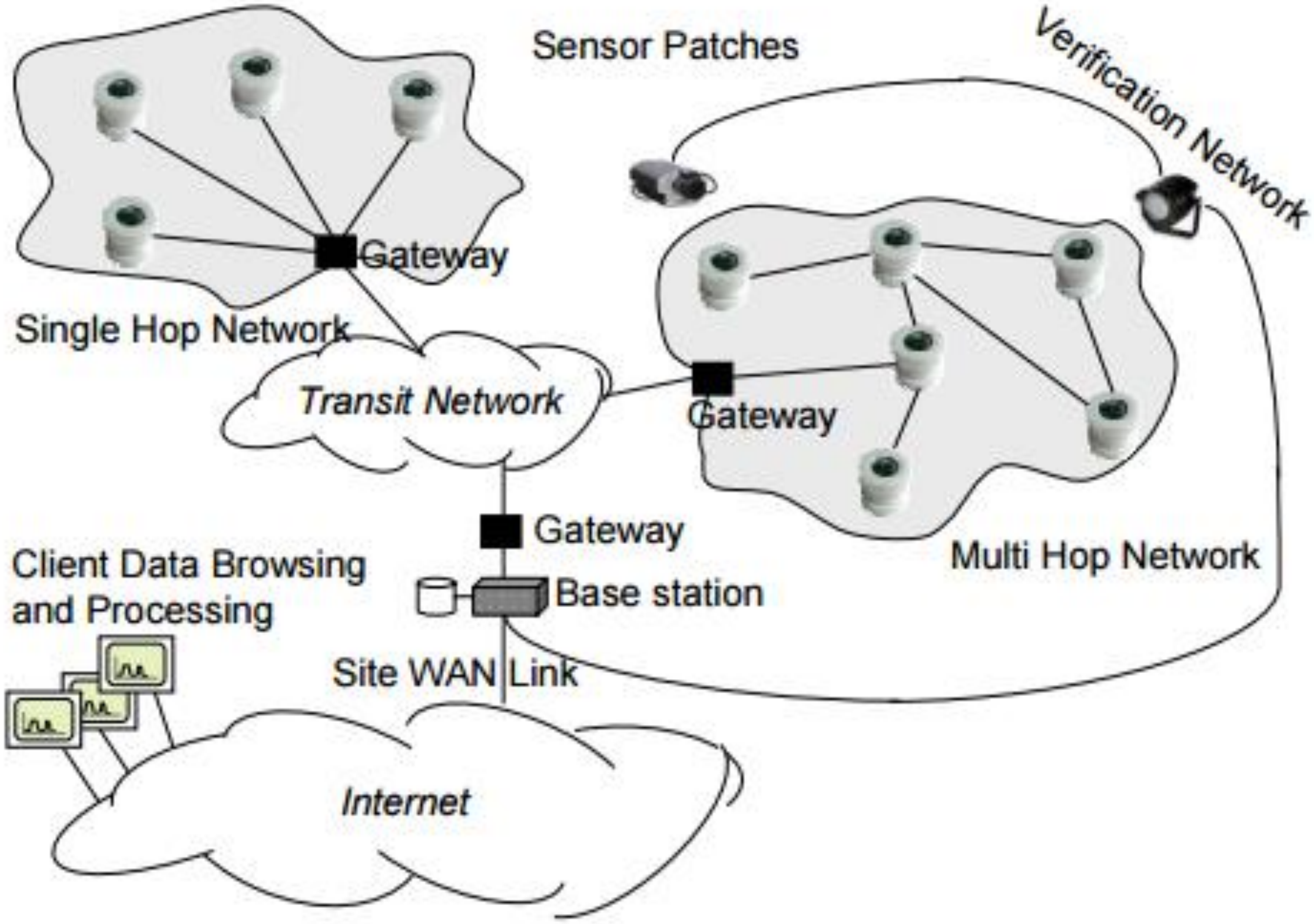
Lifetime: months



Goal: the long-term observation of the breeding behavior and nesting conditions of Leach’s Storm Petrels

Sensors:

- Temperature and humidity (in the nesting burrows)
- Infrared radiation sensors were used to detect the presence of a bird



Deployment consisted of several patches of sensing nodes, connected to a transit network via dedicated more powerful gateway nodes

A single base station provided Internet connectivity and database services for the whole deployment

Environment monitoring: PODS - 2002 - [19]

- Goal: Monitor several species of plants - Hawaii Volcanoes National Park
- Sensors: temperature, humidity, rainfall, wind, and solar radiation sensors

Redwood Eco-Physiology – 2005 [32,105]

- Goal: Monitor redwood trees **-** Sonoma, CA, USA
- Sensors: air temperature, relative humidity, and photo-synthetically active solar radiation

GreenOrbs – 2009 [75]

330 sensor nodes

- Goal**:** observe the effect of different sunlight conditions in shrub thicket
- Sensors: temperature, humidity, illumination, and carbon dioxide measurements

