Wireless Sensor Networks in a vineyard

A system-level approach



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http://www.goodfood-project.org

Ambient Intelligence in Agriculture

Mission and Medium Term Targets

Mission:

- to introduce AmI paradigms in Agriculture using WSN technology
- to implement a demonstrator for the wine chain
- to investigate portability and scalability to other food chains

Key features:

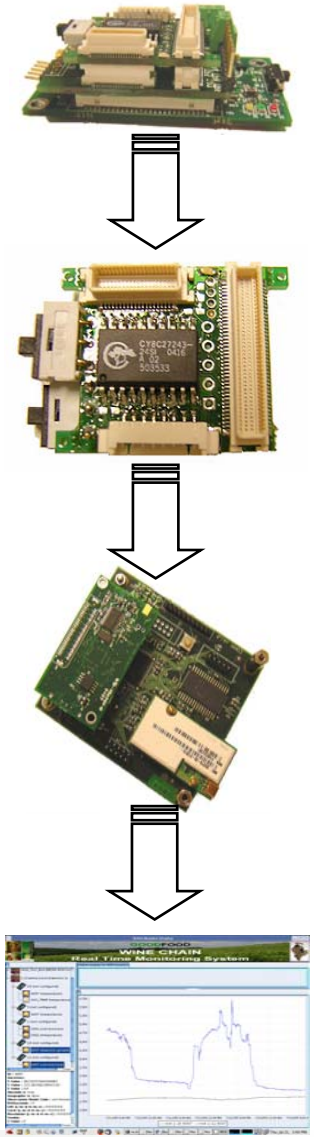


- to provide functionalities like:
  - stand-alone operation,
  - robustness,
  - energy saving and dynamic recovery strategies,
  - plug ‘n play sensor interface capability,
  - dynamic reconfiguration and mobile connectivity via GPRS
- to develop portable applications and solutions based on off-the-shelf components
- to meet regional standards (ETSI/FCC/others) and specific applications using the most suitable HW solutions

Key features

1. Development and implementation of an innovative energy efficient WSN communication protocol, *STAR MAC* based on Tiny OS (MIDRA, DET)
2. Definition and implementation of an innovative general-purpose plug ‘n play sensor interface (SSSA, Tyndall, EADS)
3. Design and development of a custom low-power GPRS gateway for Wireless Sensor Networks with a dedicated socket (MIDRA)
4. Implementation of AmI User Interface with protocol handler enhancement (Synapsis)
5. Security Issues (HTA)

The system has been tested and it is operating on field



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STAR MAC

Synchronous **T**ransmission **A**synchronous **R**eception

1. Completely **novel** approach effectively joining:
   - WISE MAC (*phase* based transmission scheduling)
   - S-MAC (*duty cycle*)
2. Efficient **power management** (*stable low power state + duty cycle*)

Sleep status (T_S , c_{sleep}=0.01 mA):

- RF OFF
- Micro & Sensor board: power save mode

MAC frame period ($T_f = T_l + T_S$)

→ **Duty cycle**

$$d_{\%} = \frac{T_l}{T_f}100 = \frac{T_l}{T_l + T_s}100$$

→ **Normalized Cost**

$$\frac{C}{T_f} = c_{Rx}d + c_{sleep}(1-d) + \frac{NC_{Tx}}{T_f}[mA]$$

STAR MAC

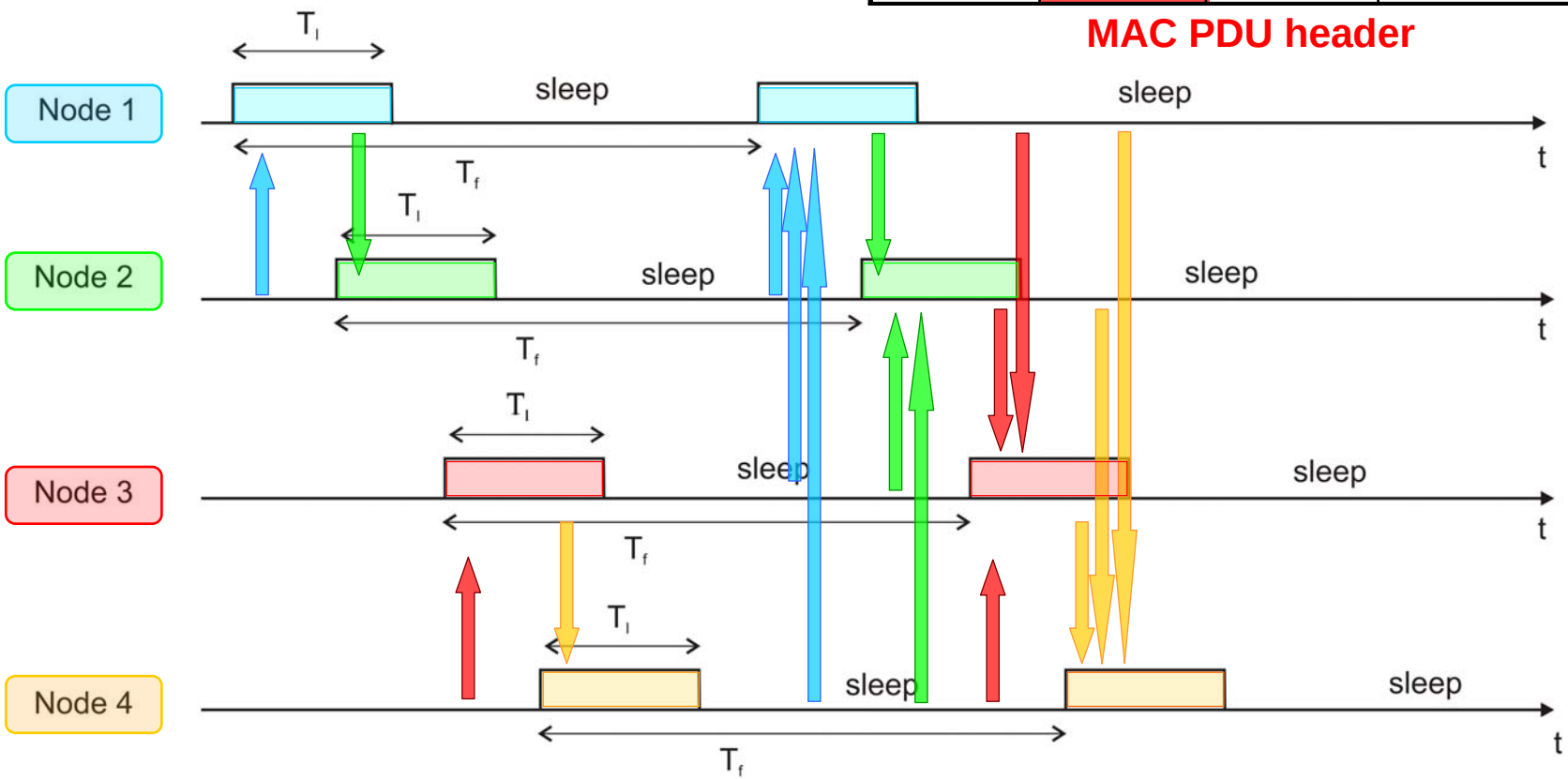
Synchronous Transmission Asynchronous Reception

3. **Weak** nodes synchronization (*2 way handshake*)

