Research Trends in Wide Area Monitoring Systems (WAMS)

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Market & Security: more uncertainties in restructured power systems

- ✓ Deregulation interests and investments on generation and distribution
- ✓ Transmission networks (capacity limits, coordination between neighboring SOs, interconnection systems, limited control resources: centralized and corrective control)
- ✓ Not-sufficient investments in Transmission Systems (authorization problems, environmental constraints)
- ✓ Blackouts re-introduced the issue whether competition and security are mutually exclusive
- ✓ New technologies can help: **PROFIT** ⟷ **Reliability /SECURITY**

Enhancement of system security

There are several countermeasures that can be adopted on different levels (*soft* and *hard* investments):

- ❖ Methodologies for automation and control – Dynamic Security Assessment (DSA);
- ❖ Communication systems for real-time data exchange;
- ❖ Adaptive relays;
- ❖ FACTS and HVDC;
- ❖ Wide Area Measurement and Control Systems;

Technology and knowledge are at hand: need of decisions at political level

WAMS: a grown-up technology

- ✓ All basic technologies for Wide Area Measurement Systems are quite established (PMUs, GPS, fiber optics, broadband communication systems)
- ✓ PMUs can be installed with minor additional costs when relays on transmission lines are substituted with newer digital relays (average estimation of 100 distance protections substituted per year on the Italian HV power grid)

WAMS: a grown-up technology

- ✓ The system observability issue is overcome since the cost of a PMU is negligible compared to the cost of a substation
- ✓ Delays due to the communication system in the range of 100-700 ms with the present technology
- ✓ Fast data processing can be obtained with suitable routines and distributed computing environment

Some possible applications of WAMS

- ✓ Improvement of dynamic power system modeling and implementation of on-line dynamic database
- ✓ Implementation of WACS architecture for enhancing dynamic performances and preventing cascade events
- ✓ Integration with dynamic security constrained optimization methodologies (DSA approach)
- ✓ Response-based approach to dynamic security
- ✓ Monitoring dynamic behavior and diagnosis of on-going degraded dynamic performances

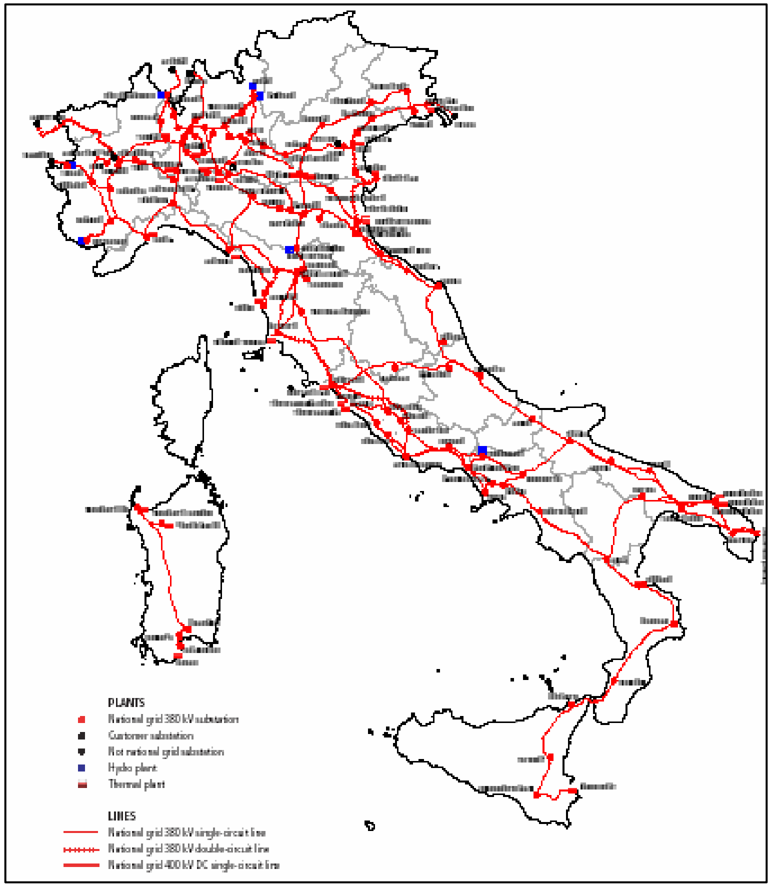
The application of WAMS in Italy

<u>Characteristics of the Italian electrical system</u>

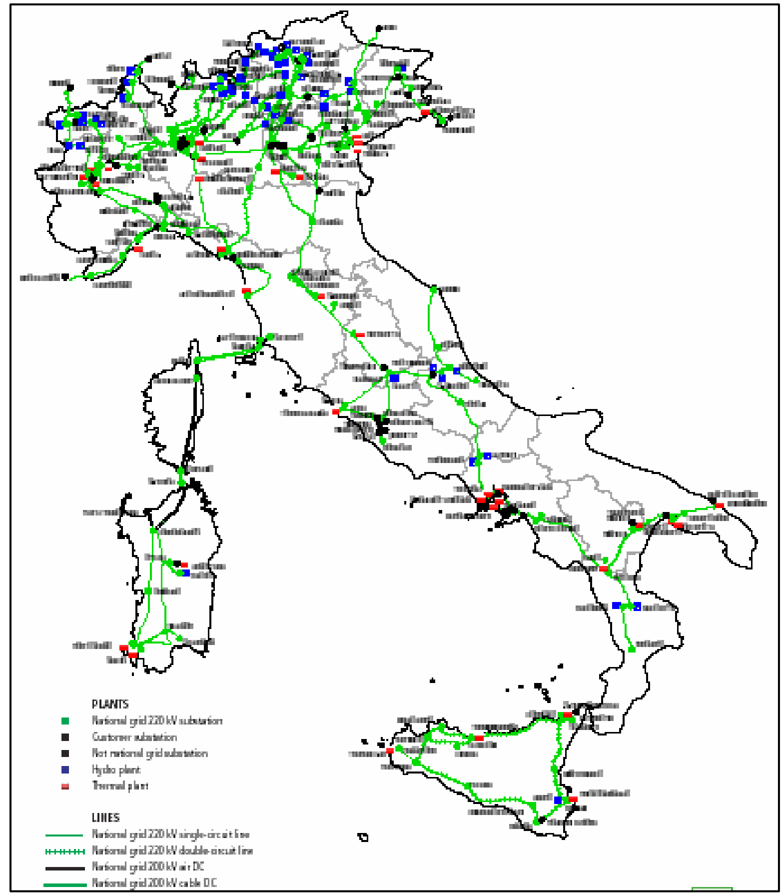
- The Italian national transmission network consists of approximately 45,000 km (28,200 miles) of lines and 320 transformation and distribution substations.
- It includes 220/380 kV lines (some 22,000 km, AC, and 1,000 km, DC) and 150/120 kV lines (some 22,000 km).
- It also includes 17 interconnection lines that allow the exchange of electricity with the foreign countries (France, Switzerland, Austria, Slovenia and Greece).
- Its generation capacity is around 80,000 MW (73% hydro, 26% and 1% wind/photovoltaic) for a peak load of approximately 54 GW

The application of WAMS in Italy

Characteristics of the Italian electrical system



380 kV system



220 kV system

The application of WAMS in Italy

The Italian WAMS project

- 30 PMUs are installed on the Italian grid (ABB RES 521)
- One sample for cycle (20 ms) and a maximum delay of 10 ms due to the PMU computing time
- Dynamics database requires maximum 20ms for each cycle
- Possible applications of the architecture:
  - state estimation
  - evaluation of security margins
  - real-time TTC
  - monitoring of inter-area oscillation
  - dynamic parameter identification
  - model validation
  - ex-post analysis of contingencies
  - validation of protection devices tuning

WAMS- Research activities

- ✓ Improve the accuracy and the reliability of the Synchronized Data Acquisition processes
- ✓ Improve the performances of the Communication networks
- ✓ Define new control architectures that move away from the traditional centralized paradigms to system distributed in the field with an increasing pervasion of intelligent devices (smart sensors).
- ✓ Develop powerful and easily scalable processing systems aimed to support effectively the intensive computations required by WAMS data processing
- ✓ Implement advanced software interfaces able to support data sharing between heterogeneous control centers and legacy power systems application

Improve the accuracy and the reliability of the Synchronized Data Acquisition processes

The main limitations of existing GNSS

- ✓ For many civilian applications worldwide, it is insecure to rely only on a single GNSS, especially a military one.
- ✓ Indeed, being designed as a military application, it is difficult to foresee for how long the GPS signal will still be available (and free of charge) for civilian applications.
- ✓ Furthermore, the GPS can be seen as an important target during war and/or terrorist attack.

