Experimental Time Dispersion Parameters of Wireless Channels over Sea at 5.8 GHz

José Carlos Reyes-Guerrero and Luis Antonio Mariscal
Dept. of Computer Languages and Systems, Nautical Science Faculty, University of Cadiz, Puerto Real, Spain
josecarlos.reyes@uca.es

Abstract - Many research works concern the design and development of new technological applications to improve marine communications. In this work, a propagation channel measurement campaign in maritime environments was carried out to investigate the impact of this kind of environments on wireless communications. In particular, we focus on time delay dispersion characteristics of mobile channels for the propagation over sea at 5.8 GHz. Specifically, a wireless link between a buoy and a ship is studied in different multipath conditions. The aim of our designed measurement system is measuring, first, a series of instantaneous Power Delay Profiles (PDPs) and, second, analyzing them over local regions. The empirical cumulative density functions of the delay parameters (mean delay and rms delay spread) and the coherence bandwidth are presented and discussed. As concluded, the delay parameters and the coherence bandwidth were found quite different even when the transmitter and receiver locations do not vary significantly.

Keywords - Maritime communications; wideband mobile channel measurements; Power Dealy Profile; delay dispersion parameters; coherence bandwidth

I. INTRODUCTION

Recently, many studies have identified an emerging demand for telecommunication services in several applications over sea. Some of them are getting great interests for the scientific community, e.g., those related to real-time monitoring of the marine environment through sensing multiple physical parameters. Monitoring systems are quite similar even though the number and the parameters type depend on the specific application such as physical, chemical and/or biological measurements (temperature, pH, salinity, turbidity, phosphates, etc.). These systems are composed of sensor nodes which could be generally buoys, ships or stable platforms over sea which, in their turn, transmit the data wirelessly to a sink node (the base station) in order to be processed and monitored. This sink node could be either installed on shore or aboard a ship. The latter is particularly interesting for some applications, especially those related to oceanographic. In this work, we focus on the wireless link between a transmitter buoy and a receiver ship in different multipath conditions.

The current wireless technologies used in this kind of applications are mainly based on VHF, cellular mobile telecommunication systems (GSM, UMTS, etc.) and satellite communication systems (INMARSAT, VSAT, etc.). However, these systems suffer from lots of weaknesses like low bandwidth and capacity (GSM, Satellite and VHF systems), short range (cellular mobile telecommunication systems), high cost for certain applications (satellite and cellular mobile telecommunication systems) and large size and weight of antennas and hardware transceivers (VHF systems) [1]. These limitations have motivated a new research activity aiming to design and develop a novel broadband wireless communication system to perform applications like the ones mentioned above. For this purpose, it could be possible to use different wireless communication standards and technologies that work well on land and which have demonstrated a good performance. The technology chosen will depend on the requirements of the specific application which will be determined chiefly by the environment, the amount of information to be sent and the minimum specified data rate.

WiMAX is an evolving technology optimized to operate on land environments where its good performance has been extensively demonstrated [2]. Several frequency bands can be used for deploying this system. The license-exempt 5 GHz band is of interest to WiMAX, because it is generally available worldwide and free for anyone to use, i.e., it could enable deployments in underserved markets like the maritime ones. 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 weaknesses 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 wireless propagation channel in these scenarios in the 5 GHz band. Propagation measurements for land have been discussed extensively [3]. Further works in this field have been done in urban and suburban environments [4], [5]. In maritime wireless links, large-scale experimental propagation characteristics, for different radio conditions and configurations, were shown in previous studies [6]-[9]. In this work, we focus on time delay dispersion characteristics, in different multipath conditions, by performing buoy-to-ship wideband channel sounding measurements over sea near urban environments. Time delay dispersion characteristics have already been studied in propagation environments over sea [10]. However, our study covers different conditions in terms of, among others, frequency band of interest, type of wireless terminals involved, propagation environment and measurement system technique. To the best of the authors' knowledge, buoy-to-ship delay dispersion characteristics over sea at 5.8 GHz have not been investigated.

II. Experimental Environment and Measurement Locations

Cadiz bay (Spain) was selected to represent a maritime challenge scenario where it is possible to take into account a lot of environment 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 placed along the shore. Therefore, large and small ships are anchored around and the fairways are very dynamics.

The measurements were carried out in a sunny day. The temperature ranged between 21 and 25.6 ºC. The humidity was around 95 %. The sea condition was calm and there were no large waves. The atmospheric pressure was about 1009 hPa. The wind speed reached 12.5 m/s.

