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Summary of results of prototype system test and evaluation

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Table of Content

Executive Summary

MOBESENS successfully developed and demonstrated of a beyond the State of the Art Ecological, Open, Modular and Scalable ICT based solution for 'always on' and 3D water quality monitoring which allows end users to monitor water quality and track contaminents.. This was achieved by the development, improvement and adaptation of a number of various elements, which were then integrated to realise the MOBESENS prototype systems. This report presents a concise summary of the technical achievements and advances made in each separate element of the project. Issues related to system integration and results obtained during deployment of the prototype system are also discussed.

The MOBESENS prototype systems enable data to be gathered quickly and reported across wide areas. The system is based on a low power wireless communication sensor network to: gather data monitored by various sensor probes; stamp them with time and location data during their transfer through a low power WiseNode network having self-multihop reconfiguration to a SinkNode gateway; and finally automatically entered them into a grid based information system to facilitate analysis and issuing of alarms as necessary. Mobility is a unique feature of MOBESENS; enabling navigation and both surface and subsurface measurements. This extends range, enables 3D area measurements and facilitates operation, even in difficult conditions. The wireless sensor nodes may form ad-hoc networks enabling rapid and reliable reporting as well as localization and tracking of e.g. contaminants. Ad-hoc connectivity enables opportunistic communication between sensor nodes installed in both fixed and mobile buoys. Renewable energy sources were studied for self-sustained MOBESENS operation and a prototype self-tuning system was demonstrated which generated enough power to support a WSN node.

MOBESENS provides an open and adaptable system, optimised for integration into a comprehensive environmental control system. MOBESENS could be extended to measure other parameters than those required for water quality, e.g. air pollution and UV exposure could also be monitored. The system is designed to be easily integrated into large-scale systems to cover larger geographical areas, e.g. Europe, and in combination with other existing environmental control systems,

Today, the MOBESENS system comprises the following elements:

1. Different types of sensor probes, i.e. an ISFET probe for surface monitoring of pH and T; a GIME-VIP system probe allowing simultaneous monitoring and profiling of the bioavailable fraction of Cd, Pb, Cu and Zn coupled to conductivity, temperature, depth, dissolved oxygen.
2. A wireless communication network capable of collecting data on tens of connected sensor probes and transporting them to a central point where these data are stored and tagged.
3. Fixed and drifting buoys allowing respectively sensor probe measurements at fixed positions or over large distances
4. Kayak capable of transporting and deploying sensor probes to pre-defined points by following a programmed track.
5. An adaptive energy harvesting module which generates sufficient power to supply the WiseNode WSN elements.

The results obtained during three field trials using MOBESENS prototype systems based on two different architectures, coupled with feedback from end-users, have shown the interest and potential of the concept for cost effective, large scale, real-time, water quality control and tracking of pollution. The feedback obtained also highlighted the need for the system to be further adapted and improved in terms of increased optimization (e.g. scalability, available type and number of sensors, data resolution…) and the requirement to demonstrate the long-term reliability and viability of the system.

1 Summary description of project context and objectives

1.1 MOBESENS motivation

Management of the environment for predictable and sustainable use of natural resources is one of the great challenges of the 21st century. Although water covers most of the planet, it is becoming increasingly difficult to ensure adequate supplies of fresh, clean water for drinking, as well as, for sports and wellness activities. The demand for water resources is increasing as the population grows. At the same time, water resources are increasingly exposed to pollutants and spills as parts of the world become ever more crowded and industrialized. Potential climate changes due to global warming may also impact water resources.

Management of water quality requires regular measurements and monitoring. Today, measurements of water quality are performed manually. The process can be slow and painstaking. Multiple point measurements are needed to cover an area. The process needs to be automated and extended to provide rapid and effective monitoring. Cost effective solutions for autonomous, mobile and self-healing solutions are needed to identify trends and to help localize and track potential problems.

1.2 Overall Project Objective

The overall objective of the MOBESENS project was to provide a modular and scalable network solution for 3D water quality monitoring. The MOBESENS wireless sensor network (WSN) will serving as a front-end for gathering water quality information monitored continuously by various sensor probes and reporting back to a water quality management information systems and, more broadly because of the modularity of the system, other environmental monitoring systems (e.g. where information from multiple sources may be fused). Unlike other solutions though, MOBESENS employs sensors capable of navigation. The mobile water quality sensors are capable of forming ad-hoc wireless networks enabling rapid and reliable reporting of information on water quality, localization of anthropogenic release in coastal area and tracking of their spreading and of the contaminants they may carry.

1.3 Specific Objectives of Constituent Technologies

1.3.1 Wireless Communication Node Network

One of the enabling technologies for MOBESENS is the ability for the nodes to function in an automated way. In the same way that the aim for the USV was to have automated guidance with very little, or no, human intervention, the same concept applies to the sensor power supplies that sustain the nodes. In order to allow nodes to function remotely without wired power or the overhead of battery replacement, energy harvesting devices were developed. In addition, the concept of wireless power transfer from the USV to the tethered buoys was investigated so that when the USV passes near the tethered buoys, it may transfer energy at a relatively fast rate to the buoys.

1.3.2 VIP system for in situ trace metal and master variable monitoring and profiling

The VIP system developed in a previous EU project (see section 3.1.1.) was chosen as one of the sensing element to be interfaced in the MOBESENS prototypes. This system fitted the innovative aspect foreseen for the MOBESENS sensors and probes. In particular, the VIP voltammetric probe, based on a patented gel integrated microsensor (GIME), is the only submersible probe available which allows reliable, continuous and simultaneous in situ monitoring and profiling of Cd, Pb (compounds of the EU priority list) and Cu, Zn (EU list 2) down to the ppt level (i.e. capability to monitor the target metals at their natural concentration level and therefore to detect at appropriate time scale any significant or sudden increase in their concentrations). Moreover, its development was oriented from the very beginning to fulfil requirements for field deployment and application under remote control; thus a first objective was to use the expertise accumulated previously as base in MOBESENS for the implementation of the hardware and firmware of a common communication interface allowing plug-and-play of the MOBESENS sensing and communication elements.

Another specific objectives was to improve the VIP system to: i) extend it capability for continuous long-term remote monitoring without maintenance during a period > 2 weeks (i.e. pre-MOBESENS capability); ii) simplify it set-up as well as avoid maintenance operation when not in use; iv) allow its interfacing to the MOBESENS communication network and its incorporation in the Ifremer USV; v) reduce its power consumption.

1.3.3 ISFET sensors

The ISFET sensors developed by MICROSENS were of interest for integration into the MOBESENS system due to their small size and inherent low power consumption. During MOBESENS the objective was on the one hand to adapt the ISFET sensor to the MOBESENS communication system and mobile supports, by developing a suitable electronic probe interface and packaging. On the other hand, the ISFET sensor had to be evaluated with respect to its measurement characteristics and long term stability. Thus the ISFET response to pH and temperature was to be studied, which can be measured respectively via the ISFET's Ta_2O_5 insulating gate and integrated temperature diode. The deposition of polymer brushes membrane, developed in collaboration with EPFL (LP-EPFL) in order to extend the measurement capabilities towards other types of charged molecules such as K^+ or nutrients, was another objective of the ISFET adaptation for MOBESENS.

1.3.4 Polymer brushes

The polymer brushes membranes developed at EPFL are required to provide sensing capabilities of the BAW sensors toward e.g. PAH. They offer also an interesting and promising new way to functionalize ISFET sensors for the specific detection of major cations and anions. Within MOBESENS, the specific objectives were therefore to synthesize specific membranes and to use them to functionalize; ISFET sensors for the specific detection of K^+, NH_4^+, and/or NO_3^-; BAW sensors for PAH detection.

1.3.5 The USV

One of the aims of the MOBESENS project was to produce an autonomous mobile system that can be pre-programmed to deploy the MOBSENS sensor probes and take samples at specific sites. The specific objectives for the mobile element, of type USV

(Unmanned Surface Vehicle) or ASC (Autonomous Surface Craft), were to fulfil the following main requirements:

- Navigate up to one nautical mile distance from the shore with light breeze conditions,
- Stop in the vicinity of a pre-defined waypoint,
- Measure chemical compounds using the MOBESENS sensor probes and/or usual physical properties of the water using commercially available probes; or take a sample of water,
- Repeat the process for each pre-defined waypoint,
- Travel back at a pre-defined waypoint on shore,

And to provide the following features:

- Samples and measurements made from 50 cm under the surface down to 40 m depth,
- No reconfiguration required ashore between successive operations of the prototype
- Possibility to integrate and set up the various sensor probes developed/improved during the project,
- Sufficient energy to carry more than one day of missions out,
- Embedding of the Harvesting Energy element.

1.3.6 Data treatment Back End

The backend or the grid acts as a support technology to the Mobesens measurement system. The latter can now push measurements and collected data into storage systems using standard RestFul based de facto interfaces. The back-end needs to provide automated storage and indexation of the measurements, eventing and publication to multiple end users (acting as clients of the back end system) of measurement events. These components serve as underlying processes to enable fully automated and real time visualisation of measurements in addition to access to histories or past events for data analysis and validation. The visualisation system should support end users in measurement data analysis and validation and provides an interface for real time visualisation of measurements as well as access, organisation and management of the measurement data.

2 Description of the main scientific and technical results and foregrounds

The Mobesens project started from state of the art technologies in the area of sensors, submersible probes, wireless communication node network, data fusion and energy scavenging, tailored those technologies and finally integrate the elements presenting appropriate performance to provide versatile, modular and scalable mobile WSN prototype systems which potentiality for cost effective, 3D monitoring of water quality and anthropogenic effluent release over large area were demonstrated by field applications.

A summary of the work performed to: develop/improve a number of specific elements; tests and evaluate these specific elements first individually and then, for those presenting appropriate performances, interfaced under various architectures are summarized below.

2.1 MOBESENS sensing elements

Advances in three types of sensor probes have been made:

- GIME-VIP system (UNIGE)
- ISFET probe (MICROSENS)
- BAW sensing device (EPFL)

The development/improvement of these sensors probes started from differed bases. The VIP system was the most advanced in term of technology for in situ field monitoring. , The BAW sensing device started from the very beginning and was the most challenging in term of technology for in situ deployment in aquatic systems. The ISFET state of the art was in between those of the VIP and the BAW technologies. In consequence the specific objectives related to the three sensor types differed, as did the outcome.

In order to increase the functionality of all sensors, polymer membranes to be chemically bounded on the sensor surface were also synthesised. In the case of the BAW sensor, the membranes are required to introduce the sensing functionality, while in the case of the ISFET and the GIME-VIP sensor, the membranes can be used to extend the sensor capability to the selective detection of given chemical compounds.

2.1.1 GIME-VIP system

The first prototype of the VIP system (Figure 1) was developed by UNIGE in collaboration with Idronaut and IMT during the VAMP EU project ([9]).

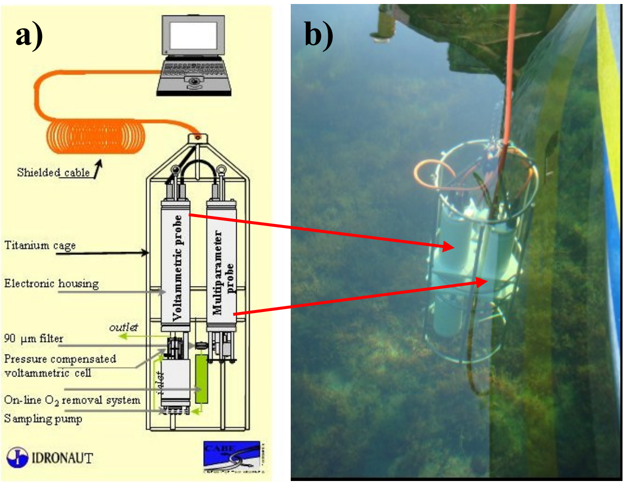


Figure 1: a) Schematic diagram of the VIP system and b) pictures of its submersible part.

The VIP profiler's core main components are: a unique gel integrated microelectrode array (GIME) which is an integrated microanalytical system coupling in a 2mm^3 volume i) a separation step allowing efficient exclusion of both fouling material from the sensor surface and influence of ill-controlled conditions on the sensor signal (e.g. D2.2; [8], and ii) a sensitive (ppt level) and simultaneous voltammetric detection of the bioavailable fraction of Cd, Pb, Cu and Zn. i.e. the most important fraction to assess metal (eco)toxicity impact (for details see D2.2 and e.g. [7], [8]); a voltammetric probe incorporating a GIME; a multi-parameter probe (OS316, Idronaut-Milan), operated by the voltammetric probe or working in autonomous mode under pre-programmed conditions, for the control of the voltammetric probe at depth and the recording of master parameters (depth, pH, O_2, T, conductivity, chlorophyll *a*) which are required for the interpretation of the voltammetric data, the metal biogeochemical cycles and ultimately the assessment of the metal species behaviour and potential impact (e.g. D6.4); a management software for configurations of the probes monitoring conditions and data processing.

During the first MOBESENS period, the work focused on technical specific developments/improvements of the GIME-VIP sensors and probes. A new sensor based on a GIME and a µ-counter electrode (µ-CE) integrated onto a single chip (Figure 2b) and a home mini-reference electrode (Figure 2c) was developed. The geometry of these new sensors allowed to design and produce of a simplified VIP voltammetric flow-through cell consisting simply on two channels machined in a Plexiglas body (Figure 2a). This simplified cell design allowed: i) to eliminate the VIP cell maintenance (required typically every two weeks for the standard pressure compensated VIP flow-through cell used previously as reported in D2.2), and thus to bring the possibility to evaluate the capability of the VIP for remote monitoring over period > 2 weeks; ii) to simplify the setup of the VIP system; iii) to reduce the production cost of the key part of the VIP voltammetric probe. These advantages are key aspects for both end users and commercial purpose.

