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# Experimental measurements of propagation characteristics for maritime radio links

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**Abstract:** This paper presents studies, carried out by Télécom Bretagne, concerning new radio technologies (mainly WiMAX, 802.16e) in the maritime environment. The aim of these studies is to reinforce the quality and the robustness of such transmissions. Several measurements were set up to characterize the propagation channel in maritime environment in order to study the communication performances of WiMAX. This characterization was obtained by specific experimental devices, developed and implemented by Télécom Bretagne. The experimentations were carried out at frequencies of 3.5 GHz (Licensed WiMAX Band in France) and 5.8 GHz (Free Band in France). Similar studies [1] and [2] were already carried out, but they did not take into account all the environment characteristics, namely tides and coast relief masking. Our study looks at these parameters for a better understanding of the propagation in operational transmission environments. In this paper, measurements were carried out by measuring the mean received power both for several distances over the sea and for a coastal point-to-point link during long periods. Part of the work presented in this paper has been obtained during the Ex'treme project.

**Index Terms:** propagation channel measurements, maritime environment, two-ray model, WiMAX.

## I. INTRODUCTION

As mentioned in [2] and [3], a basic model being able at a first order to apply to the propagation in maritime environment is the two-ray model. This model takes into account one direct path between the transmitter and the receiver and another path refracted by the sea. For this model, it is possible to calculate the level of the received field at a given point, according to: the distance between the transmitter and the receiver, the relative heights of the transmitter and the receiver from the sea, the wave polarization, the working frequency, the conductivity, the relative permittivity of the sea and the transmitted power.

The present study aims at evaluating the levels of accuracy of this model and at examining two other causes of modification of the propagation channel:

- the masking effects due to the coastal relief and islands situated between the transmitter and the receiver,

- the tide effects that modifies the refraction conditions of the indirect path.

The paper will show various propagation characteristics observed during our experiments.

## II. MEASUREMENTS

### A. Measurement Locations

The measurements were carried out in the Brest harbour. The navigation conditions were good. Indeed the climate was gentle and the waves not very high. Figure 1 represents the locations where the measurements were carried out and an example of two routes covered by the boat with transmitting equipments (in yellow the forward route and in white the backward route). The point 1 (IFREMÉR site) indicates the receiver location for all the experimentations and the point 2 (Le Caro site) notices one other spot, in order to have a point-to-point fixed connection above the sea. The Brest harbour presents various types of environments, also defined in paper [4] in which four types of environments and five groups of measurements are mentioned.



Fig. 1. Example of routes (Max Tx-Rx distance = 27 km).

### B. Measurement Equipments

At the transmitting site (the boat), two kinds of signals may be generated: a continuous sine wave or a pulsed one. The system involves two generators, one for the carrier frequencies 3.5 GHz or 5.8 GHz and the other one for the pulse shaped

signals. The pulsed wave is built with a switch and a band pass filter. Two horn antennas are installed on the boat, the first at a height of 12 meters above sea level and the second one at a height of 3 meters above sea level. At the receiving site, two systems were available, namely a spectrum analyzer controlled by a computer and a second system build with PXI cards. A controller, a signal analyzer, a frequency converter and a data storage device constituted this last one. This acquisition system can record the received signal with 80 dB magnitude range and a 20 MHz bandwidth centred on a programmable frequency included between a few tens kHz and 6 GHz.

These two systems received the signal transmitted by means of a horn antenna followed by a filter and a low noise amplifier. This antenna was placed at the point number 1 with a height of 52 meters.

The antennas were 12 dB horn antennas with  $120^\circ$  horizontal aperture and  $30^\circ$  vertical aperture. A GPS equipped a PC on the boat. The time and the position data were recorded for each trip. These data make possible to readjust the recordings of the signal received according to the real distance between the transmitter and the receiver. These data were confirmed by the equipment of the ship. The GPS information was also used for clock synchronization of the Tx and Rx devices.

The following pictures represent the devices used for the experimentations.



Fig. 2. Transmitting devices.



Fig. 3. Receiving devices.

Throughout this paper, all the presented results concern the 3.5 GHz frequency.