- Set up + recovery procedures

ID	Phase	Hop counter	Sequence Number

MAC PDU header



Multihop routing

- **Applied algorithms:**
  - ***Static*** **1 reference next hop to the gateway is a priori defined for each node**
  - ***Partial Dynamic*** **additional back up neighbors facing faults (turning off) or congestion are a priori defined for each node**
  - ***Full Dynamic*** **number and reliability of the next hop is dynamically updated depending on the network status changing**
- **Routing table for an ordinary node**

Static routing algorithm

Partial dynamic routing algorithm

Target	Next hop	Hop counter	Phase	Link quality	Battery level	Congestion level
Sink	X	N_X	φ_X	η_X	B_X	C_X
	Y	N_Y	φ_Y	η_Y	B_Y	C_Y

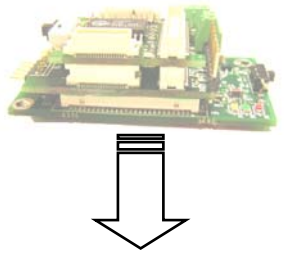
Multihop routing

- **Routing table management (building and updating):**
  - **MAC layer signaling (neighbor discovering, HELLO) ($\forall T_f$)**
  - **Network layer signaling (network discovering, PING) ($\forall T_p >> T_f$)**
  - **Cross layer protocol design inspired**

Target	Next hop	Hop counter	Phase	Link quality	Battery level	Congestion level
Sink	X	N_X	φ_X	η_X	B_X	C_X
	Y	N_Y	φ_Y	η_Y	B_Y	C_Y
	Z	N_Z	φ_Z	η_Z	B_Z	C_Z

- **Communication protocol robustness (best hop selection)**
- **Sensing messages generation ($\forall T_{acq}$) & forwarding**

Key features



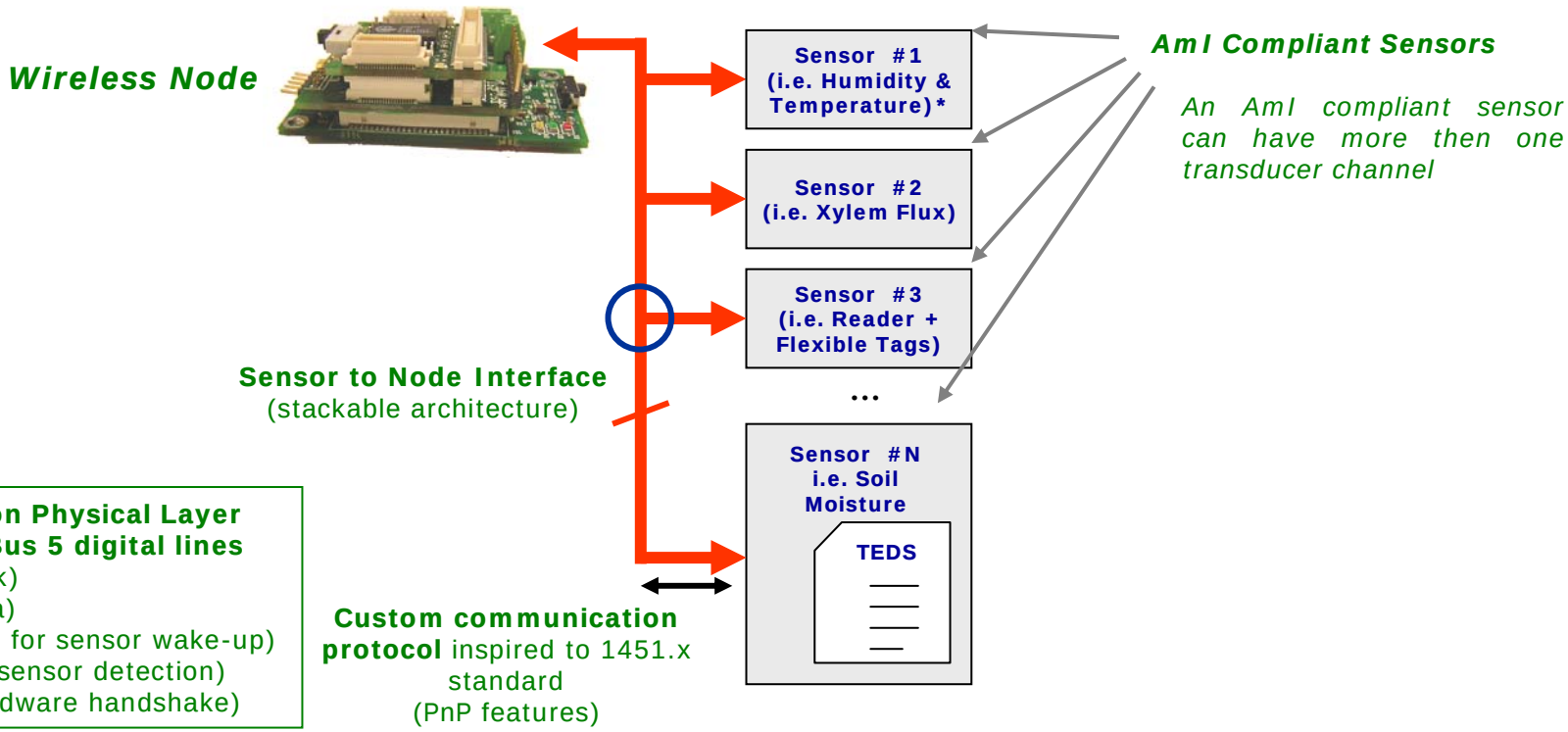
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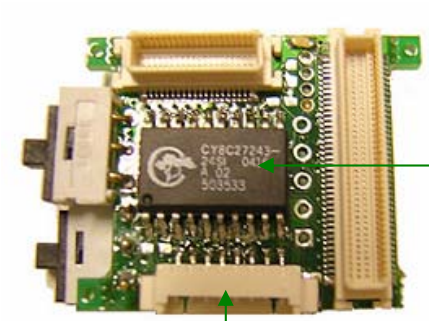
Generic Sensor Interface Board - Concept

AmI Compliant Sensor

a sensor easily connectable to whichever node of the network and able to work without changing any WSN configuration parameters (*plug and play* sensors or actuators)



Generic Sensor Interface Board - Concept



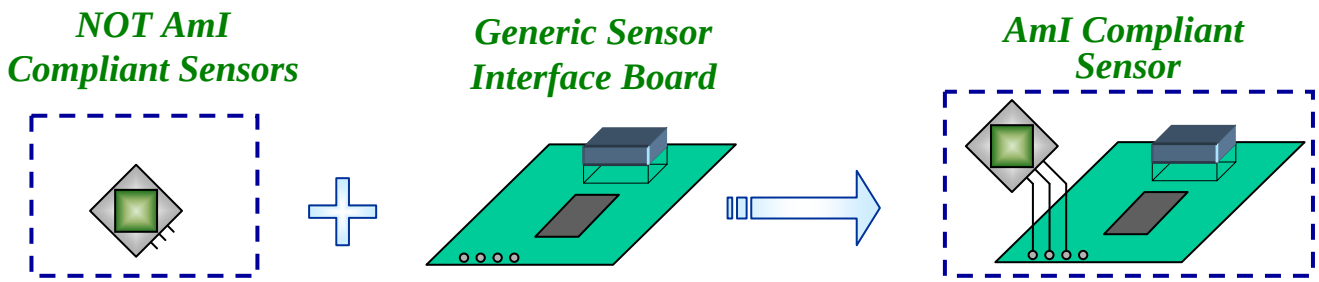
Generic Sensor Interface Board

8 bit microcontroller with run time, analog and digital reconfigurable hardware architecture:

