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Simulation of UWSNs performance evaluation

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ABSTRACT

An extremely influential phenomenon in Underwater Sensor Networks shallow areas is the multipath effect. The transmission in underwater is being applied in depth areas up to 200 m. The receiving nodes receive the signal both from the direct path as well as from the other paths formed as result of the sea surface and bottom reflections. Losses from the surface reflections will increase if the surface roughness increases or, in other words, if the wind speed blowing in the surface increases. On the other hand, losses introduced from the bottom reflections will depend from the material composition. The total delay increases for more reflections as the signal that propagates from a longer path takes more time to reach the receiver when compared to the signal from the direct path. If we want to estimate the communication ability of acoustic channel, we need to consider the different materials that build the bottom of ocean and the reflection and dispersion of the signal during transmission in such links.

Key words: Delay, link failure, lifetime of network, UWSNs.

1. INTRODUCTION

The water covers a large part of our planet, therefore the study of applications of Underwater Sensor Networks (UWSNs) is emerging as an enabling technology for underwater explorations. The nodes of this network are spatially distributed on underwater for measuring the quality of water, temperature, pressure and so on [1]. Traditionally, for monitoring the ocean bed, sensors are positioned at a fixed location to record data till the completion of the assigned task. The main disadvantage of the traditional approach is the lack of interactive communication where data recorded in the presence of a failure will not be able to be recovered. UWSNs support a wide range of applications: for example, water surveillance, detection of pollution for rivers even though these networks face limitations such as a limited bandwidth, high propagation delays, power constraints. There is also another factor such as the communication by deploying the underwater acoustics that usually requires the spending of more resources without having the opportunity for any power supply. Acoustic signal is used as medium of transmission in these networks, and it is affected by the temperature, depth and salinity of the underwater environment. These factors cause fluctuations in the speed of sound. A challenge for acoustic channel is the continuous change of underwater environment characteristics such as: multipath propagation, as result it brings a decrease of the signal strength and phase fluctuations in it; a Doppler effect created as result of the displacement of the sending and receiving nodes. Sound speed and underwater noise are other influencing factors in UWSNs performance.

The nodes in these networks are not necessarily static or positioned at the bottom of the oceans (traditional model), but they can be displaced as result of the activities or circumstances of underwater environments. According to [1] the nodes can move usually with a velocity of 2-3 m/s with water currents, so producing changing links caused by the different propagation paths between the nodes. For such a peculiarity, the most of the protocols used in Terrestrial Wireless Networks (TWSNs) become unsuitable for UWSNs. Energy consumption as well as proper use of available resources in underwater multihops networks would be improved by using an optimal package size. The study of changes of link quality is also of high importance. As, as due to waves, sensor nodes may suffer from change of the quality of the link in the intertidal environment [2]. For reducing energy consumption, clustering is used. These networks have been studied for many years and there are different studied routing protocols that can be applied in those. But due to their challenges [1], [3] in order to have the right standard platform that can support their testing, a specialized tool like Aqua-Sim, [4], was firstly developed on NS-2 [5], and now also in NS-3 [6]. Aqua-Sim is an underwater network simulator which supports a lot of protocols and features, it works in different scenarios without any requirement for a high-budget testbed. Moreover, Aqua-Sim supports three-dimensional deployment with the introduction of an effectively acoustic signal attenuation and packet collisions. However Aqua-Sim still have many limitations such as a limited arranged architecture and a restricted real-system support module.

As UWSNs work in harsh conditions it is crucial to carefully simulate the real-world components. This study will present an improved algorithm that will help in bringing more accurate simulations compared to what is done till now, by taking in consideration the presence of link failures, the movement of nodes and also the reflection from the bottom part of the underwater system. Due to this approach this algorithm is highly promising to implement various components and features for future testing.

Recently the researches attention is focused in the contest of studying wide varieties of systems to monitor the environment with the minimum cost before environmental monitoring applications can be effectively implemented in practice [7].