In order to investigate the impact of this kind of environment on the transmitted signal, a measurement campaign was planned over several fixed locations. This work focuses on two sets of measurements carried out when the transmitter (buoy) and the receiver (ship) were at the locations showed in Fig. 1. The distance between them (200 m) is a typical range expected in future marine sensor networks [11].

III. Measurement System and Signal Processing

In order to study time delay dispersion characteristics, measurements were carried out using the direct RF pulse system technique [3]. The designed measurement system, composed by off-the-shelf equipment, is fully described in Fig. 2. It basically operates by transmitting a rectangular pulse periodically with a mean power of 30 dBm from an antenna installed on the buoy and measuring the multipath signal in a receiver installed aboard the ship which was stationary near the shore (Fig. 1). Specifically, pulses at the frequency carrier of 5.8 GHz, with a mean power of 0 dBm, were transmitted from a signal generator. The pulse width and the signal period were set to 20 ns and 2.5 us respectively. This output signal was further amplified by a broadband amplifier up to 33 dBm. This signal was the input of the antenna installed on the buoy (with an attenuation of 3 dB due to the transmitter cable loss). 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 sets of measurements for 0.2 s in the time domain with a sampling frequency of 179.2 MHz. Data were sent via an Ethernet interface to a computer, where they were stored for later analysis. In addition, a GPS (Global Position System) device was also available to time-stamp the received signal and to calculate the distance between the ship and the buoy.

Figure 1. Experimental environment. Transmitter buoy (yellow) and receiver ship (red) locations.

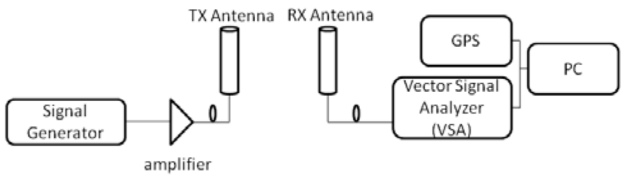

Figure 2. Block diagram of the measurement system.

From the received signal, the Power Delay Profiles (PDPs) of the channels can be estimated. Although the receiver measures the instantaneous profiles, to prevent fade effects from affecting the measurement, it is necessary to average several consecutive instantaneous profiles. In this way, possible fades or enhancements showing on the instantaneous profiles, at given delays, are smoothed out and we can focus on the delay domain. Additionally, this average process leads to an enhancement of the measured Signal-to-Noise Ratio (SNR).

Generally, the average has to be performed over a few wavelengths (local region), where the channel can be regarded as quasi-stationary. In this local region, the channel can usually be modeled as a WSSUS (Wide-Sense Stationary Uncorrelated Scattering) [12]. Thus, the first step is to sort out measured instantaneous PDPs in sets of short time intervals over which statistics do not change noticeably (WSS assumption). This task was carried out analyzing the mean received power over short time intervals and ensuring it is approximately constant over the local region finally chosen. In addition, uncorrelated scattering is generally assumed, although it depends on the specific scenario.

Once the local regions have been defined, the average of the instantaneous PDPs is carried out. The result is one PDP in each local region. Then, as a second step, it is crucial to determine the noise and/or spurious threshold of the system accurately and to allow a safety margin on top of that because they can affect the measurement significantly. In fact, we had to measure it in each location due to interferences from emissions of other wireless systems in our band of interest. As a consequence, the noise threshold is finally set to the maximum of the averaged measured spurious signal, in the local region, plus a safety margin of 0.5 dB. Finally, as a third step, a minimum peak-to-spurious ratio of 10 dB (excluding the safety margin) is used as an acceptance criterion before a multipath echo is included in the statistics [13].

IV. RESULTS

In this section we present the results on the channel characterization in the time delay domain. For that, as explained in Section III, PDPs are estimated in different local regions. Specifically, two data sets are studied. Hereafter, they are referred as a data set 1 and data set 2. Although both data sets were obtained for the same transmitter location, in the first one, the transmitter buoy was stable over the sea surface and, in the second one, the buoy was moving, according to sea conditions, which made the transmitter antenna not to point at the receiver antenna perfectly. Moreover, it should be taken into account that both data sets were not measured at the same time (the elapsed time between them was about 2 minutes).