GlacsWeb

Briksdalsbreen in Norway - **2003-2005 - [74]**

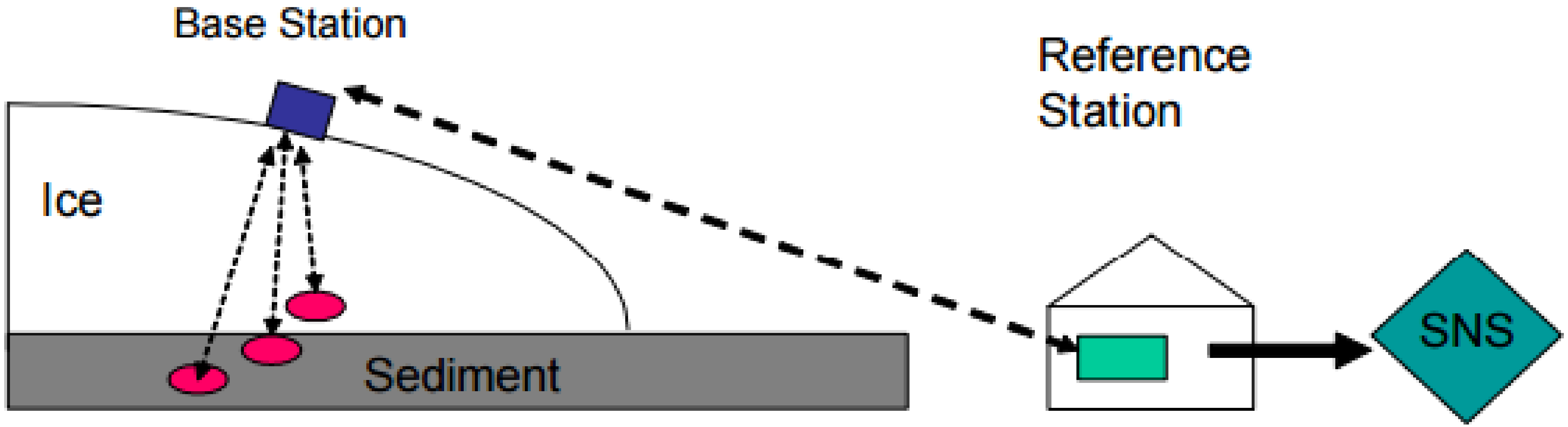
Mobility: nodes. Connectivity: intermittent. Storage: persistent (gateway). Time synchronization

Lifetime: months

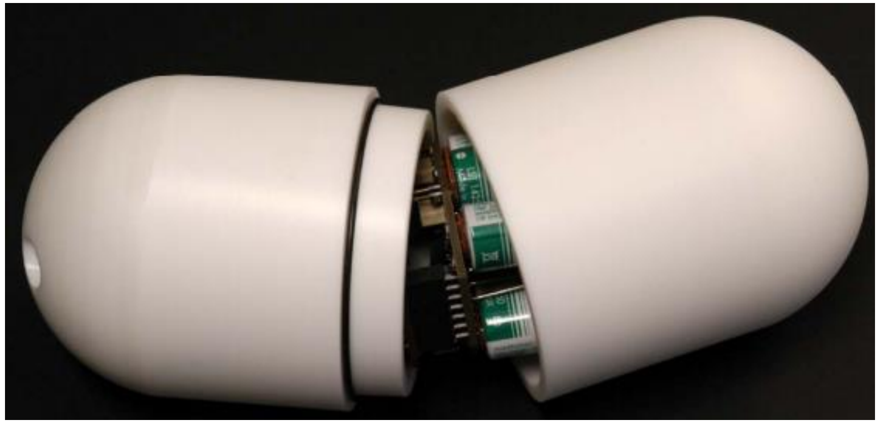
Goal: Monitor conditions inside Glaciers

Glacier environment:

- Is especially hostile to sensor nodes
- Radio communication through ice and water is known to be difficult and highly unreliable
- Remote deployment location: 2.5km distances - network had to reliably operate over long time intervals without direct interaction



Base station
- GPS
- Solar panels
- 500mW radio modem
- 2.5 km



Sensors
- PIC-based boards
- Temperature, pressure, and the orientation in the ice
- Encapsulated in robust and waterproof PVC capsules
- Probes collect data six times daily
- 50m to 80m deep

PermaSense - 2009 - [18] & **SensorScope** – 2007 [15]

- Goal: support the creation of new temperature models
- PermaSense - highly inaccessible terrain area in the Alps
- SensorScope - Le Génépi, Switzerland

Suelo - 2009 - [84]

- Goal: collect high-resolution data on soil state
- If required, the system can automatically call for human verification and assistance

SenSlide – 2005 [94,95]

- Goal: prediction of landslides through constant monitoring of ground stress

LOFAR-agro

2006- [63] - Borger-Odoorn (Drentheand, Netherlands)
Mobility: static. Connectivity: connected.
Storage: persistent (node). 109 sensors.
Lifetime: A year