So, the aim of the work is to present simulations close to real scenarios, in order to making it a crucial step in expanding underwater simulation. The remainder of this paper is as follow. First we will discuss the core differences between TUWSN and UWSN and also choice of acoustic waves in UWSN in Section 2. In Section 3, we present the underwater characteristics related to multipath and detailed calculations for the reflection on the surface and bottom part. In Section 4, we describe our simulations done for a network distributed in underwater environment for different bottom materials and different percentage of link failure by using a new approach in the DEADs algorithm. Section 5 concludes our work when the importance of our simulations are explained.

2. UNDERWATER WIRELESS SENSOR

During our study the network will be designed in the three-dimensional architecture of underwater networks, the sensor nodes are positioned at different depth to monitor a specific activity. The traditional solution for this architecture requires platforms that float to the surface (with localizing function) which will provide simplicity in setting up such a network. This solution is vulnerable mainly to the weather conditions or from various interventions. These localizers can be detected without much effort if some enemy forces will want to take them out of service, if we think about military operations cases. In three-dimensional architecture, the depth of the sensor nodes anchored at the bottom of the ocean, need to be checked from time to time for their availability. Various problems that make underwater communications difficult are brought and are compared to the terrestrial communications, as presented in Table 1. It shows how Terrestrial (TWSNs) and Underwater Wireless Sensor Networks (UWSNs) are compared for observing their difficulties especially for the last one [8].The most two important features that we are interested in and those are also the main focus of this study for UWSN are propagation delay and bandwidth. Due to the effect of multipath in underwater a high propagation delay results, that makes the choice of the right routing protocol for UWSN difficult. Bandwidth is proportional to the range transmission and the frequency, so it results limited in these networks. But it is also important to mention security and reliability in obtaining data, efficient use of acoustic communication links, choosing the optimal package size used for communication, the power consumption, positioning and distributed location for the communication nodes, environmental effects, challenges related to MAC (Media Access Control) and network routing protocols.

Table 1: Comparison of Terrestrial and Underwater Sensor Networks [8]

Parameters	TWSN	UWSN
Minimum propagation speed	300 000 km/s	1500 m/s
Communication medium	Electromagnetic waves	Optical waves, radio waves and acoustic waves
Bandwidth	890-960 MHz	1-10kHz
Maximum transmission delay	10μs	50-1000 ms
Signal transmission rate	1200-9600 bps	Tens to bps
Cost	Inexpensive	Expensive
Nodes mobility	Stable	Stable or moving sensor nodes
Latency	Low	High
Error probaiblity	Comparatively low	High

All of the above issues need to be addressed and require the attention from the different research groups.

2.1 Models of modems from research works

There are designed different underwater acoustic modems for research purposes with the objective of saving energy consumption, cost savings and for testing new communication algorithms, to increase data transmission speed or even better to comply with the environments side effects. Table 2 shows a review by comparing these modems, according to [9], where “UV” is used to indicate the presence of an unspecified value.

Table 2: Models developed by research groups for acoustic underwater communication

Modem	Platform	Modulation	Bit rate (bps)	Range (km)
WHOI Micro-Modem 2	DSP	FH-FSK/ QPSK	80-5000	11
Fish Robot Modem	MCU	AM binary	1000	0.3
Uconn Modem	DSP	OFDM	3200-6400	UV
Hermes	UV	BPSK/ QPSK	16000-87000	0.12
Aqua-Modem	DSP	AM-DSSS	133	440

Range characteristics are based on analog transmitter-receiver type and designed transducer and used. Micro-Modem 2 is an open-source modem designed in 2009 with the aim of providing a fairly flexible research platform for research related to underwater acoustic communications. It is also programmable by the user and can support multiple instruments. The modem is implemented with a Blackfin ADSPBF548 processor. The modem has three modes of operation: active mode, low power consumption detection and sleep mode and it can be used for navigation to AUVs and for the communication between them. The modem utilizes the FH-KSF technique usually in channels with difficult conditions (shallow areas, coastal areas) or in cases of communication to/from AUVs using a data transmission speed of 80bps. The other technique PSK is used in the case of simplest channels for example in deeper areas where speeds up to 5000 bps are utilized. Generally, the costs for choosing these modems depends mostly on hardware components including the transducer or the external protection of the modem.