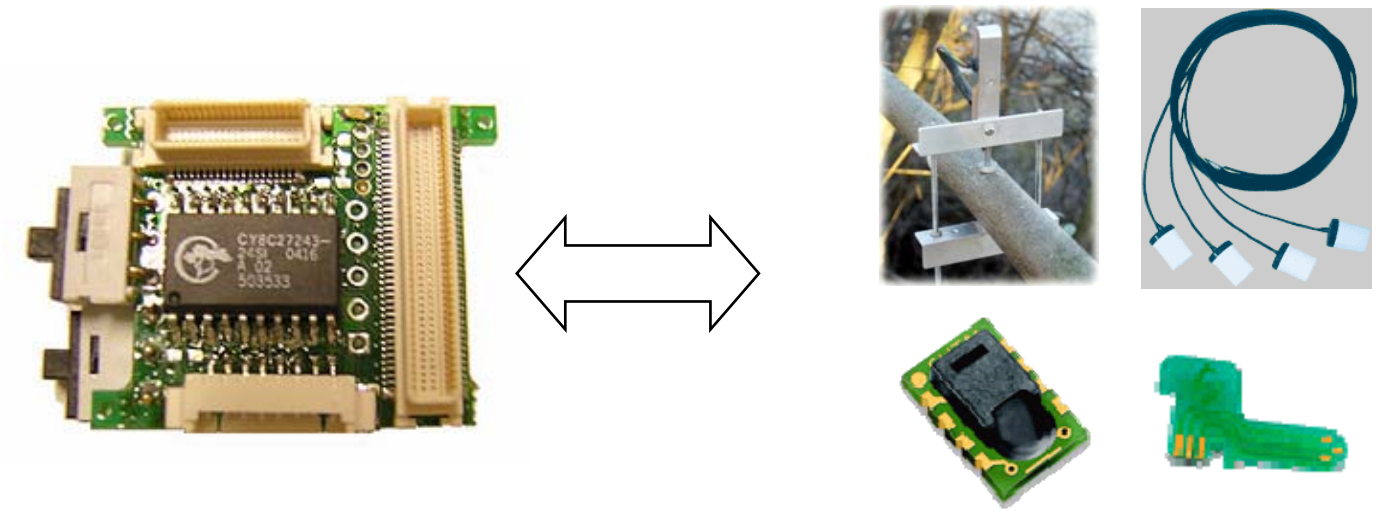
- Amplifier
- PGA
- DAC
- ADC
- Comparator
- Filter
- Counters
- Serial Comm. Ports

- Conditioned Sensor
- Unconditioned Sensor (Wheatstone bridge like)
- Unconditioned Sensor (Wheatstone bridge like) with offset
- Current Output Sensor
- Resistive Sensor (Potentiometer like)
- Capacitive Sensor
- Digital Sensor (serial interface: rs232; SPI; Microwire)

Generic Sensor Interface Board - Concept

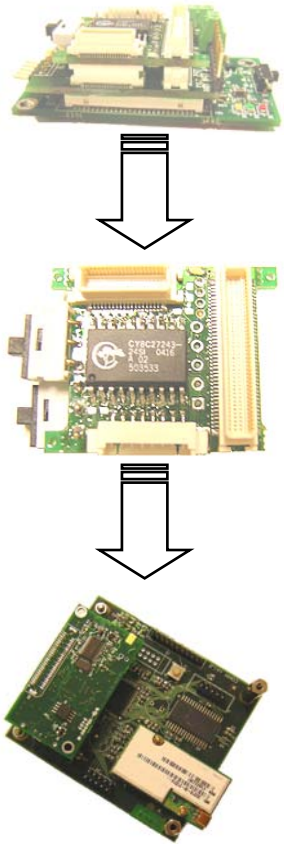


The Wine Monitoring application requires the integration of many heterogeneous sensors, such as stem diametric growth, soil moisture, differential leaf temperature, humidity, glucose.



Key features

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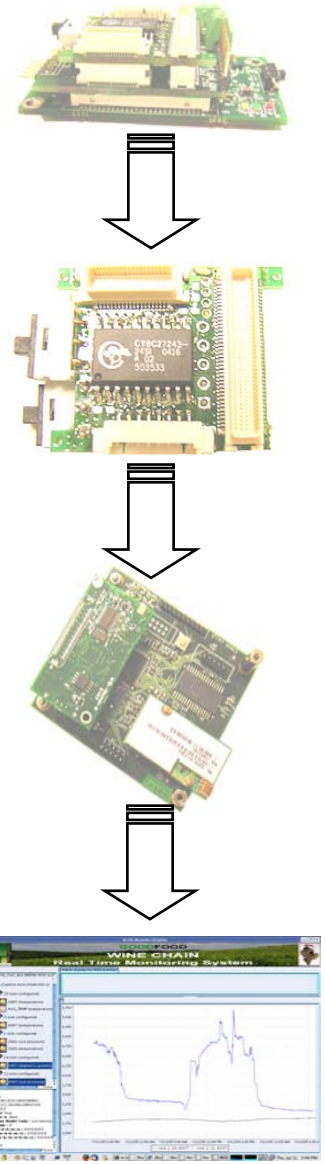
GPRS gateway

- Stand-alone communication platform, providing transparent bi-directional wireless TCP/IP connectivity for remote monitoring
- Operating in conjunction with Remote Data Acquisition (RDA) equipments:
  - WSN, connected with a Master node
  - directly connected to sensors and transducers
- Powered by solar panels
- Operative modalities:
  - Always on
  - On demand
  - Periodical connection
- Robustness
- Reconnection with dynamic IP add. assignment
- Robust dynamic recovery functionalities tested in 2 reliable operation



