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An Efficient Investigation of Wireless Sensor Network for Underwater Environment Using Acoustic

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Abstract: **The Ocean is vast as it covers around 140 million square miles, more than 75% of earth's surface. New technologies have brought us new ways to explore this vast unexplored aquatic environment which provided us with a number of applications. Existing solution of terrestrial sensor networks cannot be applied directly to underwater sensor networks. Due to several architectural difference with respect to terrestrial ones, which are mainly due to transmission medium characteristics (sea water) and the signal employed to transmit data underwater sensor network requires wireless communication and acoustics is the primary modality of choice even though it presents a difficult channel. In this thesis we develop a simulation framework to be able to evaluate Underwater Wireless Sensor Networks with a realistic approach.**

Keywords: **Underwater sensor network, Acoustic communications, simulator framework, protocol stack.**

1. INTRODUCTION

Earth is largely covered by water. This is largely unexplored area and recently humans are showing interest towards exploring it Underwater Acoustic Sensor Networks (UW-ASN) consist of a variable number of sensors that are deployed to perform the monitoring tasks over a given area. Many disasters that took place in recent past made humans to greatly monitor the oceanic environments for scientific, environmental, military needs etc., in order to perform these monitoring task industries are showing interest towards deploying sensor nodes under water.

1.1 Internal Architecture of Underwater Sensor

The internal architecture of underwater sensor is shown in figure 1.1. In internal architecture the CPU-on board controller, sensor interface circuitry, acoustic modem, memory, power supply and sensor are main component.
It consists of the main controller which is interfaced with sensor through a sensor interface circuitry. The CPU or controller receive the data from the sensor and stored it in the memory, process it and send to another sensor through the acoustic modem. Sometimes all the sensor component are protected by the Bottom-mounted instrument frames that are design to permit azimuthally omnidirectional communications, and protect the sensor and modem from potential impact of trawling gear.

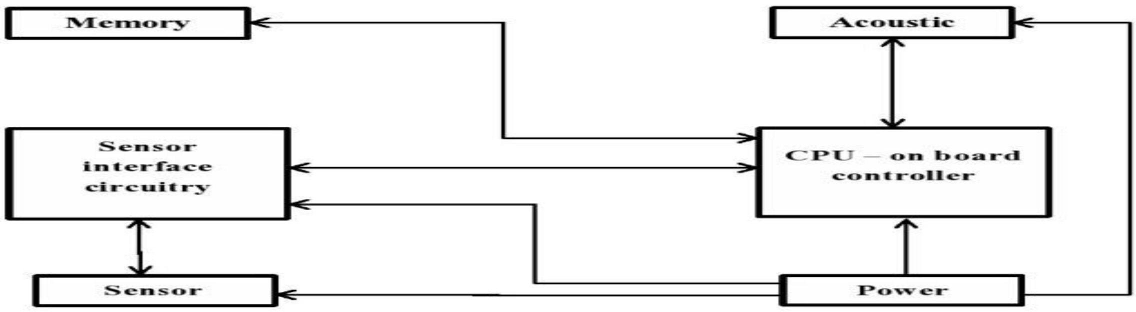

Figure 1.1 Internal Architecture of Underwater Sensor

1.2 Terrestrial Sensor Network Vs Underwater Sensor Network

The terrestrial sensor network and underwater sensor network are different in many factors. And those factors are as follows

- Architecture
- Medium
- Signal
- Power
- Memory
- Cost
- Deployment
- Spatial correlations

1.3 Applications

Some of the applications are as below:

- Fastest way for finding underwater information
- Disaster prevention
- Ocean sampling networks
- Environmental monitoring
- Mine reconnaissance
- Distributed tactical surveillance

1.4 Underwater Sensor Network Architecture

- ***2D ARCHITECTURE***

Figure 1.2 shows the most common UWSN architecture. The individual nodes are anchored at the ocean floor. The cluster heads are also anchored to the ocean floor. Cluster heads are equipped with two acoustic transceivers, namely a vertical and a horizontal transceiver. Cluster heads communicate via horizontal acoustic modes with all other individual nodes within the cluster. The data transfer from node to cluster head can be single-hop or multi-hop.

The surface station is equipped with an acoustic transceiver that is able to handle multiple parallel communications with the deployed uw-sinks. Finally base or surface station will send the sensed data to on-shore base station via RF signal.

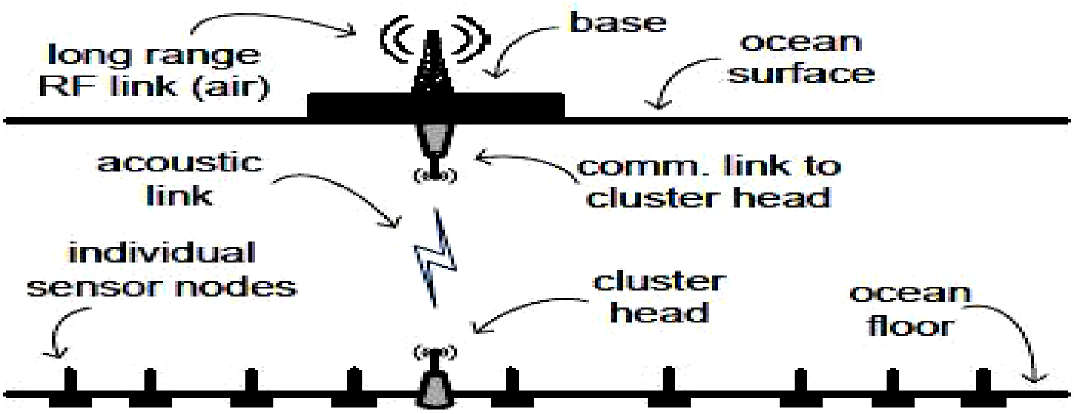

Figure 1.2 2D Architecture Of Underwater Sensor Network

This results in energy savings and increased network capacity but increases the complexity of the routing functionality.

- ***3D ARCHITECTURE***

Figure 1.3 shows an alternative 3D UWSN architecture. Three dimensional underwater networks are used to detect and observe phenomena that cannot be adequately observed by means of ocean bottom sensor node, i.e., to perform cooperative sampling of 3D ocean environment.