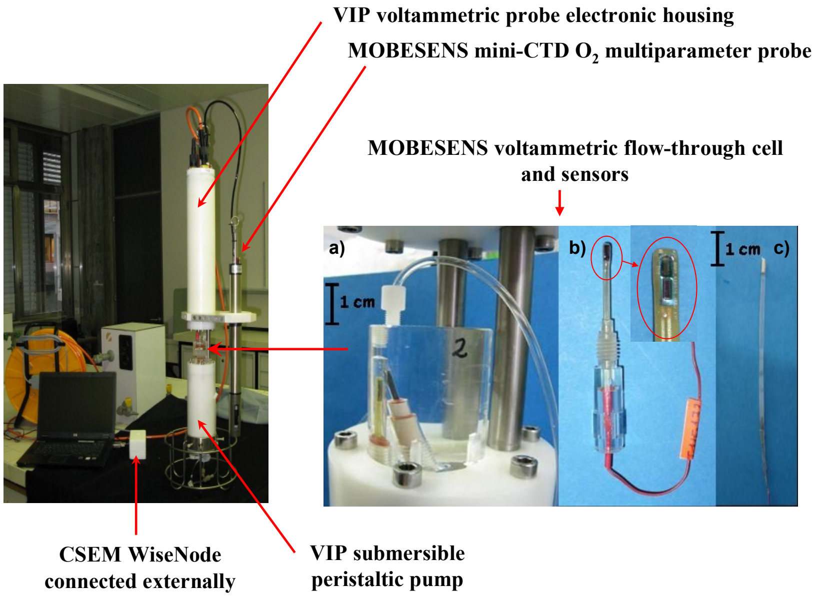


Figure 2: Photos of the MOBESENS improved VIP system and details of: a) the simplified cell, b) the on chip integrated GIME and micro-counter electrode, and c) the in-house mini-reference developed in MOBESENS (see D2.2 for details).

A mini-CTD O_2 probe was developed by Idronaut (UNIGE sub-contractor). Finally, the VIP protocol developed previously for remote control was used by WP2 and WP3 partners as a base to define the implementation of standardized probe-node hardware and firmware protocol interfaces. The elements allowed the plug-and-play of the various MOBESENS sensor probes to the communication network using a common interface, even so the sensor probes are based on different techniques and thus electronics (see Deliverable 2.1 for details).

During the second period, the work focussed on i) laboratory characterisation and validation of the new designed sensors, cell and probes; and ii) development of the VIP voltammetric probe's hardware, firmware and software to fit the MOBESENS ICT interfacing requirements. Analytical characterisation were achieved by performing systematic laboratory measurements using the new devices, first in batch then integrated in the simplified cell to perform VIP on-line voltammetric measurements over a period of typically 1 day to 1 month (D2.2. and D2.5). The main findings of these studies are briefly summarized here. The results obtained from the batch tests of the home-made mini-reference and inter-comparison with commercially available standard (Metrohm) and mini- (Dri-ref-WPI) reference electrodes showed that only the newly designed mini-reference fitted the requirement for in situ long-term natural water monitoring, i.e.: highly stable standard potential (RSD ≤ 5%) for continuous application in fresh and sea waters up to 35 days without maintenance (maximum time tested); negligible influence of pressure and T on the standard potential. Analytical performances (lower detection limit (LOD), limit of quantification, precision) determined from on-line square wave anodic stripping voltammetric (SWASV) monitoring of trace metals in synthetic electrolytes and certified natural water reference materials (SLR-4 CRM freshwater; CASS-3 CRM marine water) using the improved VIP voltammetric probe (Figure 2) are summarized in Table 1 for a pre-concentration time of 20 min.

Table 1: Analytical figure of merits of the MOBESENS improved VIP voltammetric probe determined from continuous SWASV trace metal analysis over a period of up to 1 month without maintenance and using a pre-concentration time of 20 min.

Parameters		LOD		Quantification limit	Range	Precision (3 Me)	Accuracy (3 Me)
Name	**Units**	**at 20°C**	**at 4°C**				
Cd	nM (ng/L)	0.05 (6)	0.06 (7)	0.15 (17)	0.05 (6) - 40 (4500)	≤ 10%	≤ 13%
Pb	nM (ng/L)	0.03 (6)	0.04 (8)	0.10 (20)	0.03 (6) - 30 (6200)		
Cu	nM (ng/L)	0.80 (50)	1.20 (76)	2.50 (160)	0.80 (50) - 50 (3200)		

Lower detection limits can be reached by simply increasing the electrochemical pre-concentration time. Similarly, minimum and maximum concentrations (i.e. conc. range) that can be detected may be lower or higher by respectively increasing or decreasing the pre-concentration time used. Accuracy for continuous, simultaneous measurements, at time interval of 1h to 1h30, of the three metals in natural freshwater over a period of up to 1 month without maintenance were found to be ≤ 13%. The VIP power consumption was found to be two times lower when using the mini-CTD O_2 multiparameter probe instead of the the Idronaut standard multiparameter probe (Ocean Seven 316*Plus*). These overall results demonstrated that the developments performed to simplify the VIP set-up and improve its performance for long-term autonomous monitoring were successfully achieved.

The technical improvements of the VIP voltammetric probe preformed to fit the MOBESENS ICT interfacing requirements and to allow its deployment from the Ifremer USV (Figure 3) (included: development and integration of an interface daughter board to the VIP interface module and modification of the VIP voltammetric probe internal wiring and multiple submersible connector top cover to allow the operator to select among the previous standard RS232 or Telemetry interfaces and the MOBESENS RS485 interface chosen in MOBESENS for connection to the communication network via an external or integrated WiseNode; addition of dedicated commands to the VIP firmware (MOBESENS protocol interface routine) as well as commands in the VIP management software to enable the remote control of the VIP (start measurements; VIP data transfer) via the MOBESENS communication node network ; integration of a rechargeable battery pack inside the probe electronic housing (Figure 3a). These developments were successfully achieved and tested in laboratory by CSEM and UNIGE prior the start of the MOBESENS multi-partner field campaigns.

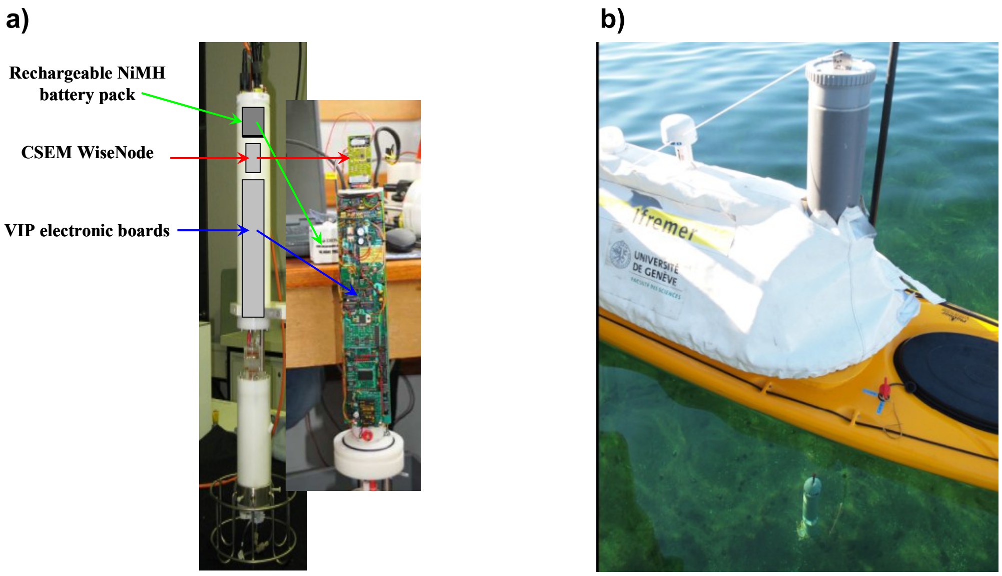


Figure 3: Pictures of a) the improved VIP voltammetric probe with integrated WiseNode and rechargeable battery pack and b) its deployment from the Ifremer drone in Thau Lagoon (D6.4).

The improved GIME-VIP voltammetric probe was successfully deployed, either from a boat or the Ifremer drone (Figure 3 b), and applied to perform surface and depth monitoring of the bioavailable fraction of Cd, Pb and Cu, simultaneously or sequentially to the monitoring of the master variables using the VIP MOBESENS mini-CTD O_2 or Idronaut OS316Plus multiparameters during the third period MOBESENS field trials in the Vidy Bay of Lake Leman (D6.4) and the Thau Lagoon (D6.5). The key findings of these studies are briefly summarized in section 3.7.

2.1.2 Polymer Bushes Membranes for the detection of selected molecules

Polymer brushes are ultrathin surface grafted polymer layers in which all polymer chains are tethered with one of their chain ends to a substrate. At sufficiently high grafting densities steric repulsions force the chains to stretch out resulting in a densely packed arrangement of surface grafted polymer chains. The use of controlled/“living” surface-initiated radical polymerization techniques allows to precisely control the thickness, composition and architecture of polymer brushes, which makes them very attractive coatings to control the surface properties of a broad range of materials.

Polymer brushes have found numerous applications including non-biofouling surfaces and cell adhesive surfaces, protein binding and immobilization, chromatography supports, membrane functionalization, responsive surface, antibacterial coatings or low friction surfaces. Despite their interesting properties and the numerous reports describing the potential of polymer brush as responsive surface, their use for “real” sensing applications has receive little or no attention so far. [1]

Our work within the MOBESENS project has focused on determining how polymer brushes can be employed as selective surface modification for sensing application. We aimed at synthesizing polymer thin films able to detect analytes of interest, with a particular focus on low detection limits and high selectivity. Two actuation mechanisms can be distinguished either the polymer layer swell or collapse upon ion recognition or the polymer layer is used as a scaffold that is functionalized with receptors.

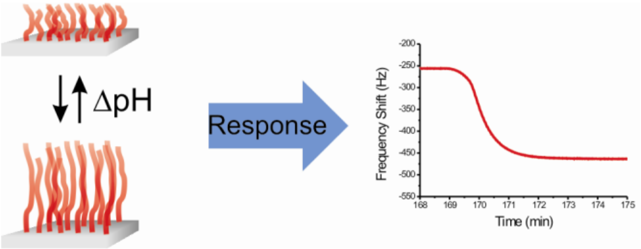


Figure 4: Schematic representation of the swelling mediated pH sensitive response of a PMAA brush coated QCM.

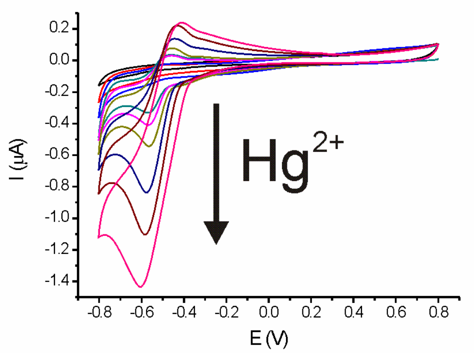


Figure 5: Typical example of cyclic voltammograms recorded with a functional polymer brush coated electrode at various mercury (II) ions concentration.

As a proof of concept our first efforts have focused on understanding the influence of brush thickness and density on the pH-responsiveness of poly(methacrylic acid) (PMAA) brushes and on developing strategies that allow engineering the pH responsiveness and dynamic response range of PMAA based brushes (Figure 4). It was observed that due to their high grafting density, the apparent pKa of surface-tethered PMAA differs from that of the corresponding free polymer in solution and also covers a broader pH range. The pKa of the PMAA brushes was found to depend both on brush thickness and density; thicker brushes showed a higher pKa value and brushes of higher density started to swell at higher pH. In a second step, we demonstrated that post-polymerization modification can be efficiently used to engineer the pH responsiveness of the PMAA brushes. By using appropriate amine functionalized acids, it was possible to tune both the pH of maximum response as well as the dynamic response range of the coatings. [4]

Next, benzo-15-crown-5 functionalized polymer brushes were used as the active layer in a potassium-selective quartz crystal microbalance sensor. These layers could be successfully used as the active coating since they present a high sensitivity and selectivity toward potassium ions. It was demonstrated that the crown-ether functionalized polymer brushes were able to detect potassium ions even in the presence of aqueous solutions that contain a high excess of a lower affinity ions. Interestingly the selectivity of the sensor was not influenced by the overall brush thickness. The sensitivity (*i.e.* magnitude of the system response), however, could be optimized by adjusting the thickness of the polymer layer. [5]

Polymer brushes are not only able to probe charge ions/molecules but we also demonstrated that they can be employed, combined with gravimetric sensors, to probe uncharged organic molecules such as polycyclic aromatic hydrocarbon (PAH). Within the frame of the MOBSENS project we synthesized and demonstrated that functional polymer films are able to probe pyrene in aqueous based solution. The limit of detection observed in this study ($5x10^{-8}$ M / 0.01ppm) was within the typical range of PAH concentration found in polluted environments. Furthermore the response was found to be reversible, and the system presented a certain selectivity.

Last, we demonstrated the possibility to use peptide functionalized polymer brushes, to probe heavy metal ions via GIME voltammetric based methods and thus extend the heavy metal monitoring capability of the VIP system (section 3.2.1) in a near future. The polymer brush enhanced the mercury (II) ion sensitivity as compared to the bar electrode and in the concentration range investigated a linear relation was observed between the system response and the heavy metal ions concentration. Furthermore this system allowed the detection of mercury down to the nanomolar concentration range. It was demonstrated that the heavy metal recognition is a reversibile and reproducible process. This work demonstrated that polymer brushes can be employed not only for QCM based sensor but can also be associated with voltammetric based detection [6]. *Note that this active polymer coating was not a requirement of the description of work, but the need of such layer for water quality monitoring emerged from discussion occurring between MOBESENS partners (UNIGE – EPFL).*

To conclude the work performed within the MOBESENS project has clearly highlighted some of the unique features offered by polymer brushes for the fabrication of sensitive and selective layers that can be used for the selective surface modification of various sensing devices in order to probe several kinds of analytes.

2.1.3 ISFET probe

The specific objective for the work on the ISFET probe in the scope of MOBESENS was to obtain a ChemFET with an integrated and optimized sensing membrane according to definitions and specifications of WP1. This included the ISFET characterization with respect to pH and temperature, the addition of ion selective polymer membranes (K^+) as well as the encapsulation of the probe and the development of a communication interface.

