

# ARMONIO – “Plug and Play” ARchitecture for a MONItoring Systems of the Portuguese Ocean

José A. Fonseca (jaf@det.ua.pt), Paulo Bartolomeu, Osvaldo Pacheco, António Macedo, Pedro Duarte  
*Dept° de Electrónica e Telecomunicações – Universidade de Aveiro*  
*IEETA – Instituto de Engenharia Electrónica e Telemática de Aveiro*

## Abstract

This paper describes an implementation of a distributed architecture for environmental monitoring systems used for hydrographic and meteorological applications. The architecture is based in the producer-consumer model and uses wireless communications and commercial telecommunications to simplify the set-up, operation and maintenance procedures. The Bluetooth standard was found adequate to be used at the so-called local monitoring systems (LMSs) which are the units that gather information in the field. The architecture of these LMSs is presented in the paper. An overview of the connection of the LMSs to the final users is also discussed.

## 1. Introduction

Environmental monitoring systems used in some specific applications can often become cumbersome in what concerns assembly, installation exploitation and maintenance. This is particularly true when dealing with systems that must cover a large geographic area, requiring often sub-systems located in remote regions, in places with difficult access and in sites with complex installation. The case of monitoring the ocean margins is one of the examples and is, in fact, the application that led to the research carried on in the ARMONIO project<sup>1</sup>.

Some of the authors have felt the problem of managing the complexity of environmental monitoring systems in a previous project [1] in which sea water quality monitoring was done. The interconnection of units, some of them under water, the installation in places subject to tide levels changing more than 4 meters, were just some of the problems encountered. Another project [2], in which other of the authors was involved, would benefit from an improvement in the architecture. This project

has brought also to the ARMONIO project experience in the development of systems for control and monitoring of environmental variables. This system, called SIMOQUA and used by the Aveiro water company to monitor the production of water for domestic use, integrates applications developed for data analysis, for extracting data and information reduction. These are built on the top of a SCADA system, supported by a common database. The developed SCADA model, allows to integrate in the same platform the quality control and the remote management of the devices.

Commercial products such as the ones that can be found in [9], [10], [11] keep the traditional architectures, using interconnection solutions such as telephone, cellular telephone, radio links, satellite telephone to build SCADA systems that don't show a common integrated architecture.

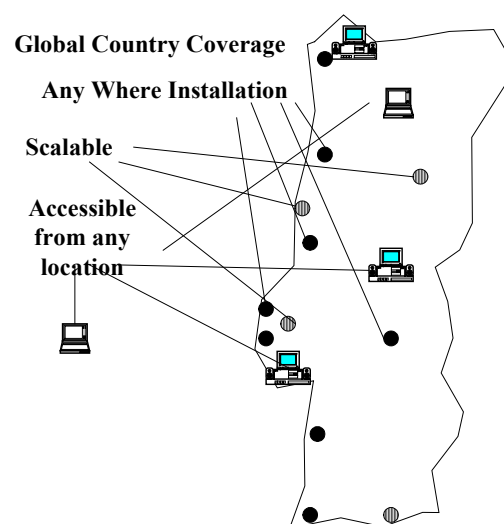


Figure 1-Geographical Area Coverage

In the case of the monitoring system studied in the ARMONIO project, there must be a set of local monitoring subsystems (LMSs, represented by the round shapes in figure 1) which collect several physical parameters of interest for hydrographic, meteorological and, in the future, military applications. Examples of such parameters are: water temperature, tide

<sup>1</sup> The ARMONIO Project is funded by Fundação das Universidades Portuguesas and the Portuguese Ministry of Defence under the Program “Ocean and its Margins”

level, conductivity, pH, turbidity, air temperature and humidity, wind speed, seismic data.

The local units must be installed all over the country, most of them in the ocean margins. The number of local units must be scalable as well as the number of physical parameters measured in each local unit. Measurement data must be accessible from anywhere. Security issues are not under consideration.

In this paper the global system operation model, the architecture thought to implement the model and some solutions already achieved are discussed. At this point of the on-going work, the emphasis is on the architecture of the LMSs and on the solutions to implement the Bluetooth based wireless versions of those units.

## 2. System operation model

The solution envisaged in the ARMONIO project to help in achieving a more user friendly monitoring system is based on the producer-consumer model. It is considered that this model has characteristics well adapted to the “Plug and Play” concept, as it will be discussed below.

Following the producer-consumer model, a measurement device is obviously a producer of data. Any entity interested in the data, e.g., a meteorological observatory, a research laboratory, an individual, can be a consumer.

When a measurement device is added to the global system it must then start producing its data and make it available to the interested consumers. To follow the “plug and play” paradigm, then this addition should just require turning the device on.