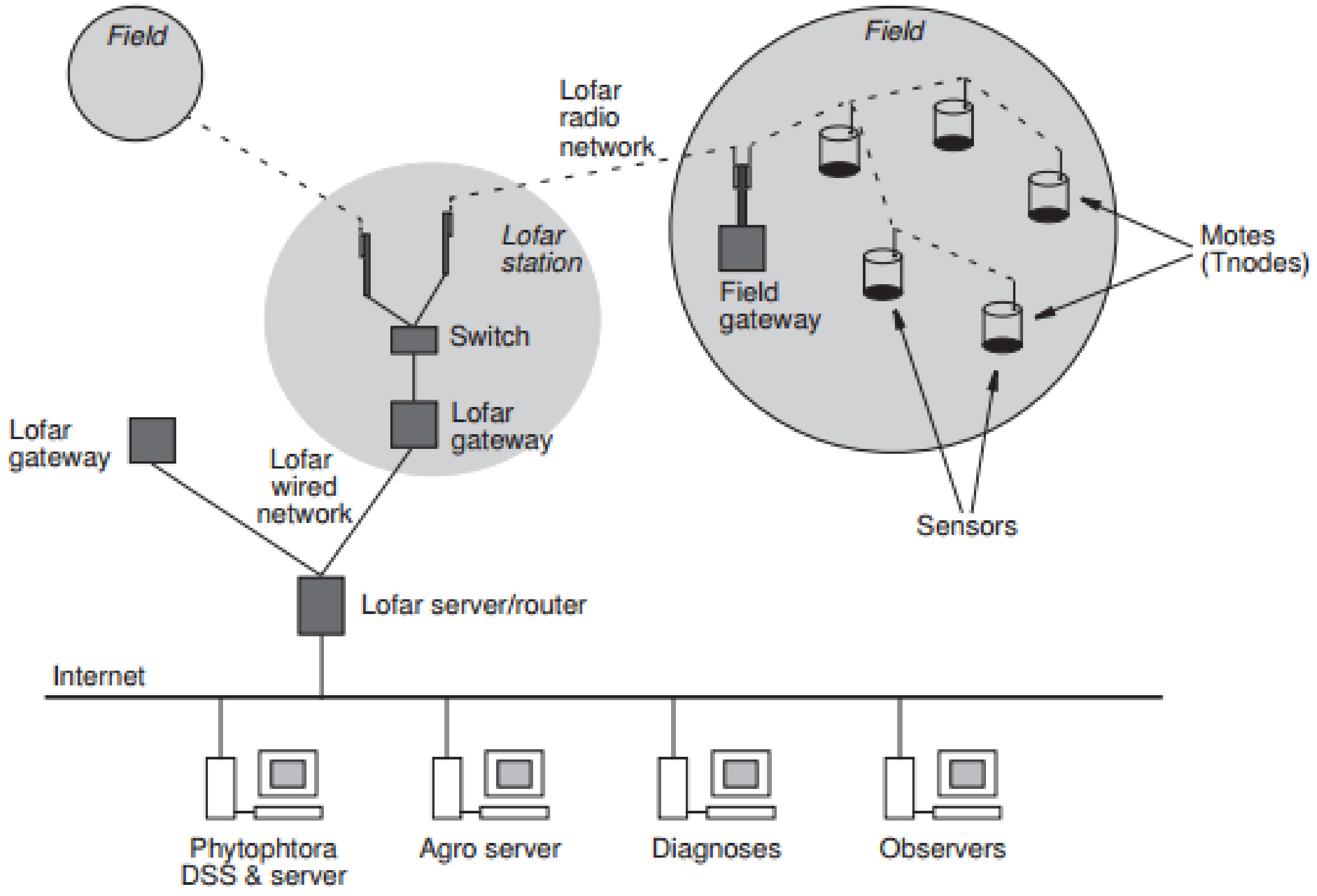
Goal: generate new insights on climate conditions favoring Phytophthora

Sensors:

- Temperature and humidity
- Waterproof PVC-based
- Once per minute

Gateway:

- Solar panel



Sensor – gateway communication:

- Directly
- Through multiple hops

Routing: **MintRoute** - multihop routing protocol to overcome possible obstructions by the growing potato plants

Gateway – LOFAR backbone network:

- Wi-fi

The Agro server: logs the data, filters out erroneous readings, and hands the accumulated data to the Phytophthora decision support system (DSS) server.

The deployed WSN never operated as intended and was hampered by a **very high packet loss rate**. According to the authors, **only 2% of the measurements** made it to the back-end system.

Vineyard Monitoring – 2004/2009 - [7, 17, 20, 78]

Lifetime: months, years

- Goal: get a more fine-grained picture of the microclimate in the proximity of the plants
- Also monitor humidity and temperature in the cellar used for wine storage

Greenhouse monitoring - 2008 - [3]

Eletronic Shepherd - Tracking of sheep – 2004 - [103]

Irrigation Control - 2005/2005/2007 - [13, 57, 81]

Soil moisture monitoring – 2004 - [23,24]

PIPENET

2004 - [101] - Boston Water and Sewer Commission

Goal: monitoring large diameter bulk-water transmission pipelines

Sensor: Bluethooth

Routing: cluster

Monitoring Road Tunnels – 2005/2007 - [26, 27, 31,78]

Substation monitoring - 2008 - [80]

Power Monitoring – 2004/2009/2010 - [4, 49,50,2]

Employed a WSN to provide information on room occupancy in order to operate a Heating, Ventilation and Air Conditioning (HVAC) system based on the actual demand

Relic protection- 2007 - [65,66]

Goal: detect unsuitable climate

Prototype deployed in the forbidden city in Beijing, China

Reliable Clinical Monitoring

2006- [63] - Barnes-Jewish Hospital (Saint Louis, MO, USA)

Mobility: node. 41 patients.

Lifetime: Months

Goal: monitor patients that do not require intensive care, but are at high risk

Sensors:

- TelosB-based wireless
- measure pulse (30s)
- blood oxygen saturation (60s)

Designed new protocol - Dynamic Relay Association Protocol

- discovers new neighbors by listening for beacons periodically broadcast by the relay node
- ssociates with the relay which has the highest Signal strength

(a) Patient node (b) Relay

2 *High-Rate Data Collection*

- Usually don’t transmit raw data to a central server for processing
- Data-rate generated by sensors
  - Usually exceeds the available communication bandwidth
  - Would quickly drain the limited energy budget if the raw sensor data is sent directly to a central unit.

- Need to implement
  - Compression
  - Filtering
  - Data processing

Four Seasons project

2004- [28,109] - abandoned four-story building in Sherman Oaks, CA, USA

Time synchronization.

Lifetime: days

Goal: monitor the health of the structure during earthquakes

Simultaneously to the sensor network experiment, a series of forced-vibration tests with conventional equipment were conducted.