Improve the accuracy and the reliability of the Synchronized Data Acquisition processes

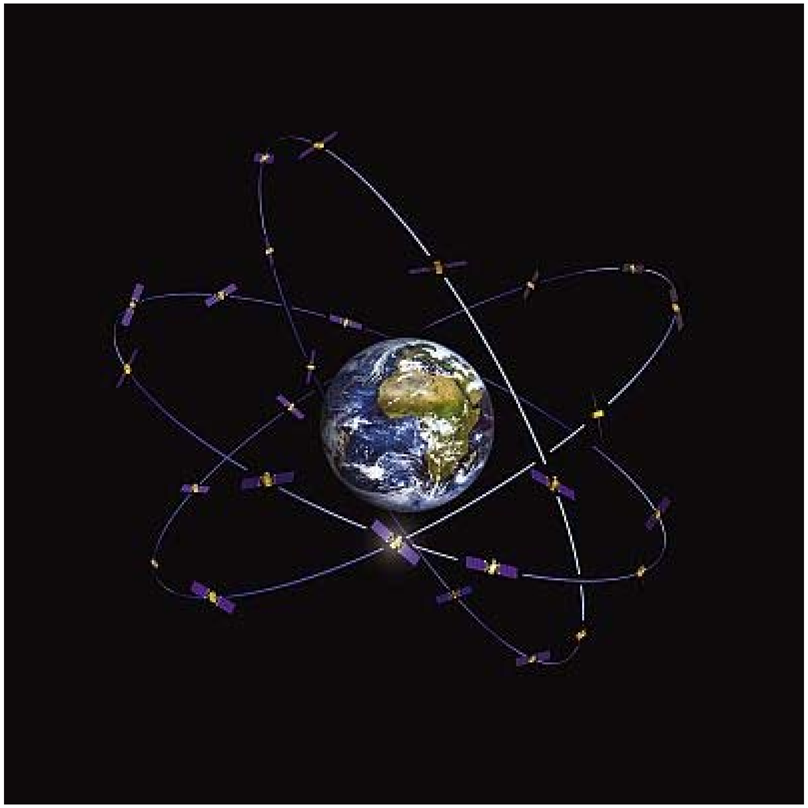
The role of the Galileo System

These were the main reasons that gave rise to the European initiative for having an alternative GNSS, designed as a non-military application, and named GALILEO

Improve the accuracy and the reliability of the Synchronized Data Acquisition processes

The role of the Galileo System

- ✓ The GALILEO comprises a constellation of 30 satellites divided among three circular orbits at an altitude of 23222 km to cover the Earth's entire surface.
- ✓ Each satellite will broadcast 10 different navigation signals, making it possible to offer the open, safety-of-life, commercial, and public regulated services



The GALILEO system

Design principles

GALILEO was designed in such a way as to permit:

- Adaptation of the response to the needs of users and to market trends;
- Minimisation of development and operating costs;
- Minimisation of the risks, other than financial risks, inherent in a project so unusual by virtue of its scope, complexity and the challenges it poses;
- Interoperability with existing systems, notably GPS, while at the same time maintaining autonomy and competitiveness.

The GALILEO system

The services provided worldwide

- The **Open Service (OS)** results from a combination of open signals, free of user charge, provides position and timing performances competitive with other GNSS systems.
- The **Safety of Life Service (SoL)** improves the open service performances providing timely warnings to the user when it fails to meet certain margins of accuracy (integrity). It is envisaged that a service guarantee will be provided for this service.
- The **Commercial Service (CS)** provides access to two additional signals, to allow for a higher data rate throughput and to enable users to improve accuracy. It is envisaged that a service guarantee will be provided for this service. This service also provides a limited broadcasting capacity for messages from service centres to users (in the order of 500 bits per second).

The GALILEO system
The services provided worldwide

- The **Public Regulated Service (PRS)** provides position and timing to specific users requiring a high continuity of service, with controlled access. Two PRS navigation signals with encrypted ranging codes and data will be available.
- The **Search and Rescue Service (SAR)** broadcast globally the alert messages received from distress emitting beacons. It will contribute to enhance the performances of the international COSPAS-SARSAT Search and Rescue system.

The GALILEO system
Main features

✓GALILEO will have an integrity signal to ensure the quality of the signals received.

✓The signals will offer a guaranteed accuracy down to **1 meter**, with value-added services achieving real-time accuracy of **10 cm** for positioning applications.

The GALILEO system
Main features

- ✓ GALILEO signals can also be combined with other GNSS system (Glonass, GPS) or non-GNSS systems (e.g. GSM and UMTS) to allow enhanced services for specific applications.

The Galileo System

Time precision

- The GALILEO time precision in terms of time errors (95% confidence) for different signals is given in Table I.

GALILEO SIGNALS CONTRIBUTION ON THE SYNCHRONIZATION ERROR

Signal	L1	E6	E5A	E5B	E5AB
Time error (95% confidence)	8.1ns	3.6ns	1.8ns	1.8ns	0.7ns

The Galileo System

Main advantages over the other GNSS solutions

- GALILEO has been designed and developed as a non-military application, while incorporating all the necessary protective security features.
- Unlike other GNSS, GALILEO provides, for some of the services offered, a very high level of continuity required by modern business, in particular with regard to contractual responsibility;
- It is based on the same technology as other GNSS and provides a higher degree of precision, thanks to the structure of the constellation of satellites and the ground-based control and management systems;

The Galileo System

Main advantages over the other GNSS solutions

- GALILEO is more reliable as it includes a signal "integrity message" informing the user immediately of any error. In addition, it will be possible to receive GALILEO at places located in extreme latitudes;
- It represents a real public service and, as such, guarantees continuity of service provision for specific applications. Other GNSS signals, on the other hand, in recent years have become unavailable on several occasions on a planned or unplanned basis, sometimes without prior warning.

The Galileo System

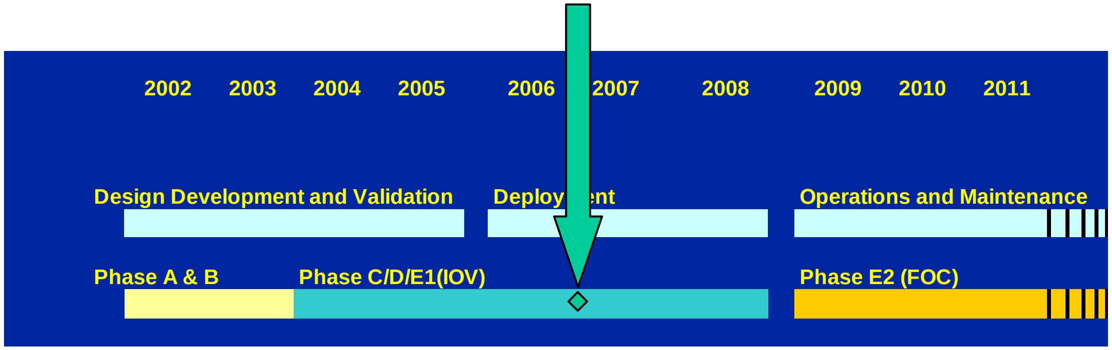
Interoperability with the other GNSS solutions

- ✓ GALILEO is designed not only to compete but also to complement the GPS.
- ✓ Thus using these two GNSS signals in a coordinated fashion would yield real improvements in terms of precision and security.

The Galileo System

Programm phases

1. **Definition of the system** (finalized):
   During the definition phase, the Commission and the European Space Agency (ESA) have mobilised a very large part of the European space industry as well as a large number of potential service providers with a view to defining the basic elements of this project.
2. **Development of the system**
   The development and validation phase (2002 – 2005) covers the detailed definition and subsequent manufacture of the various system components: satellites, ground components, user receivers.
3. **Deployment and commercial operation**
   The constellation deployment phase will consist in gradually putting all the operational satellites into orbit and in ensuring the full deployment of the ground infrastructure so as to be able to offer an operational service.



Why Satellite?

- The integration of satellite technology into power system operations is emerging
  - Large coverage area available from space
  - Improvements in satellite reliability
  - Lower data-latency
  - Lower cost small satellite buses

Applications for power systems are an active area of research in such areas as wide area measurement, control, and communication.

Improve the performances of the Communication networks

The role of satellite technologies

- The integration of satellite technology into power system operations is emerging
  - Large coverage area available from space
  - Improvements in satellite reliability
  - Lower cost small satellite buses

- Applications for power systems are an active area of research in such areas as wide area measurement, control, and communication.

Modern satellite communications

Their role in large scale power systems communication

- Examples of wide area applications that could benefit from space-based technologies are:
  - Advances in System Integrity Protection Schemes (SIPS)
  - Distribution circuits network management
  - Dynamic loading of power equipment
  - System restoration – Need for smart restoration tools
  - Application of PMUs in advanced warning systems of impending trouble or during system restoration
  - …..

Modern satellite communications

Benefits compared to other communication technologies

- Their installation does not require the construction of complex and expensive infrastructures.

- They could assure a set of intrinsic advantages such as **wide area coverage**, **easy access to remote sites**, **cost independent of distance**, **low error rates** and **adaptable to changing network patterns**.