2.2 The choice of acoustic waves in UWSN

The marine life is affected by the sounds emitted by numerous pollutions originating from the activity of people in underwater environments (e.g.: their surveillance mechanisms cause significant hearing loss for the marine creatures). These sounds spreading all around can reach the underwater creatures by causing them harm or even kill them. Various methodologies are currently in use in underwater communications in order to overcome this problem: optical, electromagnetic and acoustic, their features are shown in Table 3. Those data are taken from [10], from which it is concluded that only acoustic communications meet the requirements to be most suitable for underwater communications due to the slightest extinction of the signal during this communication. These waves have also low absorption rate in underwater environments. The main challenges of such an architecture are the different features mostly those connected with the ocean currents. In optical communications the power loss is proportional to turbidity that is a coefficient measurement related to the phenomenon of scattering caused by strong, sufficiently large particles present in the form of waste in the underwater environment.

2.3 Underwater characteristics related to multipath

The presence of fading is the cause of the signal distortion along the signal propagation in an environment with certain distribution. It occurs mainly due to the propagation of the signal through many other paths besides the direct one and the phenomenon is known as *multipath fading*. According to this phenomenon, the signal started from *transmitter* (Tx) will reach *receiver* (Rx) not only through direct path but also as a result of other objects reflections in underwater, by causing this interference into the received signal. Figure 1 shows the reflections caused by the transmission wave along the surface jumps or the bottom part of the underwater environment thus reaching the receiving node along with the multiple paths reflections. This is an effect that usually occurs in the underwater environment of shallow areas.

3. UNDERWATER REFLECTIONS CALCULATIONS

The interference at the receiver can increase the frequency of errors in the signal bits. It is known the fact that in the receiver many of the components of the original signal will reach in different times, depending on the different lengths of the propagation paths that describes the signal multipath reflections.

Table 3: Comparison of RF, optical and acoustic communication underwater [10]

	RF	**Optical**	**Acoustic**
Wave speed (m/s)	~3E8	~3E8	~1.5E3
Data rate	< 10 Mbps	< 1 Gbps	< 100 Kbps
Effective range	~1-100 m	~1-100 m	~km
Power Loss	~28 dB/ 1km/100 MHz	Turbidity	> 0.1 dB/m/ Hz
Frequency Band	~MHz	~1014 -1015Hz	~kHz
Major hurdles	Power limited	Enviroment limited	Bandwidth limited Interfernce limited

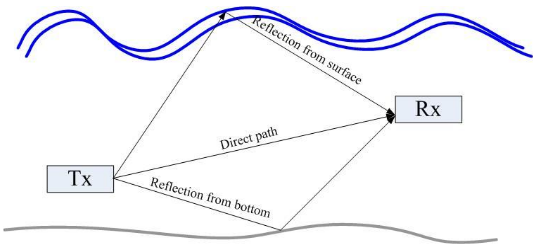

Figure 1: Multipath fading from Transmitter (Tx) to Receiver (Rx)

So, the delay spread factor of the arrival times of the signal components may be introduced, where interference would be caused if the times of arrival of the current components would overlap with the times of the arrival of pre-arrival components. Those components will cause corruption of symbols or loss of them and consequently errors in the received bits. Usually a common definition of the delay propagation factor (also defined in acoustics modem specifications) is the difference between the arrival times of the signal component that has followed the longest path with the time it takes to the signal that comes from the direct path [11]. The size of this factor in digital communications systems determines the low limit for the time duration of a symbol. It sets an upper limit on the system capacity [kbps] that is used in order to avoid interference between symbols. As the speed of the sound propagation is too low in an acoustic channel, it will be considerable also the delay propagation factor for the arrival times. The effects of multipath, included in this study, will take in consideration only the spread caused by the reflection on the boundary parts of the underwater environment (surface and bottom reflections).