Sensors:

- Vibration sensors and accelerometers
- To limit the data to a maintainable rate, the system employed silence suppression and data compression
- Synchronization: Tracked the time it took a packet to travel through the network

Monitoring Bridges

Golden Gate Bridge – 2007 - [56] – 64 nodes, sampling rate 1kHz

St. Lawrence County - 2009 - [110]

“Torre Aquila” 2009 - [25]

Trento, Italy - Medieval tower

- Contained renowned medieval fresco
- Endangered by construction of road tunnel below the building
- Sensor applied to generate a better insight into the structural behavior of the building

Underground Animal Tracking – 2010 - [73]

- Goal: Badgers tracking
- Limited radio propagation underground – Data locally stored (compression)
- When the badger was near the base station: transmission of data

Volcano Monitoring- 2006 - [108]

- Reventador, Ecuador
- Goal: collection of high fidelity data on volcano activity to enable geologists to build a clearer picture of the seismic phenomena
- 16 sensors: seismic and acoustic
- Rely on a network time synchronization protocol and a single GPS receiver (they needed precision in the order of milliseconds)
- High data rates: 1200 bytes/s per node (network: >100 Kbps)
- Each node temporarily stored the collected data locally
- Detection of predefined pattern - node signaled a detection event to the base station. Base station triggered data collection and iteratively downloaded the last 60 s of recorded data from each sensor node.

Industrial Plant Monitoring: Oil Tanker – 2005 - 61

North Sea

Goal: monitor the vibrations of industrial machinery and equipment - Predictive maintenance

150 off-the-shelf accelerometers

Data was stored persistently in a server located outside the sensor network

The oil tanker’s aft engineering spaces are constructed of steel floors and bulkheads and are subdivided into three major watertight compartments with hatchways in between.

The hatches may be periodically open and shut.

The sensor network was expected to work despite the periodically disconnected nature of these watertight compartments

Health Monitor

Data obtained from cardiac or epilepsy care monitoring employing EKG (electrocardiogram), EEG (electroencephalography) also imply high data-rates.

3 *On-Demand Data Collection*

The user triggers the collection of data

Usually involves persistent data storage on the node or within the network

ZebraNet

2002- [51,115] – Sweetwaters Game Preserve, Kenya

Mobility: nodes, base. Connectivity: sporadic.

Storage: persistent (node). Lifetime: A year

Goal: to record data on migration patterns of zebras

Sensors:

- GPS – Position recorded once an hour
- Area: 100 km^2
- Nodes could only sporadically communicate - the data was replicated to other nodes in the vicinity
- Recorded data was collected by a mobile base station on a vehicle regularly driven by the end-user through the observed area
- Solar Panels

High Fidelity Motion Analysis

2009- [70] – Spaulding Rehabilitation Hospital in Boston

Mobility: nodes. Connectivity: intermittent.

Storage: persistent (node).

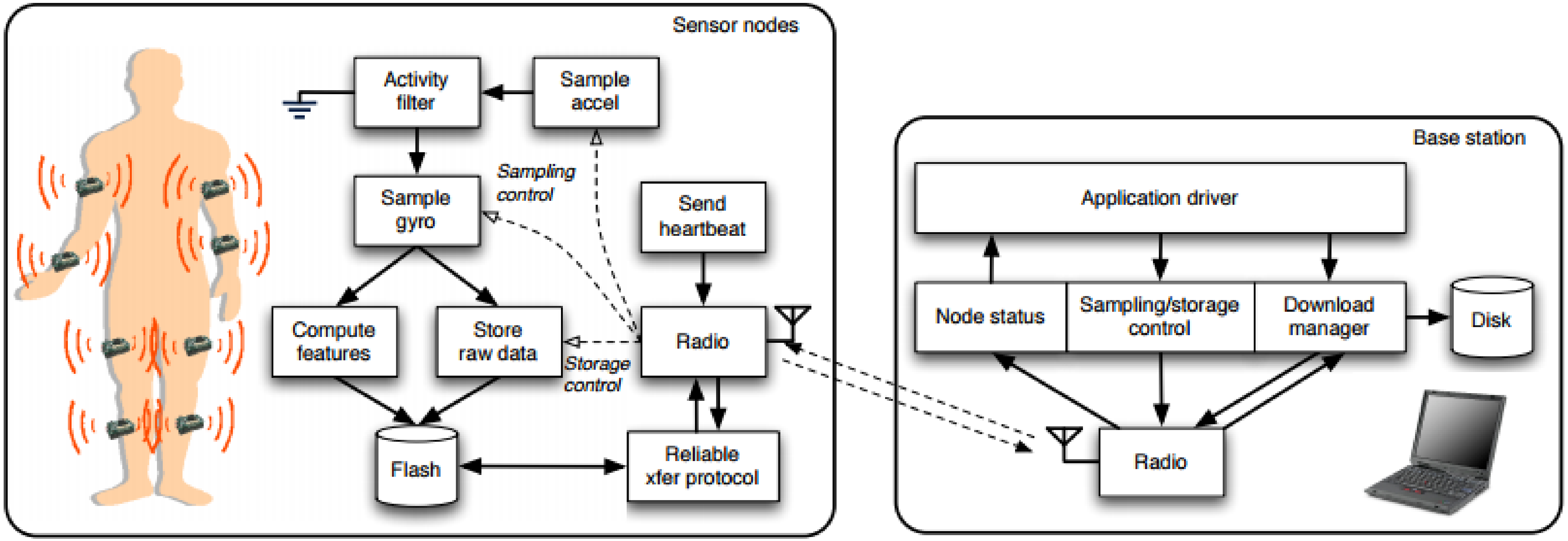
Clock synchronization

Goal: motion analysis of patients being treated for neuromotor disorders, such as Parkinson’s Disease, epilepsy, and stroke

Sensors: accelerometers and gyroscopes

Continuously sample and store sensor data in a MicroSD flash card for later retrieval

The transfer is triggered remotely by the end-user who needs to specify which specific set of data should be collected.