If the concept of measurement device is associated with just one physical parameter then the configuration requirements are minimal. An adequate acquisition period can be previously defined and a standard parameter identification can be adopted. The production of measured data can then be done using the periodicity defined. On-line changes of this value within specified ranges can be accepted with adequate procedures.

Most of the referred environment parameters face slow variations. Thus, bandwidth requirements tend to be modest. This means that the data production can be done at the rate required by the consumer that needs more resolution or by the adequate acquisition period for the parameter. Consumers that do not require the highest resolution can just discard part of the samples.

Additionally, the use of the producer-consumer model brings some intrinsic advantages that can be recalled. This is the case, for example, of the information coherence between different consumers which can be important for higher-level functions of the system. Also, the easy detection of faulty devices is also an interesting function for a large scale system such as the one described here.

## 3. Overall system architecture

The system architecture is closely tied to the producer-consumer model. At a higher architectural level, the LMSs, local monitoring subsystems, produce, in regular time intervals, information about their inner measures. This information is gathered by the different units that are the final users (consumers) of the measured data.

At this level there can be two different types of final users: system users (SUs) and private users (PUs). SUs consume directly the measurement data. Private users must get the measurement data from a system user. The number of system users is much smaller than the number of private users. System users require data with reduced latency and are meteorological institutes, research units and military units.

Data flow between LMSs and SUs is done through telecommunication networks, currently GSM as described later. The LMSs have a list of SUs and send autonomously data to each SU in the list. The normal situation is that every SU receives data from every LMS. However, in some specific cases, SUs may just require part of the data, i.e, data from a specific LMS or from a subset of LMSs. In this case a subscribing process is envisaged to enable SUs to register in specific LMSs. In this particular case it can be considered that the system uses a publisher-subscriber model.

In order to enable PUs to access data, a very simple scheme is used. One (or several) SU must have a connection to the Internet. A Web server can then access the raw database of the SU (it can obviously be in the same computer) and make measurement data available to interested PUs, independently of their location. One important requirement at this level is the “Plug and Play” operation of the LMSs. This requirement is solved by using geographically referenced information associated to each LMS. Once plugged, a new LMS added to the system starts transmitting its measurement data stamping in it its geographical coordinates.

The measurement data coming from each LMS is then identified without risk of duplicates. The resolution of the coordinates can be adapted to the application, depending on the required proximity of different LMSs.

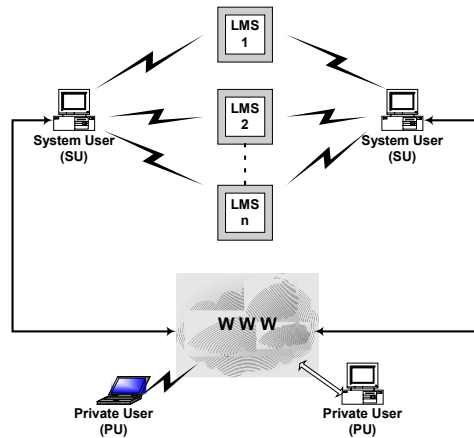


Figure 2-Overall ARMONIO Architecture

#### 4. The local monitoring subsystems

Each local monitoring subsystem aggregates a set of measurement devices and intelligent sensor subsystems. The number of these depends on the application needs. All LMSs include also at least a gateway to the telecommunication network and a GPS to stamp geographical information and time information. The possibility to have an easy connection to a debugging system based on a portable computer is also required. The LMS is thus a distributed system relying in a communication backbone (LMS-CB) to provide the interconnection between these different elements and subsystems.

Measurement devices are used for certain parameters, e.g. solved oxygen in water, when it is not easy, for complexity or economical reasons, to integrate a sensor. Typically these devices have one or more external interfaces (RS232, RS485, NMEA, etc.) that can be used to connect them to the LMS-CB. Almost always these devices show operation modes very well adapted to the producer operation, i.e., autonomous periodic data acquisition and data transmission using the available interfaces. It is then quite easy to include a small microprocessor based interface between the device external interface and the LMS-CB. Intelligent sensor subsystems are specifically developed systems that integrate a microprocessor based circuit similar to the one used with measurement devices and the

required conditioning circuits to connect a sensor. Temperature (water or air), water column, humidity are examples of parameters for which intelligent sensor subsystems were developed. In this case, the subsystem has a built-in interface to the LMS-CB.

Gateway nodes are also microprocessor based systems with a built-in interface to the LMS-CB. They integrate an interface to the telecommunications network, currently GSM. The option for GSM comes from the fact that, currently, the geographical coverage is satisfactory and the exploitation is cheap, mainly, if messages are used (SMS – Small Message System) which becomes possible due to the reduced length of data required. Also, a GSM modem is easy to embed in the gateway subsystem. Please note that more than one gateway must be provided in order to achieve some fault tolerance.