3.1 Reflection on the surface part

The scattering phenomenon is a mechanism that causes loss, interference and fluctuations. The movement of the ocean surface will generate acoustic fluctuations. On the other hand, the roughness of the bottom part can generate fluctuations when the Tx or Rx are in motion. Often, the distribution effect from a rough surface can be seen as an additional loss to the wave component that would be reflected in the direct path, resulting in the distribution of energy beyond the direction it would normally propagate.

If we consider the roughness of surface area and it is smaller compared to the wave length, the loss as a result of surface reflection would thus be expressed through the distribution process. The formula which expresses reflectivity from a rough boundary would be [12]:

$$R'(\theta) = R'(\theta) \cdot e^{-0.5\Gamma^2} \quad (1)$$

where: R' (θ) is the new reflection coefficient reduced as result of the distribution from the rough surface, θ represents the angle that forms the incidence wave with the normal of the boundary between the two surfaces and Γ expresses the Rayleigh roughness parameter. This parameter would be defined as:

$$\Gamma = 2 \cdot \mathrm{k} \cdot \sigma \cdot \sin(\theta) \quad (2)$$

where: k is the acoustic wavelength number (k=2π/λ) and σ the *rms* roughness calculated from $\sqrt{0.324 \cdot 10^{-5} \cdot v^5}$ when: v is the wind speed in m/s [9].

If the ocean surface is quite, the reflection coefficient would be -1 (the whole wave would be reflected in aquatic environment and with a phase π). In the case of rough surface (wind speed action), it will be a loss as result of the distribution and this coefficient will decrease (as result of the additional loss introduced by dispersion) eventually becoming [12]:

$$R'_{SR}(\theta) = e^{-0.5\Gamma^2} \quad (3)$$

So, whenever there is a reflection on the surface (rough surface as a result of the action of winds with a certain speed) will change the coefficient $R'_{SR}(\theta)$ and depending on it losses were determined in (dB) accompanied by any surface loss (SL) as [12]:

$$SL = -10\log\left|R'_{SR}(\theta)\right|^2 \quad (4)$$

Substitution of (3) would give [11]:

$$SL = -10\log\left|-e^{-0.5\Gamma^{2^2}}\right| = 10 \cdot \left(2\frac{2\pi f}{c}\sigma\sin(\theta)\right)^2 \log e \quad (5)$$
$$= 300 \cdot \left(f^2 \cdot \sigma^2 \cdot \sin^2(\theta)\right)$$

where: f is in (kHz) and σ in (m). The loss associated with surface reflection refers to a redistribution of the power of the incident wave in the rays which does not correspond to the rays that would be reflected if the surface was smooth and this loss in (dB) would be calculated according to (5). Equation (5) is applicable only if the coefficient of the roughness is small; so according to [13] if the term $f^2 \cdot \sigma^2 \cdot \sin^2(\theta) \le 0.25$, then SL will be less than 18 dB for each surface reflection.

3.2 Reflection in the bottom part

The model of Rayleigh is used to calculate the result of reflection from the bottom part. It takes into account that: the dispersion phenomenon is not so important for the bottom part as it was for the surface part (as the bottom part is smooth) and the only reflected energy is that coming from the bottom border of material-water (the remainder of the energy transmitted under the bottom part is not reversed). As such, in this case the loss does not depend on the frequency and it is assumed that the energy transmitted through material it does no longer reappear. Given that p and c are respectively density and the speed of sound propagation under water and p1 and c1 are the density and speed of propagation of sound in the material of the bottom part of the underwater environment, then for a final part of quiet reflection it would be dependent on the angle of incidence θ and it would be given by the reflection coefficient according to Rayleigh [11].