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3D architecture can have all nodes directly communicate to the surface base or can have only cluster heads communicate directly to the base. In the former case, all nodes are of the same type, but communication might be more energy intensive than that of the cluster head approach.

In 3D architecture, sensor node floats at different depth. Each sensor is anchored to the ocean bottom and equipped with a floating buoy that can in flatted by a pump. . The depth of sensor then can be regulated by adjusting the length of wire that connects the sensor to the anchor, by means of an electronically controlled engine that resides on sensor.

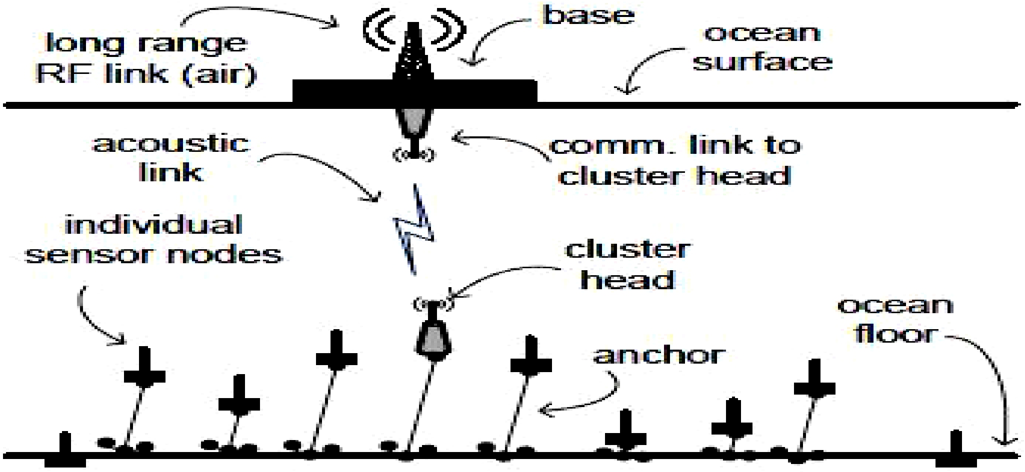

Figure 1.3 3D Architecture Of Underwater Sensor Network

- ***MOBILE ARCHITECTURE***

Fig. 1.4 shows an example of the architecture. The main important factor in this architecture is a mobility of nodes. Mobile node put extra controlling complexity in the network.

But it consumes more power because they consume extra power due to force or movement of mobile node in water. Hence they are less reliable and shorter lifetime.

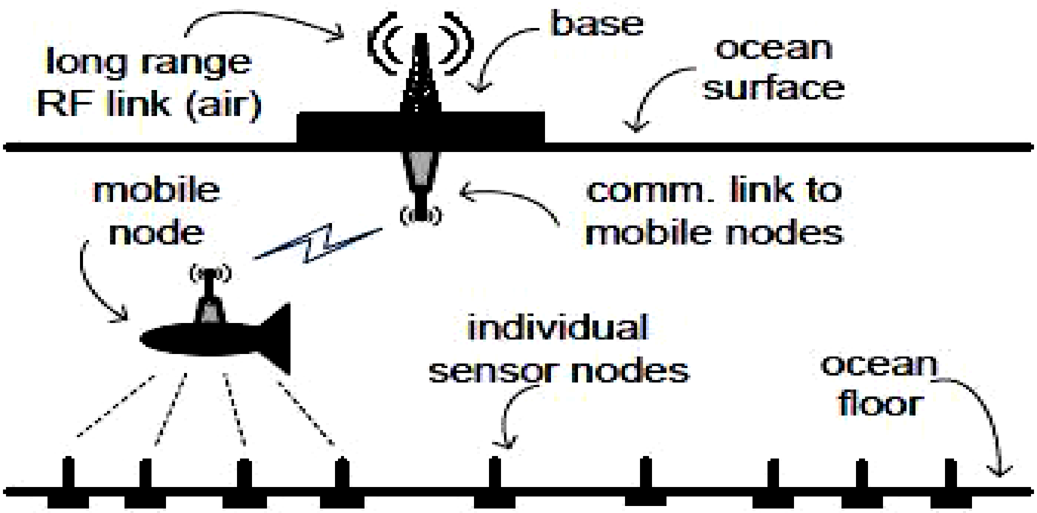

Figure 1.4 Mobile Architecture Of Underwater Sensor Network

Both mobile and static architecture has some advantages and disadvantages. So, we need hybrid architecture to highlight or underline the advantages of both architectures. In hybrid architecture that include uses both mobile node and static node by which we can transmit our sensed data efficiently from floor sensor to surface station.

1.5 Challenges in Underwater Acoustic Sensor Networks

Major challenges encountered in the design of underwater acoustic networks are as follows.

- The available bandwidth is severely limited.
- The underwater channel is impaired because of multi-path and fading.
- Propagation delay in underwater is five orders of magnitude higher than in Radio Frequency (RF) terrestrial channels, and variable.
- High bit error rates and temporary losses of connectivity (shadow zones) can be experienced.
- Underwater sensors are characterized by high cost because of extra protective sheaths needed for sensors and also relatively small numbers of suppliers (i.e., not much economy of scale) are available.
- Battery power is limited and usually batteries cannot be recharged as solar energy cannot be exploited.

Underwater sensors are more prone to failures because of fouling and corrosion.

2. UNDERWATER ACOUSTIC SENSOR NETWORKS

Underwater acoustic communication is a technique of sending and receiving message below water using sounds. The most common way to send data in underwater environments is by means of acoustic signals, just like dolphins and whales do for communicating between themselves.

Acoustic communications are the typical physical layer technology in underwater networks. In fact, radio waves propagate at long distances through conductive sea water only at extra low frequencies (30 − 300 Hz), which require large antennae and high transmission power. Optical waves do not suffer from such high attenuation but are affected by scattering. Thus, links in underwater networks are based on acoustic wireless communications.

A basic illustration of the depth at which different colors of light penetrate in ocean water. Water absorbs warm colors like reds and oranges and scatters cooler colors is as shown in the figure 2.1.