In what concerns GPS, it is possible to use an embedded module in the gateway node or a dedicated node with interface to the LMS-CB. In any case the GPS module must send periodically the time and geographical information.

Finally the LMS can include a debugging system (DS). This system will not be present all the time. So, the LMS operation must be able to support the plugging and unplugging of such a system. In what concerns the internal operation this is not a problem due to the use of the producer-consumer model and of the technological solutions to implement it discussed below. In what concerns the verification of the correct operation of the LMS at the overall system level, which could be a problem, the solution relies on the subscription process. The DS registers in the LMS gateway and in consequence it must receive all data produced by the LMS. The envisaged DSs are laptop computers with the adequate interfaces and specific software.

When looking within the LMS, it is possible to map the producer-consumer model in the operational architecture described previously. It is obvious that the measurement devices, the intelligent sensor subsystems and the GPS module are producers and that the gateway modules and debugging system are consumers. It should be noticed that the active gateway module is also producer of a special heartbeat signal used to detect its own failure.

## 5. Implementing the LMSs

The LMSs in development consist in distributed systems that can be wired or wireless. In the first case the CAN (Controller Area Network) [3] field bus is used. The wired version will not be further discussed in this paper. For the wireless version Bluetooth [4] is used. The sensor modules of the LMS are based in small processors (MICROCHIP PICs or 8051 processors) with the referred communication interfaces embedded. The gateway modules are similar, currently using a 8051-based processor.

### 5.1 Information Flow within the LMS.

The information flow within the LMS is performed according to figure 3.

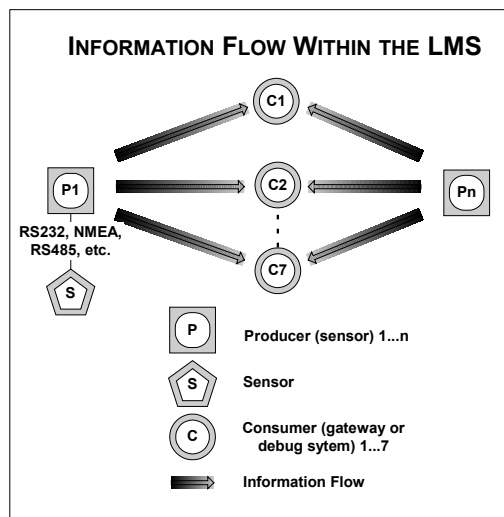


Figure 3-Information Flow

The main concept is that each producer has its own individual network. The producer and all the active consumers in the area form this network. The producer node sends information to the consumer nodes in its network using broadcasted frames. Each consumer node can belong to several local networks and, according to its function (gateway or debug system), it must route the information to the outside network or collect the received information for debugging purposes. The next section will cover the use of Bluetooth technology to implement the information flow already discussed.

### 5.2 Bluetooth network solution

Bluetooth technology presents ideal characteristics for use in systems that require a high level of autonomy, low cost, no installation complexity and robustness.

The high level of autonomy relates with the ability of the Bluetooth communications interface to operate in several low power modes [4]. These operation modes increase the longevity of the supply batteries [5] and, at the same time, the autonomy of the LMS.

The low cost comes from the mass production due to the use of Bluetooth in mobile phones and computers. It is predictable that in a few years the unit cost may reach the bound of 5€ [6].

The low complexity of installation results from the most interesting characteristic for this architecture that is the ability of forming Ad-Hoc networks [7]. This is, the establishing of a network is dynamic and does not require the human intervention. Bluetooth works with small independent networks, called piconets, with one master and up to 7 slaves. Bluetooth nodes can be members of several piconets. This type of operation will be explored in this application as it will be described later.

The robustness of the network results from the modulation technique used to transmit packets over the network (FHSS- Frequency Hopping Spread Spectrum). The communication channel is not built upon a single frequency but upon a multiple pseudo-aleatory sequence of frequencies in the ISM (Industrial Scientific and Medical) band. This property allows that minimum collision occurs in noisy environments even if there are similar networks in the neighborhood.

### 5.3 Bluetooth Implementation

The Bluetooth implementation is based on the concept exported from the L2CAP layer of group oriented communication channels. Each producer node is configured as master and each consumer node is configured as slave. The configuration process guaranties that no producer will ever be a slave in a piconet. This is done by configuring the following parameters of the Bluetooth module:

- Inquiry Scan
- Page Scan

If the configuration process disables the Inquiry Scan and the Page Scan the local Bluetooth module will never reply to those packets and therefore will never be configured in a piconet as a slave.