802.15.4
2 GB of MicroSD flash
sample block is 1200 bytes plus metadata, which is equivalent to 1 sec of sensor data sampled at 100 Hz across 6 channels

Provides a suite of custom feature-extraction algorithms such as maximum peak-to-peak amplitude, mean, and root mean square of the time series that are computed on the fly as sensor data is being acquired.

4 *Event Detection and Classification*

On-node processing to detect or classify events

Coal Mine Monitoring – 2009 - [67]

- Goal: detect collapses in coal mines - in order to ensure safer working conditions

Cane-toad Monitoring- 2007 - [46. 47. 98]

- Goal: monitoring of the increasing spread of cane toads in the North-East of Australia
- Acoustic sensors - implemented a frog vocalization recognition algorithm (autonomously classify toads)

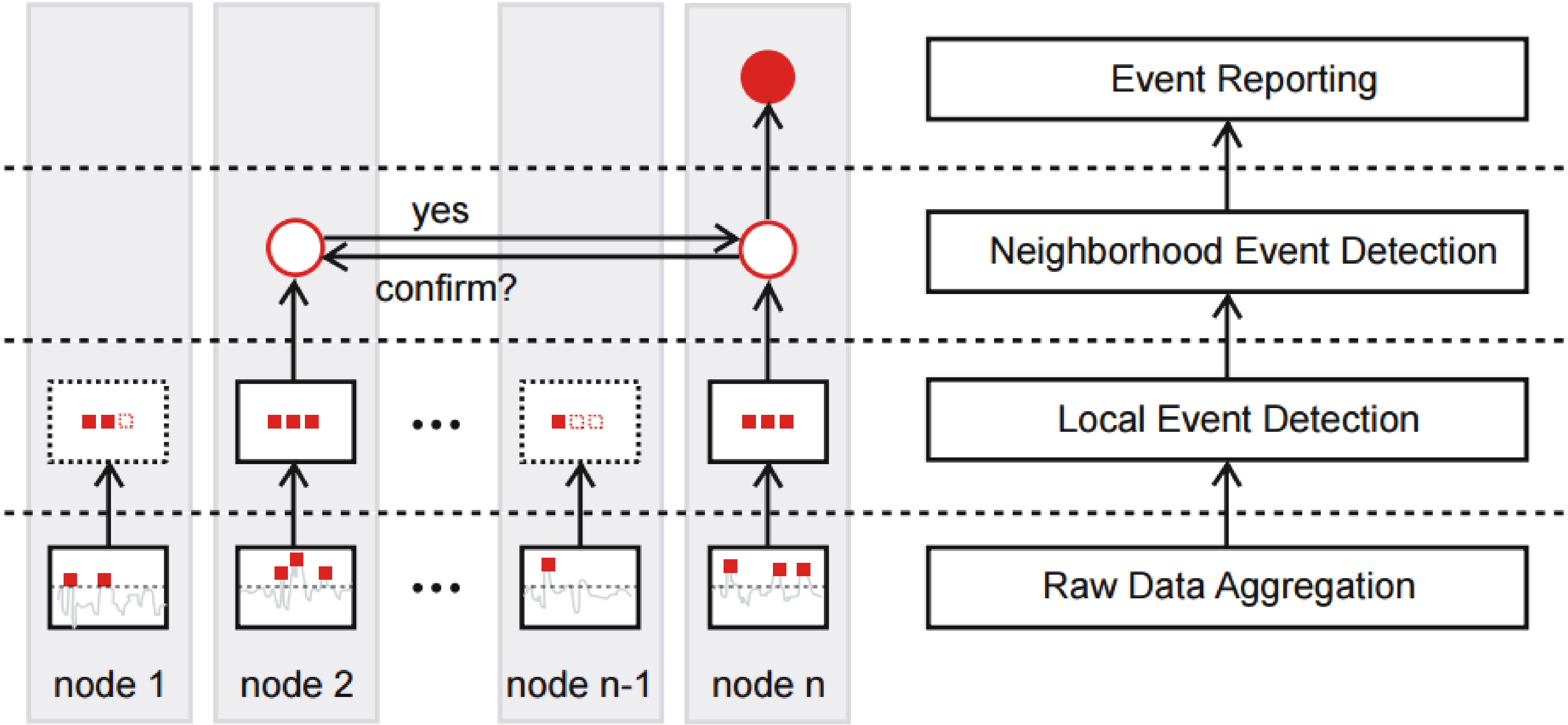
Acoustic Monitoring: VoxNet - 2008 - [6]

- Goal: acoustically detect marmots at the Rocky Mountain Biological Laboratory

Fence Monitoring - 2007 - [111]

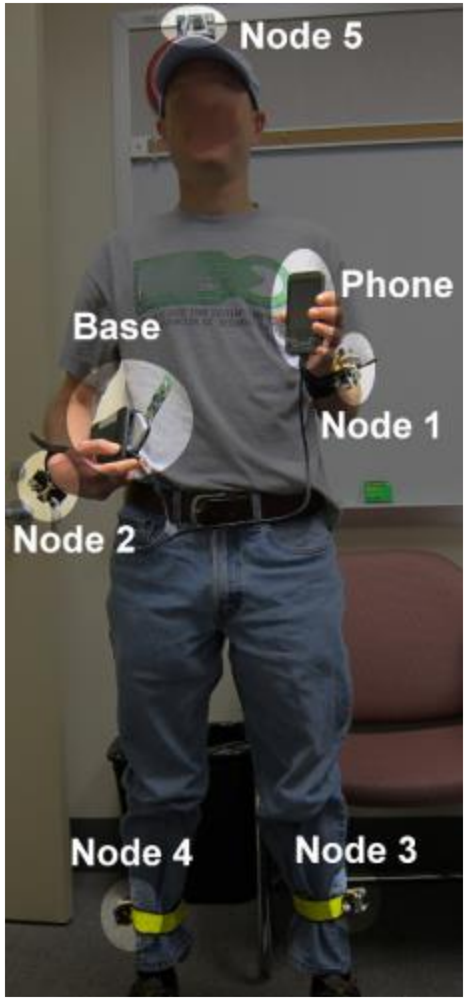
- Department of Mathematics and Computer Science Freie Berlin
- Civilian intrusion detection based on fence monitoring
- Goal: detect and report any incident occurring in the proximity of a fence


