

# An integrated simulation framework for Underwater Acoustic Networks

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## Abstract

Recently there have been many proposals for Underwater Wireless Network Simulators. Here we present a simulator proposal integrating the latest discoveries and research. This work includes the information of the location where network is located (temperature, salinity, etc.) which impacts on sound speed profile changing its value; and also the bathymetry and the floor sediment, in addition to depth, wave effect, etc. To perform the simulator these whole information provided by global databases is processed using Bellhop ray tracing tool, all integrated to build a simulation framework based on OPNET Modeler.

## 1. Introduction

Terrestrial Wireless Sensor Networks have been developed in the last two decades. As a result of this research the physical layer has been modeled and a wide range of MAC protocols, routing protocols and applications have been worked out. But in order to make this possible, standardization and simulation tools are needed for the researchers and commercial companies to test and validate the algorithms before implementing them in real hardware prototypes.

The most outstanding simulator tools used in terrestrial networks are Network Simulator 2 and 3 (NS) [1] and OPNET [2]. In those simulators you can find protocol models that are currently used by mobile wireless networks as 802.11, UMTS/3G, Zigbee, etc. Underwater Wireless Networks are just beginning to born in the world of simulators and that is the reason that today there are many proposals but no one is complete. Many of these simulators are based on terrestrial

network models reusing many elements in common, other simulators are specific underwater acoustic programmed in python, c/c++, etc. Even though there is not a definitive proposal, interesting options have been recently presented, for instance the WOSS, from Guerra, Casiri and Zorzi [3][4], claims to be a global simulator.

This paper is organized as follows: Section 2 gives an overview of the related work introducing simulators tools. Section 3 stands an overview of the simulator performance. Section 4 describes in detailed the steps that have been followed to make an integrated tool, the use of World Databases in OPNET through MATLAB [5], the creation of environmental files, and the execution of Bellhop Ray. In Section 5 it shows the MAC protocols used in the model. In section 5 present some of the simulation test results. Finally in Section 6 conclusion and future work are commented.

## 2. Related Work

Although we can find a lot of simulation tools for Underwater Networks, we have chosen three of them that we consider the most representative and that have their code is available.

### 2.1. AUVNetSim

AUVNetSim [6] is an example of simulator exclusively programmed in python for underwater wireless networks. Highlights in this simulator are MAC layer with DACAP protocol [7] and routing algorithm Focus Beam Routing (FBR) [8] including power control. But the physical layer is too simple, and so different environment conditions cannot be detailed.

## 2.2. Xie and Gibson Simulator

Base on the Monterrey Miami Parabolic Equation (MMPE) [9] a propagation model is presented and implemented in OPNET for the physical layer. Aloha and CSMA protocols for the MAC layer. This simulator stands out because its describes the physical layer with a great detailed being possible to define a scenario considering more environmental parameters like the effect of the waves, and the depth of nodes. The drawback of this model is that before doing network simulations several propagation model parameters need to be computed being this process high time-consuming. Also, the model only works on static scenarios with static conditions across the simulation period.

## 2.3. World Ocean Simulator System

The World Ocean Simulator System (WOSS) [3][4] seems to be one of latest and most complete simulator tools at the moment. It is implemented in the Network Simulator 2 package. It uses world databases that measure the sound speed profile (SSP), bathymetry and floor sediment such as the General Bathymetric Chart of the Oceans (GEBCO) and National Oceanic and Atmospheric Administration (NOAA). Combining this data with the scenario information like the latitude, longitude and depth position of the nodes, it creates environmental files that describe the scenario. With this information the Bellhop Ray tracing tool [10] is called giving as a result several files with the information of amplitude, travel times, ray coordinates and the acoustic pressure map.

## 3. Simulator Proposal

Base on our previous work on OPNET [11] we will develop a propagation model suitable for acoustic networks and taking into account the state of art trying to get the best from each of the proposals. The objective is to create a simulator able to perform simulations in scenarios located anywhere in the world. So, the obtained results will be in accordance to the local environmental conditions and will be closer to the ones measured in the real world. The purpose is to pick the world information from databases combine with OPNET

scenario information creating the environmental files. With these files OPNET connects to MATLAB through its interface and runs Bellhop ray tracing tool obtaining the result files as it can be seen in Figure 1.