In this configuration it is assumed that several piconets will be placed in the same limited space, though, several slaves will be common to those piconets (see figure 4). Because only producers will be masters, the slaves are not allowed to produce information within the piconet. The number of piconets in the LMS is

equal to the number of information producers which results in several side-by-side independent piconets. There will be no scatternet formation. If there are  $n$  producers present, there will be  $n$  piconets in the area.

## LMS BLUETOOTH IMPLEMENTATION

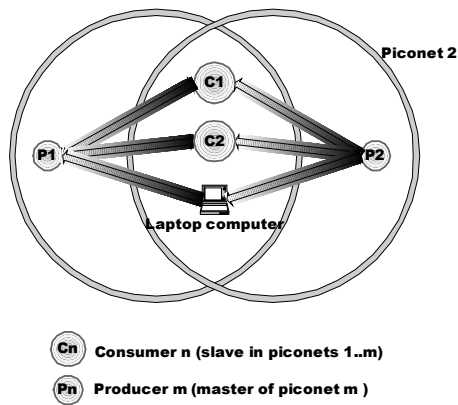


Figure 4-Bluetooth Implementation

The maximum number of local consumers in a LMS is seven; this is the maximum number of active slaves in a Bluetooth piconet. This figure is more than adequate for the application.

The referred group orientation channel is implemented with the use of the L2CAP primitives [4] for group communication. These are:

- Group Create
- Group Add Member
- Group Remove Member
- Get Group Membership
- Group Close

and allow the interface of the application layer to the L2CAP group oriented channel.

The responsibility of creating and managing the group is issued to the information producer. This way, when it returns from the sleep state, it scans the neighborhood for active consumers and creates a group channel for them. Then, it transmits the produced information and closes the group, returning to the sleep state until new local sensor data is produced. The consumers remain in active state waiting always to be added to a group of some producer in the area.

### 5.4 Current development status

Prototypes of the 8051 based modules of the LMSs are already available. They are based in a Cygnal C8051F041 processor with a Airlogic ABM-200, class 1 Bluetooth module. The gateway is using a Falcom GPS JP3 module.

Some air quality PIC based modules are also available, adapted from the ones developed for a related work [8]. Thus, a final prototype of the LMS is practically finished.

## 6. Conclusions and work in progress

In this paper a producer-consumer based architecture for environmental monitoring systems was presented. This architecture uses Bluetooth based wireless modules that are organized as Local Monitoring Systems (LMSs). LMSs use geographically referenced information from GPS to identify the measures they produce and GSM to convey data to consumer systems. The architecture seems promising to facilitate the set-up, operation and maintenance of the target applications.

A prototype of the LMS is practically finished. A demonstrator of the full system will be available in July. Besides the assessment of the system performance, future work in the scope of the ARMONIO project includes analyzing the use of Plug and Play smart sensors that follow the IEEE P1451.4 standard in the Plug and Play architecture proposed and studying the problem of identification of mobile LMSs.

## 7. References

- [1] J.F. Silva, J.A. Fonseca, A. Mota - "A Monitorização para Controlo do Ambiente", Revista SERS - Sindicato dos Engenheiros da Região Sul, nº8, pp.28-31, 1998.
- [2] O.R. Pacheco, L.P. Antunes, R. Ferreira, "Sistema de Controlo em Tempo Real da Qualidade da Água para Consumo Humano", *Electrónica e Telecomunicações*, Universidade de Aveiro, vol. 3, nº 3, 2001.
- [3] Bosch, "CAN Specification Version 2.0 - Technical Report", Bosch GmbH, Stuttgart, Germany, 1991.
- [4] Bluetooth SIG, Specification of the Bluetooth System v1.1, Volume 1, 2001.
- [5] James Kardach, "Bluetooth Architecture Overview", Intel Corporation, 1998
- [6] Jan Beutel, "Bluetooth - An Adequate Solution for Local Ad-Hoc Networking?", 2001.
- [7] Palowireless Bluetooth Resource Center, <http://www.palowireless.com/bluetooth/>
- [8] J.A. Fonseca, F. Carreiro, V. Silva, M. Evtiuguina, M. Marques, C. Albuquerque, "µVOC - A Lightweight Environmental Data and Air Samples Acquisition

*System to Install in Captive Balloons*",  
accepted for publication in Proceedings  
ISIE'2003 – IEEE Conference on  
Industrial Electronics.

- [9] <http://www.sutron.com/products/applications/DEFAULT.HTM>
- [10] [http://www.eitechnology.com.au/water\\_monitoring\\_stations.html](http://www.eitechnology.com.au/water_monitoring_stations.html)
- [11] <http://www.advantech.com.tw/efms/product-ems.asp>