Key features

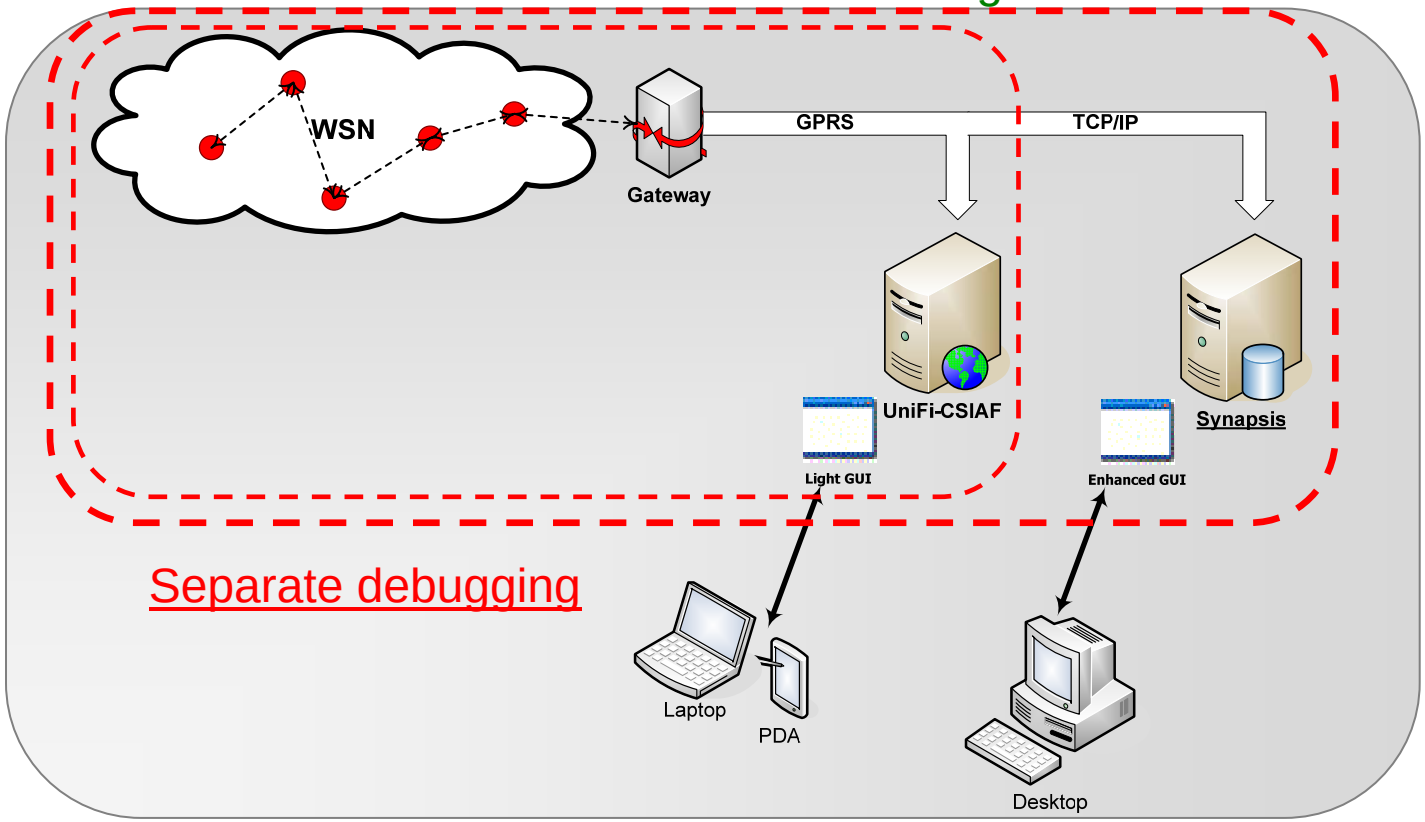
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Network architecture

Design of advanced user interface suitable to remote system monitoring and interaction in compliance with the AmI paradigm:

- ✓ Light interface (device with limited resources/bandwidth)
- ✓ Enhanced interface for remote user monitoring



"Light" User Interface

- http://www.unifi.it/midra/goodfood/
- Multiple gateway monitoring
- Low level messages logging
- 1D and 2D graphs:
  - Joint plotting
  - Interactive map
  - Time window adjusting



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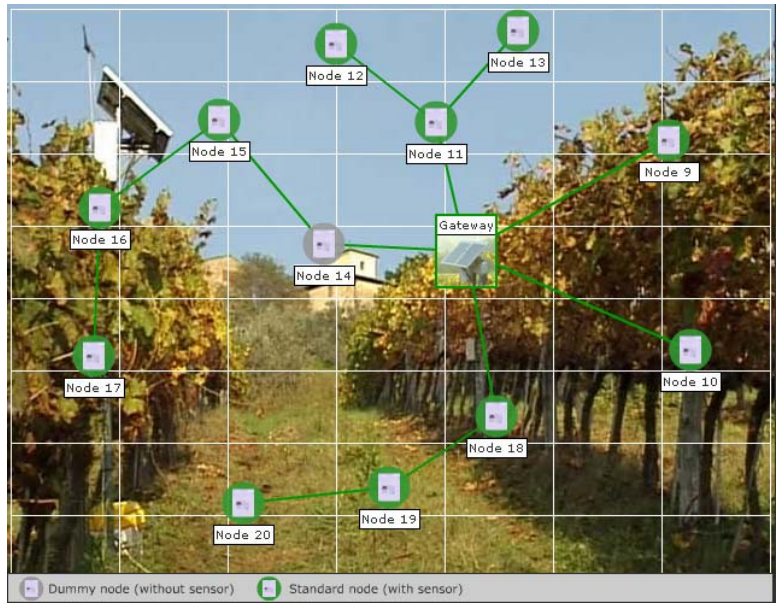
The deployment at Montepaldi Farm

13 nodes and 24 sensors

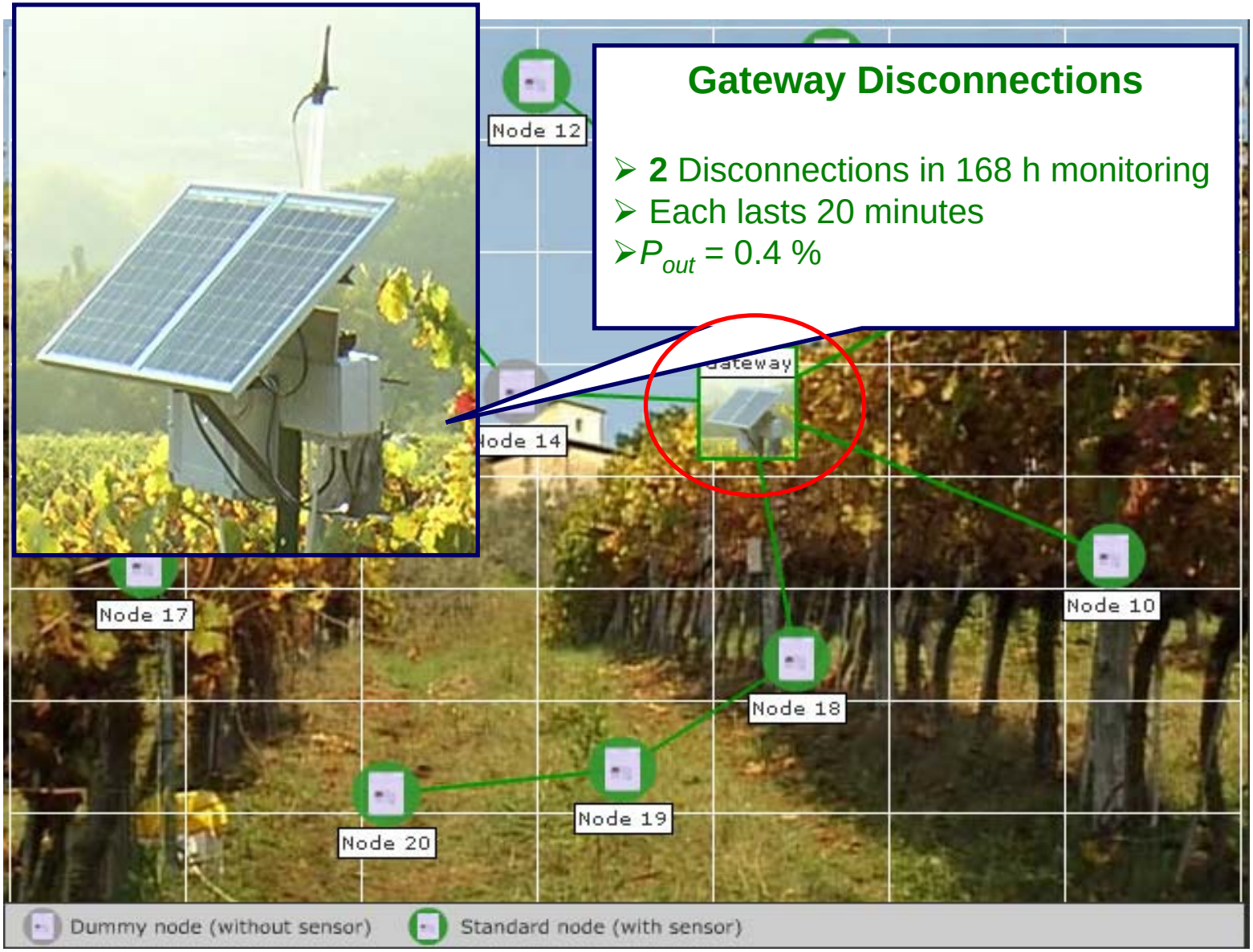
operating since October, 25th 2005

Features

- Full STAR MAC multi-hop operation
- Stand alone unattended system
- Wide environment with moderate mutipath and medium-to-low node density