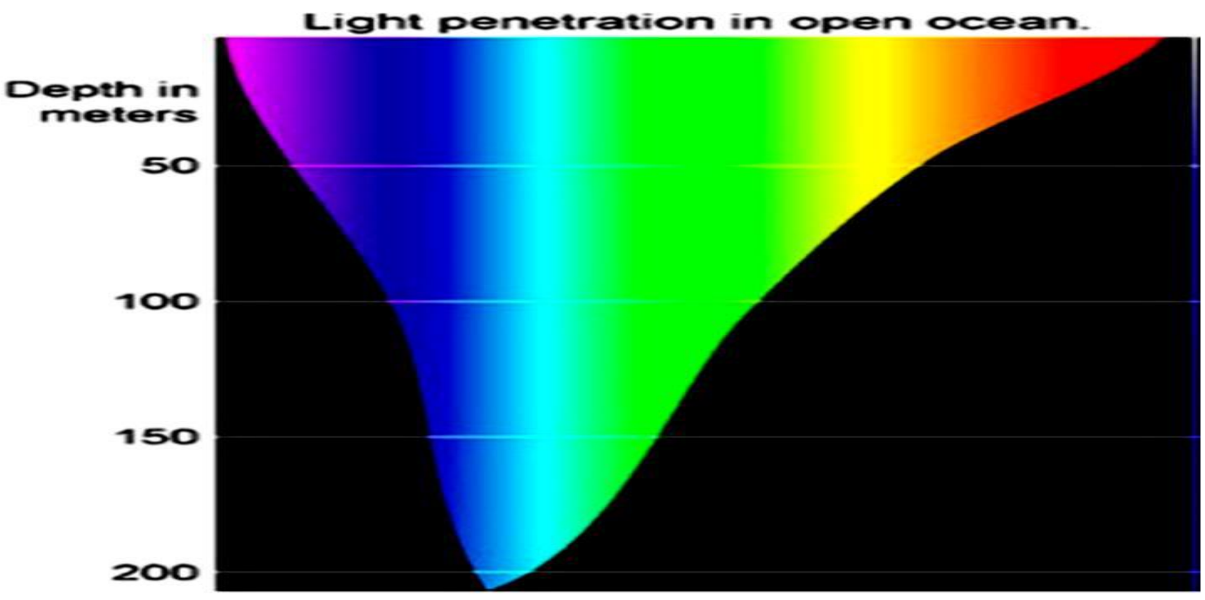

Figure 4.1 A Basic Illustration Of The Depth

2.1 Characteristics of Signal Carrier

In underwater world, there are 3 types of carrier wave that are most commonly used in wireless communication.

Signal Carrier	Advantages	Disadvantages
Electromagnetic waves	-higher frequency -higher bandwidth	-high absorption -big antenna needed -expensive -less accuracy
Optical waves	-high data transmission	-rapidly absorbed -scattering effect -less accuracy
Acoustic wave	-low absorption -travel at longer range -accurate	-data transmission slower

There are many environmental factors that have an impact on acoustic transmission in underwater acoustic communication:

- Both the surface and seafloor affect the transmission. The sea surface produces an almost perfect reflection of the acoustic waves due to different impedance from the terrestrial to underwater ambient. However, surface waves are not flat. Moreover, the shape and sediments of the seabed are also variable.
- The sea is not a homogenous environment; its temperature and salinity depend on the location in the world, the season and depth.
- The sea is not an isotropic environment due to seawater pressure and density.

Moreover, there are also other problems to take into consideration when making an underwater transmission, such as sounds produced by marine organisms, ships, surface noise, rain noise, and noise due to hydrostatic pressure changes.

3. PROTOCOL STACK

The four network layers which are used in underwater sensor network are Physical layer, Mac layer, routing layer and application layer. These layers consist of many modulations and protocols. They are listed in a hierarchal manner as below.

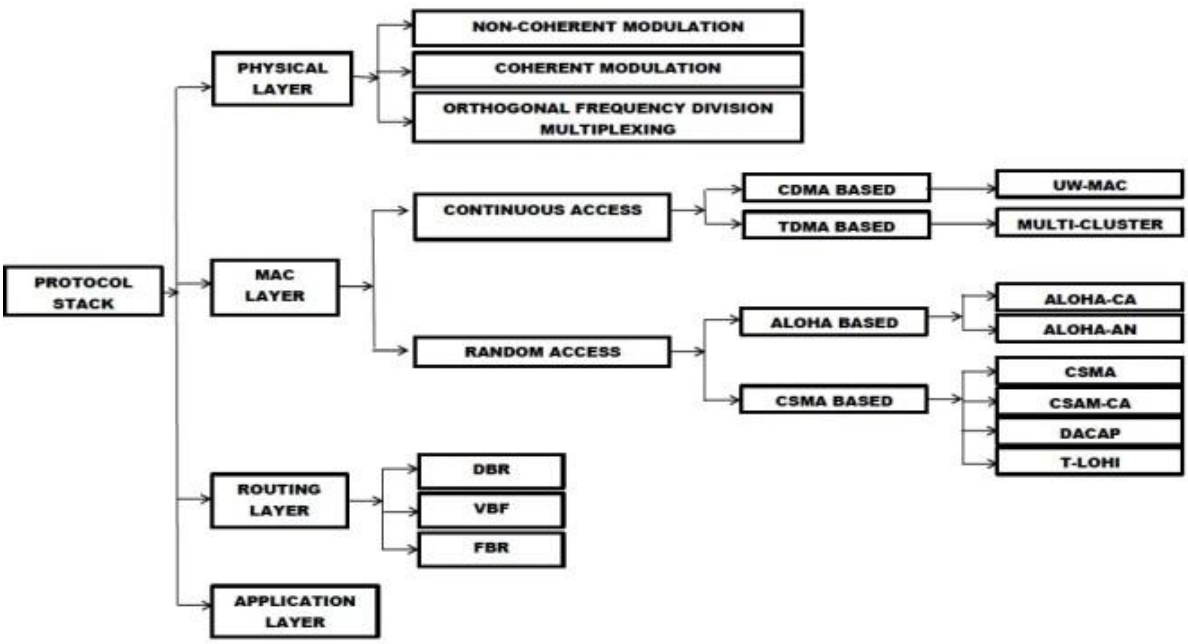

Figure 3.1 Lists Of Network Layer And Protocols

3.1 Cross Layer Design

In a traditional layered architecture, each layer interacts only with the adjacent layers in the protocol stack through well-defined interfaces. Although strictly layered architectures have served well the development of wired networks, they are known to be less than ideally suited for energy constrained wireless applications including UW-ASNs. While a layered architecture may achieve high performance in terms of metrics associated with each individual layer, it does not allow joint optimization of functionalities at different layers of the protocol to maximize the overall network throughput or minimize the energy consumption.