$$R_{BR}(\theta) = \left|\frac{m \cdot \cos\theta - \sqrt{n^2 - \sin\theta}}{m \cdot \cos\theta + \sqrt{n^2 - \sin\theta}}\right| \quad (6)$$

where: m=p1/p and n=c/c1. The losses as a consequence of each reflection from the bottom in (dB) will be as:

$$BL = -10\log\left|R_{BR}(\theta)\right|^2 = -10\log\left|\frac{m \cdot \cos\theta - \sqrt{n^2 - \sin\theta}}{m \cdot \cos\theta + \sqrt{n^2 - \sin\theta}}\right| \quad (7)$$

Incidence angle θ that appears in some formulas is not constant and it is defined with the Pekeri's geometry. Thus, although the exact calculation of the propagation delay in the underwater environment would be quite complicated, this delay between nodes i and j can be written as [14]:

$$Delay_{i \to j} = \frac{L_d}{C} + \frac{d(i,j)}{c} + \Delta\tau \quad (8)$$

where: L_d is the length of data packet (bits), C is the channel capacity (bps), $d(i,j)$ is the distance between the two nodes (i,j) that are communicating, and c is the propagation velocity of the acoustic wave in water (m/s), $\Delta\tau$ is the delay caused by the multipath propagation. The first term of (8) represents the delay in data transmission, the second term the delay in data transmission along direct path and the third term would express the delay caused by the spread from the many paths. Delay in the propagation of secondary rays (reflected), are relative to the direct path, is a very important parameter for the underwater channel which influences the performance of the system. So the delayed rays on the receiver will show multiple interference and in this case it is required to reduce the speed of data transmission.

The impulse response of the channel for the case when we have the propagation according to multipath for an underwater acoustic channel can be expressed according to [11]:

$$h(\tau,t)=\sum_{p} A_p(t)\,\delta\left(t-\tau_p(t)\right) \quad (9)$$

where: $A_p(t)$ and $\tau_p(t)$ determine the amplitude of the path depending on time and delay of propagation along that path. It is clear that the path of the acoustic channel behaves as a low pass filter. The surface reflects almost 100% of the losing of sound for also due to the high mismatch of the product p*c (p is the density of the material and c is the speed of sound propagation) between water and air while this is not the case for the part bottom. According to [13] for the surface boundary the acoustic impedance of the air is taken 420 (Pa s/m) and acoustic impedance of water $1.5*10^6$(Pa s/m) and these give a value of the reflection coefficient absolute of0.99944 for 0^0 angle of incidence (99. 9% reflection and loss 0 dB). While for the bottom part of the ocean with clay material the reflection coefficient in absolute value would be 0.06324 which would bring a loss of 24 dB (maximum possible received for 0^0 angle of incidence). Table 4, from [12], represents the geo-acoustic qualities of some typical materials of the bottom are shown there. It is noticeable that there is a connection between the porosity and the density of the material or the speed of wave propagation, where a low porosity would lead to an increase in density or the speed of sound propagation.

4. SIMULATIONS

During this study for simulating the effect of multiple reflections in the routing of UWSN, it is going to be used an improvement of DEADS routing algorithm (Depth and Energy Aware Dominating Set Based Algorithm) [15]. The nodes are divided in three main groups: *source nodes* (the one that is the deepest or have the largest value of z-coordinate), *relay nodes* (the one that are located over the source nodes but are below the destination nodes) and the *destination nodes* that are close to the surface or they are on surface.

The packet sent from source node will arrive at the relay node that is selected to have the longest distance till a threshold value (d_{ths}), the same thing does also the relay node but with another threshold (d_{thr}). Therefore, the communication is done between two nodeswhile the others are in listening mode. The value of these thresholds in both cases are calculated by using the below formula:

$$d_{th}=\left(N_d/N\right)\cdot R \quad (10)$$

but they are different because each of those use its own value of: N_d the number of alive nodes inside the node's transmission range), N is the total number of nodes in the network and R is range of transmission for every node. Our network will be simulated with 50 nodes that has a randomly distribution within a network of 200x200 m.