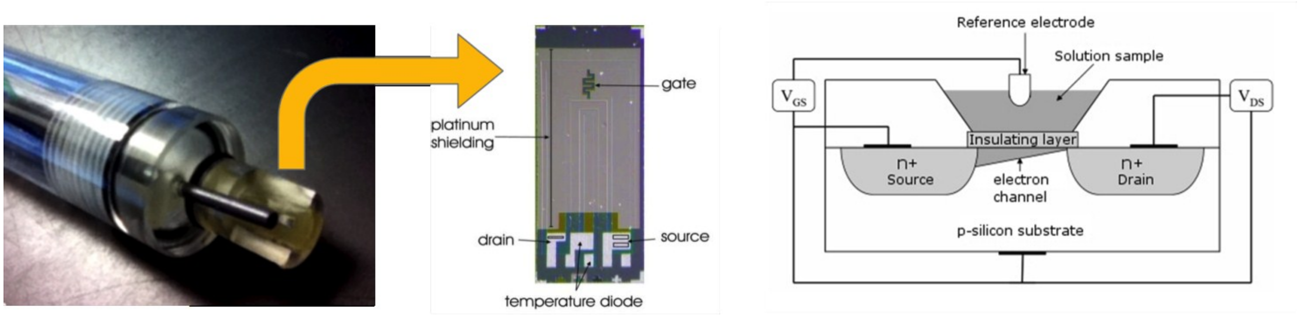


Figure 6: The ISFET sensor: Left) the encapsulated ISFET sensor head with miniature reference electrode as developed for MOBSENS, Centre) microphotograph of the ISFET sensor element, Right) Schematics of the ISFET sensing principle.

The ISFET probes were characterized in laboratory before using them in the MOBESENS field campaigns. The pH response of the Ta_2O_5 ISFET sensor shows a high sensitivity towards pH (-57mV/pH) as shown in Figure 7 (left side). Long-term tests in the laboratory demonstrate a lifetime of the encapsulated sensor of more than 4-6 weeks (see Figure 7, right side), which is in line with the MOBESENS requirements. The long-term tests also showed a linear drift of the ISFET probes' output voltage. Since the drift is linear it is possible to correct this drift via the microcontroller interface used for the signal treatment and communication with the wireless node.

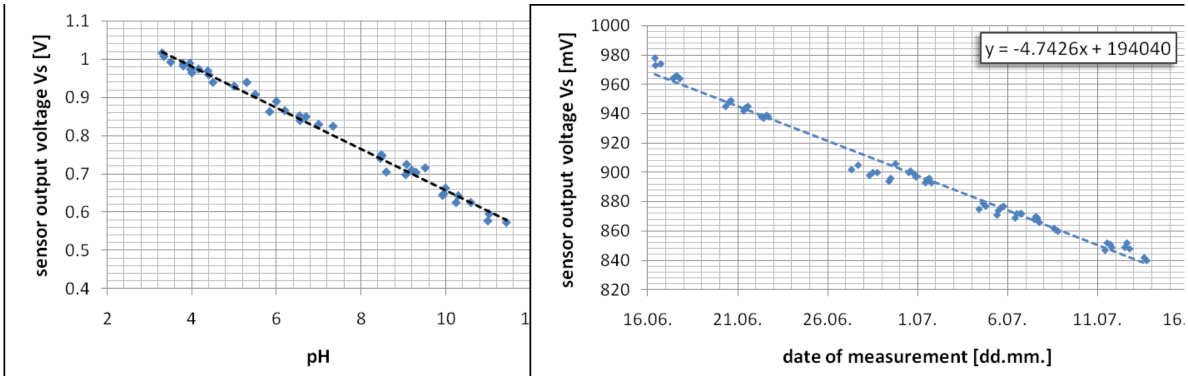


Figure 7: Left) pH response of the Ta2O5 ISFET sensor probe measuring against a mini DriRef reference electrode (WPI). Right) ISFET sensor output voltage measured over time at pH9 for a constantly submerged sensor element against a mini DriRef reference electrode.

The temperature measurement via an on-chip temperature diode, also shows a linear characteristic with a slope of -11mV/degC. This allows a temperature resolution of 0.5 degC, which is in agreement with the MOBESENS requirements.

In the scope of MOBESENS, ion-specific polymer membranes for the deposition onto the ISFET sensor surface have been developed by EPFL. With the deposition being a very challenging step, only different types of K^+ selective membranes have been tested with the ISFET sensor in laboratory. It was noted, that the two membrane types performed differently, with one being more sensitive but less selective. The laboratory experiments showed the potential of the polymer membrane approach (see Figure 8), but also indicated that more research in this area will be necessary before using the polymer membrane ISFETs in the field.

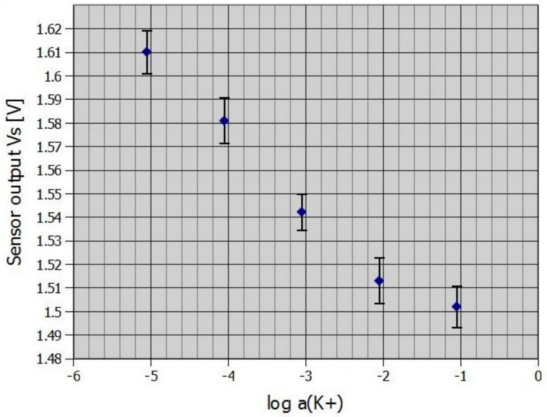


Figure 8: Response of an ISFET with K^+ selective polymer membrane to varying concentrations of KCl.

2.1.3.1 ISFET probes for MOBESENS campaigns

In preparation for the MOBESENS campaigns performed as part of WP6, the ISFET probes were assembled into different types of configurations in order to be deployed via the three MOBESENS supports: USV, buoy and drifter.

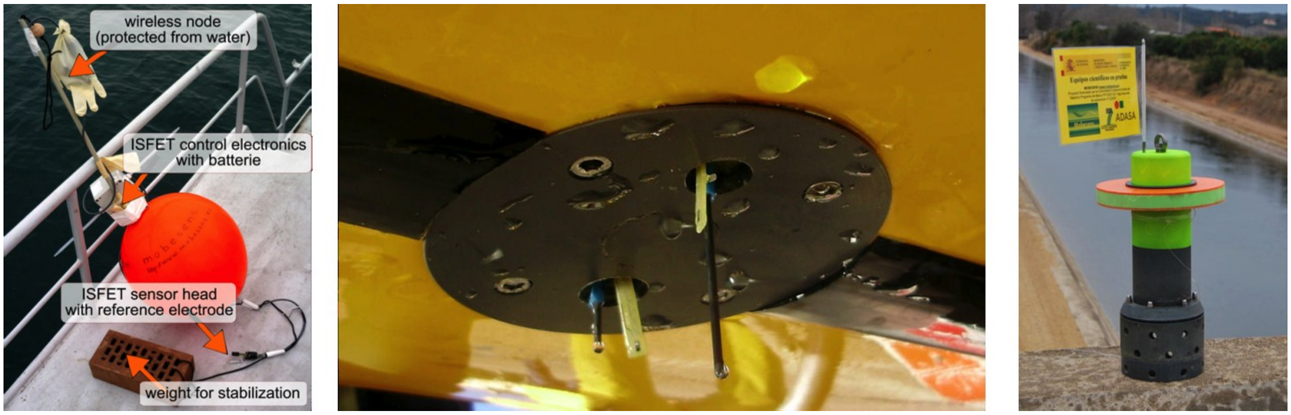


Figure 9: Photographs of the ISFET probe installed on all three MOBESENS mobile supports: buoy, USV and drifter (from left to right).

In addition to the ISFET sensor head, the probes also include the ISFET control electronics as well as the signal treatment and communication interface, developed specifically for MOBESENS in order to translate the measured voltages into pH and temperature, correct the temperature related variation as well as the time related drift of the pH sensor output voltage. The measured pH and temperature as well as the measured voltages are sent subsequently to the MOBESENS grid via the WiseNode connected to the ISFET probe communication interface.

2.1.4 BAW sensor

The specific objective for the work on the BAW sensor was the development of a micro-acoustic resonator using piezoelectric layers and selective polymer brushes membranes and the incorporation of the concept into a sensor probe according to the MOBESENS requirements.

The main activity was spent on realizing a demonstrator for the shear mode acoustic microsensor operating in a pure shear mode, and having alternate sections of piezoelectric regions with complete inversion of the polar axis, i.e. a interdigitated electrode device with a periodic Al and N terminated film of AlN (see Figure 10). Growth studies were carried out to grow N-polar sputtered AlN thin films on SiO_2, and Al polar sputtered films on Al polar MOPVE thin films. The idea was thus to obtain epitaxy on Al polar AlN, while the sputter process would itself direct to N-polarity when no epitaxial effect takes place. The result was verified with polarity-selective etching in KOH (Figure 10) as well as with piezo-sensitive atomic force microscopy. The work was published in the J.Vac.Sci&Technology (Vol. B28, p.-L61).

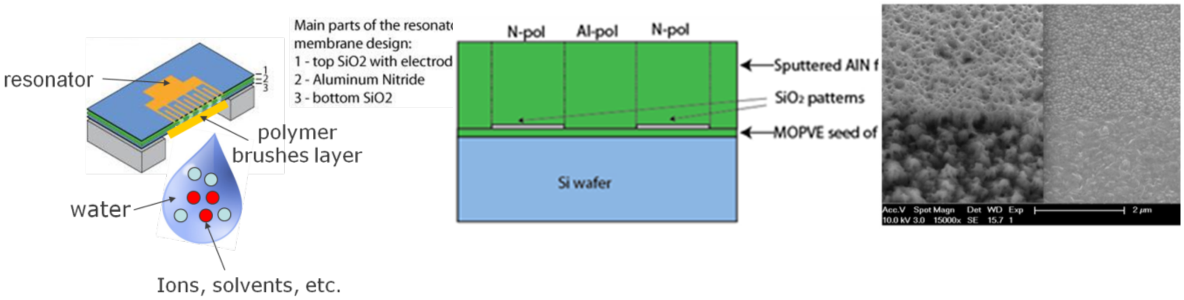


Figure 10: Left) Schematics of the BAW sensing device; Centre) Schematic view of the fabricated structure. Right) SEM images showing the surface of sputtered AlN films deposited on AlN with patterns of SiO_2 substrate after 45 seconds of etching in 5 mol aqueous solution of KOH (surface before and after etching is shown). Two different polarities are recognized by different effect of etchant.

In the following we worked on realizing a demonstrator. Unfortunately, progress was slowed down due to a number of inconvenient circumstances. The deposition tool for MOPVE of AlN allowed only to coat 2 inch wafers, whereas the sputter tool for AlN is working with 100 mm wafers only. So we had to attach the small wafer onto a standard 4 inch wafer with higher risks of damage during transport and a less precise temperature control. In addition, we had to improvise with electrode patterning on AlN. Since the latter should never be exposed to developer of positive resists, we did the patterning by evaporation through a mask (micromachined stencil). We finally obtained a device that looked fine (Figure 11), but we subsequently realized that one of the process steps had failed, and in consequence no resonance was observed (bad sputtered AlN, or bad electrical contact between electrodes and AlN).

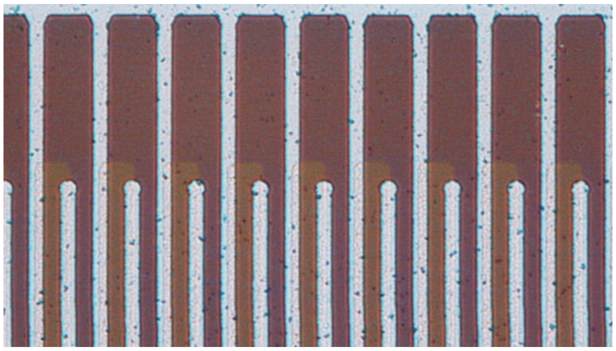


Figure 11: Top view of device. The periodicity amounts to 2x12 µm. The electrode fingers are 5 µm wide, the gap amounts to 7 µm. The different polar regions give different color contrasts.

As a result, the acoustic micro sensor was not enough advanced for tests. Additionally, the housing for immersed operation, as well a microfluidic packaging suitable for RF readout were also not advanced enough to be used (For innovation reasons, more effort was spent on the piezoelectric MEMS device). However, the development of the read-out electronics was completed and was tested using an SAW device in air.

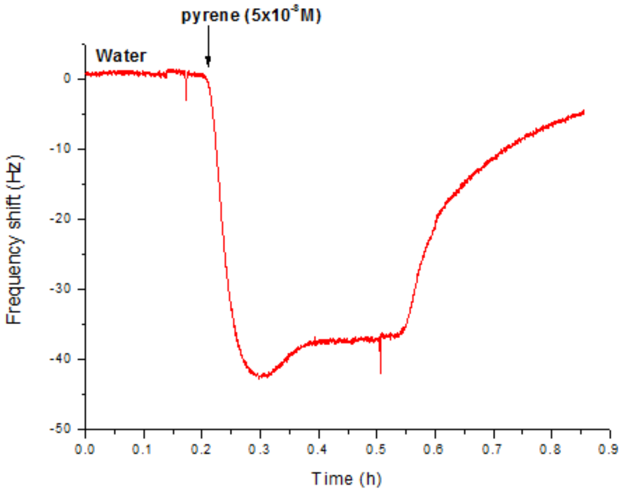


Figure 12: Frequency shift observed by a quartz microbalance coated with specific brush layers to detect PAH's upon exposure to very diluted pyrene

The functionalization of the BAW sensor was to be done via the polymer brushes membranes also developed at EPFL. In that respect, gravimetric sensors would specifically be useful for the detection of organic pollutants that are neither charged nor polar, such as polycyclic aromatic hydrocarbons (PAH). Therefore polymer brushes layers were developed to specifically detect such PAH molecules. The functioning of such layers was tested by means of a quartz microbalance. A strong signal is observed upon exposure to a $5x10^{-8}$ molar pyrene solution, showing that the ppb level could be reached (Figure 12).