- They are considered a key factor in **lowering the degree of vulnerability of complex interactive networks and critical infrastructures** as far as the electric power grids and transportation networks are concerned.

Modern satellite communications

Benefits compared to other communication technologies

- Use of satellite communications has historically been limited by
  - recurring leasing cost of services – Dedicated link $$
    - Commercial market increases supply and demand
  - intrinsic time delay
- Today these issues are not as detrimental due to
  - larger number of satellite service providers
  - continuous lowering of the cost driving factors characterizing satellite technologies.
- The profitable extension of these benefits into grid communications requires validation of the true functionalities of the modern satellite communication systems.

Modern satellite communications

Technology screening

In the frame of the technological assessment, several telecommunication subsystems have been considered for the reference scenario.

The items considered for the analysis include:

- minimum time delay
- continuous availability of service
- end-user performances (real throughput, BER, FER, etc.)
- compact and low cost terminals and antennas
- low power consumption
- support for internet-based services – Commercial Alternatives
- Coverage

BER - bit error rate

FER - Frame error rate

Satellite providers screening *(LEO vs GEO based services)*

- LEO and GEO service providers were considered.
  - From Launch Perspective, LEO is more economical
  - GEO systems require further hardened equipment - Harsher environment
- The comparative analysis has shown that LEO satellite based services are characterized as having a nominal data rate potentially suitable to support the remote monitoring and protective functionalities for grid applications.
- To enable quantitative measures
  - The LEO based satellite communication systems have been tested to determine the actual data rates on multiple downloads using the file transfer protocol (ftp) from a server located on a high-speed connection to the Internet.

LEO – Low Earth Orbit (Circles around the earth)
GEO - Geo-stationary Earth Orbit (Also, known as Geo-synchronous Earth Orbit, e.g: International Space Station)

Satellite technologies screening

Comparative analysis of LEOs based services

COMPARISON OF DATA DOWNLOADS USING PACKET AND DIAL-UP SERVICES

	Globalstar		**Iridium**	
	Packet	*Dial up*	*Packet*	*Dial up*
Average Data Rate for Highly Compressible Files	7.62 Kbps	6.31 Kbps	7.46 Kbps	2.19 Kbps
Average Data Rate for Minimally Compressible Files	6.88 Kbps	6.02 Kbps	2.28 Kbps	2.21 Kbps
Percentage of Successful Download Attempts	100%	100%	88%	70%

Satellite technologies screening

Choice of the LEO based services

- ✓ The results showed the Globalstar® system exhibits some technical advantages in terms of data exchange speed and reliability.
- ✓ In particular, Globalstar® achieved a 100% success rate in the download attempts compared to 79% for Iridium.
- ✓ Therefore, Globalstar® based services were considered in our experimental activity.

Experimental studies

Performance analysis of a LEO based communication link for large scale power systems communication

- The performance of the LEO based communication services have been tested by an experimental test bed consisting of a prototype IED that integrates advanced modeling methodologies and LEO satellites based TCP/IP communication services for the remote monitoring and protection of power components.
- The parameters characterizing the data link performance that have been considered are:
  - connection times
  - degradation of services
  - data latency

Experimental studies

Performance analysis of a LEO based communication link for large scale power systems communication

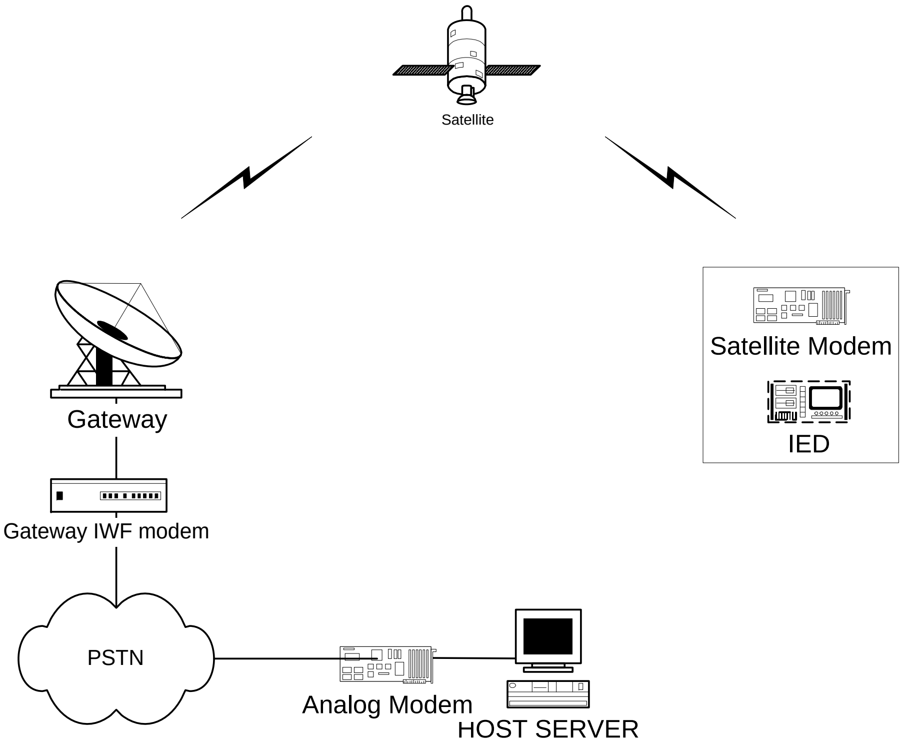
- These experimental activities have been developed connecting the IED to the Internet by the Globalstar® satellite gateway and submitting multiple queries to the remote device by a web connected host server.
- As far as the connection modalities of the host server are concerned, several kinds of internet connections, based on both Local Area Networks and private Internet Service Provides (ISP), have been explored.

Experimental results

Experimental results

Asynchronous data connection

The asynchronous data connection between the host server and the remote microcontroller is established by a dedicated PPP (point to point protocol) link over the full-duplex satellite communication channel.

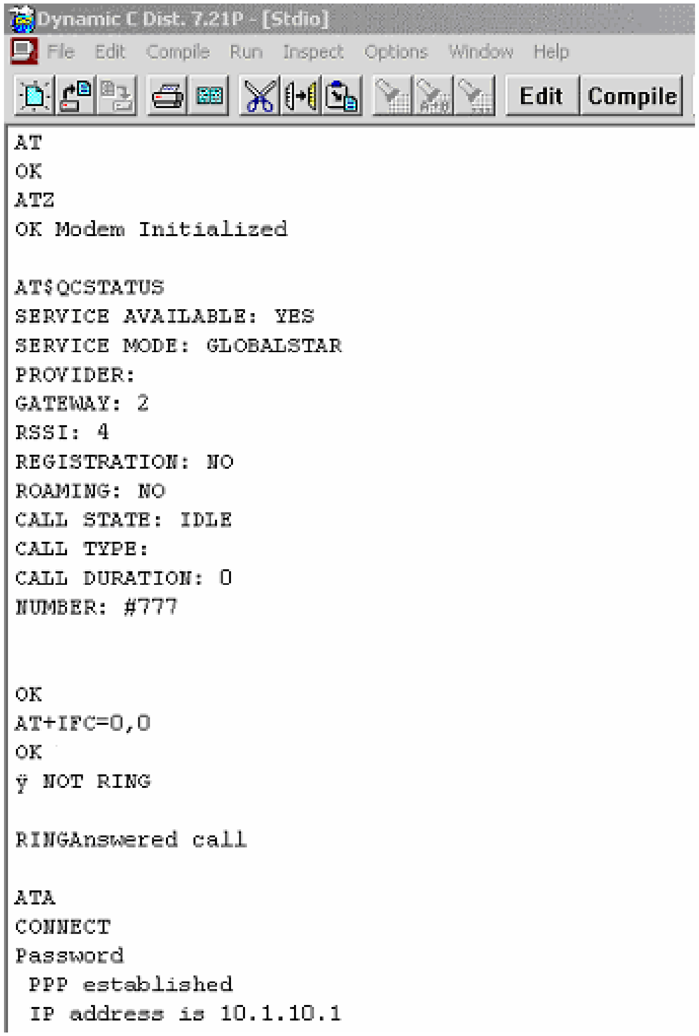


Experimental results

Asynchronous data connection

In this case, once an incoming calling is detected, the remote microcontroller activates a PPP connection according to the following functional steps:

- Authentication phase using the Password Authentication Protocol (PAP);
- PPP negotiation;
- TCP/IP initialization.



Experimental results

Asynchronous data connection

Several field trials have provided the following **average results**:

- System access: 289 ms

Data Connection set-up

- RLP negotiation: 380 ms
- PPP negotiation: 1366 ms

Concerning the effective throughput, the raw code channel rate of the Globalstar® air interface is declared to be 9.6kbps, but an **effective throughput rate** of 7.2 to 7.5 kbps has been observed at the application layer.

