



## Wireless System Application for In-Scale Marine Vehicles

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### ABSTRACT

Advances in information and communications technology have enabled the use of wireless communication techniques in all sectors for the transmission of information in different forms. Wireless communications and distributed computing have made it possible to develop the remote experimentation environment for in-scale marine vehicles which is the subject of this work. The present article describes a wireless system architecture suitable for communication among several in-scale vehicles and a station base located on land, which can control the vehicles and acquire data from all of the sensors on board the different vehicles at a distance via wireless communications.

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### 1. Introduction

The evolution of wireless networks has, thanks to their mobility, provided the solution to the problems of numerous Ethernet networks whose common denominator was the requirement of flexibility of use. In this paper, we summarise the evolution of the different communication standards and discuss which is the most suitable for the application of a remote experimentation environment for in-scale marine vehicles.

The need for mobile connections to Internet in the work environment has led to the creation of wireless networks (Stallings, 2003). After the initial problems of compatibility between the different standards, the development by the IEEE of a standard, 802.11, led to the widespread use of these wireless systems in multiple environments -corporate, home... In this paper, the remote experiments are carried out in an open en-

vironment on the coastline of the Bay of Santander where there are very few interferences and obstacles.

Within the framework of the new technologies, one powerful tool is the communication networks (Internet) (Halsall, 2006), which constitute an important medium for organising and giving support to the information. There are several criteria for establishing a classification between experimentation environments: one is the way of accessing the experimental resources and another is the nature of the resources available. The former is the so-called local access, i.e. experimentation "in situ" with the resource itself. Another way is through remote access, which is known on a regular basis as experimentation through Internet, where physical presence in the area where the system is operating is not necessary (Garcia et al., 2006). This work corresponds to the second way (remote access) since the marine vehicles are unmanned in-scale physical models and are controlled remotely from land. The physical in-scale models, which are replicas of full-size vessels, were designed to be autonomous and controlled remotely from a station base on land in order to perform sea vessel trials (Revestido et al., 2006). The model tests are performed such that the model and full-scale vessels exhibit similar behaviour, so that the results for the model can be transferred to the full scale vessel by a proportionality factor (Journe and Massie, 2001). The remote experimentation environment for marine vehicles is capable of acquiring data from all of the instruments

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of the different vehicles and also to interchange data among them, which is managed by the station base.

A suitable Wireless system architecture for remote experimentation must have the following properties:

- Communication between the station base and each in-scale vehicle at any time from any point of the experimentation area. The same is required for communication among the in-scale vehicles through the station base.
- A wide broadband capable of transmitting a large amount of data including images in real time.
- Sufficient coverage to develop manoeuvring tests in an area of around 300 m<sup>2</sup>.

## 2. Wireless Standards

This section outlines the emerging wireless broadband access technologies (Mehmet and Tugcu, 2007). We explain some of the latest standards in the IEEE 802.11, which we consider to be the most suitable for the application of the remote experimentation environment for in-scale vehicles.

### 2.1. The physical layer

The main problems for developing the standard revolved around the compatibility of the wireless environment and the most prominent LAN environment at that time, the Ethernet standard. To solve this, a batch of protocols was developed in which the physical layer enables transmission through two methods: infrared and short-reach radio, (Crow, 1997) (Tanenbaum, 2003) (Heegard, 2001) Frequency Hopping Spread Spectrum (FHSS), Direct-Sequence Spread Spectrum (DSSS), Orthogonal Frequency Division Multiplexing (OFDM) and High-Rate DSSS (HRDSSS). This paper focuses on the study of transmission through short-reach radio, sufficient for the wireless application developed, in this case in HRDSSS and OFDM, given that these are the signal multiplexing mechanisms used in the standards, 802.11 a, b and g.

The HRDSSS technique is based on the substitution of each bit of information by a sequence of bits called a “chipping code”, which allows the data to be identified as belonging to a specific emitter. Standard 802.11 establishes that the minimum number of chips must be 11. In theory, HRDSSS enables several systems to function in parallel, each receiver filtering the corresponding data with its chipping code. In practice, the parallelism is achieved through the use of different frequency bands. It transmits in the 2,4 GHz Industrial, Scientific and Medical (ISM) band. The OFDM technique uses different frequency bands (48 for data and 4 for tuning) and enables up to 54 Mbps to be sent in the band of the spectrum that does not require a licence (ISM of 5 GHz). This is considered as a disperse spectrum technique, in which a mathematical process called Fast Fourier Transform is used. It uses a Quadrature Amplitude Modulation (QAM) encoding system to reach 54 Mbps. This is a technique that offers great resistance to transmission medium degradations due to multipath fading and a good ratio of bits/Hz.