### III. MEASUREMENT RESULTS

#### A. Theoretical Results

As indicated in the introduction a basic model being able to apply to the propagation in maritime environment is the two-ray model. It takes into account a direct way between the

transmitter and the receiver and a way refracted by sea surface. We consider this model for simulate the propagation over the sea, the figures 4 and 5 show simulation examples.

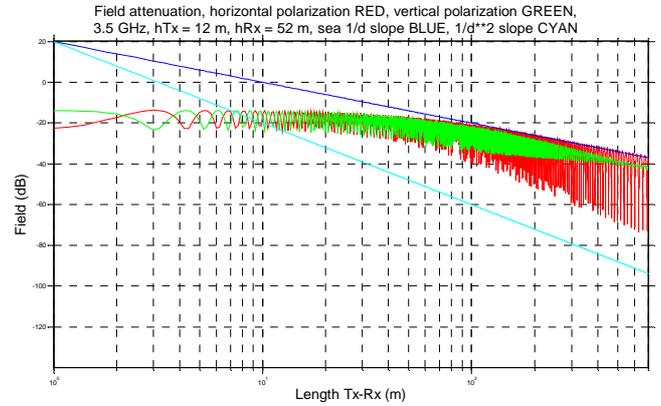


Fig. 4. Simulation with two-ray model: level of the received field according to the length Tx-Rx.

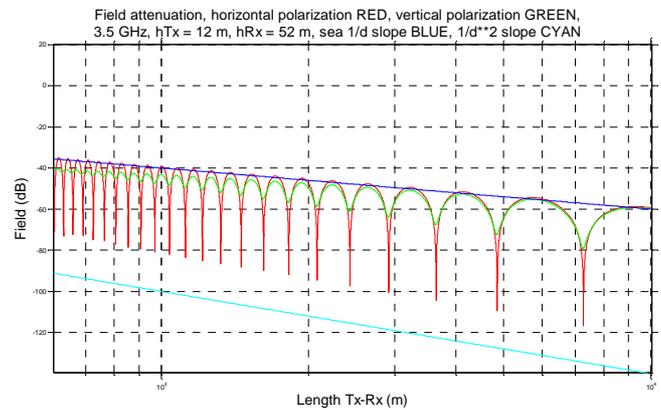


Fig. 5. Simulation with two-ray model: level of the received field according to the length Tx-Rx.

From the simulated results we can notice what follows:

- the average slope of path loss is proportional to the Tx-Rx distance approximately up to the radio electric horizon, as for a connection in free space,
- the average slope of path loss is proportional to the squared of the Tx-Rx distance, approximately beyond the radio electric horizon,
- the horizontal polarization presents major and recurrent fading (up to 60 dB) depending on the Tx-Rx distance,
- the vertical polarization presents major and recurrent fading (up to 30 dB) depending on the Tx-Rx distance,
- the fading of horizontal and vertical polarizations are phase opposite until a distance of few hundred meters,
- the distance interval between fading for both the horizontal and vertical polarizations exceeds the hundred meters for transmitter-receiver distances greater than approximately 1 km.

#### B. Experimental Results

These preceding characteristics were verified during experiments and some measurement results are presented now.

Geographical representations have been obtained from “Google Earth”. Figure 6 represents an example of route during which measurements were carried out.



Fig. 6. Example of route where the measurements were carried out (Max Tx-Rx distance = 14 km).

The following figure shows measurement results for the level of the received field, on this “mixed” course, corresponding to the two-ray model previously described but involving also some partial or total masking effects.

Results shown figure 7 compares the levels of theoretical values from the two-ray model, and measured ones of the received signal for a distance from A to C.

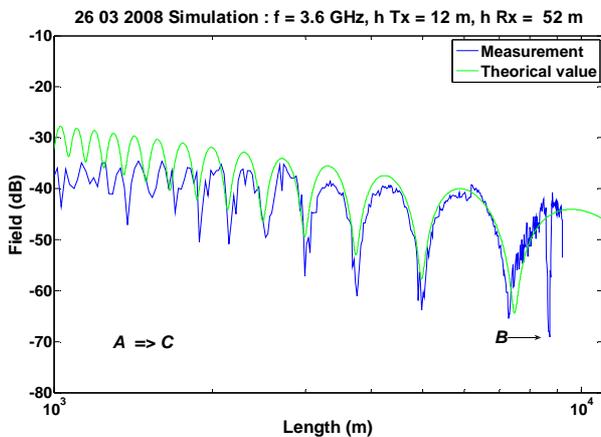


Fig. 7. Level comparison of the measured received signal with simulated values. In blue: measurements, in green: simulations