ScatterWeb


Event Reporting
yes
confirm?
Neighborhood Event Detection
Local Event Detection
Raw Data Aggregation
node 1
node 2
node n-1
node n

Activity recognition: PBN Practical Body Networking) 2011[54]

- Goal: activity monitoring
- Combined a five node BSN with an Android smartphone in order to enable reliable activity recognition



Human Monitoring: Behavior Scope - 2008 - [71,14]

- Goal: in-house monitoring of elders
- Nodes equipped with PIR sensors were distributed in the monitored apartment
- Create a model of the daily habits of the person

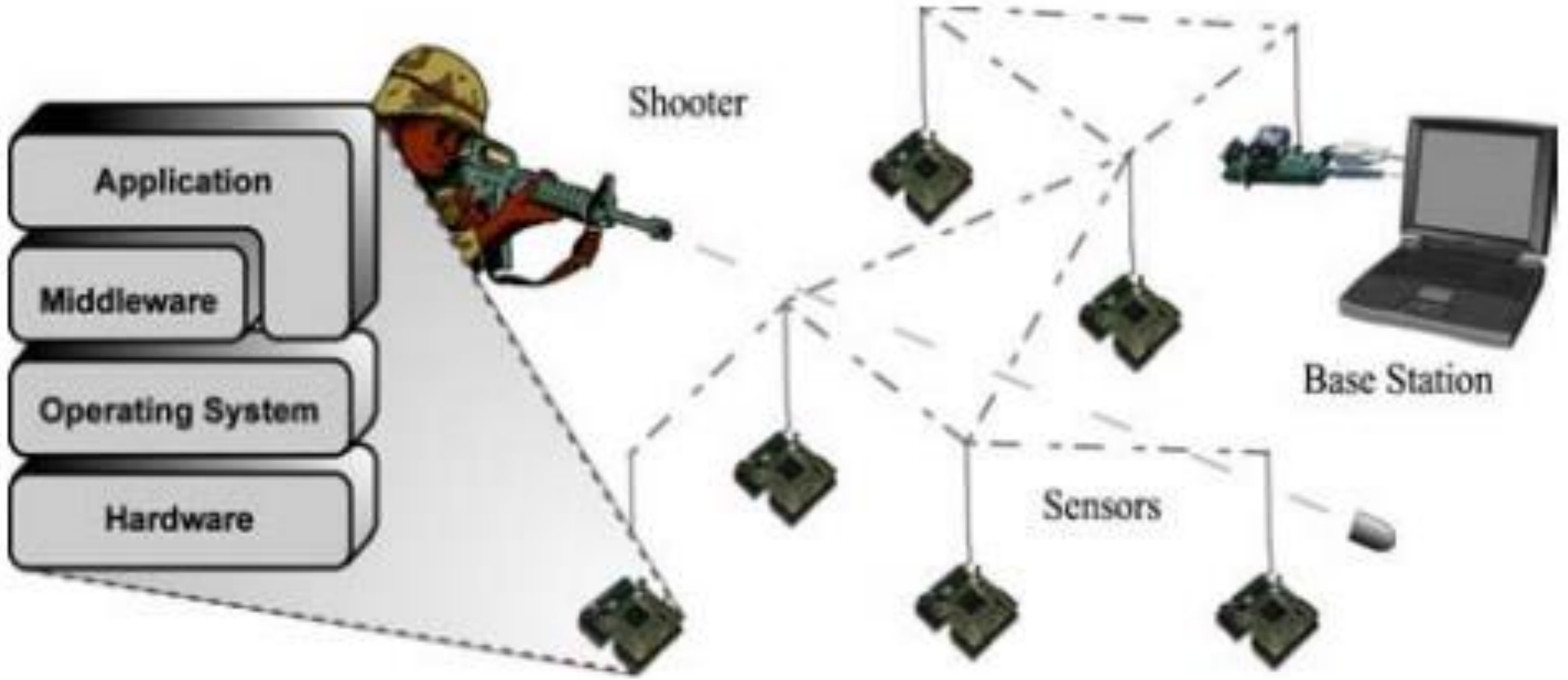
Fall Detection: WeCare - 2010 - [5]

