Wireless Communications for marine sensor networks

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***Abstract*—Current marine wireless communication systems used for monitoring applications based on buoys suffer from lots of weakness. Many research works concern the design and development of new technological applications to improve marine communications. Particularly, a wireless sensor network (WSN) based on WiMAX standard at the 5.8 GHz band (license-exempt band) could be a good candidate. WSNs are a highly attractive solution in that they are easy to deploy, operate and they are composed of many relatively inexpensive sensor nodes. As an initial task, a propagation channel measurement campaign in maritime environments was carried out to investigate the impact of the wireless channel on inter-node communications. This work provides radio measurements between two nodes of a marine WSN near urban environments. In particular, a link between a buoy and a small ship is investigated. The designed measurement system is described and the experimental measurements are shown. This investigation is useful, among others, for planning Worldwide Interoperability for Microwave Access (WiMAX) networks offshore around these challenge environments.**

Propagation channel measurements; WiMAX; maritime environment; Wireless Sensor Networks;

I. INTRODUCTION

Recently, many studies have identified an emerging demand for telecommunication services in several applications over sea. Some of them are getting great interest for the scientific community, e.g., those related to real-time monitoring of the marine environment through sensing multiple physical parameters. Although the number and kind of parameters depend on the specific application, e.g., physical, chemical and/or biological measurements (temperature, pH, salinity, turbidity, phosphates, etc.), monitoring systems are quite similar. These systems are composed of sensor nodes, frequently buoys, which transmit the data wirelessly to a sink node (the base station) for processing and monitoring purposes (see Fig. 1). This base station could be installed on shore or aboard a ship. This last case is particularly interesting for some applications, e.g., those related to oceanographic campaigns.

Current wireless technologies used in this kind of applications are mainly based on VHF, cellular mobile telecommunication systems (GSM, UMTS, etc.) and satellite communications systems (INMARSAT, VSAT, etc.). However, these systems suffer from lots of weakness [1], like low bandwidth or capacity (GSM, Satellite and VHF systems), short range (cellular mobile telecommunication systems), high cost for certain applications (satellite and cellular mobile telecommunication systems) and the large size and weight of antennas and hardware transceivers (VHF systems). These limitations have motivated a new research activity in this field. The general goal is to design and develop a novel broadband wireless communication system to perform applications like the one mentioned above.

A Wireless Sensor Network (WSN) [2] based on WiMAX standard ([3], [4]) could be a good candidate to accomplish this task. WSNs offer a new paradigm for marine monitoring, as in many other applications such as structural health monitoring, traffic control, precision agriculture, environmental, underground mining, etc. WSNs are a type of autonomous, self-organized ad-hoc network composed of tens, hundreds or even thousands of smart sensor nodes that can monitor large physical environments. In a WSN, sensor nodes have not only the sensor component, but also on-board processing, communication, power, and storage capabilities (all are limited resources). This work focuses on aerial WSNs, i.e., sensor nodes communicate each other through the air over sea. In Fig. 1 a general architecture of this kind of network is showed, where the two most common topologies are illustrated: star, where the type of inter-node communications is point-to-point, and mesh networking, where inter-node communications are multihop, i.e., a node could send the measured data to the base station through intermediate nodes. Moreover, in both topologies, there is, at least, one node which is in charge of communicating all data to a base station.

Many design issues in a WSN differ from traditional systems and networks on land; hence, they present unique

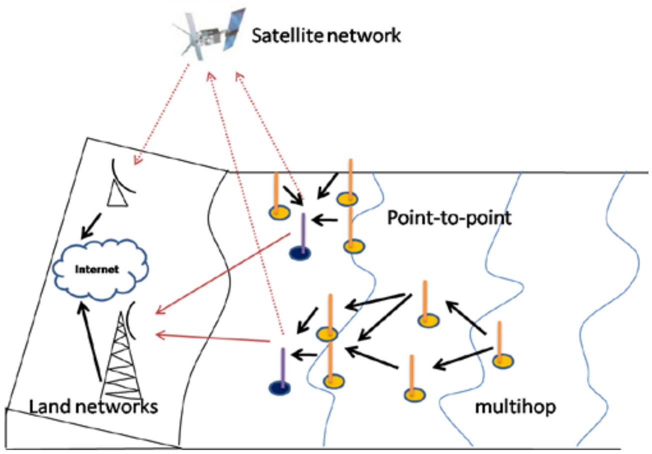

Figure 1. General architecture of a marine Wireless Sensor Network.