Cross layer design breaks the barrier of rigid interaction only among neighboring layer, by allowing interaction among different layer that may lead to higher network efficiency and flexible QoS support. The cross layer design technique is to make efficient use of the bandwidth – limited acoustic channel.

The objective of their work is:

1) Study the interactions of key underwater communication functionalities such as modulation, forward error correction, medium access control, and routing; and

2) Develop a distributed cross-layer communication solution that allows multiple devices to efficiently and fairly share the bandwidth-limited high-delay underwater acoustic medium.

4. FRAMEWORK SIMULATOR

There are lot of simulation tools for underwater networks, we have chosen three of them that we consider the most representative and that also have their code available for testing and comparing results..

4.1 AUVNetSim

This simulator exclusively programmed in python. Highlights in this simulator are the MAC layer and the routing layer, including power control. But the drawback is that the results are difficult to compare with new research discoveries and the definition of the channel is too simple, and so different environmental conditions cannot be detailed.

4.2 Xie Gibson simulator

This propagation model is presented and implemented in OPNET for the physical layer, and the MAC layer. The drawback of this model is that many model parameter needed and very time consuming. Also, the model only works on static scenarios with static conditions across the simulation period. The code necessary to build this simulator is not available.

4.3 WOSS (world ocean simulator system)

One of latest and most complete simulator tools at the present time. . 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 scenario information like latitude, longitude and depth position of the nodes, it creates environmental files that describe the scenario.

5. SIMULATOR FRAMEWORK PROPOSAL

The simulator framework is based on OPNET, MATLAB and the Bellhop ray tracking tool. Uses information related to underwater scenario characteristics like bathymetry, salinity, and seafloor composition, found at real worldwide locations that are downloaded NOAA and GEBCO worldwide ocean databases. This information is obtained with the OPNET network scenario module in order to create the corresponding environmental file.

In OPNET, it is very easy to set the network world location just by clicking on an area or introducing the GPS coordinates manually as shown in the figure 5.1.

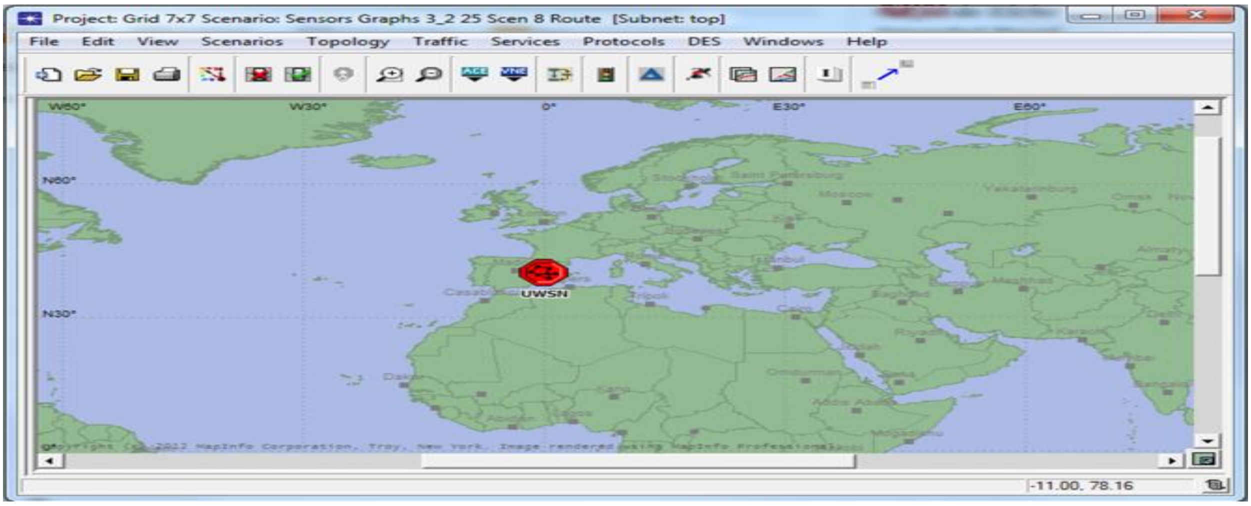

Figure 5.1 OPNET Simulator

Then, inside the network, the nodes can be deployed manually or by introducing their coordinates manually as in figure 5.2.