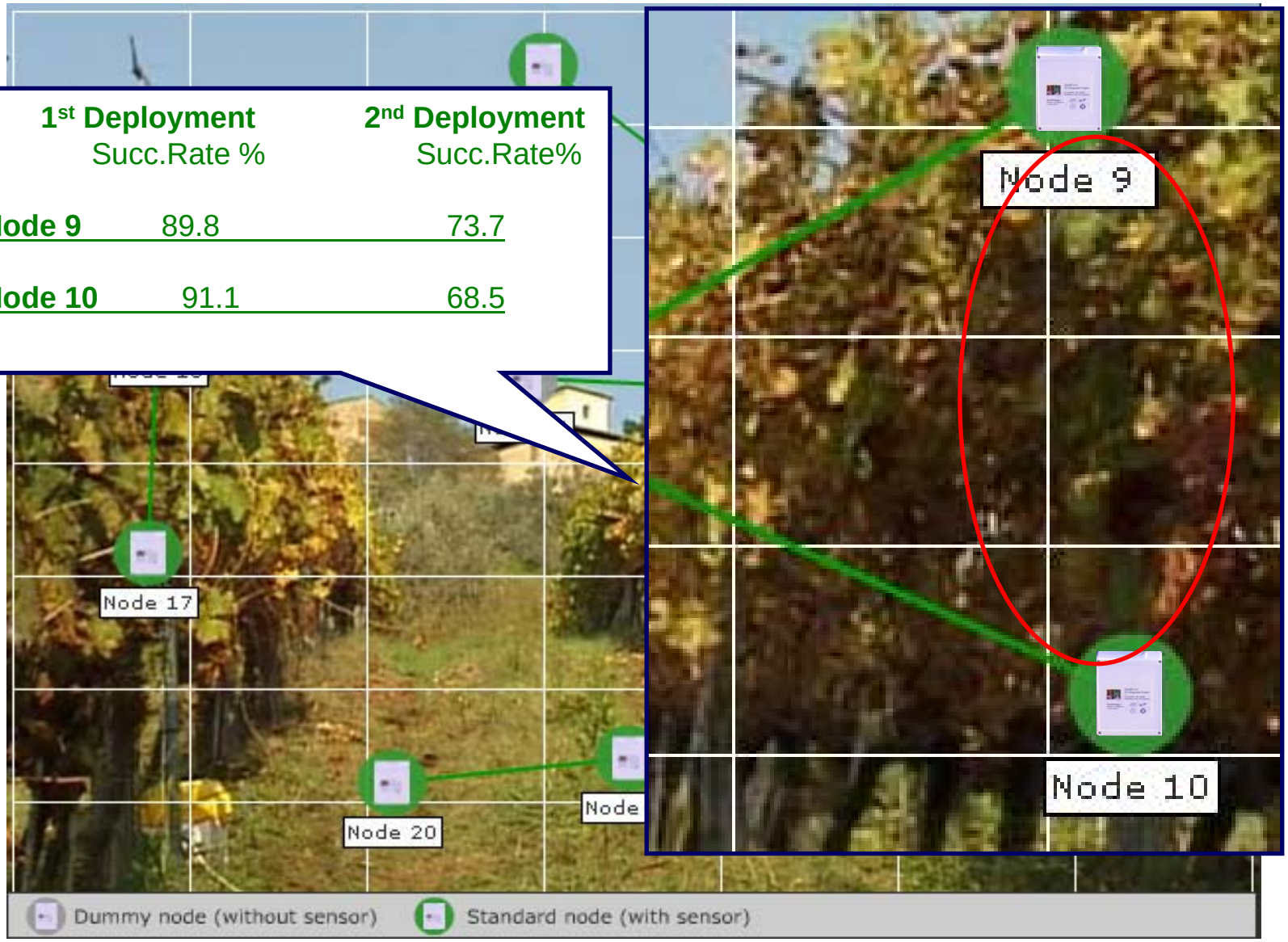


QoS at WSN level



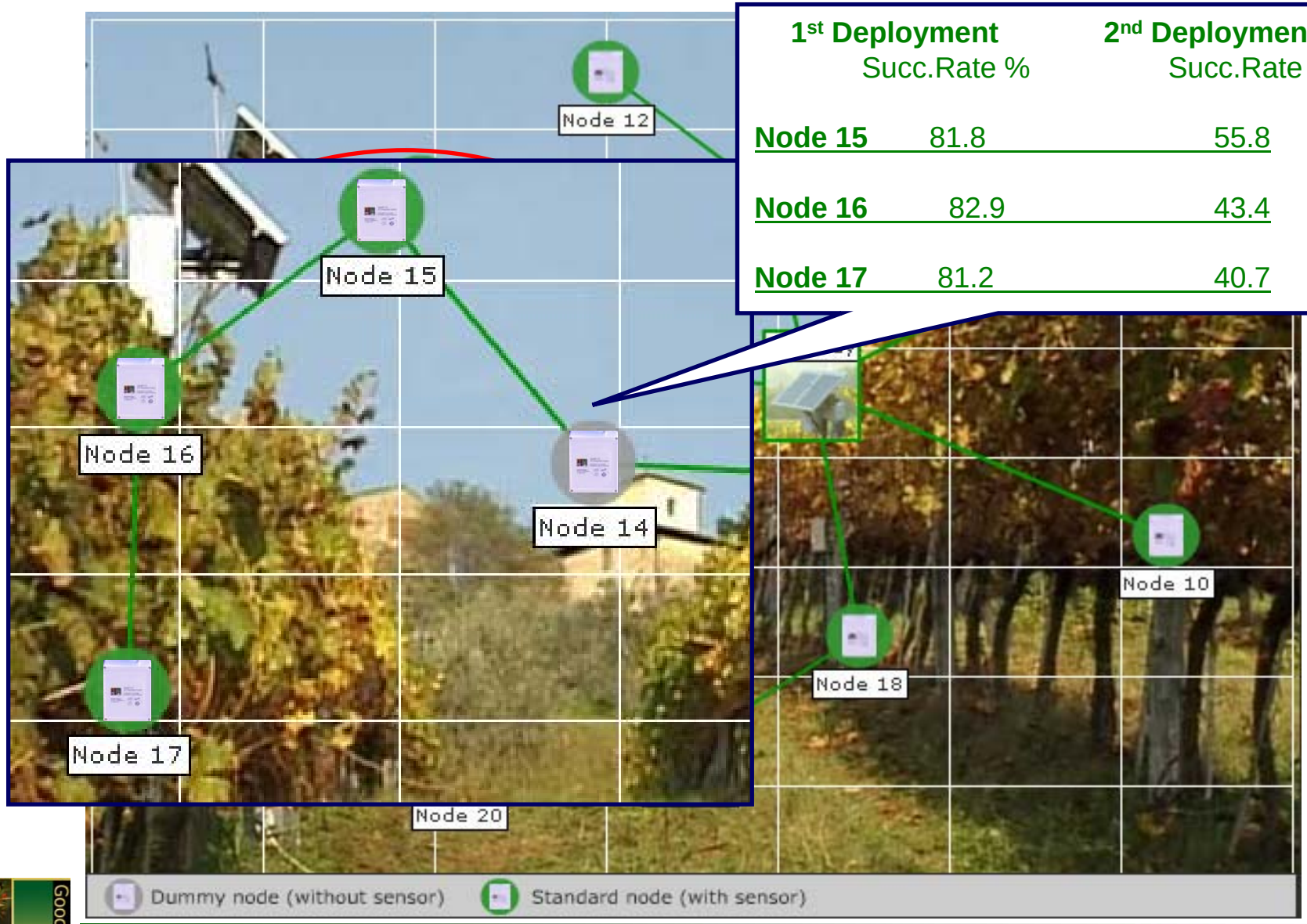
QoS at WSN level

	1st Deployment Succ.Rate %	2nd Deployment Succ.Rate%
Node 9	89.8	73.7