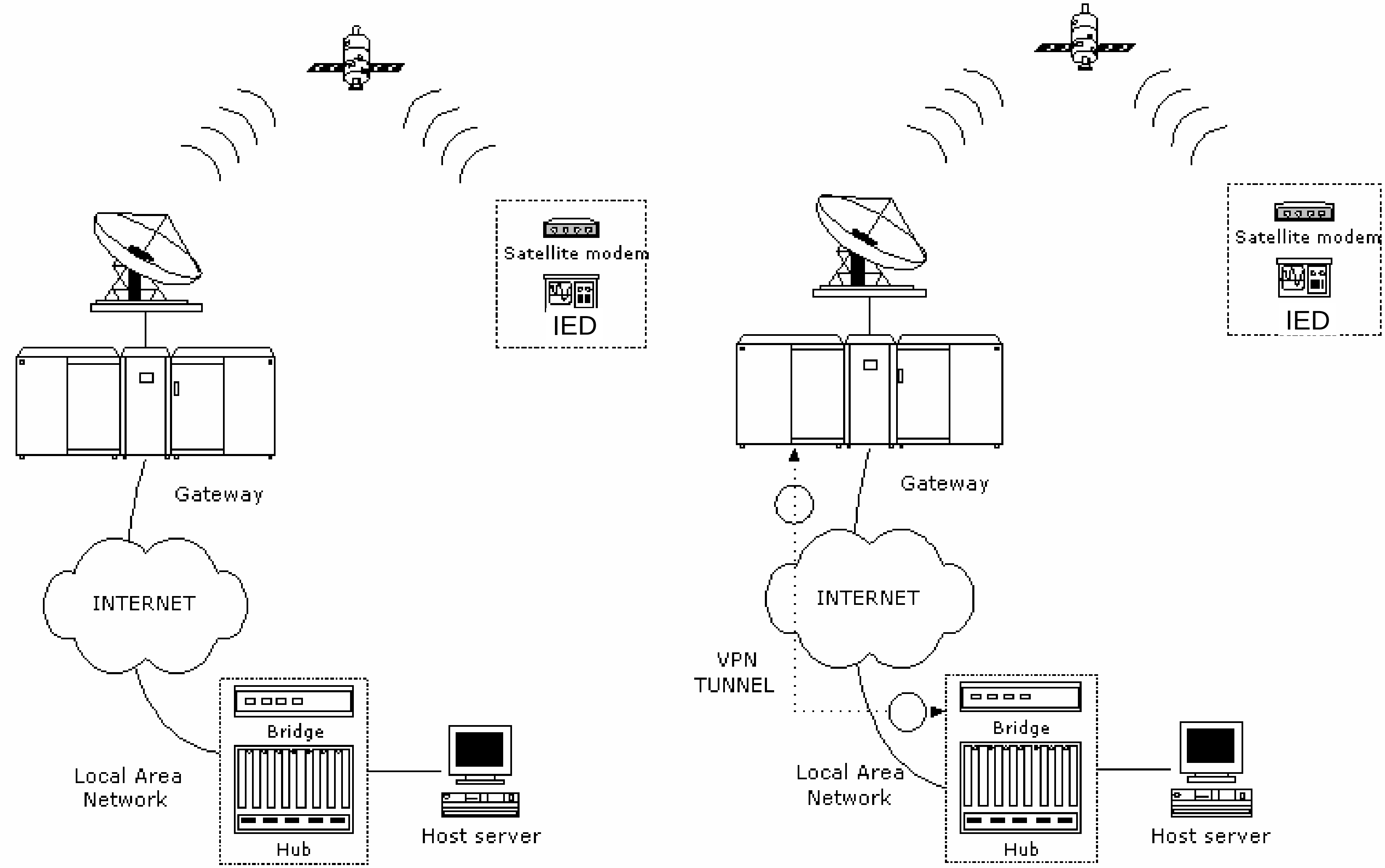
Experimental results

Packet data connection

- In this regard the experimental activities have been oriented to estimate the **latency** in transmission of several host server configurations.
- This has been realized with a JAVA applet that invokes a CGI function resident on the IED and measures the time until the IED notifies the correct command execution.
- For the host server internet connectivity, the following case studies have been considered:
  - Host connected by a Satellite modem
  - Host connected by a Satellite modem on a Virtual Private Network (VPN)
  - Host connected by a GPRS modem
  - Host connected by a GPRS modem on a Virtual Private Network (VPN)

Latency estimation

Host connected to internet by a Satellite Modem



Latency estimation

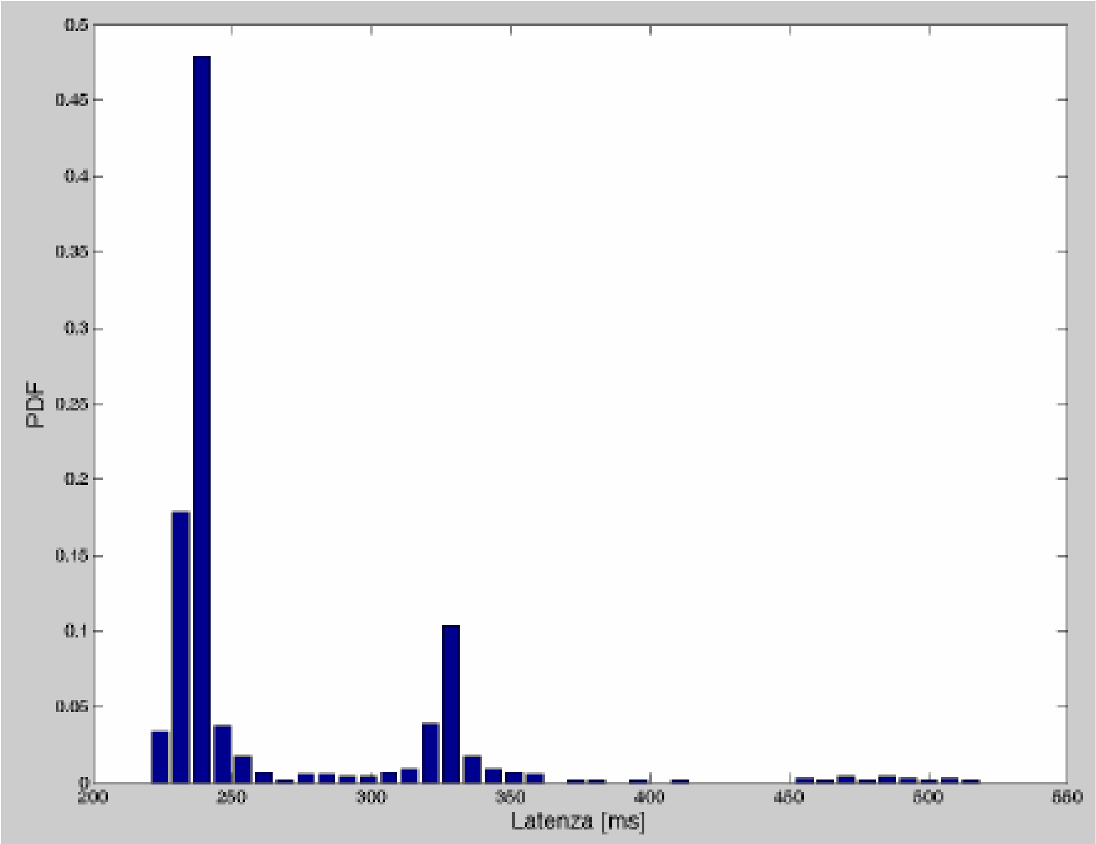
Host connected to internet by a Satellite Modem

PDF – Probability Distribution Function

Probability that the latency time lies in a certain interval (i.e. between t1 and t2).

This probability is calculated by integrating the function PDF between the two extremes t1 and t2.