### 2.2. Linking layer

The various versions of the 802.11 standard have the same linking layer, based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) technique, in order to resolve the problem of the greater complexity of the wireless environment with respect to the Ethernet environment. This complexity manifests itself in two specific problems.

- The problem of the hidden station, in which the transmissions performed in a cell zone cannot be detected in another station zone.
- The problem of the exposed station, when a station A is to transmit to another station B and finds that the channel is occupied even though there is no transmission towards B, which prevents A from carrying out the transmission.

In order to coordinate the data transmission and solve these two problems, the use of CSMA/CA offers two operating modes (Carballar, 2004):

- Point Coordination Function (PCF), in which a base station or access point is used to coordinate all of the information traffic in the cell. The standard 802.11 establishes that the base station periodically emits a series of frames including control information which reaches all of the stations included in the cell.
- Distributed Coordination Function (DCF), in which the physical medium is shared among all of the cell stations competing for access to the medium. DCF contemplates a mechanism for the detection of the physical channel and another for the detection of the virtual channel. The physical mechanism makes it possible, when a station wishes to transmit, to detect the channel and verify whether there is any signal in the medium that surpasses a given threshold. If this is inactive, the station transmits, otherwise it waits until it is inactive to begin to emit. Should there be a collision, the Ethernet binary exponential back-off mechanism intervenes. The logic mechanism implies the sending of a frame called the Request to Send (RTS) frame from the station that wishes to transmit to the receiver station, requesting permission to send the information. This latter station responds with a Clear to Send (CTS) frame giving permission. In response, the emitter station transmits its frame and the receiver station responds to the data with an Acknowledgement (ACK) frame. The other stations receive the RTS frame, and depending on the information that this frame offers, calculate the time that the channel will be occupied, imposing on themselves a Network Allocation Vector (NAV) signal. To solve the problem of the intrinsic noise of the ISM channels through which the stations of a wireless network transmit, the frames are divided into fragments sent through the stop and wait protocol, thus increasing the data transfer speed.

There are three different frame types defined by the 802.11: data, control and administration. In all of these, there is a frame control field including data on the version of the standard being used, the frame type, whether or not there are fragments and

the encoding. They also have a field that indicates the duration of the frame within the channel and a series of address fields, as well as a frame check field. These are the fields which are common to all the frames. Obviously, the data frames also have a data field where the information sent is kept.

### 2.3. Network Architecture

As regards the network architecture, there are two types of topology that enable the interconnection of the stations:

- Independent Basic Service Set (IBSS): This allows communications between the various terminals that make up the network without any central station to coordinate the communications. It is also known as “ad-hoc”.
- Basic Service Set (BSS): This uses a station or Access Point to coordinate the communication between the different network stations. It is also known as “infrastructure”. In the 802.11 standard, a series of physical level specifications can be identified (802.11a, 802.11b, 802.11g and draft 802.11n) defining the signal transmission techniques on the physical level. The characteristics of these four recommendations are briefly summarised here (Roldan, 2004):
- 802.11a: Functions in the 5 GHz ISM band, uses a QAM modulation and OFDM encoding. Transmits up to 54 Mbps.
- 802.11b: Functions in the 2.4 GHz ISM band, uses an HRDSSS modulation. Transmits up to 11 Mbps.
- 802.11g: Functions in the 2.4 GHz ISM band, emits at 22 Mbps and uses OFDM modulation.
- 802.11n: At present, the second version of the draft (sta, 2010) allows transmission at 300 Mbps and uses in combination 2.4 and 5 GHz ISM bands thanks to an antenna technology called Multiple Input Multiple Output (MIMO), which also allows the dark areas existing in the coverage area of the wireless network to be eliminated.