Node 10	91.1	68.5

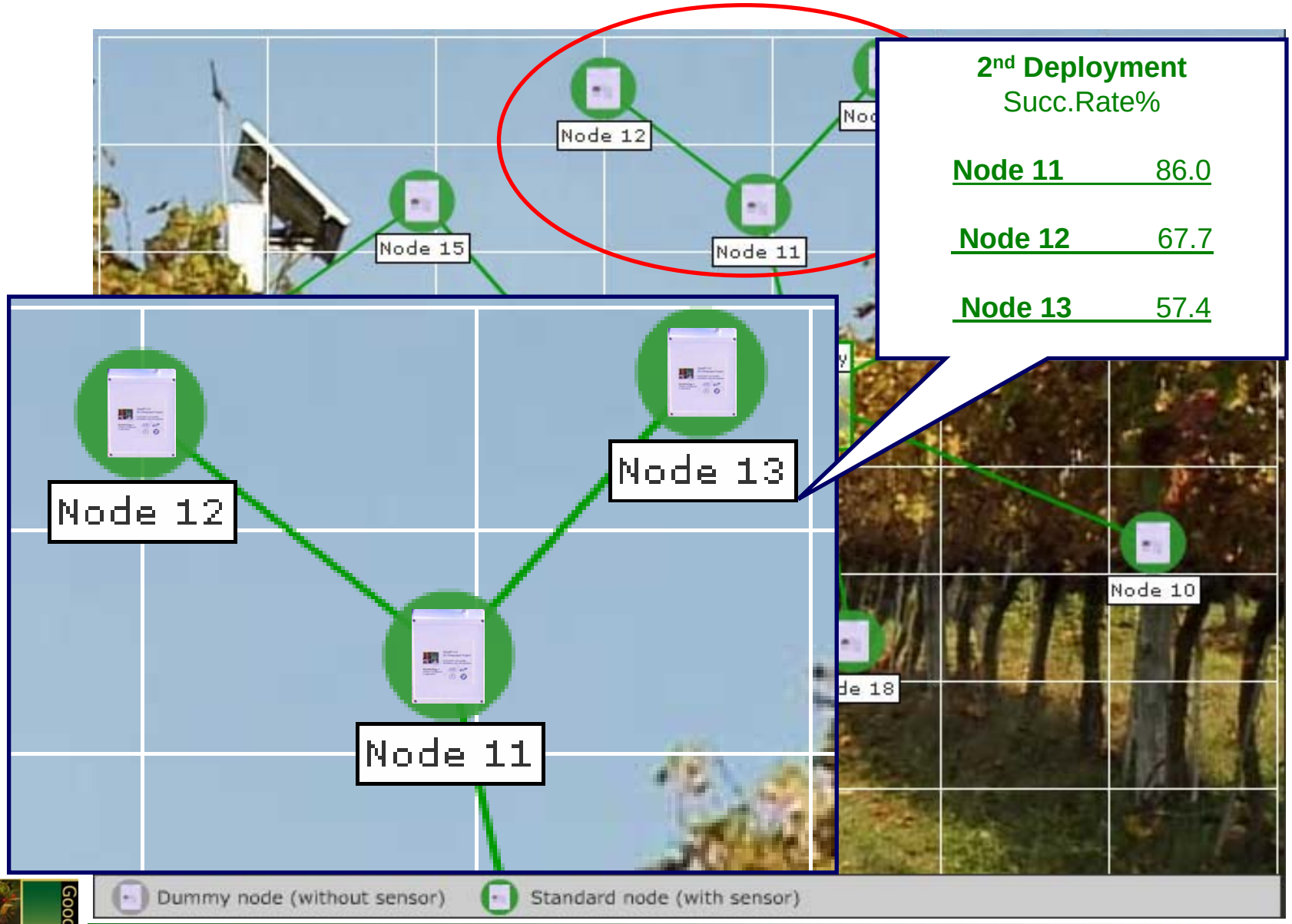


QoS at WSN level

	1st Deployment Succ.Rate %	2nd Deployment Succ.Rate %
Node 15	81.8	55.8
Node 16	82.9	43.4
Node 17	81.2	40.7