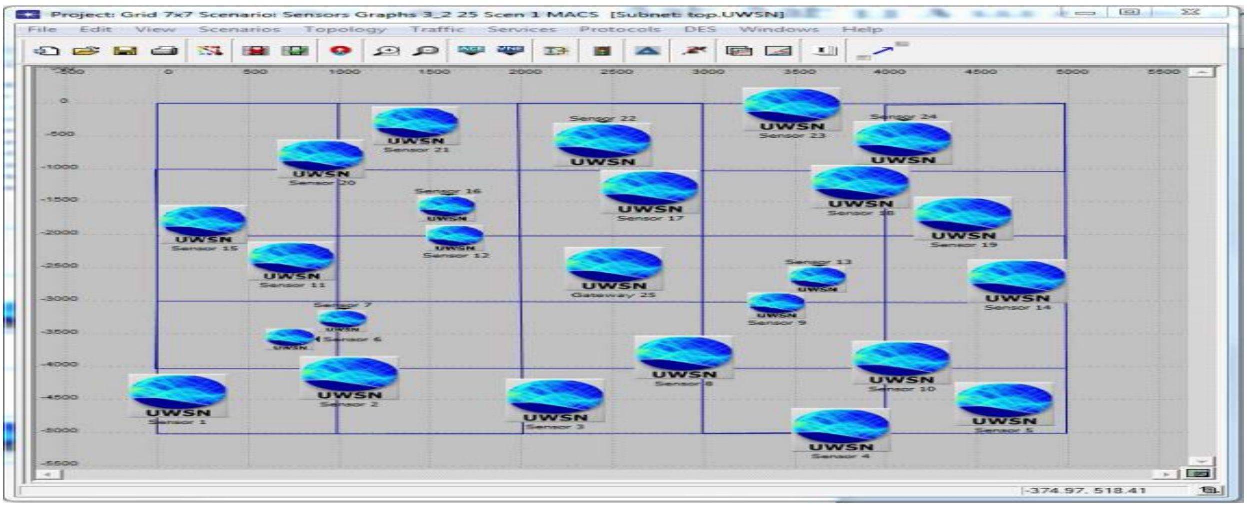

Figure 5.2 Simulator Network. Deployment Of Nodes

Each node has several parameters as shown in figure 5.3. These parameters are required by the protocol and used during the simulation.

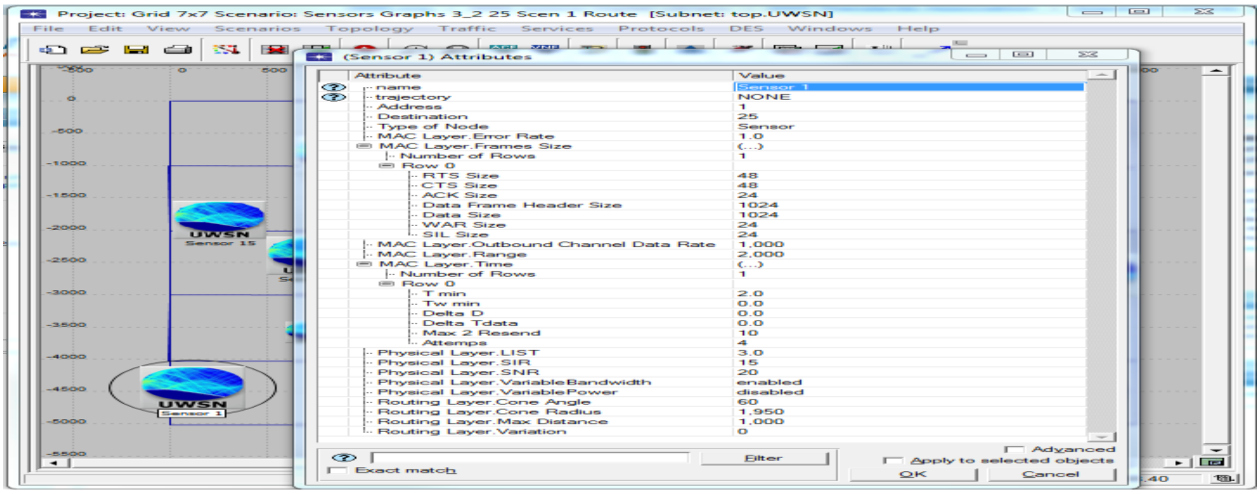

Figure 5.3 Nodes Parameters

Among specific node parameters, the simulator has many global attributes to define the network environment and the protocols to evaluate as displayed in figure 5.4.

Both the nodes and global attributes can have one or more values. Hence set of simulation can quickly configure. For instance, the packet delivery ratio can receive a fixed value (10packets/sec) or range of values (2 to 20 packets/sec). This makes evaluating the effect of variation of one or more parameter easily.

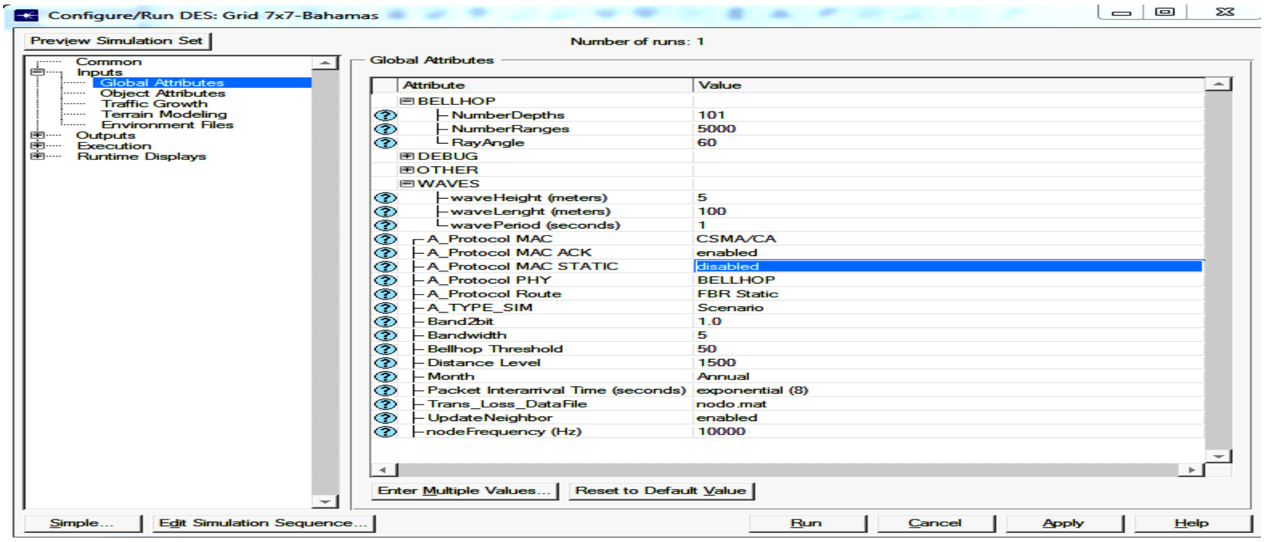

Figure 5.4 Simulation Network Parameters

By using the scenario definition and its environmental conditions, the purpose is to pick the world information from databases combined with OPNET scenario information creating the environmental files. With these files, OPNET connects to MATLAB through its interface in an automatic process and runs Bellhop ray tracing tool obtaining the result files. This is like black box for the user, who has to run the simulation.

6. PROPAGATION MODEL

There are three steps to complete the process: obtaining the information from the databases, creating the environmental file, and executing the Bellhop to get the result.