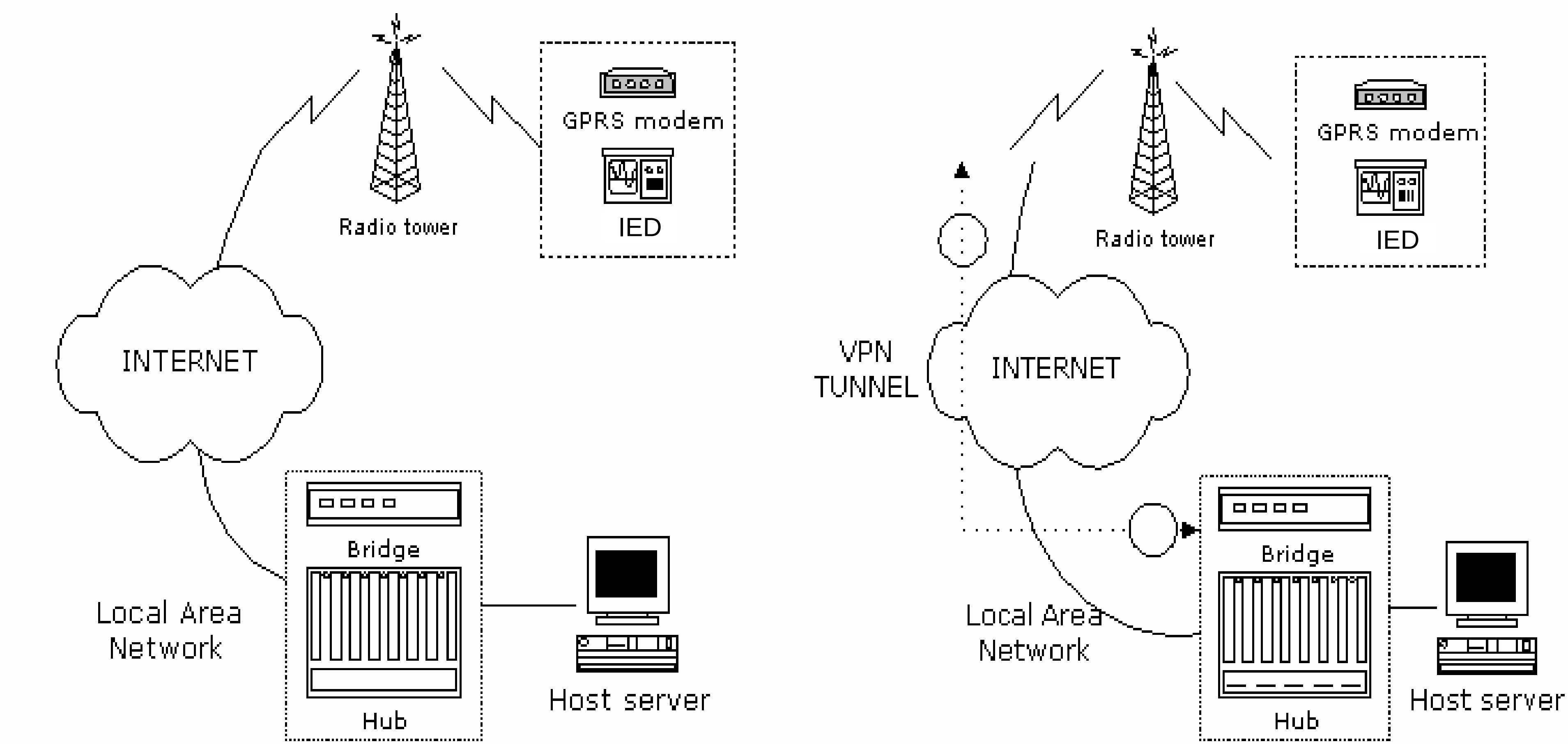
The integral of the function between 0 and infinity is one (the probability that the latency time is between zero and infinity is one).



Statistical characterization of the data latency evolution
(Client connected to the VPN by a satellite based data link)

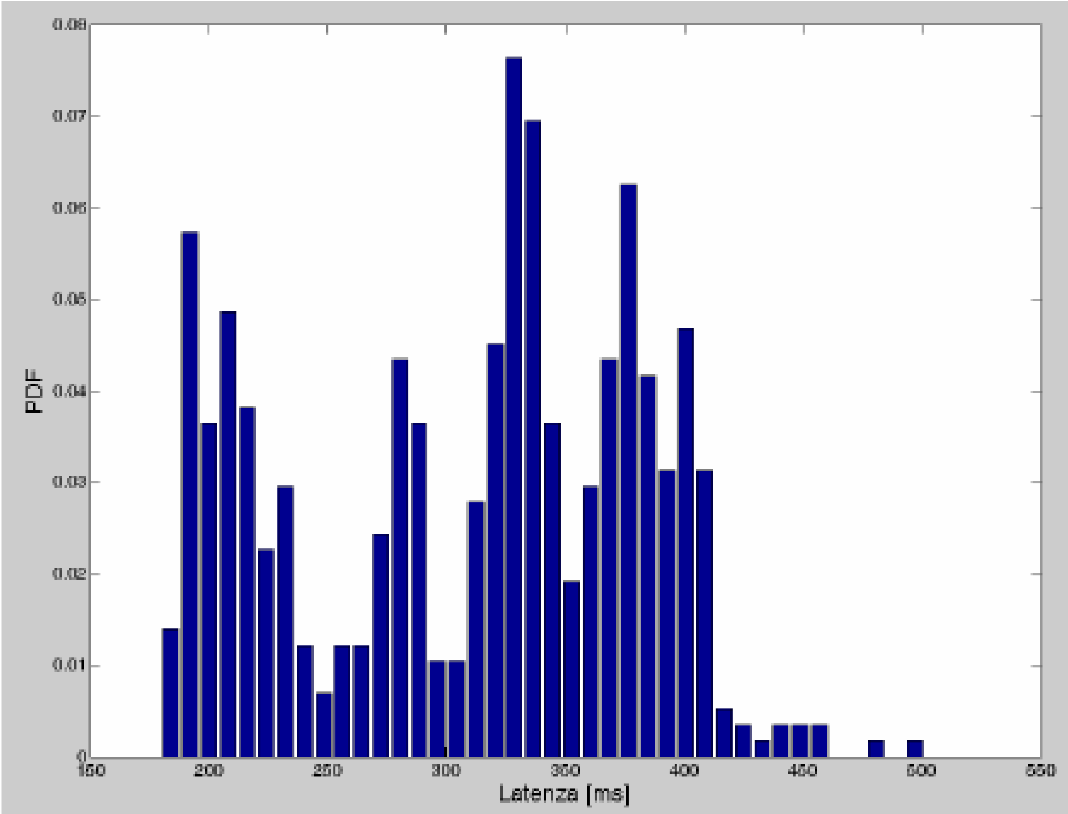
Latency estimation

Host connected to internet by a GPRS Modem



Latency estimation

Host connected to internet by a GPRS Modem



Statistical characterization of the data latency evolution (GPRS based VPN)

Satellite network

Data packets		
TX = 577	RX = 543	Lost = 34 (6% Lost)
Latency [ms]		
Min = **250**	Max = **740**	Mean = **290**

GPRS network

Data packets		
TX = 560	RX = 527	Lost = 33 (6% Lost)
Latency [ms]		
Min = **254**	Max = **682**	Mean = **275**

Satellite based VPN

Data packets		
TX = 697	RX = 695	Lost = 2 (0%)
Latency [ms]		
Min = **220**	Max = **519**	Mean = **263**

GPRS based *VPN*

Data packets		
TX = 578	RX = 576	Lost = 2 (0%)
Latency [ms]		
Min = **180**	Max = **501**	Mean = **308**

Results discussion

- Experimentally obtained figures of merit for various host server configurations for the remote management of Intelligent Electronic Devices (IED) have shown the data latency and lost data packets for satellite networks versus GPRS networks are comparable.
  - Similar to mobile phone technology – Wireless local area connection to a Cell Tower
- Further research is merited to validate the use of satellite based communication systems for a multitude of wide area grid applications.

WAMS architectures based on smart sensors

- Modern trends in power systems operation ask for an increasing pervasion of distributed monitoring systems.
- This process is hindered by the low scalability levels characterizing the existing monitoring systems, traditionally based on client server based paradigms.
- This has stimulated the power systems research community to define new monitoring architectures that move away from the older centralized paradigm to system distributed in the field with an increasing pervasion of smart sensors.
- According to these considerations much research efforts are oriented toward the definition of a fully decentralized monitoring architecture based on self organizing Wireless Sensor Networks (WSN).

WAMS architectures based on smart sensors

A Wireless Sensor Networks (WSN) - Consists of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions at different locations.

The application of WSN in power systems monitoring is gaining an increasing interest in the scientific literature due to their intrinsic benefits as far as:

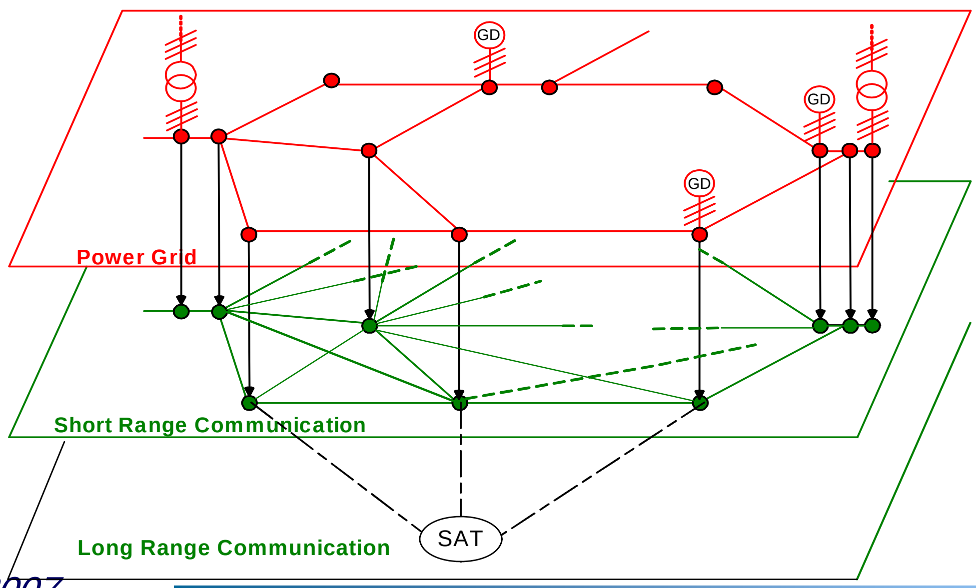
- **Bi-directional routing for command and control**: the two-way communication nature of the network allows network designers to send calibration commands to sensors, wirelessly trigger relays, or send messages out into the network for display or control of remote devices.
- **Self-Healing**: built-in redundancy ensures that if a node happens to drop out of the network, messages will automatically route to an alternate node, ensuring reliability and robustness.
- **Distributed Intelligence**: their architectures support distributed computing paradigms, ubiquitous and pervasive computing.
- **High pervasive**

WAMS architectures based on smart sensors

- Effective integration of WSN in electrical power grids asks for overcoming several critical issues induced mainly by the large geographical distribution of the electrical system that make complex the WSN coordination.
- To address this problem the employment of Information and Communication Technologies could play an important role by allowing a global area WSN coverage.