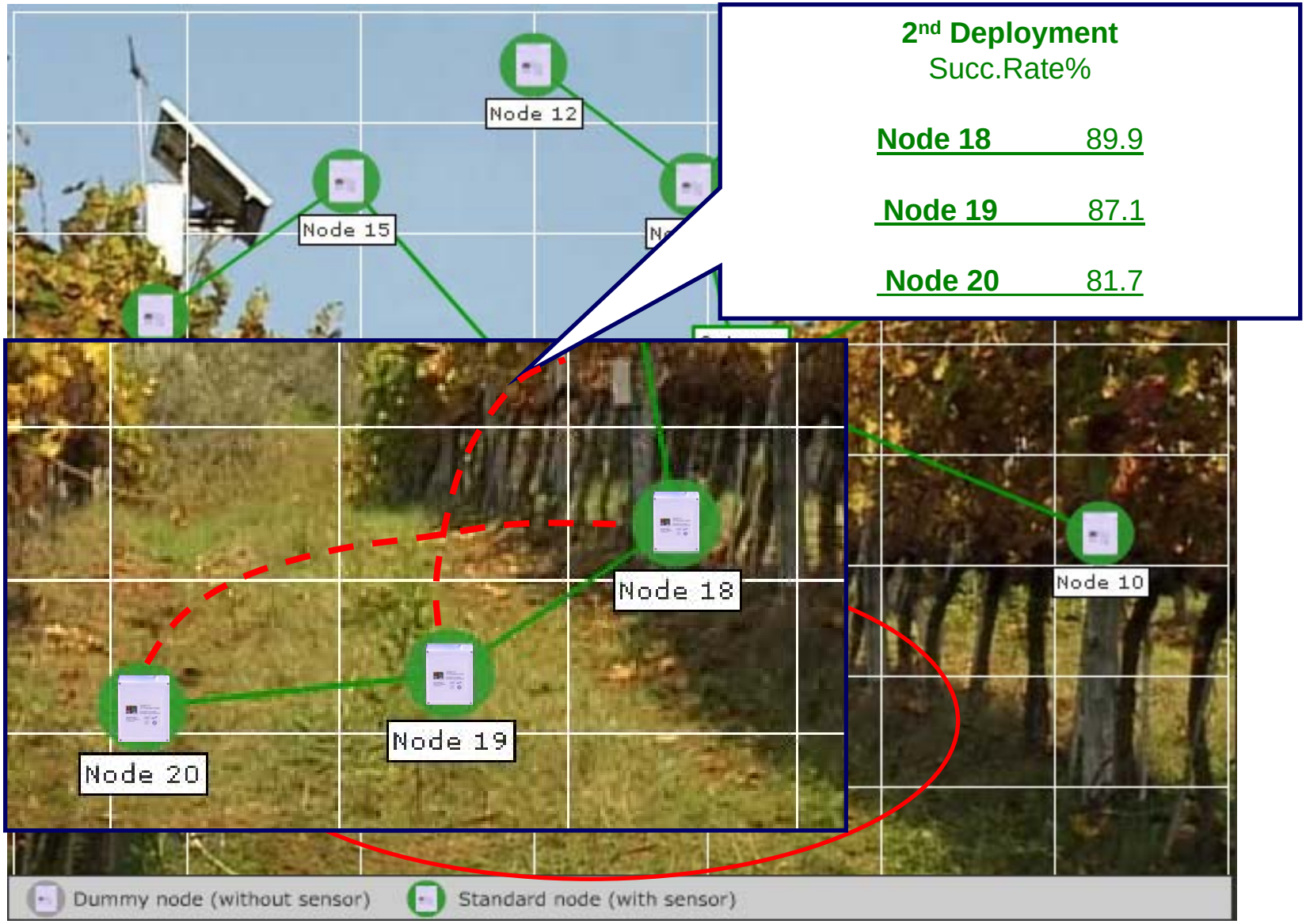
QoS at WSN level



2nd Deployment
Succ.Rate%

Node 11	86.0
Node 12	67.7
Node 13	57.4

QoS at WSN level



2nd Deployment
Succ.Rate%

Node 18	89.9
Node 19	87.1
Node 20	81.7

QoS at System level
Dynamic Recovering Strategies

- Outdoor operation in adverse environment
- Dead-lock at node level (collisions, EMI, in-band jamming)
- Temporary lack of connectivity at Gateway (dynamic radio resource management, temporary outage of radiomobile channel, radiobase maintenance)

Mandatory requirement : unattended operation

Node level

Dynamic Time-out Recovery (DTR)

Gateway level

Dynamic session re-negotiation (DSR)

Forced session re-negotiation (FSR)



The Greenhouse

6 nodes and 24 sensors

Motivations

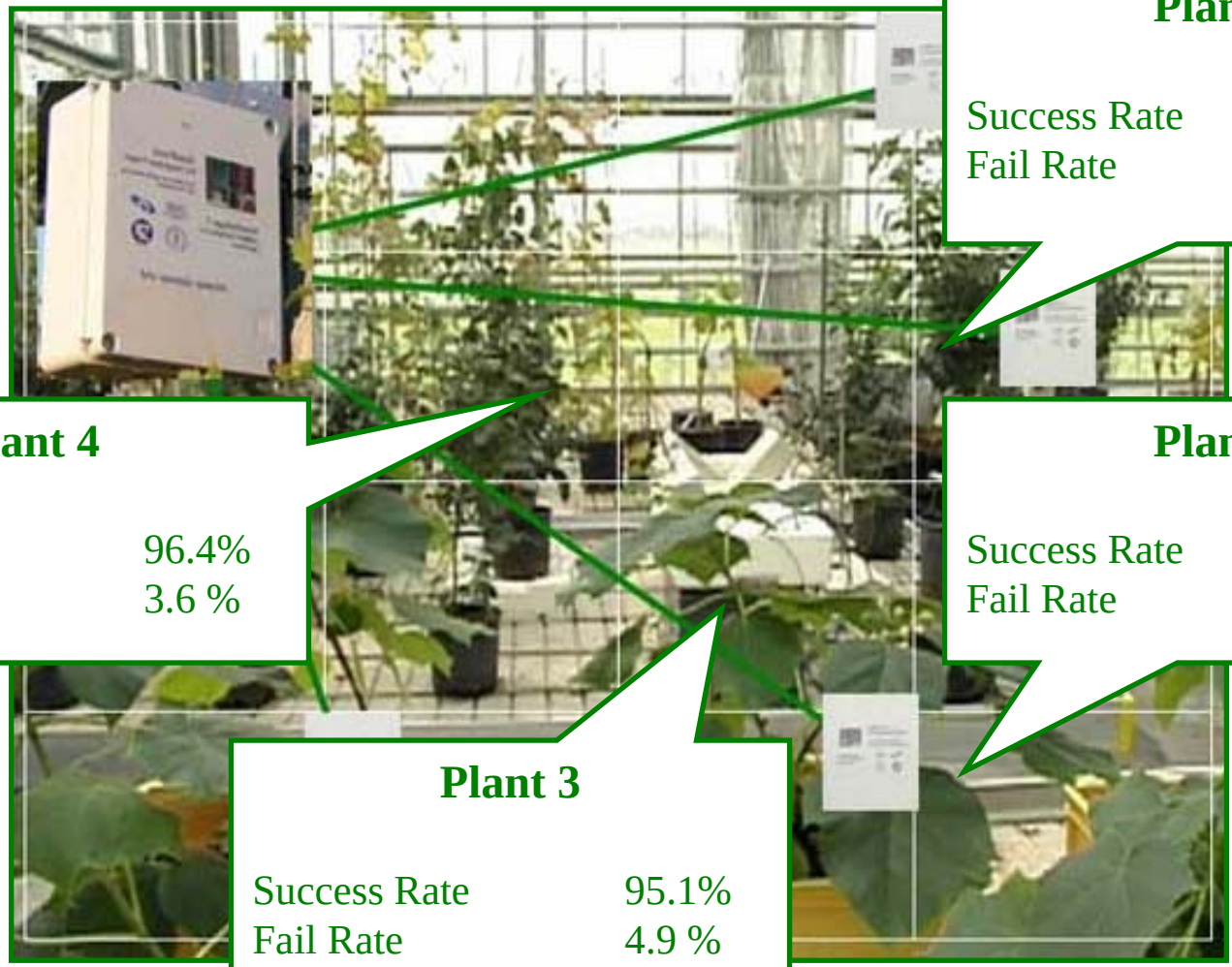
- Global system validation completed through a set of advanced case-studies to be presented



Features

- Single hop configuration in a very restricted area
- STAR MAC protocol forced to star topology
- Assigned routing direct to GW
- Highly dense communication & multipath environment
- Up to 5 sensor per node