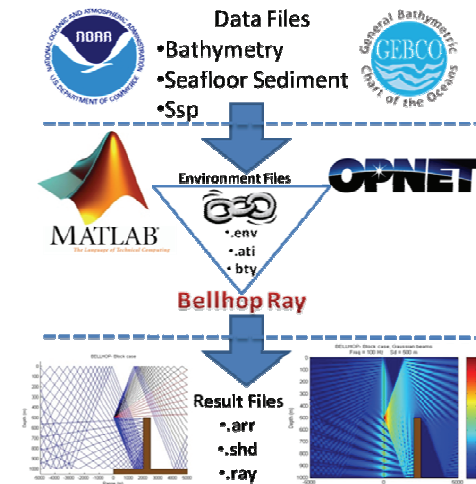


Figure 1. Simulator Summary

In the following section the implementation of the simulator is described in detailed.

## 4. Propagation Modeling

As shown in Figure 1 there are three steps to complete the process, obtaining the information from the databases, creating the environment file, execute the Bellhop to get the result.

### 4.1. World Databases

Three world databases are used to model the environment files:

- Bathymetry [12]: Is provided by the GEBCO. A file containing the world bathymetry data in a global 30 arc-second grid released in January 2009 and updated in November 2009. This information will be use either for the bottom scenario relief as well as for the sound speed profile generation.

- Seafloor Sediment [13]: The National Geophysical Data Center (NGDC) from the NOAA provides a "Deck41" database that contains surficial sediment descriptions for over 36,000 seafloor samples worldwide. Mainly we have ten types of floors in the ocean: gravel, sand, silt, clay, ooze, mud, rocks, organic, nodules, hard-bottom if no one is available no-data value will be return.
- Sound Speed Profile (SSP) [13]: Provided by the World Ocean Atlas (WOA) in the NOAA. Contains information of the worldwide sound speed in different moment of the year, can be specified an average of the year, by the season or even more detailed by the month. We can see an average representation in Figure 2 of the sound speed values depending on the latitude and the season of the year. It can be appreciated that the greatest differences are in in shallow waters.

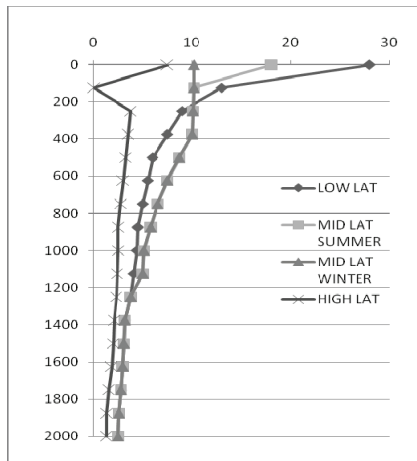


Figure 2. Sound Speed Profile Average Values

All this databases are formatted in netcdf; to read them we use MATLAB with the mexnc library and the SncTools [15]. We make a connection between OPNET and MATLAB using the interface of MATLAB for executing "c" code. So as to make this possible the simulation must be compiled including the required libraries for this purpose "libeng.lib, libmat.lib, libmx.lib and libmex.lib", the include files in "C:/matlabR2008b/extern/include" and finally update the LIBPATH with "C:/matlabR2008b/extern/lib/win32/microsoft"

and "C:/matlabR2008b/bin/win32". A full explanation of the configuration can be found in [16].

#### 4.2. Environmental Files

Once we have all this data in OPNET, it is combined with the information of the nodes (latitude, longitude and depth) and global parameters of the scenario such as frequency, wave information (height and length), the month of the year, etc. The results are three environment files required by Bellhop [10]:

- Environment file: The general structure of the \*.env can be seen in Figure 3. The values of the Sound Speed Block and the Bottom Block are gathered from the databases. The Array block is data from OPNET nodes global position, and the Surface line, Output Block and Beam block are simulation global parameters.