2.2 USV

The USV (Figure 13) was built in order to be handled by one operator and its shape was optimised in order to reduce the needs for propulsion energy. The prototype is engine-driven, and powered by batteries. It is self-righting and complies with the regulations in force in the studied areas.

This system transmits constantly route information and recorded data in near-real time via a bi-directional radio-relay link. The USV system operates in coastal areas, estuaries and/or lagoons up to 1 nautical mile from the shore in autopilot mode.

Figure 13: Pictures of the USV developed by Ifremer.

A solution based on an evolved master system positioned on land station communicating with a mobile slave platform was chosen so as to minimise energy consumption.

For this project, a new communication architecture based on existing radio technologies such as WIFI, WIMAX, 3G, was used. This architecture allows efficient real time data exchange (instrumentation, sensors…) and management of mobile or stationary wireless equipment.

The choice of WiFi radio technology in this architecture is justified, on the one hand, by its reliability and stability, and, on the other hand, by its many industrial applications available today, demonstrating the maturity of this technology. A maximum amount of information is able to be sent at high speed via the WiFi link, over a distance of several kilometres. This information may be: environmental data, housekeeping data, route data, audio and video recordings, proprietary data flow.

As there is no onboard software on the USV, software can easily be modified on land on PCs without altering the USV's architecture, even if the USV is in operation. The proposed solution draws upon serial standards links common to all boats, which also means that commercial or open source software can be used for the navigation system. Permanent, complete control of the USV as long as the communication link is up. Additional sensors can easily be added onboard: depth-finders, magnetic compass, anemometer, wind vane… as well as Ethernet sensors for onboard cameras. Software development restricted to specific Mobesens module(s) on PCs as the solution relies on existing proprietary or open source navigation systems.

2.3 Communication and localization

Having an efficient way of collecting the data measured using the different sensors developed and improved during the MOBESENS project was a key element to the success of the project in terms of integration but also to ensure that the large quantity of data collected could be treated in an efficient manner. The wireless communication sensor network (WSN) technology proposed prior to the start of the project proved efficient and totally in line with the low energy / low cost / high efficiency challenge of the project. As a matter of fact, the proposition of using the capabilities of an “off the shelf” radio to extract relative localization proved to be a better than expected solution in some cases in line with the MOBESENS requirements.

The measurements used to validate the models were collected during the 3 field tests that took place on the Lake Leman, the Thau Lagoon and the Ebro River, as well as from 2 smaller deployments made on the lake Leman. In all cases, the main goal was to collect as many data as possible using the lightest setup possible.

The hardware was composed of:

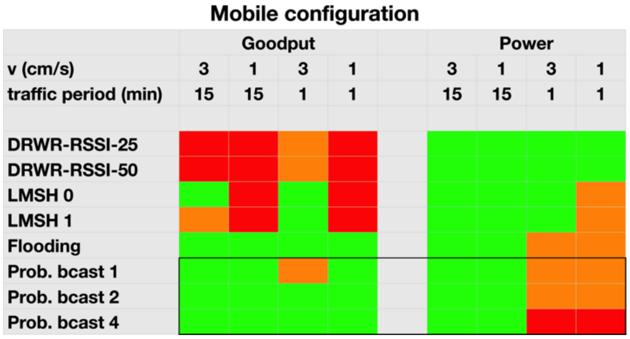
- 10 buoys equipped with wireless sensor network nodes
- 1 computer centralizing the information
- 1 GPRS gateway to send the data to the Grid via Internet

Figure 14: Buoys deployed in the Lake Leman

The analysis of the results of all tests and deployments done previously led to a number of improvements in technical areas as well as in the deployment process. The last deployment made in May 2011 took benefit of most of these improvements. Therefore, it is used to validate all previous work.

2.3.1 Transporting the data

Very early in the project, the WSN was capable of reliably transport the data collected. Different routing techniques were used and tested during the project. Form a static table, algorithms were produced, simulated and implemented to evaluate the influence of mobility of the different characteristics of the network.



Mobile configuration

	Goodput					Power			
v (cm/s)	3	1	3	1		3	1	3	1
traffic period (min)	15	15	1	1		15	15	1	1
DRWR-RSSI-25	🟥	🟥	🟧	🟥		🟩	🟩	🟩	🟩
DRWR-RSSI-50	🟥	🟥	🟧	🟥		🟩	🟩	🟩	🟩
LMSH 0	🟩	🟥	🟩	🟥		🟩	🟩	🟩	🟧
LMSH 1	🟧	🟥	🟩	🟥		🟩	🟩	🟩	🟧
Flooding	🟩	🟩	🟩	🟩		🟩	🟩	🟧	🟧
Prob. bcast 1	🟩	🟩	🟧	🟩		🟩	🟩	🟧	🟧
Prob. bcast 2	🟩	🟩	🟩	🟩		🟩	🟩	🟧	🟧
Prob. bcast 4	🟩	🟩	🟩	🟩		🟩	🟩	🟥	🟥

Figure 15: The influence of routing algorithm on Power and GoodPut

2.3.2 Localisation of the nodes

The usage of RSSI to conduct localization is a quite ambitious goal. The measured dispersion of the relationship between RSSI and distance Figure 16 makes these techniques unsuitable for most localization needs.

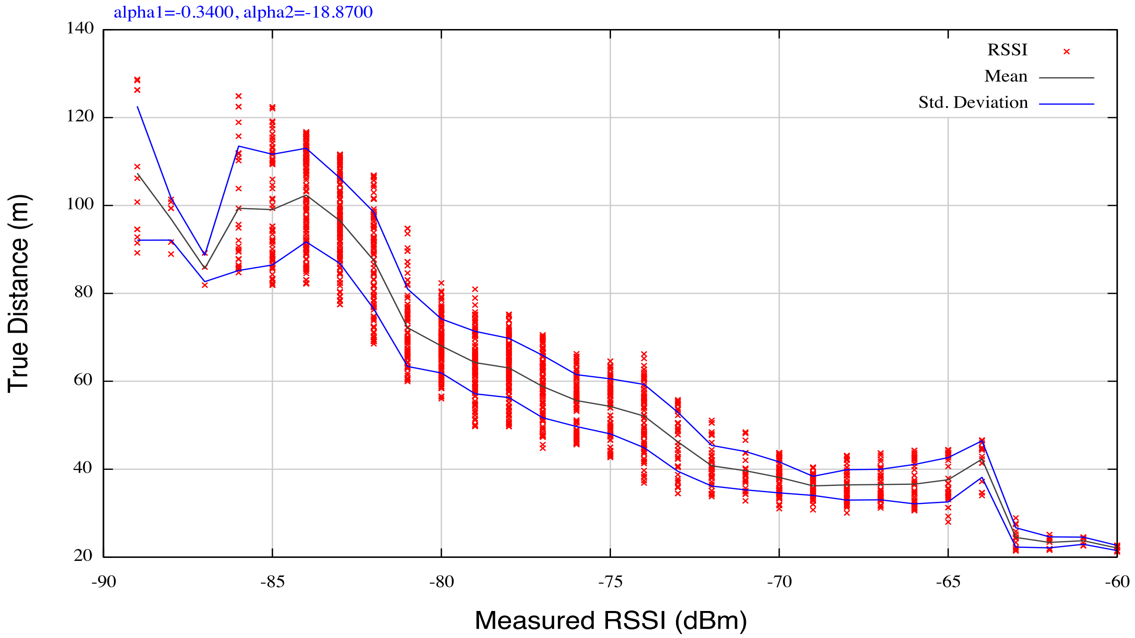


Figure 16: RSSI Dispersion

In MOBESENS, on the other hand, it proved efficient in many occasion, especially when the node to be localized was positioned inside of the mesh of nodes Figure 17. In absolute, this could be seen as a major limitation but tests conducted without forcing one node to be mobile and the others to be mobile and focusing on positioning nodes all from the others showed very promising results. It is possible to obtain, with the obvious symmetries the correct location of all nodes in relation with its neighbours Figure 19 and Figure 20.

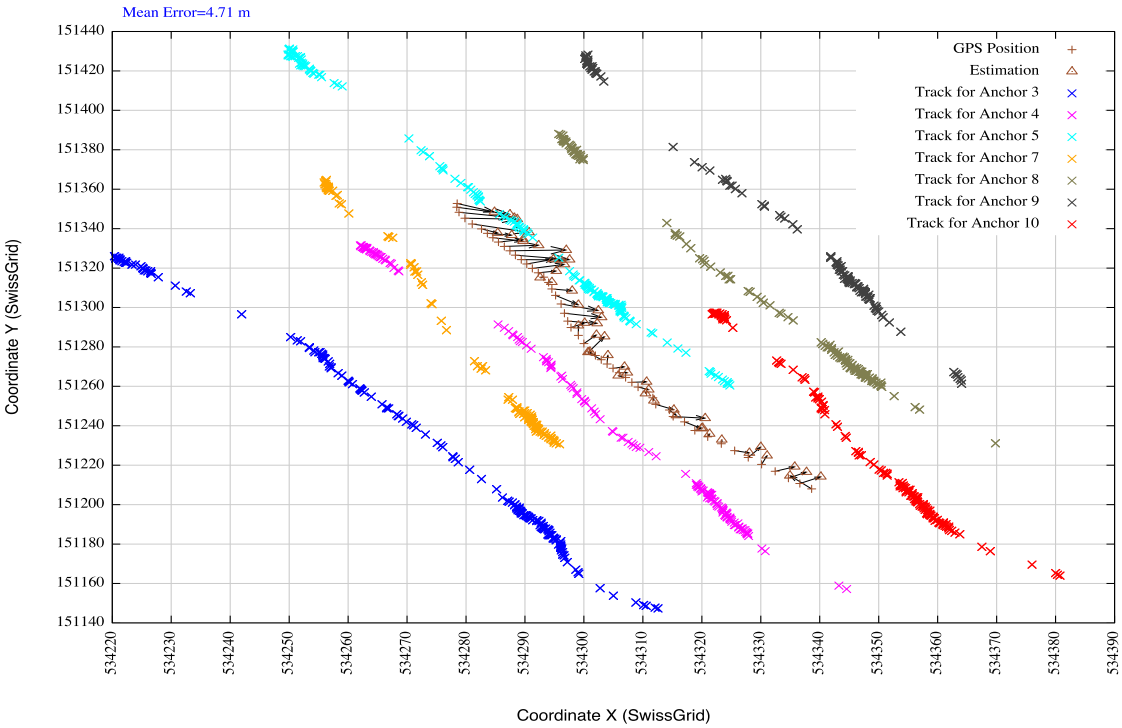


Figure 17: Position estimation for node 6 as compared with the GPS position (all other nodes are considered as anchors with known position).

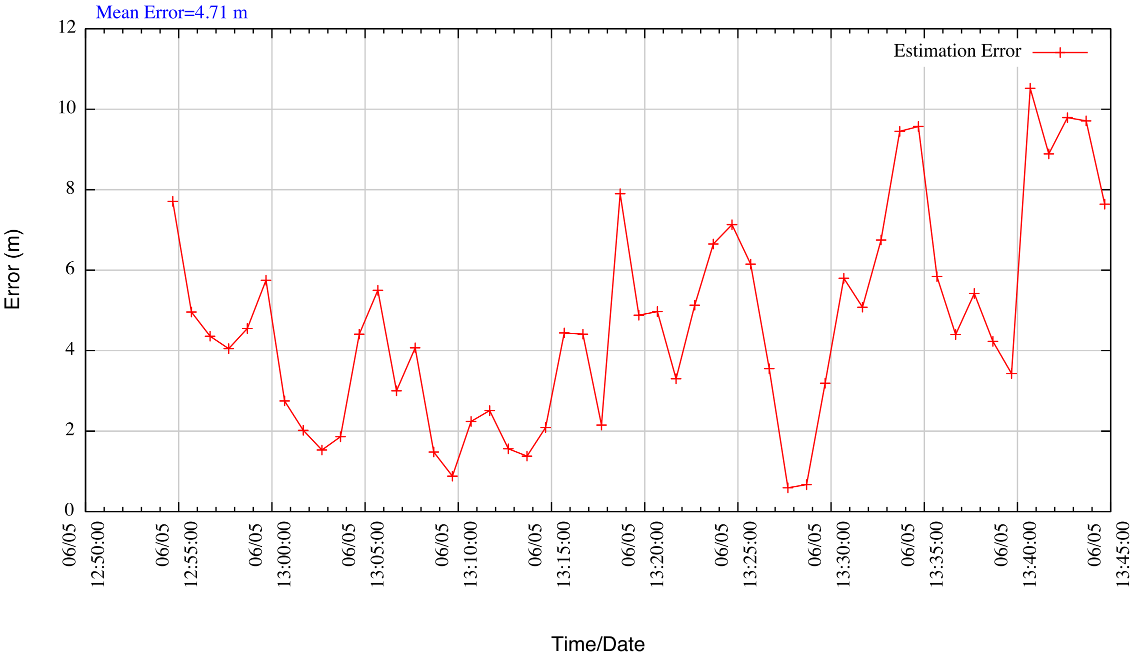


Figure 18: Position error between GPS and Sequential Bayesian Localization for node 6

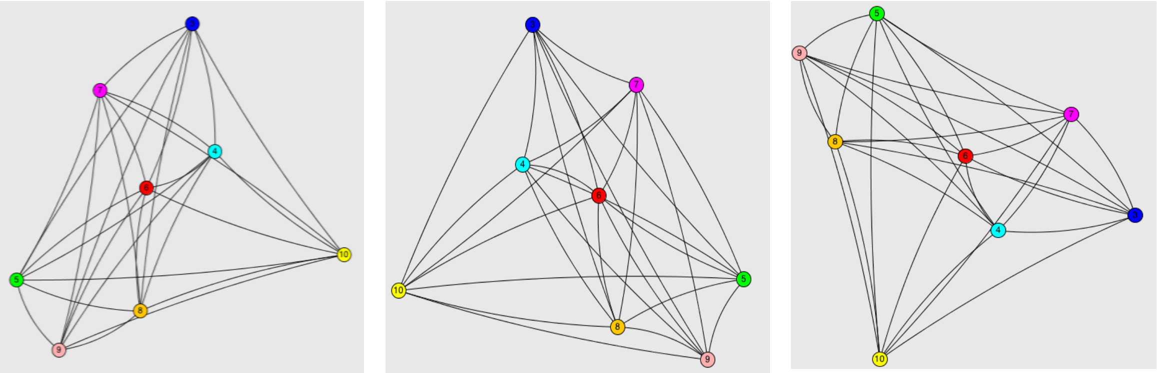


Figure 19: 3 different runs of the force-directed algorithm for set #30.