Greenhouse Test Site : Results



Plant 1

Success Rate	95.9%
Fail Rate	4.1 %

Plant 4

Success Rate	96.4%
Fail Rate	3.6 %

Plant 2

Success Rate	95.9%
Fail Rate	4.1 %

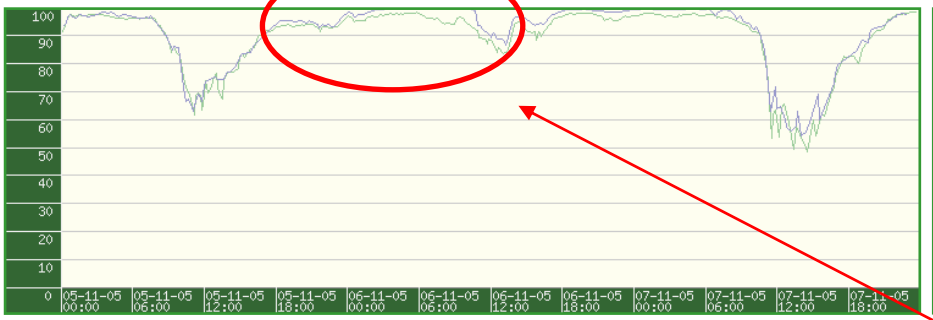
Plant 3

Success Rate	95.1%
Fail Rate	4.9 %

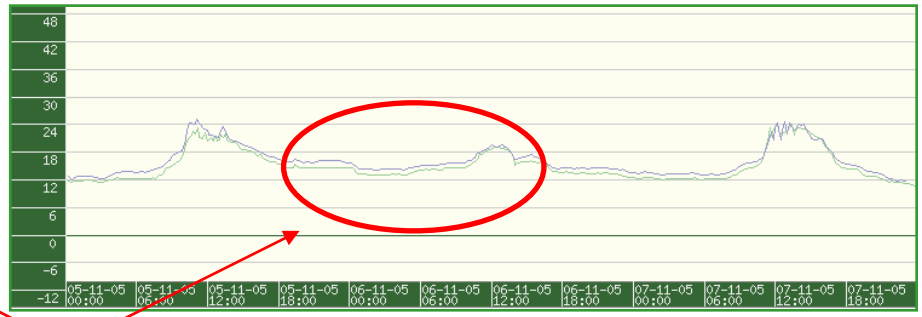
Pilot Site WSN

Case Study: *Autumn heavy rain*

Air Humidity Sensors



Air Temperature Sensors



Soil Moisture Sensors

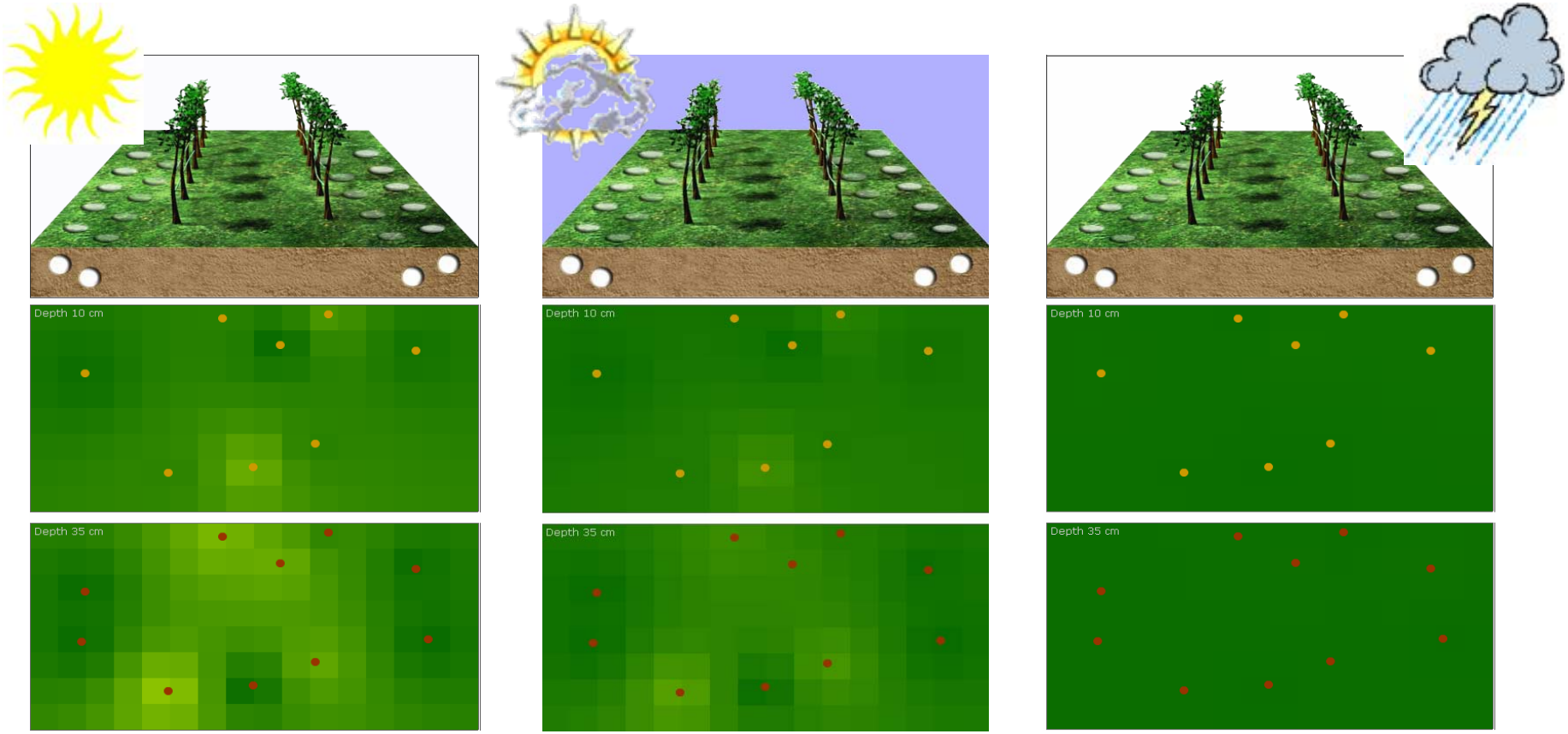
Rain Fall



Pilot Site WSN

Case Study: *Autumn heavy rain*

Soil Moisture Trend @ different depths in different weather conditions



Conclusions

End-to-end solution for WSN vineyard monitoring

Key features:

- Energy efficient multihop routing MAC protocol and dynamic recovery strategies
- Plug ‘n play sensor interface and TEDS functionality
- Embedded GPRS Gateway for WSN
- System architecture, with multiformat platforms and user interface
- End-to-end QoS
- Stand alone, unattended operation

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Pilot Site WSN Configuration : Results Comparison

Laboratory vs Montepaldi Pilot Site

Node Configuration	Packet Delivery Ratio			
	Max	Min	Max	Min
Directly to Gateway	98.1%	92.6%	91.1%	76.5%
2 Hops	81.5%	70.4%	82.5%	81.8%
3 Hops	70.4%	68.5%	82.9%	81.2%
4 Hops	66.7%	64.8%	82.4%	81.4%

Possible Causes

- Channel Errors
- Collisions
- Dropping at Gateway Buffer

Ongoing activities

- ✓ **Protocol enhancements:**
  - **STAR+ MAC**
  - **Partially dynamic multihop routing**
- ✓ **Topological messages**
- ✓ **remote control ad firmware up-grading capability**

Further developments

- ✓ **Protocol enhancements:**
  - **Physical:**
    - **Adaptive threshold for the received power**
  - **Routing:**
    - **Fully dynamic multihop**
    - **synchronous (downstream) sensing**
    - **asynchronous or event-based sensing (upstream + downstream)**
- ✓ **Re-configurable communication paradigm for highly time-varying scenarios (*mobile agents*)**
- ✓ **Advanced traffics management:**
  - **QoS oriented**
  - **Differentiated services**