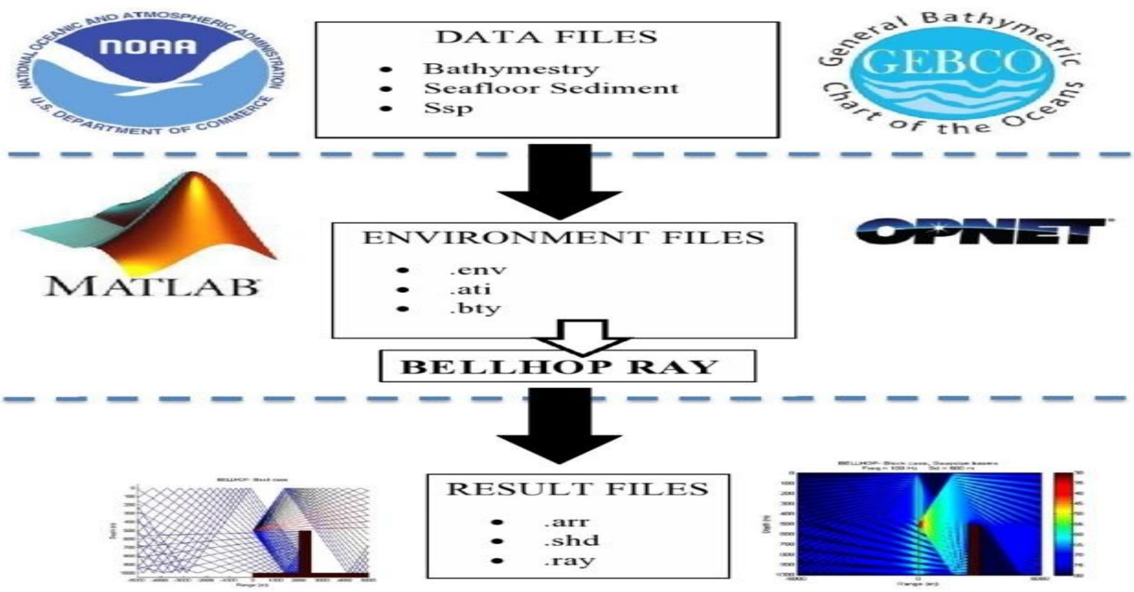

Figure 6.1 Simulator Summary

6.1 World Databases

There are three world databases are used. They are explained as follows.

• *BATHYMETRY*

It provided by GEBCO. This information will be used for the bottom scenario relief and for the sound speed profile generation.

• *SEAFLOOR SEDIMENT*

The National Geophysical Data Center (NGDC) from the NOAA provides a database that contains surface 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 returned.

• *SOUND SPEED PROFILE (SSP)*

Provided by the World Ocean Atlas (WOA) in the NOAA, it contains information of the worldwide sound speed at different times of the year. It is available the average values during the year, a season or a particular month. The sound speed values depend on the latitude and season of the year. The greatest differences are in shallow waters.

All these databases are formatted in netcdf. To read them, we use MATLAB with the mexnc library and the Snctools. We make a connection between OPNET and MATLAB using the interface of MATLAB for executing “c” code.

The simulation must be compiled including the required libraries for this purpose:

“libeng.lib, libmat.lib, libmx.lib and libmex.lib”,

The included files in "C:/matlabR2008b/extern/include". And finally, update the LIBPATH with "C:/matlabR2008b/extern/lib/win32/microsoft" and "C:/matlabR2008b/bin/win32".

6.2 Environmental Files

Once we have all this data in OPNET, it is combined with the information of the nodes and global scenario parameters such as signal frequency, wave information, month of the year, etc. The results are three environmental files required by Bellhop:

• *ENVIRONMENTAL FILE(*.env)*

The general structure of the can be seen in Figure 6.2 Environmental File (left), Bathymetry and Altimetry definition (right). The values of the Sound Speed Block and the Bottom Block are gathered from the databases. The Array block is data from the OPNET nodes global positions, and the Surface line, Output block and Beam block are simulation global parameters.

• *BATHYMETRY FILE (*.bty)*

This uses two columns, range (km) and depth (m). This is created from the databases taking into account the global position of the network nodes.

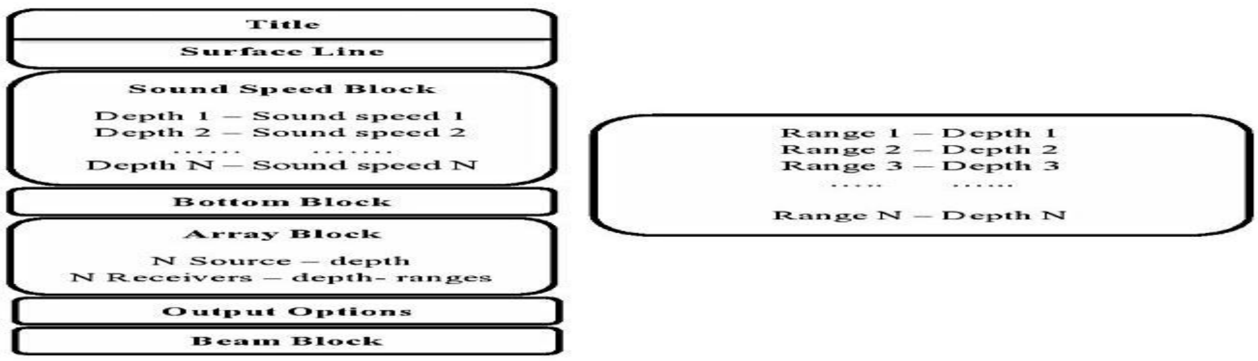

Figure 6.2 Environmental file (left), Bathymetry and Altimetry definition (right)

• *ALTIMETRY FILE (*.ati)*

This uses two columns, range (km) and depth (m). This file is created with -two global parameters, "Wave Height" and "Wave Length".

If we plot the BTY and the ATI files, the result is a 2D vision of the scenario as shown in Figure 6.3, where the wave shape and the bottom relief are represented.