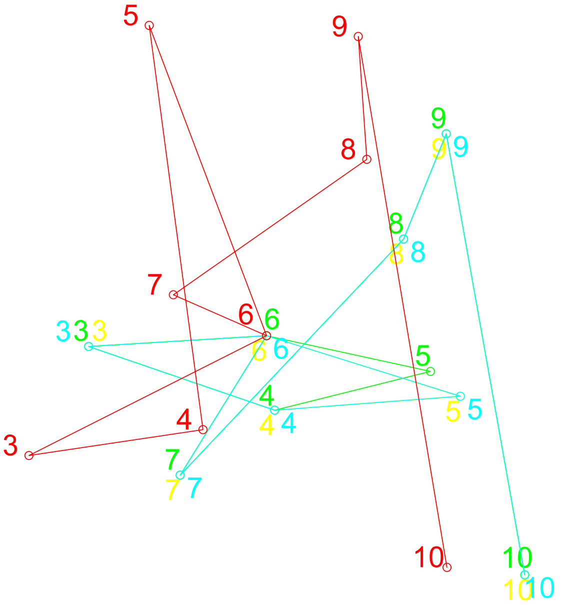


Figure 20: Superposition of the 3 solutions with the real positions for set #50

2.4 Data storage, analysis and visualisation

The objectives of the GRID or back end system developed in WP4 are to:

- store, annotate and manage the MOBESENS water quality measurements and
- to make data available on demand through an open interface and visualisation system for analysis, monitoring and decision.

The entire GRID or back end system was custom designed and implemented specifically for MOBESENS. The actual cluster or infrastructure is located in the city of Evry in France on the Télécom SudParis Campus (ex GET-INT) Évry, close to Paris in France. The computer cluster is accessible through a web interface and via the Internet at the following URL : http://www.mobesens-vs.eu.

The storage and indexation space associated to this back end system are running on a cluster composed of 32 nodes each including an 8-core Intel Xeon E5540 machine with 24 GB RAM.

2.4.1 GRID Implementation

The MOBESENS grid architecture has been implemented to handle data collected by the MOBESENS measurement devices, received through the MOBESENS measurement system and wireless ad hoc network. Even if preliminary developments started early in year 1, enhanced gradually in year 2, the grid has been consolidated during the third year to interact more with end users. Feedback from the en users enabled fine-tuning of the visualisation system and the representation of data according to their needs. The MOBESENS Grid or back end system is composed of four main implemented elements:

1. a storage space to save any collected measurements and associated information (meta data) in the grid. The storage is based on the Tahoe [2] system acting as a secure peer-to-peer distributed storage solution, known for its efficiency and simplified management. A MOBESENS specific interface was designed to interact with Tahoe based storage systems. This enables tailoring the storage space to the MOBESENS concepts and the overall grid architecture.
2. an indexation system_that compiles and processes metadata provided by the sensor nodes, end-users and applications to enable efficient searching and finding. The tool used to perform the indexation is eXist-db [3], which has been developed for the indexation of XML documents.
3. an eventing system that waits for specified events and outcomes to perform related and associated actions. This module is one of the key elements of the MOBESENS grid as it provides in real time end-users with measurements and related data as they are collected and reported by the MOBESENS measurement and wireless sensor networking. The implemented and integrated eventing system in the overall MOBESENS architecture relies on a JMS Server (Java Message Server) and the ICES faces framework. Both have been modified and adapted to suit the MOBESENS needs and requirements.
4. a RESTful compliant API that allows sensors to push their collected data into the grid and enables web-based clients to visualize these data using the same API.

The measurement data processing by the GRID can be summarised by describing the interactions between the wireless sensor network gateways and the grid and the transformation of data during the transfer from the MOBESENS measurement system to the GRID..

2.4.2 Data processing by the MOBESENS grid

The gateways relay the raw data received from the wireless sensor network to the grid using the IEEE 802.15.4 communication protocol. The data is processed upon reception by the grid as illustrated in the sequence diagram depicted in Figure 21 and as follows:

1. received raw data are stored unaltered in the storage space.
2. raw data are translated to the XML format selected to ensure compatibility with de facto description and service architecture standards from web-services and W3C.
3. the XML version of the data is stored in the storage space.
4. The XML version of the data is indexed and integrated by the indexation system.
5. The XML version of data is encapsulated in a message and sent to the ActiveMQ eventing server.
6. The gateway is fed back with a unique ID that references each data component.

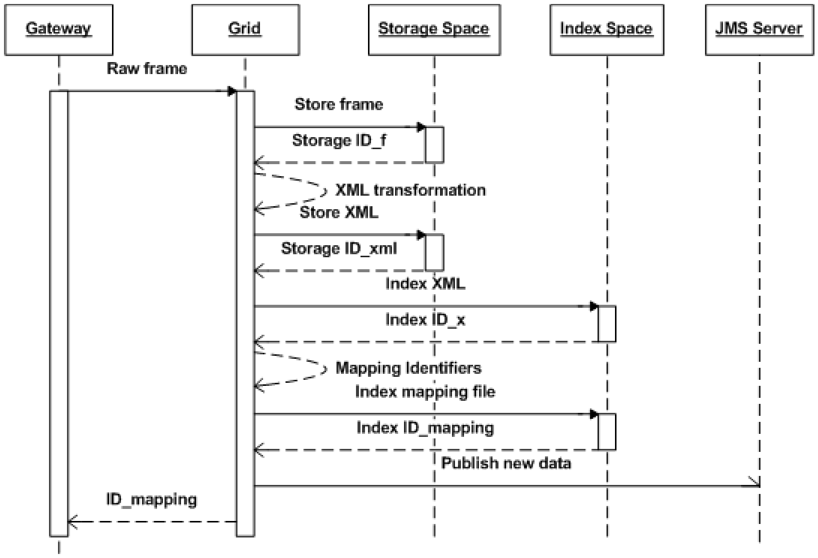


Figure 21: Gird data processing of raw measurements collected via the MOBESENS WSN

In order to guarantee the interoperability between the gateways, the grid and third-party applications, a HTTP REST interface has been developed to allow the gateway to send data frames to the grid and third-party applications to interact with stored and indexed data in the grid. This interface is generic enough to adapt to new sensors and nodes that may join the network. For example, a node identified by NodeID can send a frame to the grid by encapsulating it into a PUT request as indicated below

- http://fServerAddressg/fSensorTypeg/NodeID.

SensorType corresponds to a unique identifier associated to each sensor type. A unique identifier (UID) is returned as a response to the node. This UID can be used to retrieve the same data from the grid using a GET request:

- http://fServerAddressg/UID

One can note that a unique ServerAddress can be used for both PUT and GET operations.

Data stored in the storage space are persistent. This means that unless they are intentionally removed, data remains in the grid regardless of the state of the application (alive, active or not) that stored them in the grid. As a result, in order to navigate through data stored and indexed in the grid without necessarily knowing their identification, a dedicated interface has been made available. This interface receives queries from users or applications using the Xquery language. The interface returns the list of UIDs that match the query in criteria and attributes. An XQuery request can be sent to the grid using the following http request:

- http://fServerAddressg/search?query=fQueryg

Additional processing has also been implemented to translate the GPS coordinates, as reported by the localisation and wireless ad hoc routing system, into XML format for unified handling by the grid and to facilitate interoperability with de facto data representation standards. In fact, the pre-processing includes an algorithm to fuse KML data coming from the GPS logger with data coming from the measurement devices themselves. The algorithm flow diagram for the fusion of the GPS logger data and the ISFET reported measurements is provided in Figure 22.

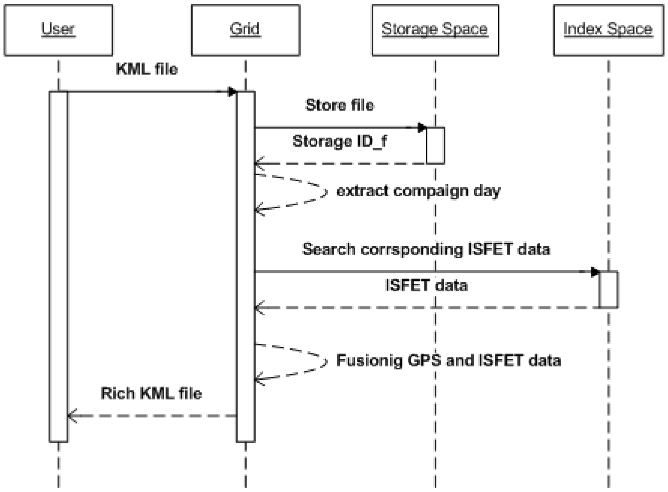


Figure 22: Fusion algorithm of the GPS logger data and the ISFET measurements

2.4.3 Grid performance

Various experiments have been performed in order to check the performance of the implemented GRID or back end. The ability for the GRID to provide and visualize data in a real-time manner was specifically assessed.

In the first test, the system was stressed or tested at high load to study how it would behave and scale with a larger number of involved sensors in measurement campaigns. To conduct this assessment or performance evaluation, the Gateway is emulated using a laptop which regularly sends GPS position frames of different nodes to the system. In the same laptop, a browser is used for visualization to display times at which data was sent following measurements and received.

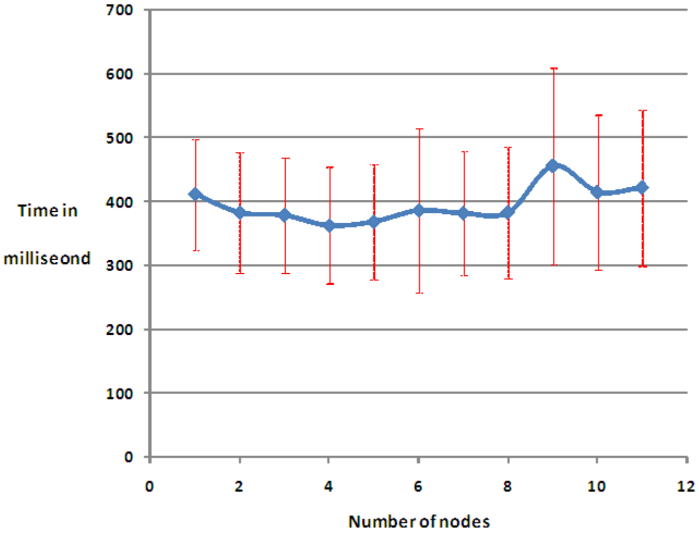


Figure 23: End-to-end update latency

For each experiment, each node sends one hundred messages, e.g. for the experiment with eight nodes, 800 messages have been sent to the system. The mean and the standard deviation of the end-to-end delay between sending and receiving frames are computed. Results are presented in Figure 23 that depicts a low end-to-end delay. The delay remains below 500m despite the variations in performance due to a test in a production setting, the resources are not dedicated to the MOBESENS data processing, management and processing alone but also used for other jobs in parallel. In essence the evaluation is conducted over a production cluster or grid. With only 500 ms delay overall, the back end system can be considered as behaving in quasi real-time with respect to water monitoring and water physico-chemical parameters (both change slowly in the natural environment over much longer time scales) and as stable.

In the second test, it is the message size that varies to assess the impact of data type on the system. The gateway sends one hundred message of each size to the system. Figure 24 shows the mean and the standard deviation of the delay between sending the message and receiving the identifier, e.g. ID_mapping in Figure 22, for each message size in a logarithmic scale. The maximum payload length in the WSN is 128 bytes. Inserting or *PUTting* a node message in the system takes less than 100ms. this delay and penalty is quite reasonable compared to the communication delay between the gateway and nodes in the WSN.

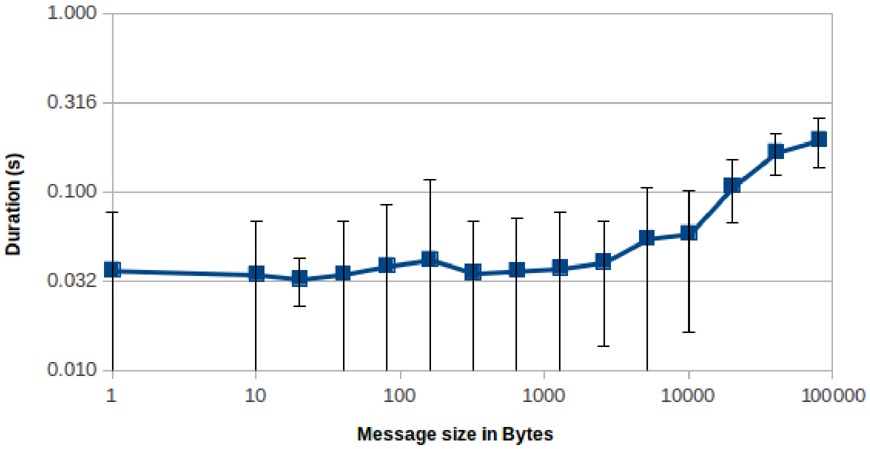


Figure 24: The GRID response delay depending on the size of the message.

In the third test, the gateway launches simultaneous or parallel threads to send a 40 byte message to the GRID. Threads emulate nodes that send a message at the same instant to the GRID. This experiment is performed one hundred times for each number of threads.