WAMS architectures based on smart sensors

- The architecture could be deployed by a cluster of sensors networks each monitoring a specific electrical grid section.
- The sensor nodes belonging to homologous cluster could communicate by a short range digital communication link while the connectivity between the different clusters could be assured by a Wide Area Network.



WAMS architectures based on smart sensors

- The research activity intend to give a contribution toward the definition of a fully decentralized monitoring architecture by proposing the employment of self organizing Wireless Sensor Networks (WSN).
- Specifically, we propose the employment of a cluster of sensors networks each monitoring a specific electrical grid section.
- The sensor nodes communicate according to the following paradigm:
    - In the same cluster by a short range digital communication link based on the IEEE 802.15.4 standard for wireless personal area networks (WPANs)
    - Amongst different clusters by a Satellite based Virtual Private Network (VPN).

WAMS architectures based on smart sensors

- Moreover, in order to deploy a fully decentralized monitoring architecture we propose the employment of a **cooperative paradigm** in which the spreading of information occurs as a result of the local coupling between adjacent nodes which act as mutually coupled adaptive oscillators
- The idea is to start from the mathematics of **populations of mutually coupled oscillators** for designing high pervasive/self organizing sensor networks for power systems monitoring.
- Each network node is composed by a **sensor**, that acquires a physical variable (i.e. the voltage module), and of a **dynamical system** (oscillator) initialized by the sensor acquisition.

WAMS architectures based on smart sensors

If the oscillators of nearby nodes of the same sensors network are mutually coupled by the following local coupling strategy:

$$\dot{\theta}_i(t) = \omega_i + \frac{K}{c_i} \sum_{j=1}^{N} a_{ij}\, F[\theta_j(t) - \theta_i(t)] \qquad \forall i = 1, \ldots, N$$

Θ_i is the state of the internal oscillator associated to the *i*-th sensor node

ω_i is the physical variable acquired by the *i*-th sensor node;

C_i codifies the attitude of the *i*-th sensor node to adapt its state in function of its neighbors;

K is a gain factor;

a_{ij} assumes the value +1 if the nodes *i*-th and *j*-th are coupled;

F [.] is a odd monotone crescent function;

WAMS architectures based on smart sensors

Then **each dynamic system on each node converges to the same value ω*(i.e. they tend to synchronize):**

$$\dot{\theta}^*(t) = \omega^* = \frac{\sum_{i=1}^{N} \omega_i \, c_i}{\sum_{i=1}^{N} c_i}$$

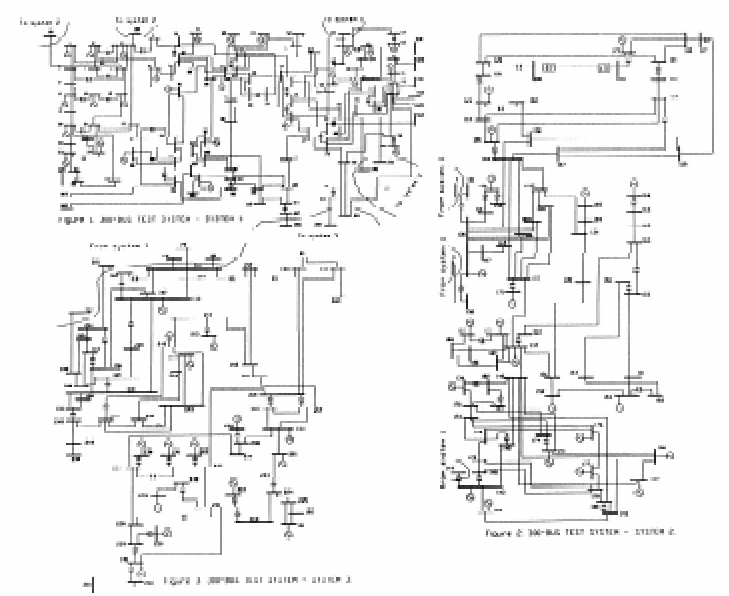
This value could be interpreted as the mean value on the grid section of the monitored physical variable (i.e. the mean value of the grid voltage module).

WAMS architectures based on smart sensors

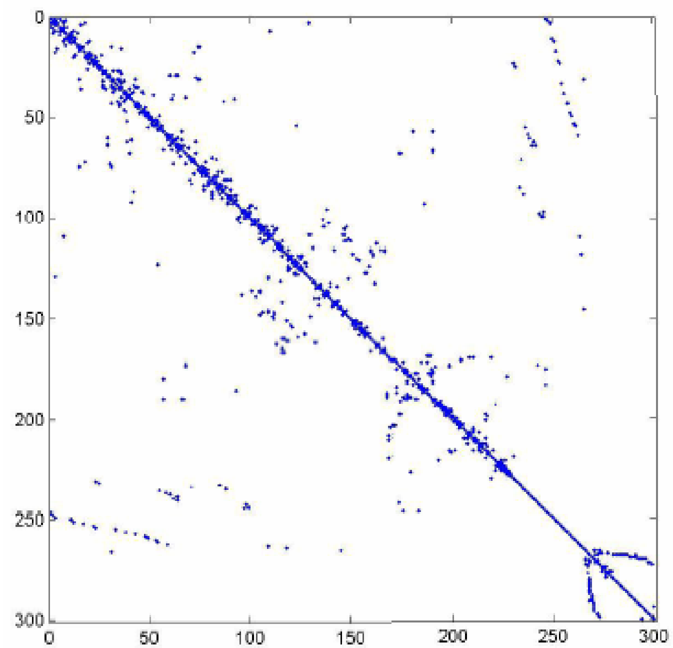
- According to this paradigm each node knows both the performances of the monitored section and the global performances of the monitored grid section computed by local exchanges of information with its neighbors nodes.
- Thanks to this feature each node could automatically detect local site anomalies by comparing its acquisition with the equilibrium oscillator state.
- Moreover **system operator** can assess the mean value of the monitored variable for each grid section by **inquiring any node of the corresponding sensors network** without the need of a central fusion center acquiring and processing all the node acquisitions.
- This makes the overall monitoring architecture highly scalable, self-organizing and distributed.