## 3. Wireless System Architecture

For the remote experimentation application, the wireless network uses draft 802.11n for the following reasons:

**Transmission Capacity:** the 300 Mbps allow a great deal of information to be transferred as images in real time.

**Reach:** Draft 802.11n provides a reach of several hundred metres in open land, which is particularly necessary in the marine vehicle network model with which we are working, given their mobility and the wide range of action of around 300 m over which the tasks must be performed.

The wireless network model proposed is organised around a router, with coupled access points which work under the standard draft 802.11n, allowing on the one hand communication between the different stations located on the vehicles and on the other hand the transmission of information to other networks and the Internet (Figure 1). The vehicles are equipped with industrial PCs and a device such as the Programmable Automation Controller (PAC) of National Instru-

ments which act as stations. These devices are not equipped with wireless adaptors. Also, in the case of the PAC, although there is the possibility of amplifying the device with modules that include wireless adaptors, it is also true that the PAC, for obvious reasons, does not at present other the installation of wireless devices of draft 802.11n. However, in both cases, the industrial PCs and the PAC, have Ethernet cards which allow us to carry out the installation of the wireless network. For this, we use access points which can work in two ways: as points of access themselves or as Ethernet clients. Due to the requirements of the remote experimentation environment, these devices have been connected to each of the stations in Ethernet client mode. In this configuration, the wireless devices allow you to “hook up” to an already existing wireless network, in this case that of the access point associated to the router, through the selection of the corresponding Service Set Identification (SSID).

To configure the connection, an IP network card of class C has been selected for the router AP. When we configured the Ethernet cards of the industrial PCs and the PAC, we assigned them addresses corresponding to the same IP network of class C. Once this was done, the communication between the different stations is checked. Once the communication is established, the wireless network is configured. Subsequent developments of the wireless network of the remote experimentation environment will involve the setting up of 10-12 dbi antennas with amplifiers in the mobile station access points and in the router, in order to attain several kilometres of effective reach while maintaining a high capacity of transmission without unwanted losses. This will allow us to move from a purely experimental context to practical applications in real contexts of maritime navigation.

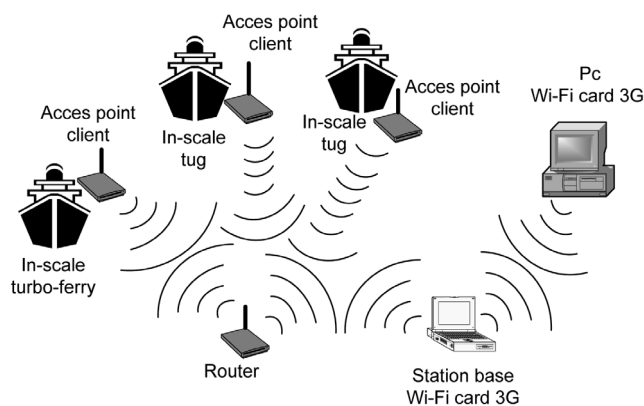


Figure 1: Wireless network architecture.

## 4. Software Support

This section outlines a software support, as outlined above, developed for various trials and manoeuvres for marine vehicles (Velasco et al., 2006a)(Velasco et al., 2006b). The software support, through the web and using DataSocket technology, can monitor data and modify the parameters of all of the instruments of the platform from a distance. To do this, a soft-

ware support was developed for carrying out the Guidance, Navigation and Control of the physical model in a wireless network. Figure 2 shows a schema of the on-board elements, with the in-scale vehicle and on-land elements.

On-board Elements of the in-scale vehicles:

- Components for the propulsion and steering of the vessel: motors, servos, speed controller and turbojets.
- Components of the control circuitry: PWM (Pulse Width Modulation and receiver station).
- Sensors: Global Positioning System (GPS), electronic gyrocompass, Inertial Measurement Unit (IMU) and accelerometers.
- Digital Camera placed at the bow of the vehicle to see the horizon view of the ship.
- Communication components: industrial PC and access point.

On-land Communication Elements:

- One laptop (station base) with a router.
- One radio control station which takes over the steering of the vessel in case of failure of the Wi-Fi network.