There is a good agreement between the theoretical values of field attenuation and the measurements. The level differences at the beginning of the travel are mainly due to antenna effects. Indeed, the Tx and Rx antennas has only 30 degrees vertical apertures, and the receiving antenna at point A was located at 52 meters above the sea, whereas the transmitting antenna was onboard a small ship. The sharp level fluctuation at the end of the record (position B) is a masking effect due to a small island.

For a better understanding of the masking effects, other experimentations were realized. The following figures show

some obtained results. Figure 8 shows a trip with an important masking effect and figure 9 shows the measurement results received field levels on this way.



Fig. 8. Example of route with an important masking effect.

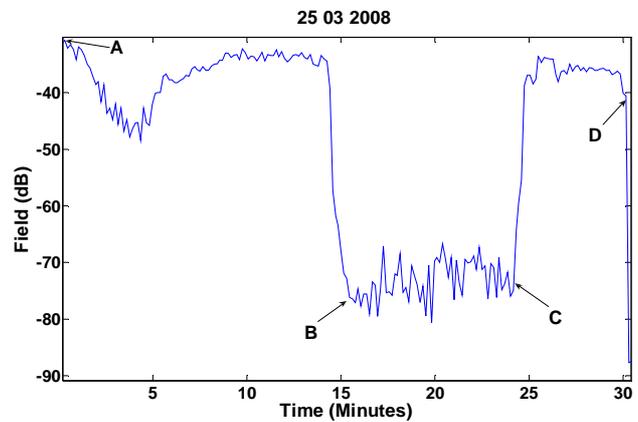


Fig. 9. Received field level with an important masking effect.

Sailing behind and near from point B causes a sudden fading of the field level (approximately 40 dB). The cause of this is the important height of this obstacle (76 meters). Other experimentation is shown with the figures 10 and 11. It is a long way where an important cliff is located between the starting point and the arriving point.



Fig. 10. Example of measurement location with an important masking effect.

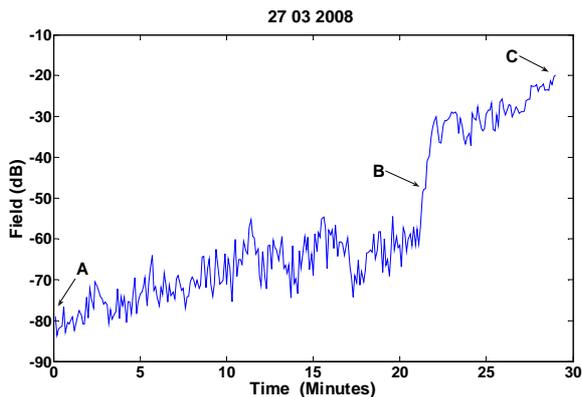


Fig. 11. Level received field with an important masking effect.

Here two effects are opposed: increase of the field level with the reduction of the transmitter-receiver distance and the masking effect growing when the boat gets closer the coastal point. In this configuration, it is the first that prevails slightly. At the point B, the mask effect causes a reduction of 25 dB as previously indicated to the passage behind the island.

### C. Tide effects

In the two-ray model, the relative heights of Tx and Rx antennas are important characteristics in calculation equation. In our situation, the effective antenna heights of course varied with the tide effects, which imply a modification of the indirect path. To evaluate this phenomenon the figure 12 presents the results of the field level received over a radio link between Tx and Rx on the ground, but above sea. Figure 13 presents the hours of tides corresponding to the measurement period.

These figures show the strong incidence of tides on the point-to-point fixed connection above sea. We note that for this link geometry, the maximum of the field levels were obtained for tide heights from approximately 1 and 6 meters. The minimum of the field levels were obtained for tide heights from approximately 2.5 meters.

Other descents of the field levels occur near 7 meters of tide heights, indicating that in the event of strong tide (over 8 meters), a minimum of field level would again be reached.