challenges and constraints. The design, implementation and deployment of a WSN for marine applications pose new challenges as the impact of the marine environment on the sensor network limits and affect their development. The following are some of the most important differences:

- Energy is the main constraint in the design of all node and network components. Energy consumption is high since it is generally necessary to cover large distances.
- It is required greater levels of device protection due to the aggressiveness of the marine environment. This has a direct impact on the device cost.
- The influence of node movements, e.g., due to tides, waves, ships, etc., in the network performance have to be studied in depth.
- There are added problems in the deployment of the network nodes as well as their maintenance because they are integrated with the buoy platform, flotation and mooring devices, etc. Additionally, possible acts of vandalism can take place.

For wireless communications, each sensor node incorporates a radio module, which is chosen, among others, to suit the desired range. Sometimes, in order to increase the range, higher output power in the transmitter, improved LNA (Low Noise Amplifier) in the receiver and higher antenna gains, in both, are used. There are several types of antenna (omnidirectional, sector type, etc.) which are chosen on the basis of characteristics such as the radiation pattern, the gain, the bandwidth, the beamwidth, the efficiency, and the wave polarization. In the case of marine WSNs, sensor nodes antennas should have an omnidirectional radiation pattern and a specified minimum vertical beamwidth so that the radiated power is nearly the same in all directions on the horizontal plane. This is necessary in that the movement of the sea can cause the node to move rotationally, vertically or horizontally, thus altering the original position of the buoy platform. However, this kind of antenna radiates great part of the power in lot of directions and hence the range is smaller than with more directional antennas. Furthermore, the omnidirectional receiver antennas pick up more interferences from other networks and multipath signal from the own WSN. Other important factor that must be taken into account is the height of the antenna with respect to the flotation device supporting the node, since over long distances, visual Line-Of-Sight (LOS) is not sufficient for propagation due to additional attenuation originated by sea, which obstruct the LOS signal. The range of these nodes is affected by that height according to the Fresnel Zone theory [5]. In some circumstances the techniques described above to improve the communication range are not sufficient to improve the communication performance and a carefully study of the specific environment is required to acquire knowledge about the wireless propagation channel.

It could be possible to use different wireless communication standards and technologies that work well on land with a demonstrated performance for inter-node communications. The technology chosen will depend on the requirements of the specific application which in turn will be determined chiefly by the environment, the amount of information that has to be sent and the minimum specified data rate.

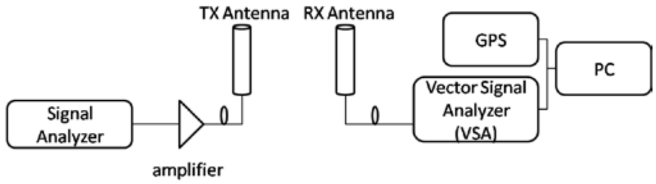

Figure 2. Block diagram of the measurement system.

WiMAX is an evolving technology that is optimized for operating on land environments where its good performance has been extensively demonstrated. Several frequency bands can be used for deploying this system. The license-exempt 5 GHz band is of interest to WiMAX because this is generally available worldwide and it is free for anyone to use, i.e., it could enable deployments in underserved markets, like the maritime one. In particular it is the upper 5.725 GHz-5.850 GHz band that is most attractive due to the fact that many countries allow higher power output compared to other bands. This facilitates less costly deployments. Regarding range and peak data rates, field tests on land have shown tens of kilometers and Mbps, respectively. All these potential characteristics overcome the weakness described above. However, the performance of WiMAX networks in marine environments is not optimum due to the different radio propagation conditions. Hence, the main goal is to optimize the WiMAX standard for maritime applications.

An initial and crucial task for the optimization of this standard over sea is to study the radio propagation channel in these scenarios in the 5 GHz band. Particularly, in this work, buoy-to-ship propagation measurements were performed over sea near urban environments.