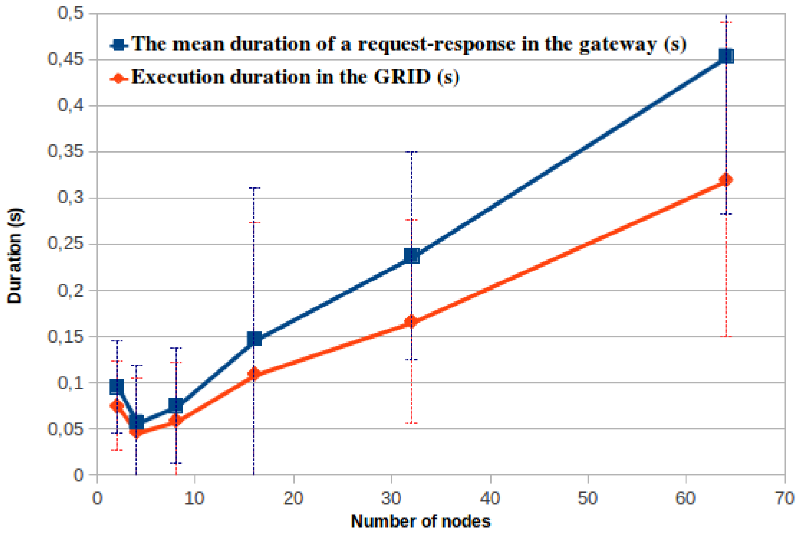
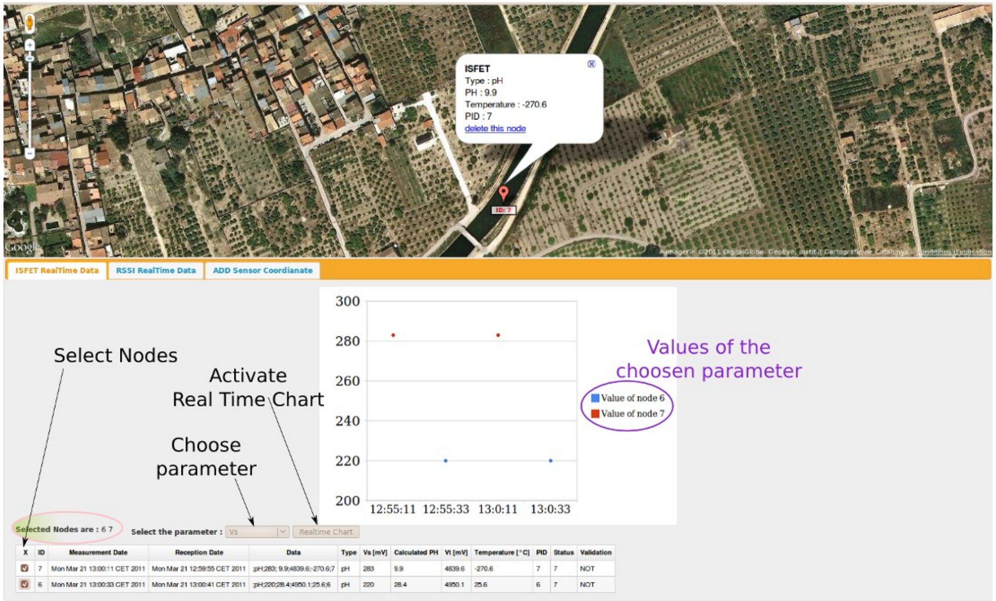


Figure 25: The GRID response delay depending on the number of nodes.

Figure 25 displays two curves: the blue curve shows the mean delay between sending the message and receiving the identifier in return in each thread. The red curve depicts the mean and the standard deviation of the execution in the system, e.g. system internal function calls represented in Figure 22. The results show that for example if 64 nodes start communication with the system at the same instant, each communication will end after on the average within 45ms while the execution of storing, indexing and transforming functions in the system takes 32ms. Hence, it is expected that in 45ms all communications will have been taken of and will have ended. The GRID implementation leads to very good system performance.

2.4.4 Grid in MOBESENS campaigns

Apart from getting a specific piece of data using its UID or searching for a set of data matching a set of criteria, the grid architecture we developed in the scope of the MOBESENS project displays the most up-to-date data in a real-time as described in D4.4.2. Concrete examples of data corresponding to data collected during various MOBESENS measurement campaigns and field tests are presented to illustrate the grid visualisation services designed by MOBESENS to support scientists and end users in their analysis, validation and exploitation of the measurements. Figure 26 shows a sample output of received and displayed measurement data from the ISFET as well as GPS, RSSI and VIP data received via the ad hoc wireless sensor network and localisation system. This end user view of the data through the visualisation system graphical interface enables users to display graphs of ISFET and VIP data in real time on a graph and provides also means for validation of the data by experts.



ISFET
Type : pH
PH : 9.9
Temperature : -270.6
PID : 7
delete this node

Selected Nodes are : 6 7

X	ID	Measurement Date	Reception Date	Data	Type	Vs [mV]	Calculated PH	Vt [mV]	Temperature [°C]	PID	Status	Validation
☑	7	Mon Mar 21 13:00:11 CET 2011	Mon Mar 21 12:59:55 CET 2011	;pH;283; 9.9;4839.6;-270.6;7	pH	283	9.9	4839.6	-270.6	7	7	NOT
☑	6	Mon Mar 21 13:00:33 CET 2011	Mon Mar 21 13:00:41 CET 2011	;pH;220;28.4;4950.1;25.6;6	pH	220	28.4	4950.1	25.6	6	7	NOT

Figure 26: Visualisation of ISFET, GPS, RSS and VIP data and measurements

This view can be used to validate ISFET data received in real time following the steps depicted in Figure 27 by relying on the display provided by the visualisation system.

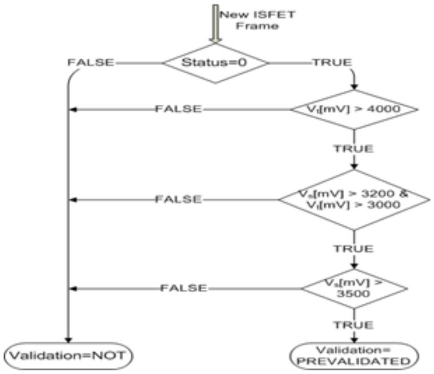
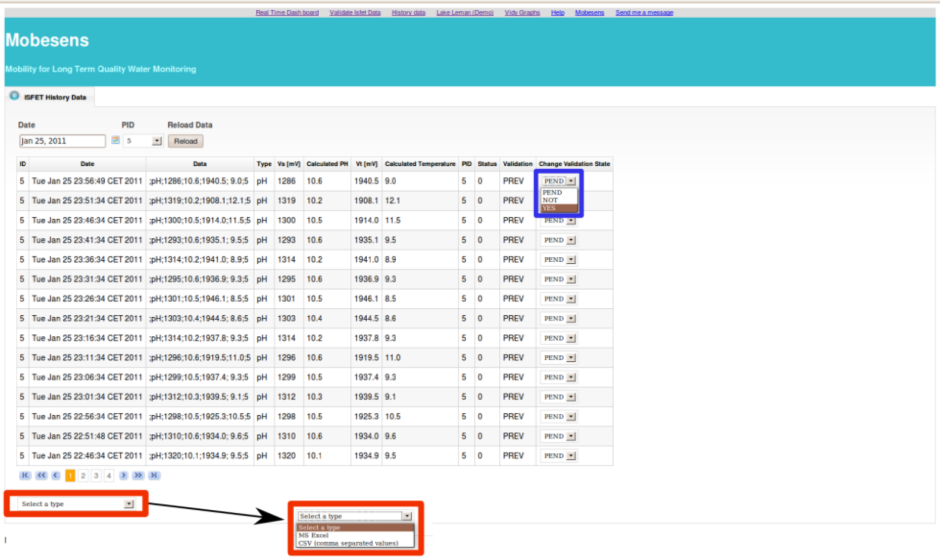


Figure 27: Pre-validation process enabled by the visualisation system

Histories on collected and stored measurements can also be provided and displayed via the interface. Time series on ISFET data and GPS coordinates and maps can be reconstructed and visualised as shown in Figure 28.



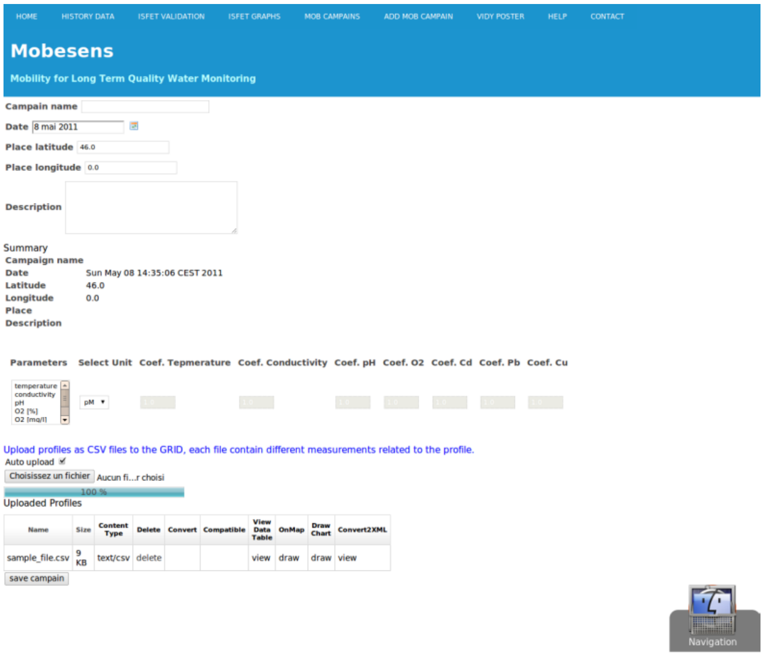
Date: Jan 25, 2011
PID: 5
Reload Data

ID	Date	Data	Type	Vs [mV]	Calculated PH	Vt [mV]	Calculated Temperature	PID	Status	Validation	Change Validation State
5	Tue Jan 25 23:56:49 CET 2011	;pH;1286;10.6;1940.5; 9.0;5	pH	1286	10.6	1940.5	9.0	5	0	PREV	PEND
5	Tue Jan 25 23:51:34 CET 2011	;pH;1319;10.2;1908.1;12.1;5	pH	1319	10.2	1908.1	12.1	5	0	PREV	
5	Tue Jan 25 23:46:34 CET 2011	;pH;1300;10.5;1914.0;11.5;5	pH	1300	10.5	1914.0	11.5	5	0	PREV	PEND
5	Tue Jan 25 23:41:34 CET 2011	;pH;1293;10.6;1935.1; 9.5;5	pH	1293	10.6	1935.1	9.5	5	0	PREV	PEND
5	Tue Jan 25 23:36:34 CET 2011	;pH;1314;10.2;1941.0; 8.9;5	pH	1314	10.2	1941.0	8.9	5	0	PREV	PEND
5	Tue Jan 25 23:31:34 CET 2011	;pH;1295;10.6;1936.9; 9.3;5	pH	1295	10.6	1936.9	9.3	5	0	PREV	PEND
5	Tue Jan 25 23:26:34 CET 2011	;pH;1301;10.5;1946.1; 8.5;5	pH	1301	10.5	1946.1	8.5	5	0	PREV	PEND
5	Tue Jan 25 23:21:34 CET 2011	;pH;1303;10.4;1944.5; 8.6;5	pH	1303	10.4	1944.5	8.6	5	0	PREV	PEND
5	Tue Jan 25 23:16:34 CET 2011	;pH;1314;10.2;1937.8; 9.3;5	pH	1314	10.2	1937.8	9.3	5	0	PREV	PEND
5	Tue Jan 25 23:11:34 CET 2011	;pH;1296;10.6;1919.5;11.0;5	pH	1296	10.6	1919.5	11.0	5	0	PREV	PEND
5	Tue Jan 25 23:06:34 CET 2011	;pH;1299;10.5;1937.4; 9.3;5	pH	1299	10.5	1937.4	9.3	5	0	PREV	PEND
5	Tue Jan 25 23:01:34 CET 2011	;pH;1312;10.3;1939.5; 9.1;5	pH	1312	10.3	1939.5	9.1	5	0	PREV	PEND
5	Tue Jan 25 22:56:34 CET 2011	;pH;1298;10.5;1925.3;10.5;5	pH	1298	10.5	1925.3	10.5	5	0	PREV	PEND
5	Tue Jan 25 22:51:48 CET 2011	;pH;1310;10.6;1934.0; 9.6;5	pH	1310	10.6	1934.0	9.6	5	0	PREV	PEND
5	Tue Jan 25 22:46:34 CET 2011	;pH;1320;10.1;1934.9; 9.5;5	pH	1320	10.1	1934.9	9.5	5	0	PREV	PEND

1 2 3 4

Figure 28: ISFET history data for analysis of stored measurements

Dedicated interfaces have been also designed for the VIP measurements according to user feedback and expressed needs. This type of interface is shown in Figure 29 where means to upload VIP profiles from stored files enable users to display various graphs or tables to analyse the data. The data can also be stored in XML format to ease portability and data exchange and cooperation with other frameworks.



Campain name
Date: 8 mai 2011
Place latitude: 46.0
Place longitude: 0.0
Description

Summary

Campaign name	
Date	Sun May 08 14:35:06 CEST 2011
Latitude	46.0
Longitude	0.0
Place	
Description	

Parameters | Select Unit | Coef. Tepmerature | Coef. Conductivity | Coef. pH | Coef. O2 | Coef. Cd | Coef. Pb | Coef. Cu

Upload profiles as CSV files to the GRID, each file contain different measurements related to the profile.
Auto upload ☑
Aucun fi...r choisi
100 %
Uploaded Profiles

Name	Size	Content Type	Delete	Convert	Compatible	View Data Table	OnMap	Draw Chart	Convert2XML
sample_file.csv	9 KB	text/csv	delete			view	draw	draw	view

Figure 29: VIP profiles management interface

2.5 Energy scavenging

At the start of the project, several methods of harvesting energy were investigated; formulae were derived allowing the mechanism with the greatest potential to be taken forward to prototype stage. As can be seen from Figure 30, the inertial based pendulum and resonant disk harvesters were the most promising techniques (other than solar, for which there was little research potential outside of the material science domain) and so both of these inertial devices were taken to the prototype stage.