Other complementary results confirm the influence of the sea state but this influence requires to be better quantified by new studies and experiments.

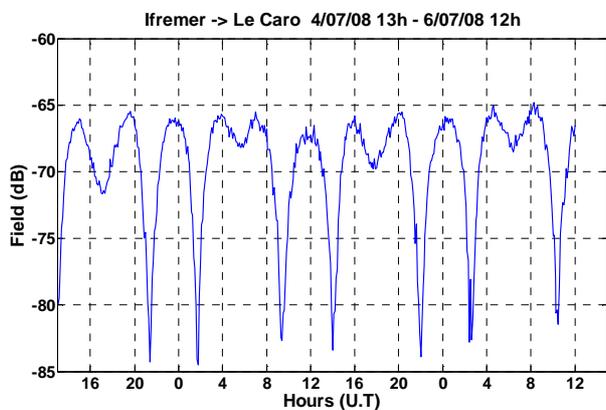


Fig. 12. Received field level according to the Universal Time.

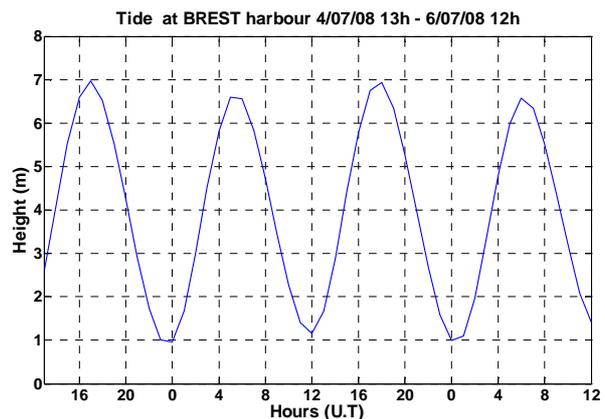


Fig. 13. Tide according to Universal Time.

Obviously, these tide effects also exist for radio links between a boat and the ground and should be taken into account.

## IV. DATA ANALYSIS AND SYSTEM IMPACTS

The theoretical results and the experimental validations show that the propagation channel in maritime environment has diversity at three dimensions:

- a polarization diversity which is present until distances ranging between 10 meters and 500 meters. Experimental studies in cross polarizations must be made to consolidate this observation,
- the vertical polarization mode is better adapted starting from distances of a few hundred meters,
- a horizontal space diversity (and temporal for a transmitter and/or a receiver in mobility). This diversity, inversely proportional to the Tx-Rx distance is thus reduced with this distance,
- a vertical space diversity proportional to the relative height variations of the transmitting and receiving antenna.

The results confirm also that the masking effects are more or less important according to the distance relatives to the masks. Moreover, the influence of the sea states is certain on two levels and request still to be quantified in experiments:

- pointing defaults of the receiving and/or transmitting antennas [5] and [6],
- modification of the refraction conditions of the indirect way.

Studies and experimental complements are necessary to refine the description of the channel behaviour, in particular for the presence of obstacles (coastal relief, large ship ...) near one or both connection ends, being able to create complex situations of multi-paths.

To take benefit from these diversities of the propagation channel in maritime environment, the following solutions on the systems could be examined:

- throughput and/or emission power adaptability according to the reception level and/or the signal to noise ratio (thus depending from distance and masking effects),
- taking advantage of the natural channel diversity:

- using two transmitting and/or two receiving antennas with orthogonal polarizations (vertical and horizontal), with a reception strategy to be determined (combining, best level, ...). This solution would be useful until approximately 1000 m (in harbour and harbour approach). Beyond 1000 m, vertical polarization is preferable,
- take advantage from channel horizontal diversity by using two (or more) receiving antennas approximately distant of half of the maximum interval between two fading, with a reception strategy to be determined (combining, best level, ...). But the effectiveness of the solution depending on the Tx-Rx distance is proportional to the size of the ships concerned.
- exploit the channel vertical diversity by using two (or more) transmitting antennas and/or two (or more) reception antennas separated by the height from approximately half of the maximum interval between two fading in altitude, with a reception strategy to be determined (recombination, best level, ...). Vertical and polarization diversities could be combined. The solution would be effective for connections between two points at ground and above the sea, for connections between a ground point and a ship, and for connections between two ships, with however a respectively decreasing efficiency for these three cases.
- control the Tx-Rx antenna pointing.