WAMS architectures based on smart sensors

Voltage Monitoring



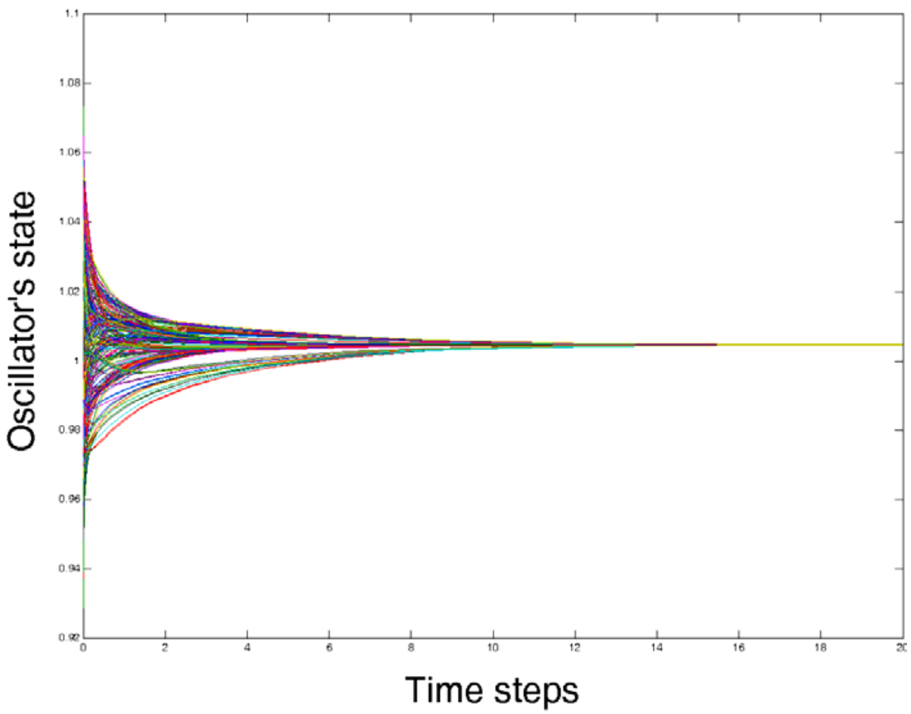
IEEE 300 bus test network



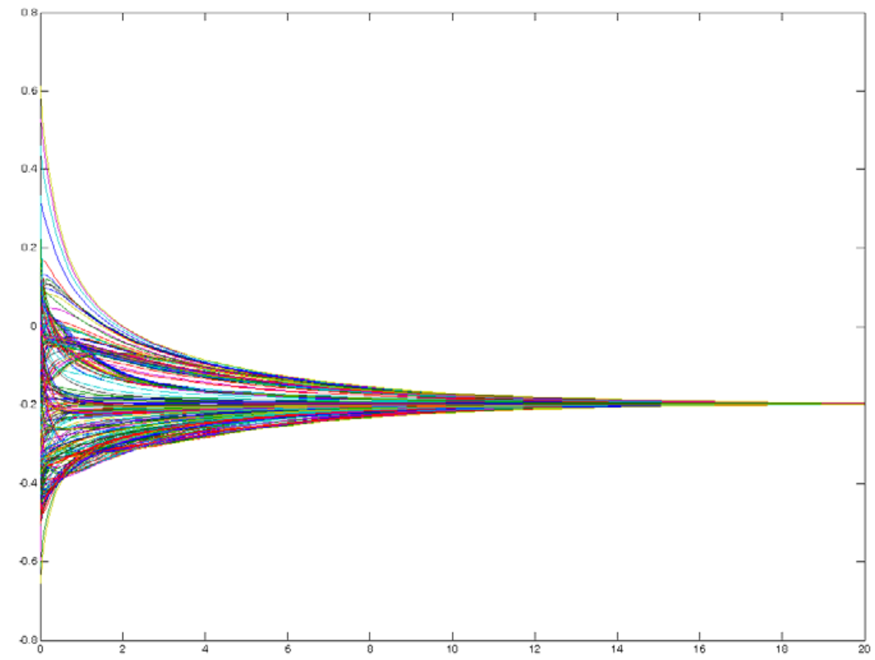
The WSN graph is obtained by the electrical adjacent matrix
Electrical connection ➔ Communication connection

WAMS architectures based on smart sensors

The WSN oscillators synchronize



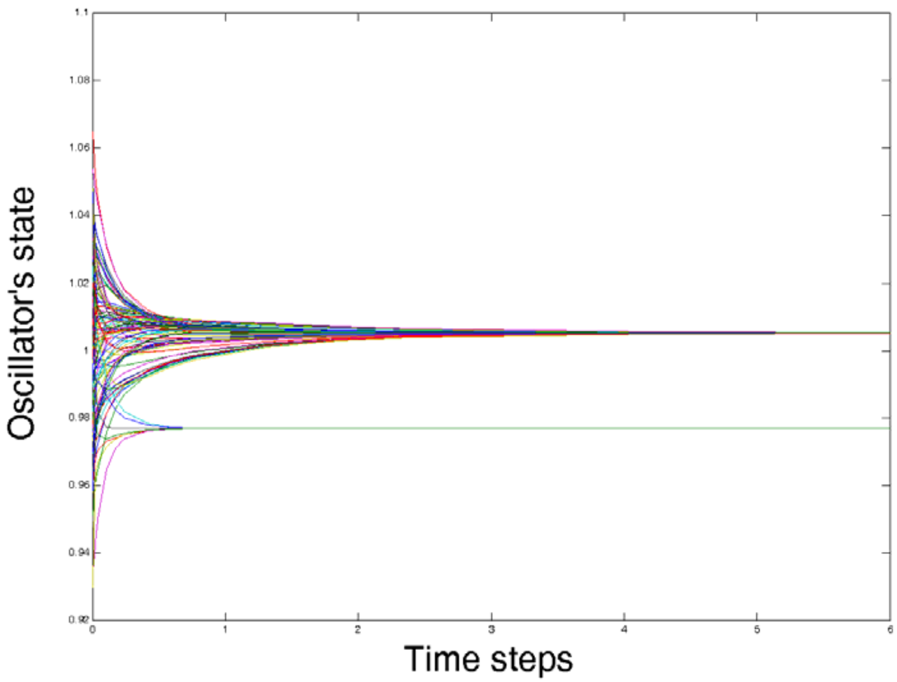
Case A: The acquired variable is the Voltage module
The oscillators converge to the **mean grid voltage module**



Case B: The acquired variable is the Voltage phase
The oscillators converge to the **mean grid voltage phase**

WAMS architectures based on smart sensors

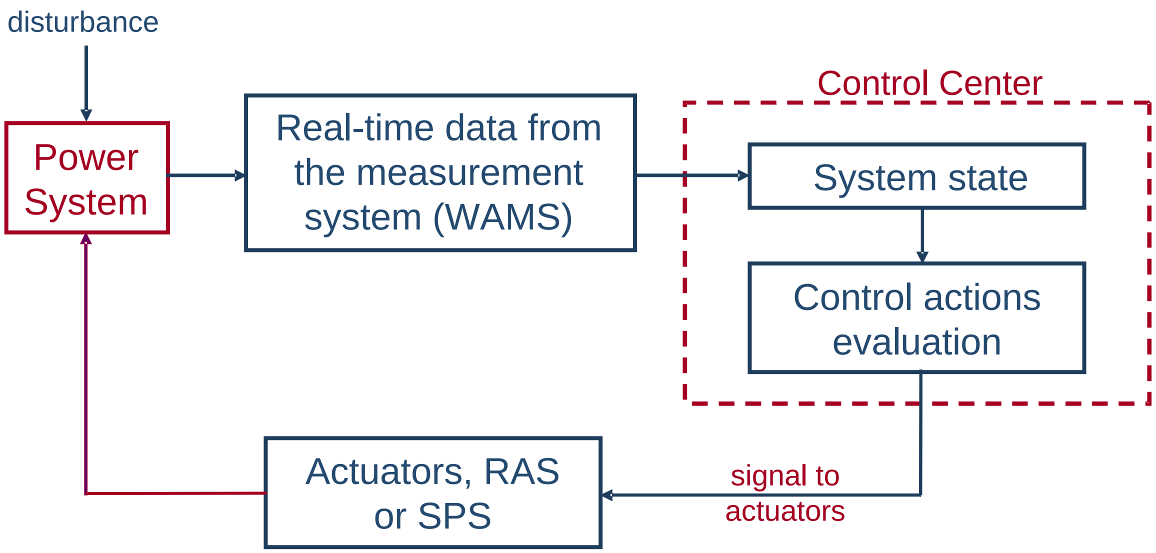
- In the past examples only one WSN was considered for the entire power system
- But it is more interesting to consider a cluster of WSN each one monitoring a particular grid section
- In this case each node's oscillator of the same cluster converges to the mean value of the monitored variable of the corresponding grid section



The acquired variable is the Voltage module
There are two WSN monitoring two separate grid section
Each oscillator of the same WSN converges to the **mean voltage module of the corresponding grid section**

From Event-based to Response-based approach

WAMS integrated **with advanced computing platforms** might allow to achieve the passage from a control strategy based on the forecasting of possible system states (event-based) to a strategy where the system might react to the actual system dynamic behavior (response-based)



From Event-based to Response-based approach

- In addressing this problem **Grid computing** could play a strategic role.
- The diffusion of this paradigm was motivated by the idea of harnessing a lot of distributed computing resources to solve large-scale problems.
- In this new scenario, thanks to the possibility of using a large collection of resources at low cost, power systems computations can be addressed by harnessing a large, extensible pool of computational resources dynamically acquired on reliable data networks.

Integrate Grid technologies in WAMS

- We are exploring the possibility to create a distributed architecture for power system computations based on grid computing.
- The proposed solution merges two main sub-systems: (1) a data acquisition sub-system composed of a network of sensors; (2) a computational engine built atop a computational Grid.
- These two subsystems are completed with a web-based user interface for data presentation and a database for persistent data storage.