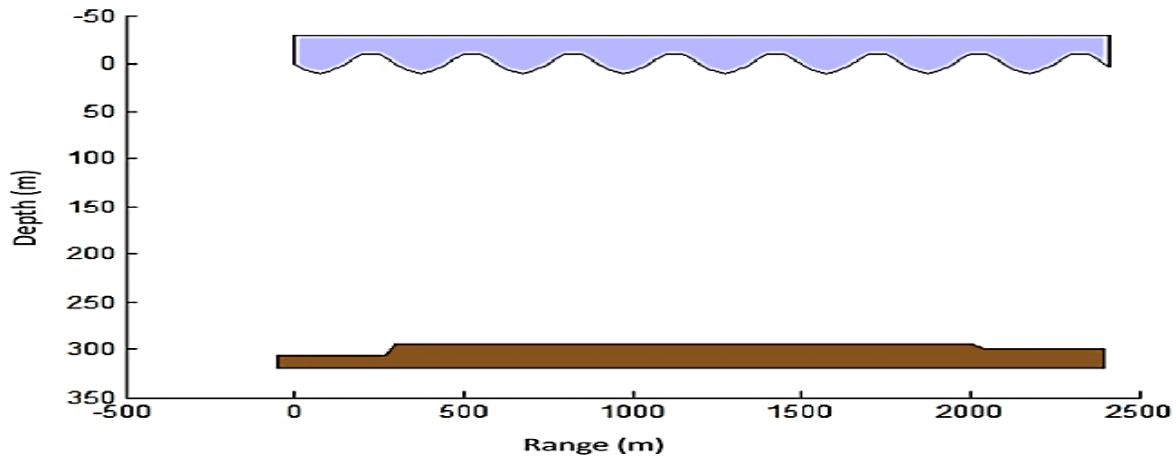

Figure 6.3 Plotting BTY and ATI files

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

OPTION R: *.RAY FILE

The *.ray file contains the ray coordinates and we can clearly see the behavior of the rays and the reflections along the scenario in Figure 6.4.

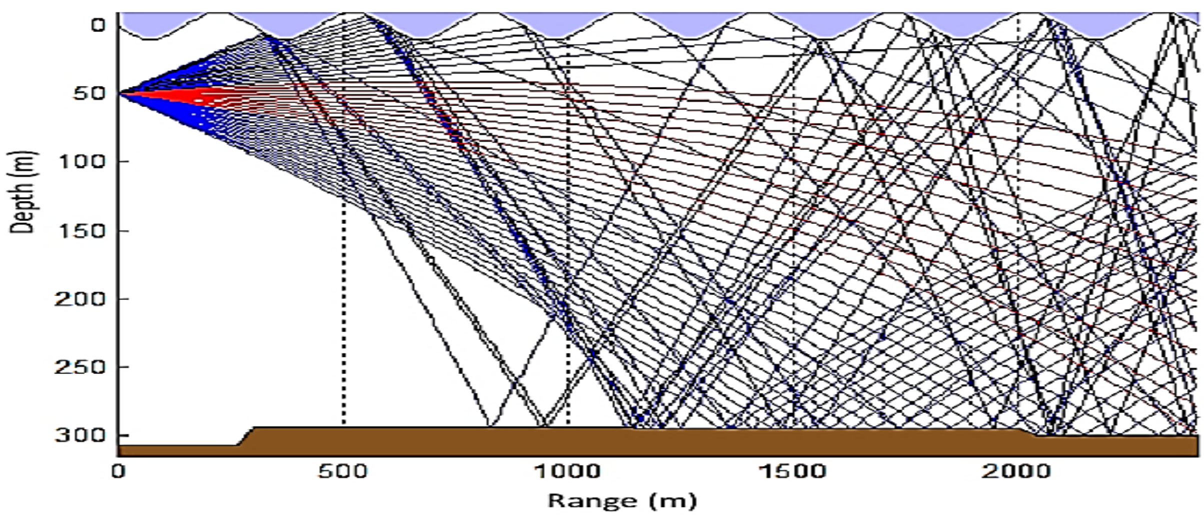

Figure 6.4 Plotting ray files

This *.ray file will be very different depending on the proximity to the surface of source node, and the height and length of the waves, the shape of the bottom depth and the types of sediment that can be found in the scenario location.

OPTION C: *.SHD FILE

The *.shd file contains the acoustic pressure, which can be calculated in a coherent, incoherent or semi-coherent way. Figure 6.5 shows a coherent execution. The pattern of the pressure fits with the ray plot.

OPTION A: *.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 6.6, we plot the arrival times depending on the node depths.

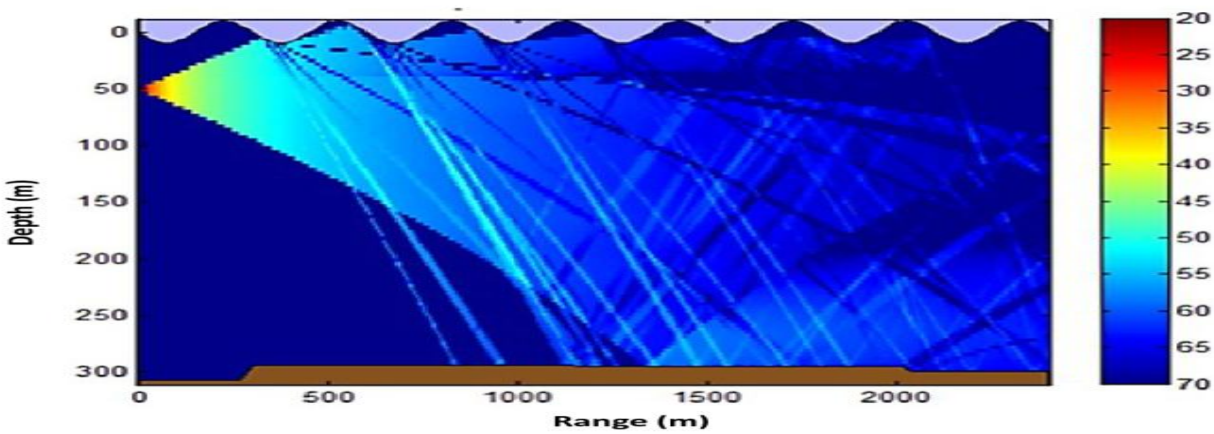

Figure 6.5 Plotting SHD file (with ATI and BTY)