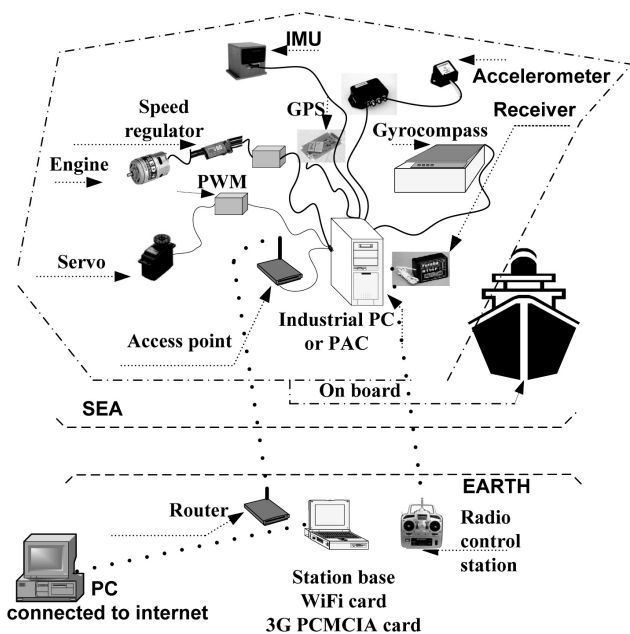


Figure 2: Elements required for the remote experimentation environment.

#### 4.1. Development of software support of environment

For the development of the software support, LabVIEW has been selected as the graphic programming environment. Figure 3 shows the different control signals of the system actuators which may be: the signal of the propulsion speed, the signal of the propulsion direction and the signals of the stabiliser flaps. Each engine is controlled by a speed variator, a servomotor and a PWM control circuit.

All of the manoeuvres are programmed in this software support so that they can be performed automatically. To do this; the Industrial PC has a resident application, SCADAIn-

dustrial.vi, which controls the movement of the turbojets in order to perform the manoeuvres. It also captures and stores the data from all of the instruments that make up the platform.

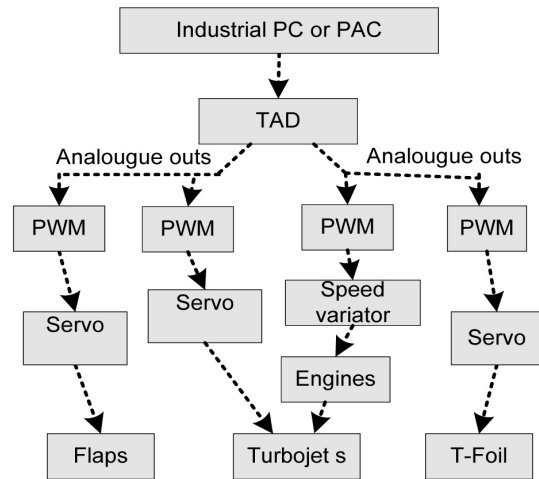


Figure 3: Control of propulsion.

#### 4.2. Software support communications system

In a first stage of the project, the communication between the computer located on land and the one positioned on the sea vessel was made through a wireless network using Wi-Fi technology based on the standard 802.11g. This had the disadvantage that it was not appropriate for the transmission of images because of the limitation of 22 Mbps, making it necessary to use multidirectional antennas to amplify the signal in order to obtain a coverage of around 300 m, the result being the same as if the two pieces of equipment had been connected to a typical local area network. By having an access point in repeater mode, the coverage is tripled, with the only drawback that the technical specification forbids Wi-Fi Protected Access (WPA) encrypting between two access points configured in repeater mode, so that all of the information we send can only be encrypted in Wired Equivalent Privacy (WEP) mode, an encryption which has proven to be vulnerable, even in its 128 bit version. The above-mentioned antennas were large enough to modify the dynamic behaviour of the in-scale vehicle, which was a problem for marine trials. By the time standard 802.11n appeared, wireless networks could be made without large antennas thanks to MIMO antenna technology, which meant that there was no modification in the vehicle dynamics and also that the transmission of images from a video-camera was possible.

Another important feature of the communication system is that the station base can in turn communicate with one or several PCs equipped with a 3G UMTS mobile telephone card with transmission speeds of 384 Kbps. The station base laptop also has a 3G PCMCIA card, which allows access to Internet. Once connected to Internet, it is possible to connect with any other PC or PCs connected to Internet. These PCs may be connected to Internet via an Ethernet cable or using a 3G PCMCIA card.