In Fig. 3 and Fig. 4, two examples of PDPs are depicted, which belong to data set 1 and data set 2, respectively. Both PDPs are shown before applying the noise threshold (after the first step as explained in Section III). It can be noticed that the multipath shapes are clearly distinct. This is due, among others, to antenna pointing effects (as discussed, the transmitter antenna moves according to the buoy movements, and the radiation pattern is not omnidirectional in the vertical plane) and the position variations of some of the objects in the surrounding environment. Comparing both examples of PDPs, LOS (Line of Sight) and low delays multipath components are found stronger for the data set 1. Moreover, some additional non neglected multipath components appear at higher delays in this same set. All of them have a spiky shape, which seem to correspond to different scatters located near the receiver (see Fig. 1).

In order to quantify these factors, time delay dispersion parameters (the mean delay and the rms delay spread) and the coherence bandwidth were extracted from the PDPs. The mean delay and the rms delay spread have been calculated after removing noise and spurious signals from each estimated PDP (Fig. 3 and Fig. 4 are examples of this kind of PDPs before removing noise and interference signals) and setting the first arriving path as the origin of the delay axis. The equations of both parameters are thus (1) and (2) respectively, where p denotes the power amplitude values and τ the discrete delay values. Moreover, τ_M is the delay value in which the first echo

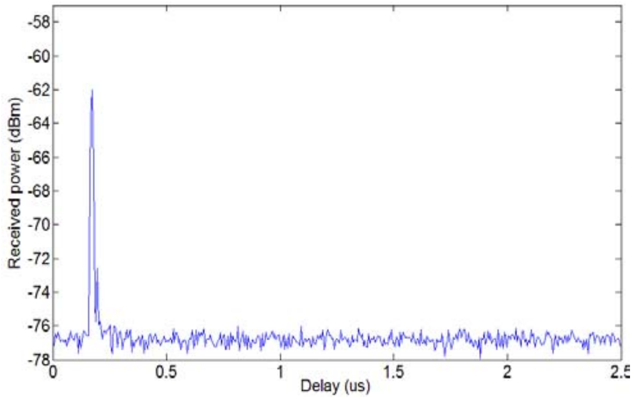

Figure 4. Averaged PDP example for data set 2.

arrives [13].

$$D = \frac{\sum_k p_k \tau_k}{\sum_k p_k} - \tau_M \quad (1)$$

$$S = \frac{\sum_k p_k (\tau_k - D - \tau_M)^2}{\sum_k p_k} \quad (2)$$

Given that each data set was recorded for 0.2 seconds and the time span during which quasi-stationary is assumed (local region) was set to 0.5 ms, we performed statistical analysis with delay parameters from 400 PDPs. In Fig. 5 and Fig. 6 the empirical cumulative distribution functions (CDFs) for both data sets are presented for mean delay and rms delay spread, respectively. The results can be easily understood since the more delayed and powerful multipath components are included in the estimated PDPs (data set 1) the higher values for the delay parameters are expected. In fact, according to Fig. 5, the mean delay remains below 20 ns at a percentage above 98% for data set 2 (some higher values are found, but these could be due to spurious signal effects), while it remains below 31 ns for data set 1. In addition, according to Fig. 6, the rms delay spread remains below 10.4 ns at a percentage above 97% for data set 2, while it remains below 29.1 ns for data set 1. Thus, the delay parameters reach higher values for data set 1 as expected.

In addition to the previous results, the frequency correlation function was estimated in each local region in order to investigate frequency correlation characteristics. It can be

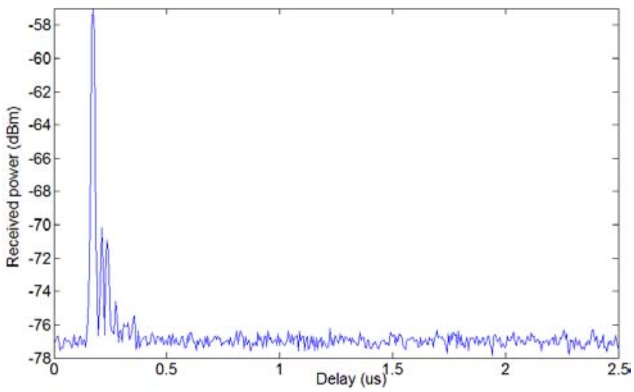

Figure 3. Averaged PDP example for data set 1.