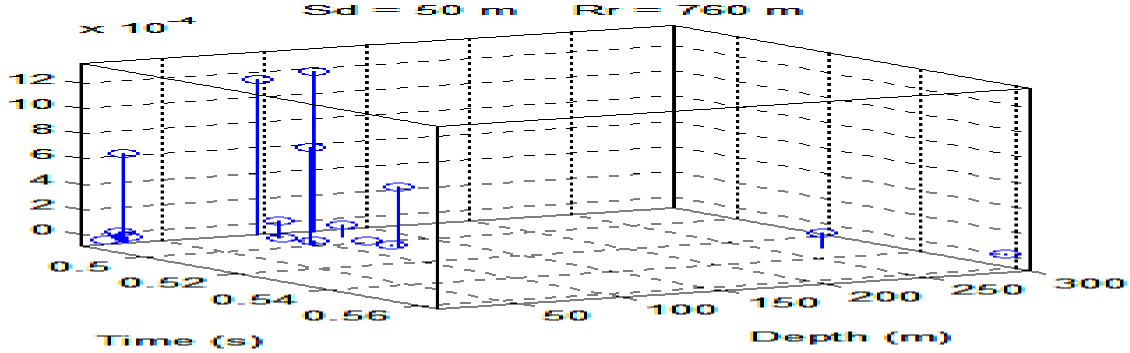

Figure 6.6 Plotting ARR files

OPNET lets export the network to many presentation formats. The network deployment can also be explored to Google Earth, where realistic vision of the nodes is displayed.

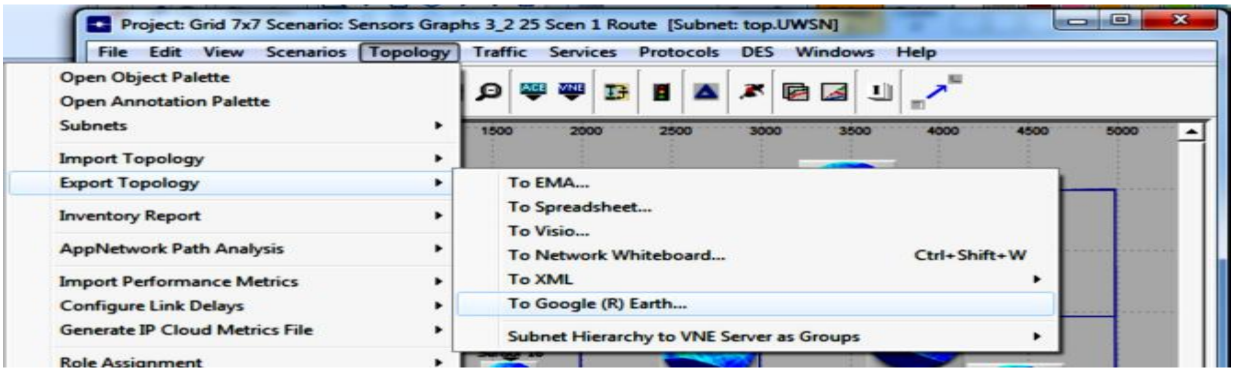

Figure 6.7 Simulator export to Google Earth

Figure 6.8 show the OPNET deployment in Google Earth where a real 3D vision of the network topology may be displayed, so the real distance of the nodes to the sea floor can be checked and a better node deployment could be done.

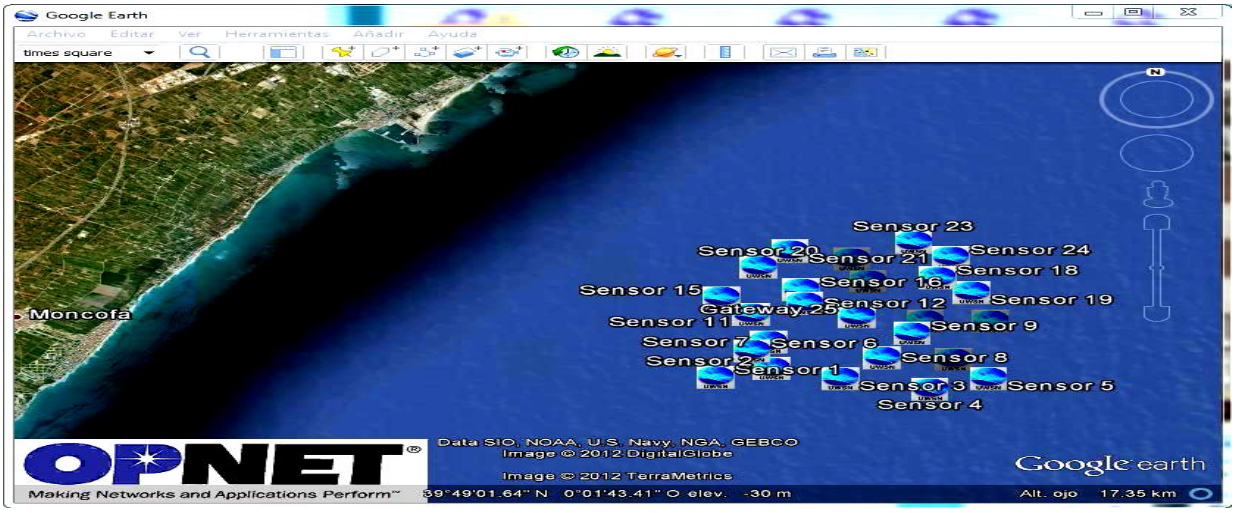

Figure 6.8 Google Earth network deployment

7. CONCLUSION

The main purpose of this research was to develop a simulation framework to be able to evaluate Underwater Wireless Sensor Networks with a realistic approach, so that the results can be inferred into real scenario networks with the same performance. An entire study is about, testing different propagation models, analyzing the behavior under different environmental conditions, Evaluating in network layers. Analyze the behavior of Acoustic Link Models in the underwater environment, including different locations, effect of ocean waves, node movement, depths of the transmitter and receiver nodes. It is easy to test and easy to use for non-technical users.

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