#### 4.3. Publication of Vis in DataSocket Server and in Web Server

In order to be able to access the SCADA type application being run on the Industrial PC via the wireless network and at the same time be able to access this application from another or other PCs through Internet, it was necessary to combine DataSocket technology and the web publication of LabVIEW in the software support, as can be seen in Figure 4.

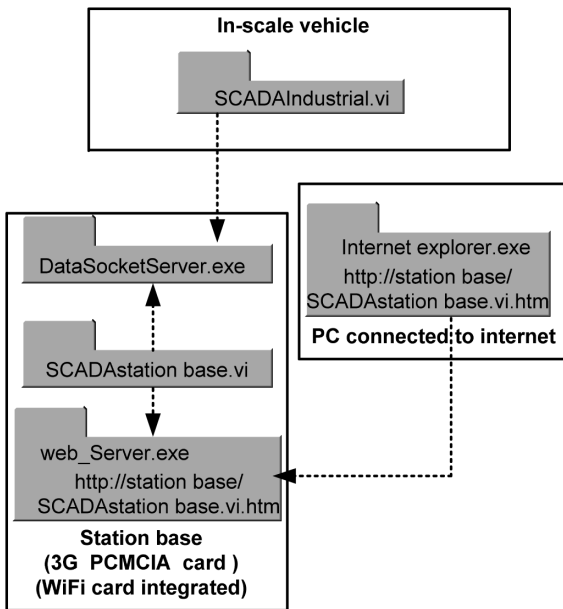


Figure 4: Software System Applications.

There are two graphic interfaces with the same appearance: one called SCADAIndustrial.vi which is run on the Industrial PC and another called SCADAstation base.vi which is run on the station base. These two applications interchange information bi-directionally through the LabVIEW DataSocketServer in the station base. Any control modified by the use in the remote application of the station base will automatically be modified in the application of the Industrial PC. At the same time, the SCADAstation base.vi application publishes its data on the web server which is also in the station base. Thus, any other PC connected to Internet may have access to this application and take over the control at any moment. A PC, or more than one PC, can be connected through Internet. It must be borne in mind, however, that only one of them can assume control of the application while the others can only visualise the data. The implementation of the communications system described above might have been undertaken using only DataSocket technology. However, apart from the SCADAIndustrial.vi for the Industrial PC and SCADAstation base.vi for the station base, it would have been necessary to design one application for each computer connected to Internet that was required to connect to the station base. This is why web server technology is also being used since, in this way, any computer connected to Internet can access the station

base by typing in the corresponding address in a search engine, such as a web browser, without the need to create a new application for each computer that was required to connect to the station base. For all of these reasons, the most adequate solution is to combine DataSocket technology with the LabVIEW web server technology.

When using DataSocket technology, each of the controls of the SCADAIndustrial.vi application or the SCADAstation base.vi application which form the user interface, such as the scroll bars, on/off buttons, text frames, etc. are the elements denominated 'items'. These items are published through a DataSocket Server capable of publishing data so that other client processes can read them or write them. In our system, the SCADAstation base.vi application is connected to the DataSocketServer where all of the items of this application are published, in reading and writing mode (Figure 5). In the same way, the SCADAIndustrial.vi application is connected to the DataSocket-Server through the wireless network to access the data published by the client application of the station base. The Client application of the Industrial PC subscribes to the data published by the station base and has only reading capacity, not writing.

The technology includes the DataSocket Transfer Protocol (DSTP) communication protocol used by LabVIEW, a protocol based on TCP/IP. It is possible to connect the DataSocket-Server using DSTP URL, as shown in the following example.

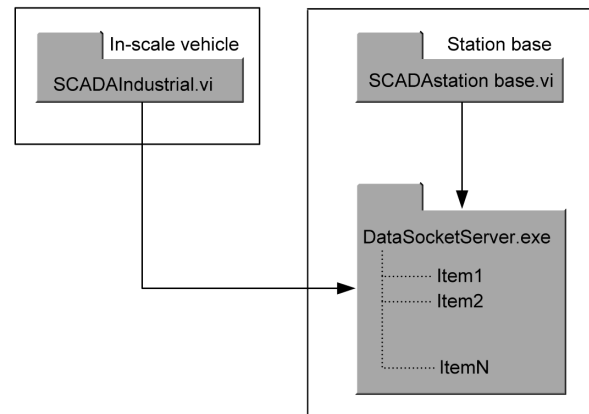


Figure 5: DataSocket communication.