- Goal: detect falls
- Employed a combined BSN and WSN to detect falls

5 *Localization and Tracking*

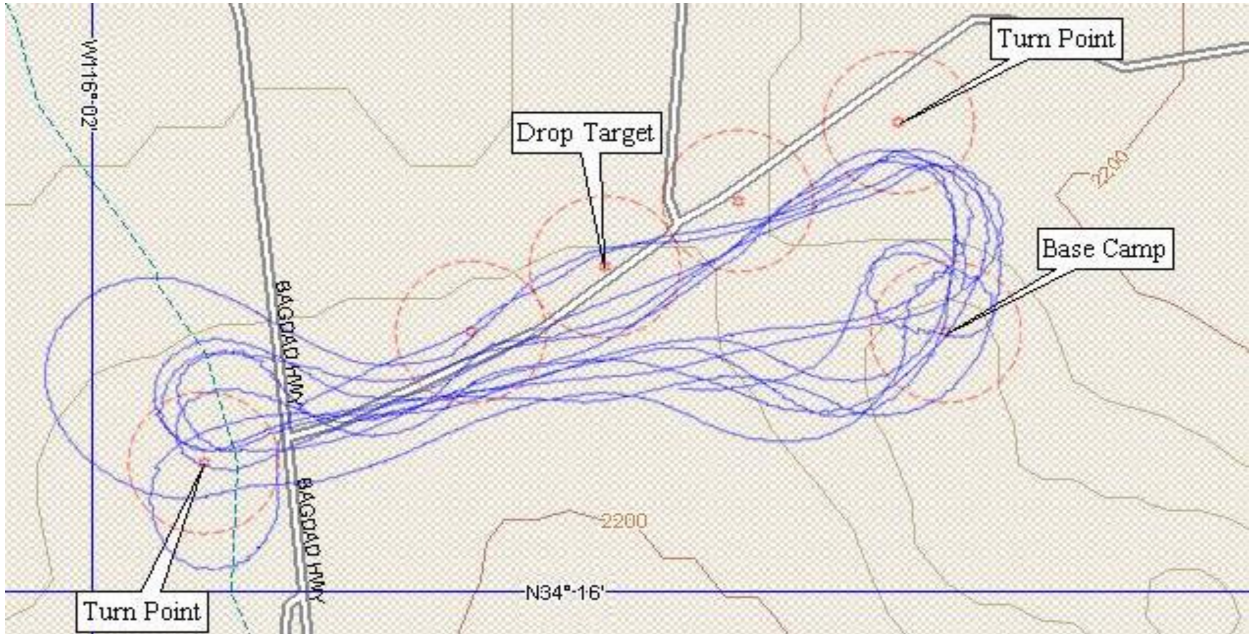
Sniper Localization: PinPtr – 2004 - [99]

- Goal: accurately estimate the position of snipers
- Sensor nodes were equipped with microphones to detect the muzzle blast of firearms
- Performed sound-based localization using distributed data processing am classification of the weapon generating the blast



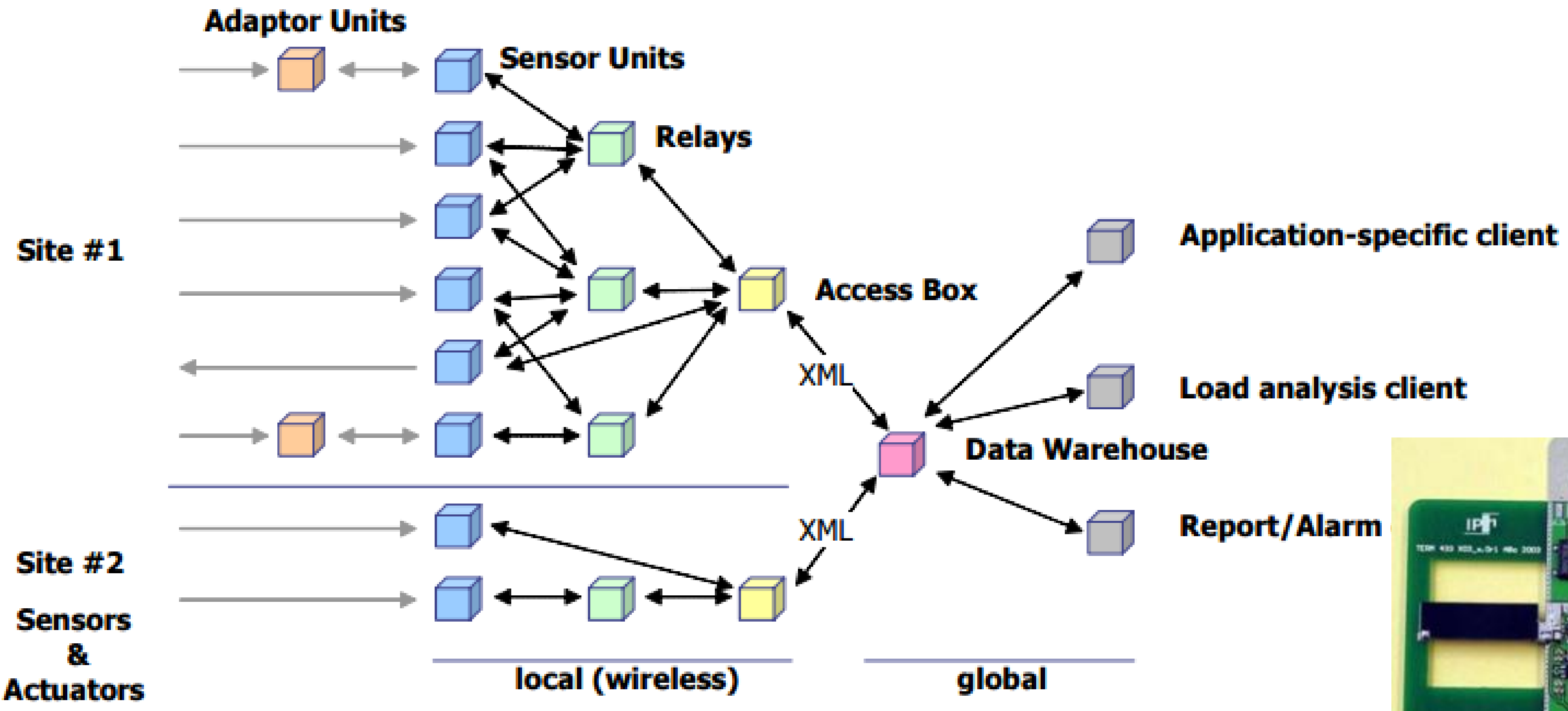
Intrusion Detection: 29Palms – 2001 - [83]