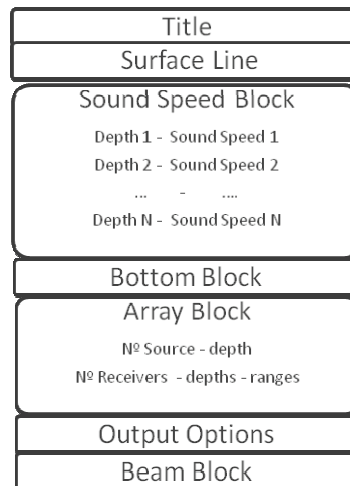


Figure 3. Environment file definition

- Bathymetry file: Two columns range (km) and depth (m) define the \*.bty of the scenarios. This is created from the databases bases taking into account the global position of the network nodes.

- Altimetry file: Two columns range (km) and depth (m) define the \*.ati, this file is created with two global parameters “Wave Height” and “Wave Length”.

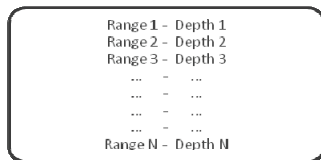


Figure 4. Bathymetry and Altimetry file definition

If we plot the BTY and the ATI file the result is a 2D vision of the scenario:

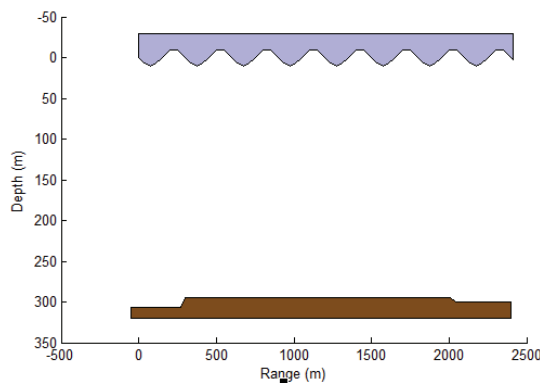


Figure 5. Plotting BTY and ATI files

It can be shown in the upper part the wave shape and down the bottom relief. So now it can be defined the scenario of a simulation placed in any part of the world.

### 4.3. Bellhop Execution

Again we use the MATLAB interface from OPNET to communicate and execute the Bellhop Ray tracing tool with the files created in the previous step as parameters. Depending on the desired output option different result files will be created:

- Option A: a \*.arr file is created, that includes the travel times and amplitude information
- Option R: a \*.ray file is created, that includes the ray coordinates.
- Option C: a \*.shd file is created, that includes the acoustic pressure.

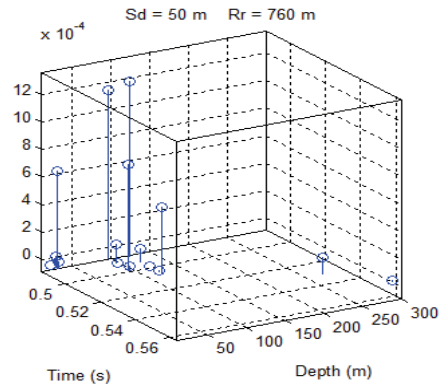


Figure 6. Plotting ARR file

The \*.arr file contains the information of the amplitude and travel times of the rays that arrive at the receiver position, in Figure 6 we plot the arrival times depending on the depths of the nodes.

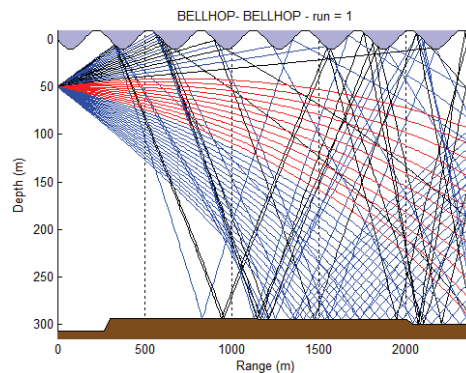


Figure 7. Plotting RAY file

The \*.ray file contains the ray coordinates and we can see very clearly the behavior of the rays and the reflections along the scenario, that will be very different depending on the proximity to surface and the height and length of the waves as well as the proximity, the shape of the bottom depth and the types of sediment that can be found in the scenario location.