Integrate Grid technologies in WAMS

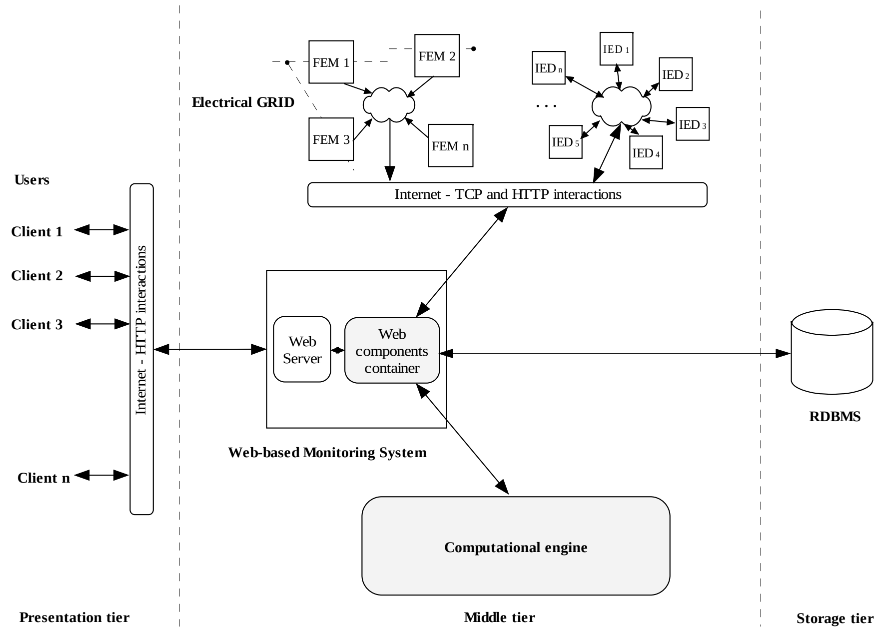
- This special kind of Grid, characterized by heterogeneous and multipurpose devices ranging from computers, personal devices, sensors, data base and Web system can be more properly defined as "**Pervasive Grid".**
- This new vision of Grid is the focus of most of researchers in the field of distributed and grid systems due to its large applicability in modern large scale networked infrastructures, especially for "homeland security" problems.

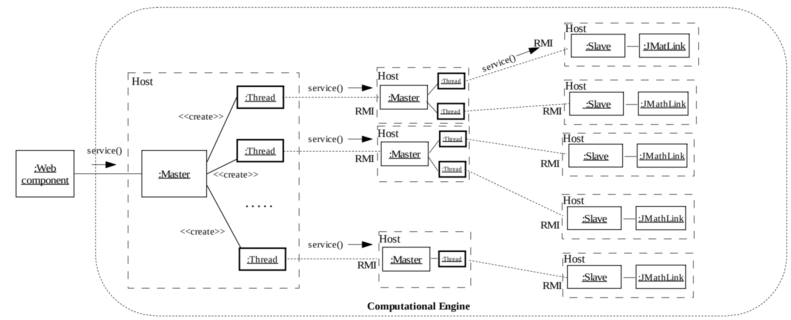
Integrate Grid technologies in WAMS

The proposed architecture is based on an economy-driven broker that

- (1) identifies the optimal asset of the computational resources needed to satisfy the user requirements (i.e. resource discovery and resource selection process);
- (2) splits a sequential object-oriented task (i.e. a set of contingencies) into sub-tasks (i.e. a sub set of contingencies), according to a hierarchical master/slave computing model;
- (3) automatically distributes sub-tasks to the set of selected computational resources.

Integrate Grid technologies in WAMS





The proposed architecture

Integrate Grid technologies in WAMS

Expected benefits:

Traditional approaches lack extensibility, reusability, and scalability that a Grid middleware is able to provide.

– *Extensibility* is useful to extend the current functionalities in order to perform other kinds of analysis;
– *Reusability* is important in order to employ the software infrastructure in different context characterized by different electrical network sizes and accuracy of analysis;
– *Scalability* allows to adapt the infrastructure to growing networks without decreasing performances.

Advanced tools for supporting information sharing in WAMS

- Information sharing in WAMS represents a crucial issue to address since it faces considerable drawbacks derived, mainly, to the difficulties to upgrade the existing management systems, typically based on proprietary-low scalable architectures and designed to support mainly intra-company information exchanges.

- In this connection the adoption of **web services** could contribute to overcome some of the cited limiting aspects

What is a Web Service?

- ✓ It is a new paradigm for enterprise application integration built on the foundation of open standard and common infrastructure.
- ✓ It is an interface that describes a collection of modular, self-describing and self-contained applications that are network-accessible through standardized XML messaging.

What is a Web Service?

- ✓ The interface hides the implementation details of the service, allowing it to be used independently of the hardware or software platform on which it is implemented and also independently of the programming language in which it is written.

- ✓ The use of standard XML protocols makes Web services technology platform-, language- and vendor-independent, thus an ideal candidate for use in integration of legacy power system applications.

Research activities

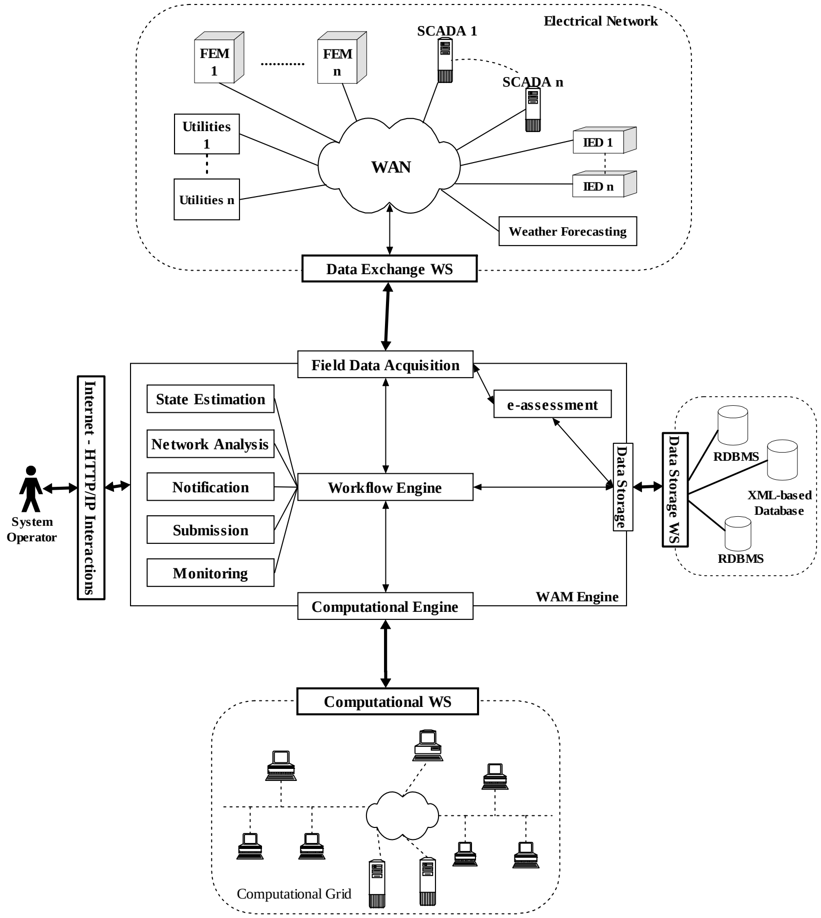
We are developing a WAMS architecture based on the following interactive Web Services:

- *GISinterfaceWS*: it acquires georeferential information on the current network topology and the control devices asset by interacting with the available Geographical Information Systems (GIS).
- *DataAcquisitionWS*: it acquires the network field data interacting with the entire set of SCADA systems and Field Electrical Measurements (FEM) by standardized XML messaging.
- *eAssessmentWS*: it develops the network thermal monitoring by interacting with a network of intelligent units, installed in the most critical sections of the electrical network, that assess dynamically the load capability of the main plants components.

Research activities

- *ComputationalWS*: it employs a parallel solution engine, based on a computational grid realized according the hierarchical master slave pattern , to develop the calculations needed to support the entire set of power system monitoring services as far as state estimation, network analysis, on-line security assessment etc.
- *DataStorageWS*: it is used to permanently store historical data and alarm conditions that can be analyzed off-line by using a Web browser. The service can be remotely accessed by using a *data access* middleware.

The proposed Web Services based architecture



The experimental test bed

- It integrates a proprietary SCADA system, (ION Enterprise 5.0), a GIS (ArcGIS –ESRI), several industrial based Field Electric Measurements (ION™ 7330 and 7600 power meters) and a prototype version of an *Intelligent Electronic Device* (IED) for the e-assessment of the power components loadability.
- These facilities are interfaced by a web services based monitoring framework implemented by the SOAP engine Axis ver. 1.1.
- The overall middleware infrastructure to manage the framework has been implemented by using the JAVA language and related technologies, provided by the JDK 1.3.x and the J2EE® platform. An Apache Web server has been connected to the Tomcat/4.1.18 Web components container.

The first experimental results

The first experimental results obtained show as the adoption of the Web Service Technologies in WAMS represents an effective tools to integrate monolithic and hard to customize power system control and monitoring software tools allowing system operators to easily manage proprietary hardware instrumentations and multiple software modules.

Thank you for your attention!