- Goal: Vehicle detection and tracking
- A WSN was dropped from an unmanned aerial vehicle (UAV) to monitor a road for vehicle movements
- Nodes equipped with a two-axis magnetometer: allowed the detection of vehicles in a perimeter of 5–10 m
- Allowed to track vehicles once they were detected
- The information on detected vehicles was temporarily stored in the network and later collected by a second flyover of the UAV



Cold Chain Management – 2004 - [88]

- Goal: monitor climate conditions while some goods travel through the cold chain
- Ultra-low power Wireless



6 *Actuation*

Building Automation: HVAC (Heating, ventilation and Air Conditioning) – 2005 [34]

- Goal: Control temperature
- Control logic based on the current climate in various parts of the building and a set of preferred temperature levels specified by the building users

Animal Control: Bulls fighting - 2007 - [107]

- Goal: control the behavior of bulls (avoid fights)
- The bulls were equipped with sensor/actor nodes that allowed to apply unpleasant but harmless stimuli to the animal.
- Constantly monitored the distance between the bulls and their aggressiveness level

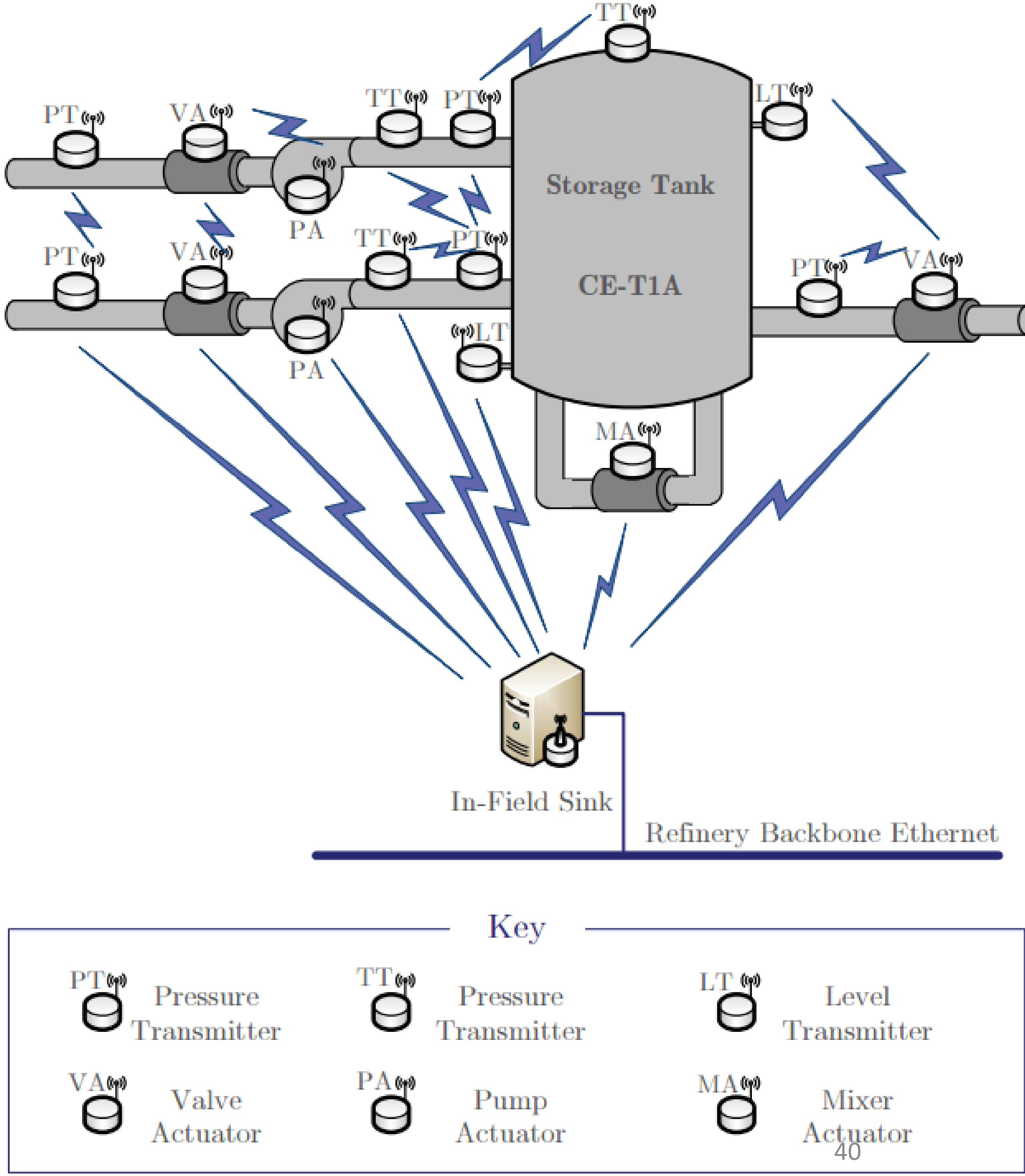
Animal Control: Networked Cows - 2004 – [22]

- Goal: Keep cows within a limited area with the help of virtual fences

Industrial plant monitoring - GINSENG

Sines, Portugal – Oil refinery – 2013 - [85,116]

Goal: monitoring several areas through various types of sensors, but also for actuating on several devices, such as valves, in a closed loop fashion



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