Propagation measurements for land have been discussed extensively [5]. Further works in this field have been done in urban and suburban environments [6], [7]. Besides, although [8], [9] and [10] present experimental measurements of propagation characteristics for maritime radio links, they do not apply to conditions covered by our study. To the best of the authors' knowledge, buoy-to-ship path loss characteristics over sea at 5.8 GHz near urban environments have not been investigated. In this work, we focus on large scale characteristics in NLOS (Non-Line-Of-Sight) and LOS (Line-Of-Sight) paths. We discuss them analyzing the measured received signal in a real marine scenario. This work is helpful, among others, to deploy WiMAX systems in these challenges scenarios.

II. MEASUREMENT SYSTEM

Measurements were carried out by transmitting a 30 dBm Continuous Wave (CW) from an antenna installed on a buoy and receiving this signal in a receiver installed aboard a ship. This measurement system is fully described in Fig. 2. A 0 dBm CW signal at 5.8 GHz was transmitted from a signal generator. This output CW signal was further amplified 33 dB by a broadband amplifier up to 1 W (transmitter cable loss was 3 dB). This signal was the input of the antenna installed on the buoy. The used antenna had the following main characteristics:

9dBi gain, vertical polarization, omnidirectional radiation pattern in the horizontal plane and 7º beam-width in the vertical plane. This transmitter antenna was mounted 1.9 m from the sea surface. The receiver antenna was the same as the transmitter one and it was mounted 3.3 m from the sea surface. The received signal by the antenna was the input to a vector signal analyzer which was in charge of measuring it. A computer was connected to the analyzer in order to record the received signal to further processing. In addition, a GPS (Global Position System) device was also connected to the computer to time-stamp the received signal. Moreover, the GPS signal acquired by the computer was useful to calculate the separation distance between the ship and the buoy. The instantaneous received signal from a CW transmission was measured. Then, the local mean power was calculated from this signal each second.

III. EXPERIMENTAL ENVIRONMENT AND MEASUREMENTS ROUTES

Cadiz bay (Spain) was selected to represent a maritime challenge scenario where it is possible to take into account lots of environments characteristics. This zone has a heterogeneous topography with dense populated urban areas including large infrastructures and buildings. Moreover, some nautical clubs and an important commercial port are along the shore. Therefore, large and small ships are anchored around and the fairways are very dynamics.

The measurements were carried out during a shiny day. The temperature ranged between 20 and 25 ºC. The humidity was around 95 %. The sea condition was calm and there was no large wave. The atmospheric pressure was 759 mm. The wind strength reached 3 and 4 force level.

In order to investigate the impact of these kinds of environments on the transmitted signal, a measurement campaign was planned over the route showed in Fig. 3; this figure represents several intermediate waypoints along the route.

Figure 3. Route followed by the ship (red) and fixed location of the buoy (green) in the experimental scenario.

IV. RESULTS

A. Theoretical Results from Reference Models

A simple model being able to apply to propagation in maritime environment, under some assumptions, is the two-ray model. This model is considered in this work as a theoretical reference [5], [11]. It takes into account two rays between transmitter and the receiver: a direct ray and a reflected one by the sea surface.

It is possible to calculate the path loss at a given point, according to (2): the magnitude and phase of the reflection coefficient on the sea (|*R*| and *β*, which also depend on the wave polarization, the incidence angle of the reflected ray on the sea, and the conductivity and permittivity of the sea), the phase difference (*Δ*) due to the different path lengths between the direct ray and the reflected one (it also depends on the relative heights of the transmitter and the receiver from the sea), and *d* and *λ* that were defined in (1). Therefore, l_{2r} is the propagation path loss that predicts the two-ray model which is frequently used to calculate the propagation path loss over sea surface when isotropic antennas are assumed.

$$l_{2r} = \frac{\left(\frac{4\pi d}{\lambda}\right)^2}{1+|R|^2+2|R|\cos\ (\Delta+\beta)} \tag{2}$$