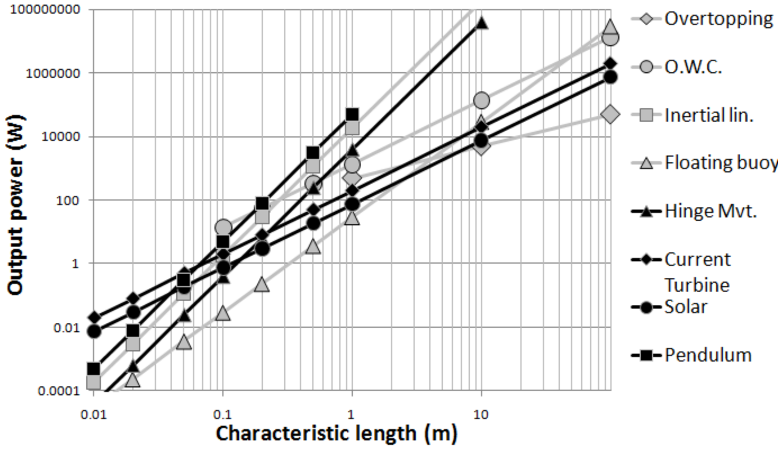


Figure 30: Comparison of power generation techniques for harvesting in a marine environment in a moderate sea state

With the prototype pendulum harvester in this project we have demonstrated for the first time the tuning of the resonant frequency and electrical damping of an inertial energy harvester using a power electronics interface. This is significant both to MOBESENS (because the excitation frequency of the harvester is changeable and dependent on sea state) and in many other energy scavenging applications where the characteristics of the driving source are time variant. The changes in damping and resonant frequency are shown in Figure 31 and Figure 32.

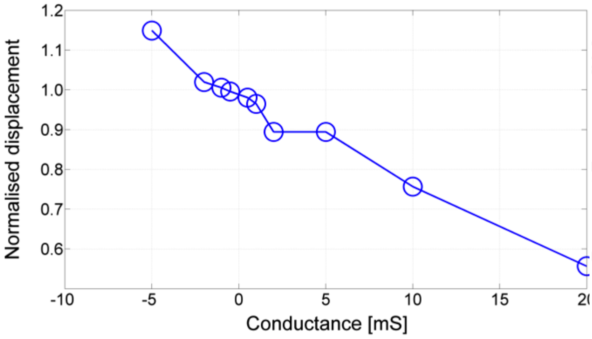


Figure 31: Change in generator damping with emulated load conductance

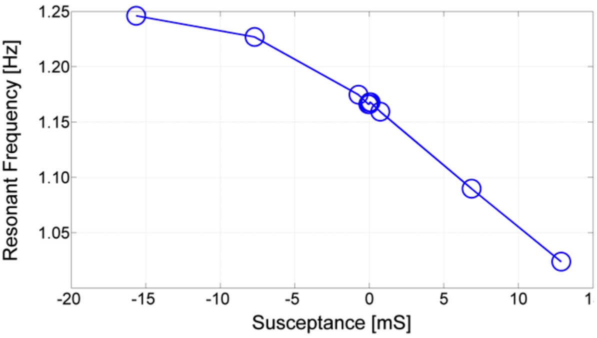


Figure 32: Change in generator resonant frequency with emulated load susceptance

The advantages in terms of the increase in power generation from the generator (Figure 33) are highlighted in Figure 34, where the power output at low and high frequency can be increased by adding a synthesized capacitance to the emulated load impedance in the h-bridge interface.

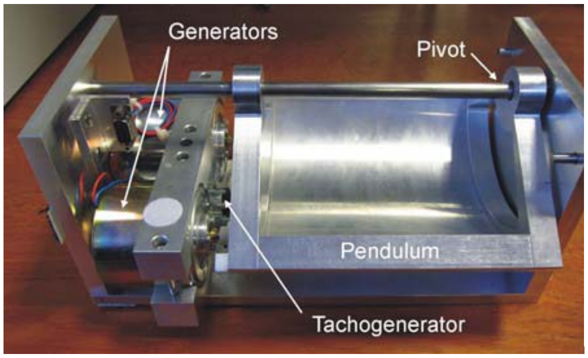


Figure 33: Wave-driven energy harvester

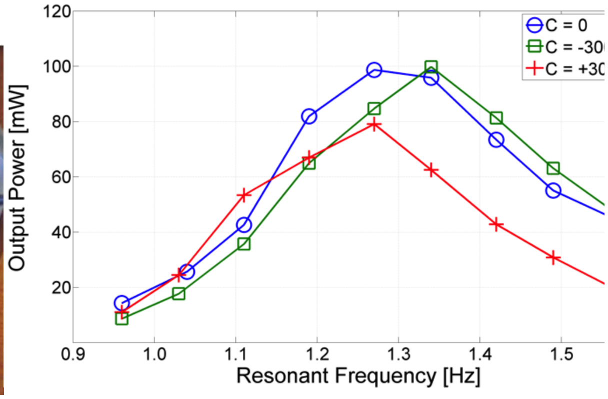


Figure 34: Generator power output for different reactive loads

The pendulum harvester was deployed several times in the kayak during field testing. The results of the last test (Sept 2011, Bay of Brest) are shown in Figure 35. TA data logger was used to collect measurements data for the performance of the pendulum. The grey trace shows the battery current (positive means the battery is being charges and negative means the battery is supplying power) as measured at 0.1 s intervals. The black trace shows the net useable power that is generated and stored in the battery. The reason for the downward trend (i.e. net power consumption rather than generation in the first 20 minutes is that the kayak was being prepared and launched. The kayak was set into the open sea as of the 25 minute mark, at which point power was generated. The phase in which energy was generated corresponds to around 3 mJ in around 95 minutes, which corresponds to a power generation of 0.5 mW and is sufficient to power one of the CSEM low power radios with a relatively high duty cycle.

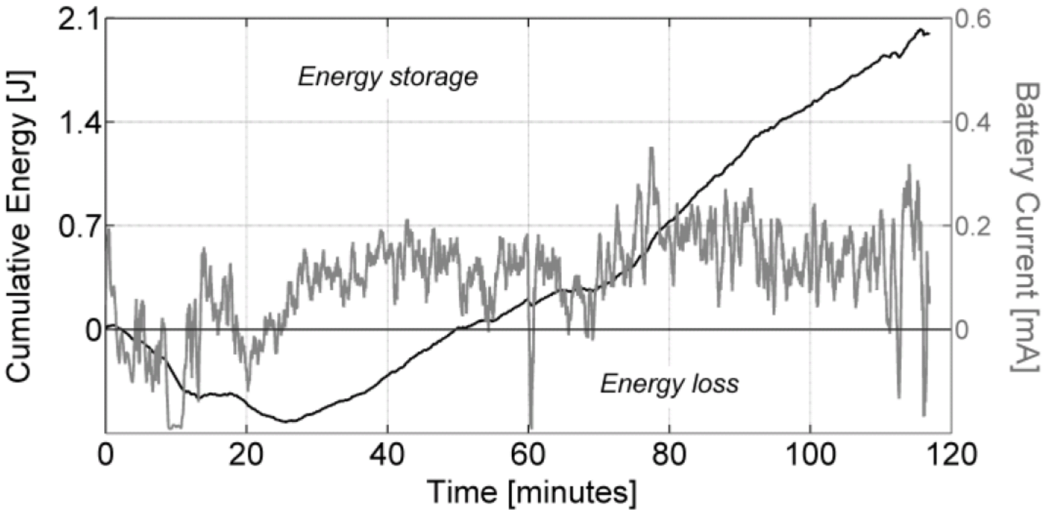


Figure 35: Test results from pendulum field deployment in kayak

2.6 Wireless Power Transfer

In a parallel strand of work, investigations were undertaken into the concept of transferring power wirelessly from a transmitter on the USV to receivers on the buoys.

We had previously showed that in order to achieve efficiencies of wireless power transfer above 90%, coil Q-factors of over 1000 are needed. To prove that such high Qs could be achieved and that the theory reflects practice, Q measurements were undertaken for the resonating primary and secondary coils which were fabricated from copper pipe, as shown in Figure 36. Furthermore, a proof-of-concept in terms of the coil design was needed to see if a cost effective solution of building coils from copper piping could yield good results, alleviating the need for expensive Litz wire fabrication. The complete test fixture mountings were fabricated using Perspex, to avoid the generation of eddy currents that would provide inaccurate measurements. Coil spacers between turns were used to maintain a distance of 2 cm between the centres of the pipe. This helped to reduce the proximity effect between turns.

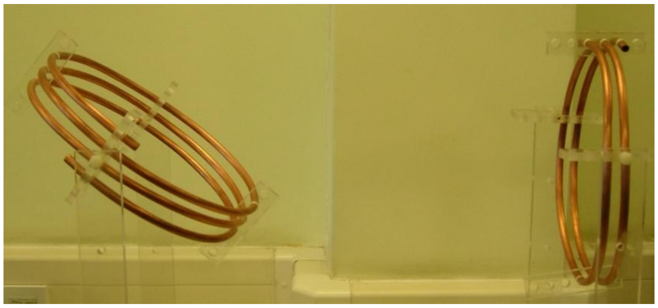


Figure 36: Misaligned 3 turn (left) and 2 turn (right) 30 cm diameter coils.

Q factor measurements were conducted for several coils with copper piping having a 1 cm cross-sectional area and a 1 mm wall thickness. Figure 37 shows measurement results for a 3 turn 30 cm diameter coil.

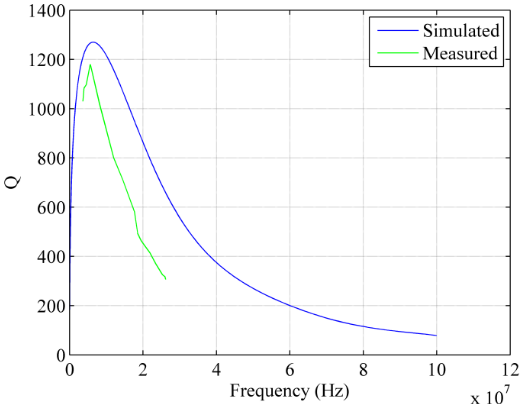


Figure 37: Simulation and measurement results of Q vs. f for a 3 turn 30 cm diameter coil.

As can be seen, a reasonably good agreement between measurements and results was realized for different coil configurations, having taken great care in setting up the experiment considerations for the test. The mismatch between measurements and simulated results are mainly due to the fact that the Q of the tuneable air capacitors was only available for the highest rated values and therefore. When the capacitor value was changed by tuning, the Q was also modified to a lower value than the best value given on the datasheet. In addition, even though rigorous procedures were taken, to ensure that both probe coupling factors remained as equal as possible, it is likely that the mechanical characteristics of the cables, *e.g.* the sagging of the cables between the output ports of the series network analyser and the probes, may be enough to increase the precision error.

A class E driver circuit was constructed to power the primary coil and the load comprised of simple resistors. The test setup can be seen in Figure 38

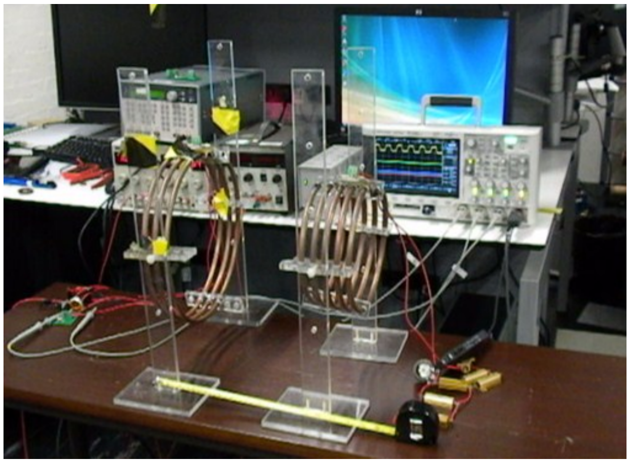


Figure 38: Wireless power test setup in the lab

An efficiency of power transfer of 18 % was achieved with this system. This level of efficiency is sufficient to prove the concept but increased in efficiency is necessary if we are to practically deploy the system. Work on improving the efficiency of the driver is continuing after the formal completion of the MOBSENS project.

In summary, resonant tank Q factors above 1,000 have been simulated and measured for a medium range wireless power transfer system. The results and the measurement techniques shown provide a design framework to achieve efficient inductive links with an air-gap of more than 50 cm. Furthermore, coil and test fixture fabrication procedures were conducted to achieve low cost and reproducible designs. When tested with a class E driver circuit, power transfer efficiencies of 18 % were obtained.

2.7 MOBESENS prototype systems

Versatility of the elements, presenting performances fulfilling the requirements defined for the field applications, to build modular mobile WSN were demonstrated by the development of MOBESENS prototype systems under two different architectures which were field applied in respectively the Ebro river (Figure 39) and the Vidy Bay of Lake Leman and the Thau Lagoon (Figure 40).