## V. LINKED MARITIME PROJECTS

### A. *Ex'treme project*

This project proposes the implementation of a broadband connectivity between the ground and the ships on sea. It will offer broadband services, mainly to increase the safety on the sea and to exchange information at short distances from the coast.

Moreover this project is based on complementary radio technologies to ensure IP services towards the passengers and the members of crew. The *Ex'treme* project is pioneer in the sector of the broadband services on the sea. This is because the existing IP Mobile service offers are not yet really dedicated to the maritime field.

The public concerned is mainly: pleasure boats, passenger liner, fishing vessels and ships of service. Moreover a great range of services will be proposed to these users: information on safety, the management and diffusion of an alarm, video transmissions, video monitoring, videoconference and applications of collaborative work, Internet access...

The partners of this project are: Alcatel Business Systems, Thomson-GrassValley, IFREMER, C2 Innovativ'Systems, Morgan'Conseil, Chantiers de l'Atlantique, and Télécom Bretagne.

### B. *ImaginLab project*

ImaginLab project is a test and experimental regional platform, adopted by FUI 6. It will make it possible to test new products and services. The infrastructure design and installation are carried out jointly by the pole Images & Réseaux and the UEB (Université Européenne de Bretagne), this later one having delegated its mission to Télécom Bretagne.

The infrastructure is made up of three inter-connected technological platform. The "Internet du futur" platform, located in Lannion, works on IMS (IP Multimedia Subsystem) architecture. The "Images en mobilité" platform, located in Rennes, will be used to diffuse mobile television services. The "haut débit sans fil" platform, located in Brest, will make it possible to test high-speed services on radio links, such as applications intended for the professionals or accessible services from a boat located near the coasts.

In this project, Télécom Bretagne uses its knowledge in the wireless transmission domain. These studies will relate to the wave propagation studies in different environments (urban, suburban, white zones and maritime areas).

### C. *Palmyre project*

The Palmyre project consists in a realization of a modular platform for the evaluation of both systems and new communication concepts in frequency bands going from HF to microwaves, within realistic experimental situations.

This platform is being developed by a hardware and software infrastructure group

Partners of this project are teams from the "Institut d'Électronique et de Télécommunications" in Rennes, the "Laboratoire d'Électronique des Systèmes Temps Réel" from University of Bretagne Sud, the "Micro-ondes, Electronique and Signal & Communications departments" from Télécom Bretagne and the "Université de Bretagne Occidentale" in Brest.

### D. *Navtrack project*

The general concept of this project is constituted of two technical guidelines:

- the first consists in locating in real-time all the boat race actors, using a radio transmission (868 MHz) to transmit GPS data, which are decoded on ground. A suited cartography traces the trajectories. The virtual images are enriched by environmental data (wind, currents, tide...)
- the second aims at transmitting on line the images of the boat race by a radio transmission at 5.8 GHz.

Partners of this project are teams from "DETI", "Ecole Navale – IRENav", "AGESSI", "Technopole Brest Iroise", "Electronique department from Télécom Bretagne" in Brest and from "SeatizenPro" in Villeneuve-Loubet.

## VI. CONCLUSION AND PERSPECTIVES

This paper presented experimental researches carried out by the CaPSyS team of Télécom Bretagne on the new radio technologies in the maritime environment. This characterization of the propagation channel is necessary to

understand the behaviour of radio waves in a maritime environment. Moreover, with this study, the performances of WiMAX systems can be analyzed according to the characteristics enumerated above. It is thus possible to take advantage of this analysis to propose some improvements of the transmission systems for better performances.

Télécom Bretagne develops new testing systems, in particular multi-channel receiving and transmitting systems, in order to explore the channel diversities quoted previously (MIMO spatial and polarization diversities) and for a better understanding of the propagation mechanisms in operational transmission environments (terrestrial as well as maritime). WiMAX (or others) transmission systems will also be operated simultaneously with channel sounding equipments, in order to compare the propagation channel characteristics with transmission performances.

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