Therefore, in order to calculate the expected received power from this theoretical model when the transmitter and the receiver antenna gains are g_t and g_r, respectively, and the cable loss is l_c, (3) can be used:

$$p_r = \frac{p_t g_t g_r}{l_c l_{2r}} \tag{3}$$

B. Experimental Results

In order to accurately describe real propagation scenarios, experimental data are necessary. Fig. 4 shows the measurements carried out as explained in Section II over the route plotted in Fig. 2. The expected received power for the two-ray model was estimated as indicated in (3). The differences between the measurements results and the results expected by the theoretical model are clear. First, level differences at short distances are mainly due to antenna movement effects and the poor alignment due to the different antenna heights. Second, there are some groups of measurements that fit quite well the expected theoretical

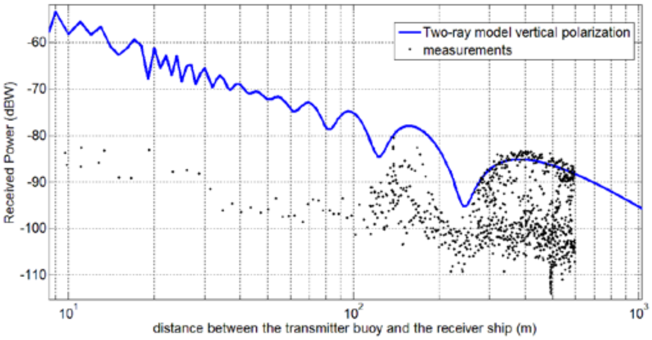

Figure 4. Measured received power in the maritime environmet over the route showed in Fig. 3 and the theoretical results expected by the two-ray model for vertical polarization.

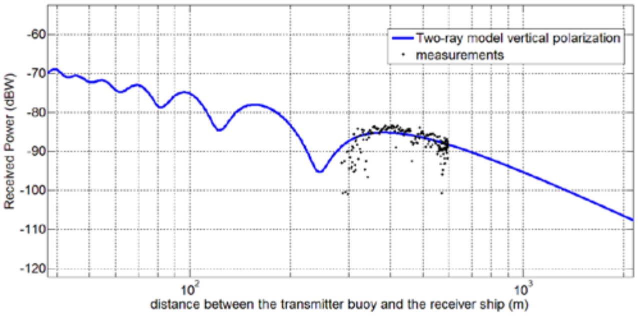

Figure 5. Measured received power in the maritime environmet over the route showed in Fig. 2 from 1 to 2 waypoints and the theoretical results expected by the two-ray model for vertical polarization.

results. In fact, Fig. 5 shows the results represented in Fig. 4 only for the way from 1 to 2 (see Fig. 3), where LOS condition was checked experimentally. Third, the received signal suffers high additional losses and signal dispersion in respect of which predicted by the theoretical model when the LOS signal is totally or partly blocked. It was also checked in other research works with different configurations [12], [13].

It was difficult to maintain the LOS condition in the real marine scenario due to temporal LOS blocking by ships and sea waves. Besides, the curvature of the earth blocks the signal gradually with the distance. Signal strength can experiment large-scale variations due to macroscopic objects within the propagation environment that create shadow zones. For instance, in sea environments, large ships, buoys, coast relief, buildings near harbor, islands situated between transmitter and receiver, etc., can create high variations in the received signal and this phenomena is not distance-dependent. Hence, the received power can be modeled as a random process.

V. CONCLUSIONS

Research activities on the use of WSNs for oceanographic monitoring are still in a starting point. It points to several exciting challenges which require further interdisciplinary collaboration. This work presented experimental researches on new wireless technologies applied to marine environments for this kind of applications. The characterization of the wireless propagation channel is necessary to understand accurately de behavior of radio waves in these scenarios.

It should be noticed that two-ray model fits measured received signal reasonably well when LOS condition remains. At short distances it is necessary to take into account the antenna effects. In addition, the received signal suffers high additional losses when LOS condition does not remain; furthermore, higher dispersion values were found. This limits the coverage zone of WiMAX. Other important aspect to be considered before deploying these systems over sea is the presence of nulls as predicted by two-ray model at short distances. This is likely due to severe absorption, diffraction and scattering mechanisms. Therefore, careful networking planning is needed in order to ensure broadband connectivity everywhere over sea.

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