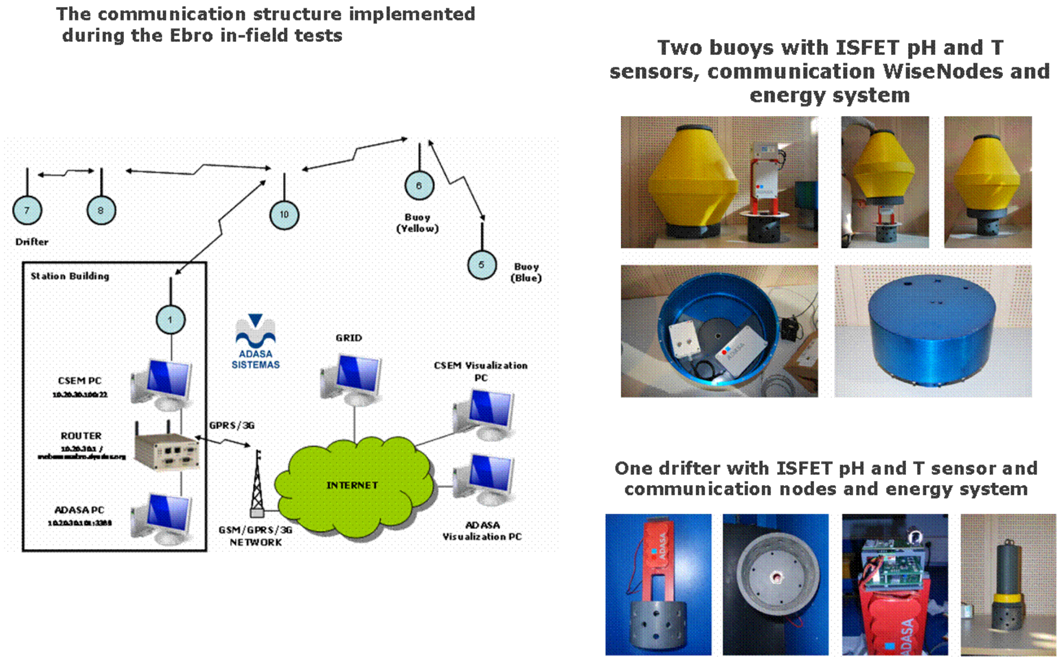


Figure 39: Architecture of the MOBESENS prototype system developed for the field test in the Ebro river

Results obtained with the MOBESENS prototype systems during the three MOBESENS field tests have demonstrated the promising capability of wireless communication network, based on miniature radio-frequency nodes with self-multihop reconfiguration and localization capability to: collect data gathered by various sensor probes installed on mobile elements; stamp them with location information; transfer them to gateways and then, via internet, to a GRID with data storage, analysis and visualisation capabilities.

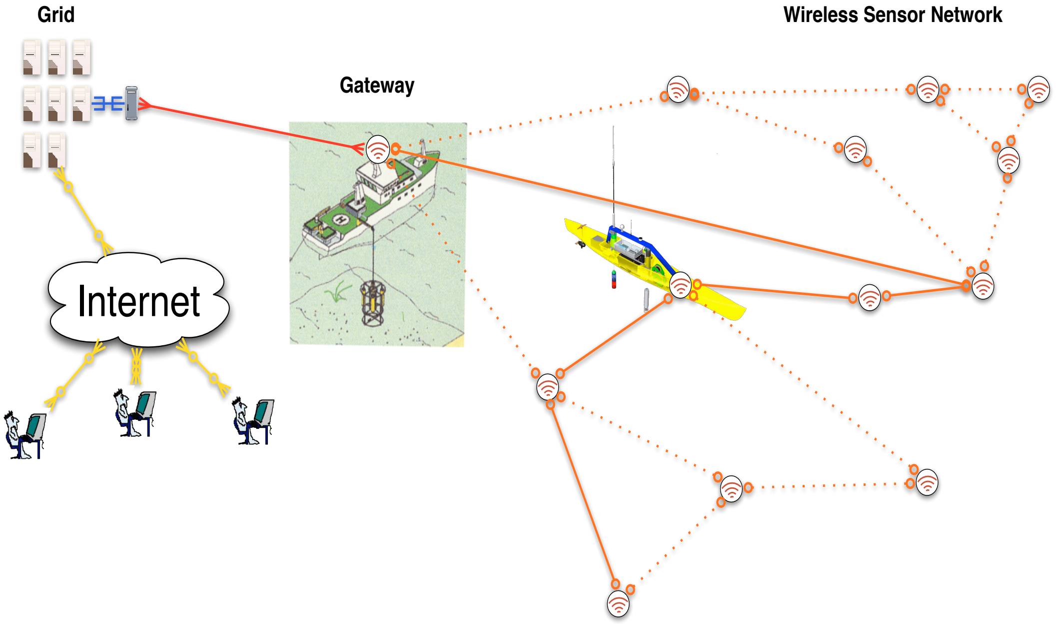


Figure 40: Architecture of the MOBESENS prototype system developed for the field tests in the Vidy Bay of Lake Leman and the Thau Lagoon.

They have show that ISFET sensor are promising to provide low cost, miniature sensor probes for pH and T measurements provided that internal calibration are added and packaging improved to avoid hardware deterioration.

They have confirm the capability of the improved VIP voltammetric probe to perform reliable and accurate monitoring and profiling of the bioavailable fraction of metals at the ppt level up to 1 month without maintenance (D2.5).

Results obtained during the field campaign in the Vidy Bay of Lake Leman have clearly demonstrated the interest and potentiality of the VIP system deployed from mobile devices (either boat or autonomous surface vehicle (USV) such as the Ifremer drone) to: detect and trace the spreading of anthropogenic effluent inputs in coastal area by performing 3D screening of master variables and in particular conductivity (Figure 41); and to evaluate the metals it may carry by intercomparaison of the metal bio-available concentrations, determined from VIP profiling at selected sites, in mass water impacted or not by the effluent spreading (Figure 42 a) (D6.4).

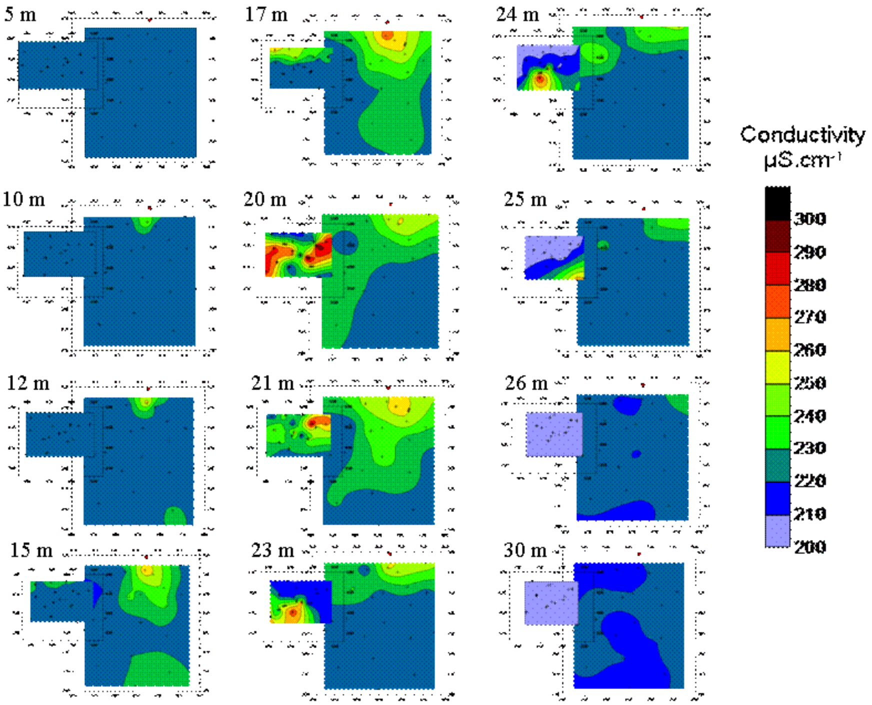


Figure 41: Examples of 3D visualization of the waste water treatment plant sewage effluent spreading monitored in the Vidy Bay [10].

Finally, inter-comparison of bio-available metal concentration measured in situ with the VIP with total and total dissolved metal concentrations measured in collected samples using traditional laboratory techniques during the Vidy Bay and Thau Lagoon field trials (Figure 42 b) have clearly confirm that the speciation, and therefore the proportion of the bio-available fraction, of the trace metals varies significantly: from one metal to an another due to significant different in their sorption properties; as a function of physico-chemical conditions and water composition (fresh and marine water) (D6.7).

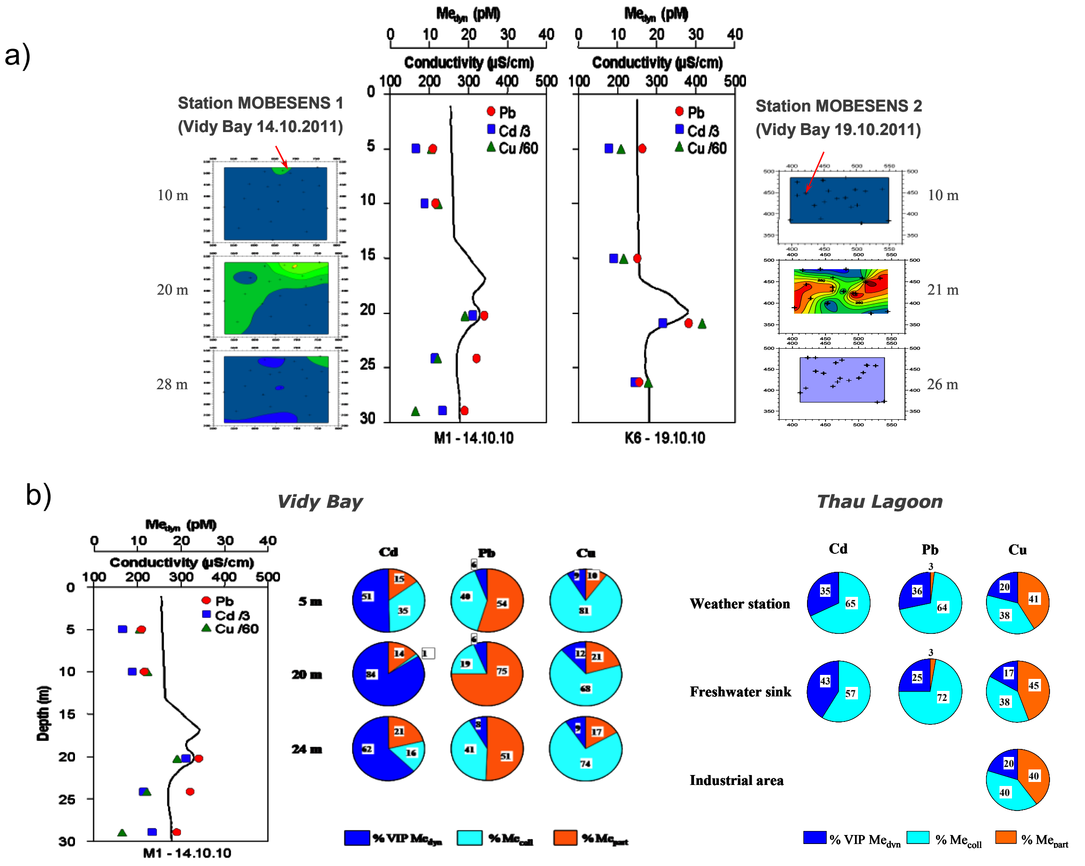


Figure 42: a) Exemples of bio-available concentrations of Cd, Pb and Cu monitored in water mass impacted (~20 m) or not by the Vidy waste water plant effluent release; b) metal speciation in the Vidy Bay mass water impacted or not by the WWTP release [10] and in various stations of the Thau Lagoon.

The results clearly demonstrated that the present legislation based on the measurements of total or total dissolved metal concentrations is inappropriate to assess the (eco)toxicological impact of metals. In situ measurements of the specific metal fractions, and particular the fractions of the metals potentially bioavailable is a pre-requisite condition. To achieve this at minimum cost, reliable sensor probes integrated in a MOBESENS system appears to be a system of choice (D6.8).

3 Conclusion

The MOBESENS project started with the goal to develop a modular and scalable network solution for water quality monitoring with the unique advantage over previous systems of employing sensor probes and communication nodes installed in mobile elements such as drifters and USV. The MOBESENS wireless sensor communication network (WSN) serves as a front-end for gathering water quality information monitored with various sensor probes. This data is then reported back to water quality management information systems and - if possible - other environmental monitoring systems thus enabling rapid and reliable reporting of information on water quality, localization of anthropogenic release in coastal area and tracking of their spreading and of the contaminants they may carry.

While the first year of the project was utilised to develop, improve and adapt the individual constituent MOBESENS elements, years two and three were dedicated to integration, tests and optimization of the components, ending with three successful field campaigns which demonstrated the mobility, sensing, communication and energy harvesting elements together. The different campaigns demonstrated the potential of the system developed in MOBESENS, especially with respect to the combination of autonomous mobile sensing elements and wireless communication allowing the 3D monitoring of selected area.

The MOBESENS vision of a beyond the State of the Art Ecological, Open, Modular and Scalable ICT based solution for 'always on' and 3D water quality monitoring system has been able to demonstrate its potential and has equally been brought closer to reality via the joint efforts of the MOBESENS partners.

Another key objective of the project was to stay as close as possible to the needs of the end-users. To achieve this, partners were integrated in the consortium who were able to take an active part in the specification and validation process. In addition, the consortium felt it was important to present on a yearly basis the results to external experts in the area of water monitoring. At the third and last meeting, the conclusions of the external advisory board were:

- There in an interest for automatic monitoring systems, but users want working solutions: typical questions from users are: how much it costs, which parameters can be implemented, and when it will be available.
- Even though all developed elements were seen to be very interesting for end-users, there was less interest in the complete MOBESENS package solution. End-users were more interested in utilizing parts of the MOBESENS system for integration with their own systems.

The Mobesens project is has reached a relatively advanced prototype stage, which has allowed several reliable deployments to be undertaken. However, the system is not currently of production quality and is therefore not the ideal product for water monitoring as wished by scientists. In any case, there is probably not one ideal solution for all monitoring requirements, as each individual campaign would bring its own challenges. However, from the experience gathered during the project and the feedback received by all the persons who were in contact with the project as members of our advisory board or observers during deployments, the MOBESENS prototype has demonstrated a reliable working solution to the problem of long term, continuous monitoring of large water areas as well as demonstrating the need of modular WSN that can be quickly deployed to evaluate the spreading of polluted anthropogenic release and thus there potential impacts on the environment and human health. This MOBESENS system concept and the modules that it integrates (Chemical sensor probes, USV, Buoys, Drifters, WSN, GRID, energy harvesting)will need to be pushed closer to an industrial prototype system, or a line of products, so that an authority or their representative could select elements tailored both in terms of cost and capabilities to their particular area of monitoring and/or monitoring requirements.

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