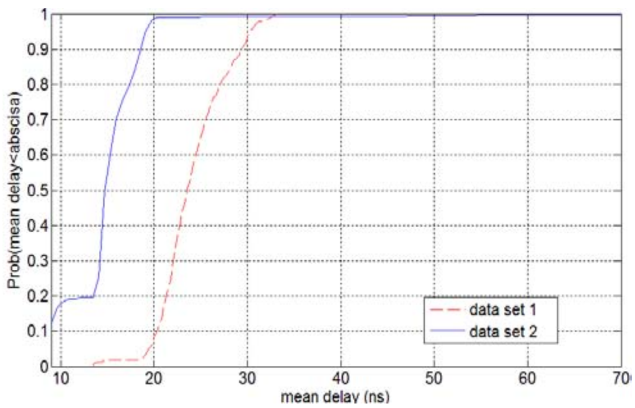

Figure 5. Experimental CDFs for mean delay.

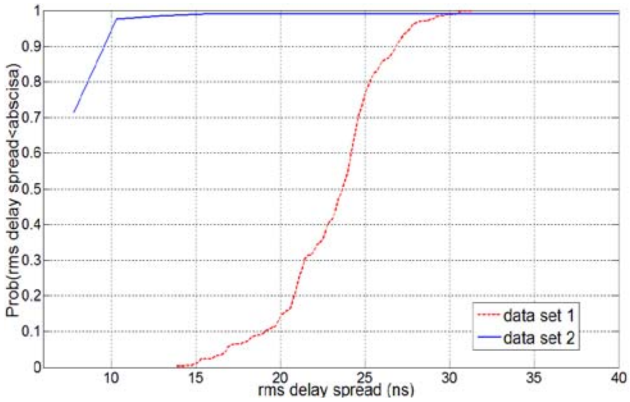

Figure 6. Experimental CDFs for rms delay spread.

calculated through the Fourier transform of the PDP as indicated in (3), where Δf is the frequency separation.

$$C(\Delta f) = \sum_k p(k) e^{-j2\pi\Delta f\tau} \quad (3)$$

Performing the magnitude of this frequency correlation function and normalizing it to give a maximum value of one, we can compute the coherence bandwidth for a certain percentage. For instance, the empirical CDFs for coherence bandwidth using a correlation value of 0.9 for both data sets are presented in Fig. 7, where we can see that the coherence bandwidth is inversely related to rms delay spread as expected; e.g., higher coherence bandwidth values are expected for data set 2 because rms delay spread values were found lower.

V. CONCLUSIONS

Characterization of marine wireless propagation channels is necessary to understand accurately the behavior of radio waves in these challenge scenarios. In this work, we focused on time delay dispersion characteristics in different multipath conditions. For this purpose, two experimental data sets of PDPs were analyzed.

Through a comparison of the results obtained from both data sets, it could be concluded that the delay parameters were found quite different even when they were obtained in similar operational conditions. Moreover, coherence bandwidth values were found inversely related to rms delay spread values, as expected.

In addition, the estimated PDPs were found with a spiky shape that can be explained by the nature of the channel. Similar results were obtained for several transmitter locations

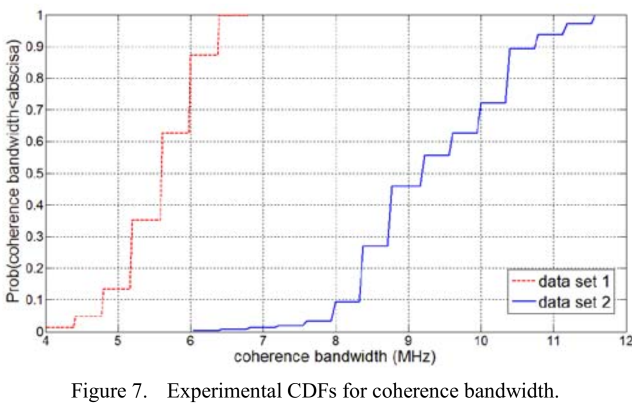

Figure 7. Experimental CDFs for coherence bandwidth.

in the campaign. Therefore, the antenna radiation patterns should be chosen carefully due to they can affect PDP estimations significantly.

In some cases, delay parameters remain small. Thus, depending on the signal bandwidth of a wireless system operating in this channel, the fading can be regarded as flat and, hence, the channel could be modeled as narrowband. Larger efforts acquiring additional data in similar propagation environments are necessary to perform a large scale characterization.

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