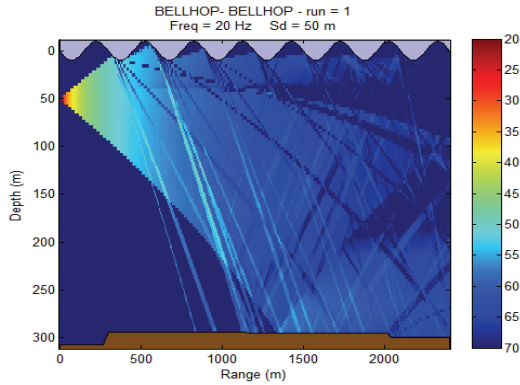


Figure 8. Plotting SHD

The \*.shd file contains the acoustic pressure, that can be calculated in a coherent, incoherent or semi-coherent way. Figure 8 shows a coherent execution. The pattern of the pressure fits with the ray plot.

### 5. Simulation Test

For testing the simulator the same node deployment network within a range 2000 meters has been placed in several world locations. The depths of the nodes will vary depending on the scenario we simulate depending if we are in shallow or in deep part of the ocean.

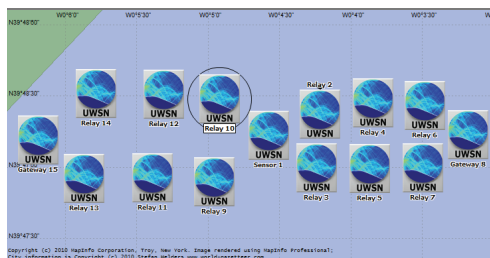


Figure 9. Nodes deployment

Here we show the results for three different locations. In each one of them the environmental conditions differ for the bathymetry, the sound speed profile, the sediment floor, and the altimetry base on the wave parameters.

They try to differ as much as possible to see the different results that can be obtained with different circumstances.

### 5.1. Valencia – Spain

The first one is placed in coordinates  $39^{\circ}48'13.14''N$  and  $0^{\circ}4'34.53''O$ . The nodes depth varies from 5 to 20 meters and the wave height 0.5 meters and wave length is 80 meters. This is an example of shallow waters with a low shape of the altimetry. The sediment floor of the bottom of the scenario is gravel. We can see the node deployment in Google Earth and the result for the Bellhop ray execution.

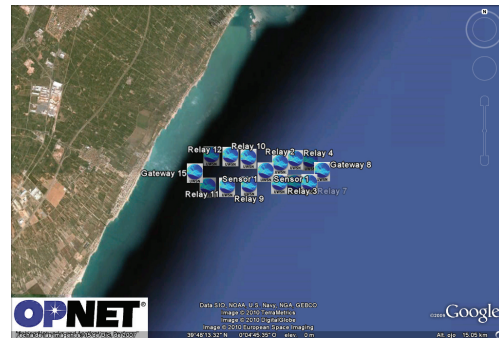


Figure 10. Nodes in Valencia

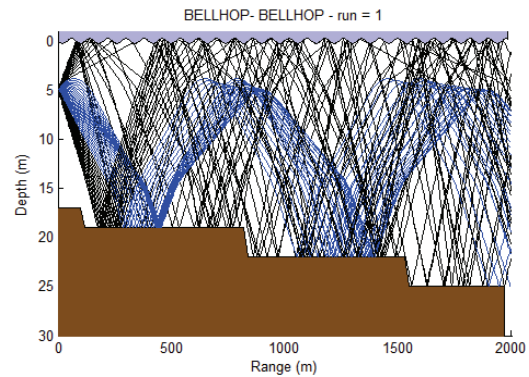


Figure 11. Bellhop Ray result for Valencia

The result is a slow variation of the depth in the scenario as the nodes are farther from the coast and how the rays reflect a great number of times in the bottom and the ceiling. This example could represent a typical network scenario close to the coast.