The URL below connects in the DataSocket server the data called Item1 which is being run on the same computer, the local computer, which may be the station base where the SCADAstation base.vi application is available.

Dstp://localhost/Item1

The URL below connects the data from the in-scale vehicle to the Item1 in the DataSocketServer which is running in the station base connected to the wireless network.

Dstp://DireccionStation base/Item1

In this way, data are exchanged through the wireless network between the industrial PC and the station base with a single DataSocketServer.

Once the above-mentioned applications are connected to the wireless network using DataSocket technology, the net-

work can access from an external network, such as Internet, the SCADAstation base.vi application via the web server. For this, it is necessary to key in the corresponding address in a web browser, such as Internet Explorer. The parameters of this URL specify on the one hand the web server address, which in this case is the address of the station base, and on the other hand the name of the corresponding application (SCADAstation base.vi). The full address is given below: <http://address.server.web/nameVI.htm>

The SCADAstation base.vi application of the station base and the application embedded on a web page which can be seen when the corresponding address is keyed in Internet Explorer are shown in Figure 6.

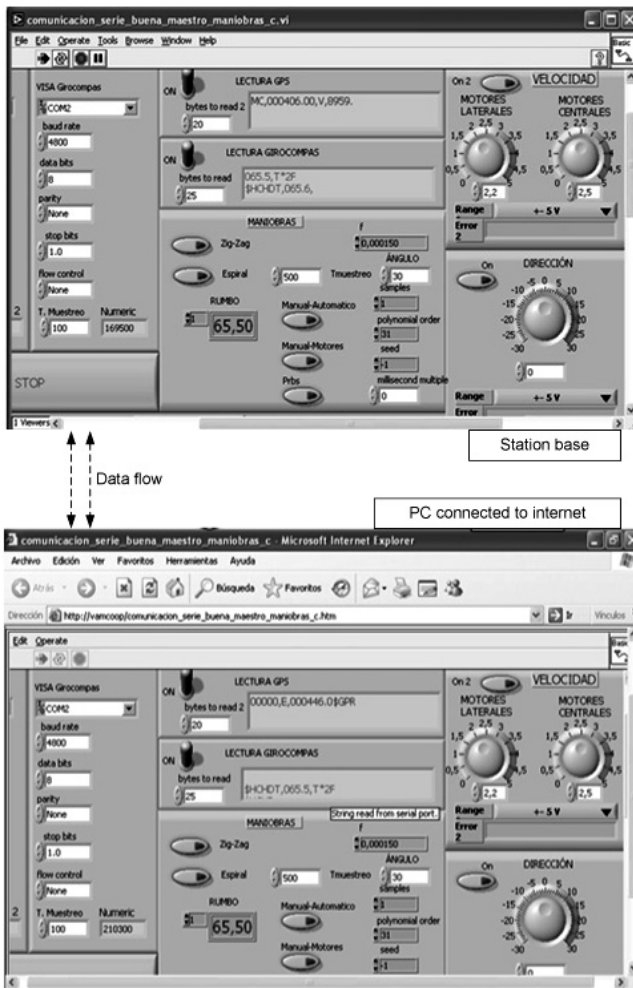


Figure 6: Communication via web between a PC connected to internet and the station base.

## 5. Conclusions

This paper has reviewed the wireless standards considered to be the most suitable for the application of the remote experimentation of marine vehicles. Taking into account the requirements of this experimentation environment, the standard draft 802.11n has been selected, as this allows extensive reach with MIMO technology and has a great capacity of transmission. The correct functioning of the wireless network has been verified in an open environment, as is the Bay of Santander. Also, this network has been equipped with the capacity to connect to Internet by means of 3G technology in order to enable access to the remote experimentation environment from any computer that is connected. In this way, a user with an Internet connection is able to visualise and change parameters of the application of the base station, with all of the possibilities that this implies not only for research but also for education.

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