### 5.2. Hawaii – USA

This is in coordinates  $20^{\circ}39'13.10''N$  and  $156^{\circ}44'39.84''O$ . The nodes depth varies from 10 to 300 meters and the wave height 20 meters and wave length is 200 meters. This is an example of middle case water with a high shape of the altimetry. The sediment floor in this region is ooze. The map and the result are:

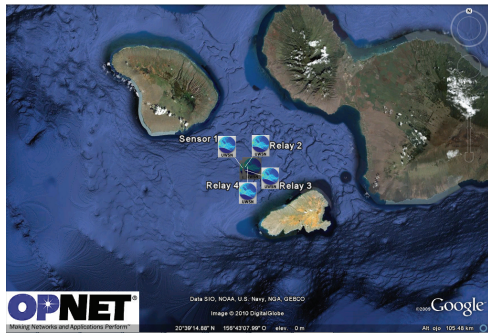


Figure 12. Nodes in Hawaii

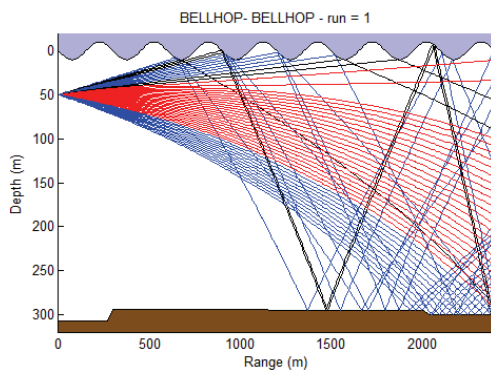


Figure 13. Bellhop Ray result for Hawaii

With this pattern scenario the rays travel having fewer reflections against the waves and the floor than in the previous one. This scenario is representative for network deployed within the surroundings of a group of islands.

### 5.3. Random Location – Atlantic Ocean

Finally a random location to test a deep water place is shown in coordinates  $4^{\circ}52'4.80''N$  and  $34^{\circ}57'0.00''O$ . The nodes depth varies between 250 and 2000 meters. The waves shape it has 10 meters for the wave height and 100 meters for the wave length. The sediment floor in this region is mud and organic. In the map of Figure 14 we see the Atlantic Ocean between South America and Africa.



Figure 14. Nodes in Atlantic Ocean

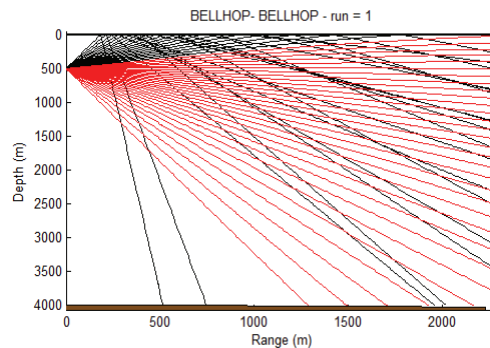


Figure 15. Bellhop Ray result for Atlantic Ocean

This time source and the receivers are far from the bottom and the waves and so they do not have a great effect in the way the rays behave. This scenario tries to show a network in the middle far away from the coast.

## 6. Conclusions and Future Work

A global complete simulation tool for underwater acoustic network has been developed. To achieve this it has been used world databases to make the generation of the scenario for the simulation an automatic process. OPNET is used as the principal tool that contains the code for the Routing, MAC and Physical layers, and this last one uses the interface of MATLAB to make use of the Bellhop Ray tracing.

As future work is planned to analyze the result of simulating node scenarios with few differences between them, changing a bit the location or the node deployment or even the waves surface. And also the behavior of similar networks topologies in completely different scenarios to test the MAC protocol such as Aloha, DACAP or T-Lohi and also evaluate routing protocols like the Focus Beam Routing and the impact of environmental parameters in the performance.

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