Table 4: Ocean bottom materials

Bottom type	**m**	**n**	**c1 [m/s]**	**p (%)**
Clay	1.5	1.0	1500	70
Sand	1.9	1.1	1650	45
Gravel	2.0	1.2	1800	35
Limestone	2.4	2.0	3000	-
Basalt	2.7	3.5	5250	-

Table 5: Delay simulated for Sand

Refl.	**5 %LF**	**15 %LF**	**25 %LF**	**35 %LF**	**45 %LF**
2	296.8	297.2	298.2	297.8	297.9
6	834.5	834.3	835.2	836.6	838.4
10	2078.7	2079.7	2078.6	2060.1	2062.2
14	3.7 E+06	3.9 E+06	3.9 E+06	3.8 E+06	3.7 E+06
18	2.1 E+10	2.1 E+10	2.1 E+10	2.1 E+10	2.1 E+10
20	1.5 E+12	1.5 E+12	1.5 E+12	1.5 E+12	1.5 E+12

Table 6: Delay simulated for Gravel

Refl.	**5 %LF**	**15 %LF**	**25 %LF**	**35 %LF**	**45 %LF**
2	296.2	297.1	296.9	297.9	298.5
6	831.3	832.1	832.4	833.9	836.3
10	1520.8	1519.1	1515.7	1521.6	1529.3
14	4.4 E+05	4.5 E+05	4.5 E+05	4.4 E+05	4.3 E+05
18	1.3 E+09	1.3 E+09	1.3 E+09	1.3 E+09	1.3 E+09
20	6.7 E+10	6.9 E+10	6.9 E+10	6.8 E+10	6.7 E+10

Each node will have a power of 4J and the packet size that will be transmitted is 2000bits. It is considered a maximum number of 20 reflections: 10 from the surface and the rest from the bottom. To be closer to the real scenario we have also simulated the presence of nodes movement and the presence of link failures. So, our nodes will move randomly within the range of [0,1] m in x or y axes. While the percentage of link failures implemented are shown in any case in the results of the simulations. The metrics that will be taken in consideration are: a) network lifetime (the number of communication cycles until the first node in the network dies), b) delay (ms) calculated as the total delay needed to send the packet from the transmitter to the receiver including the transmission delay as well also the propagation delay.

Table 7: Delay studied for 5% link failure

Reflections	**Basalt**	**Gravel**	**Sand**	**Limestone**
2	296.7	296.2	296.8	296.3
6	833.9	831.3	834.5	826.4
10	2075.4	1520.8	2078.7	1375.5
14	3.7 E+06	4.3 E+05	3.7 E+06	2604.5
18	2.1 E +10	1.2 E+09	2.16 E+10	2.9 E+05
20	1.5 E+12	6.6 E+10	1.4 E+12	6.2 E+06

Table 8: Delay studied for 50% link failure

Reflections	**Basalt**	**Gravel**	**Sand**	**Limestone**
2	298.2	298.9	299.4	298.1
6	831.4	837.4	839.3	835.4
10	1373.4	1536.3	2071.4	1419.1
14	1960.1	4.3 E+05	3.7 E+06	4.5 E+04
18	9026.7	1.2 E+09	2.1 E+10	6.7 E+07
20	93402.9	6.6 E+10	1.5 E+12	2.6 E+09

Table 9: Lifetime for 5% link failure

Reflections	**Basalt**	**Gravel**	**Sand**	**Limestone**
2	2992	3110	2990	3117
6	2246	2366	2207	2588
10	2054	2412	1997	2402
14	2376	2285	2328	2054
18	2394	2342	2351	2393
20	2378	2377	2397	2320

Table 10: Lifetime for 50% link failure

Reflections	**Basalt**	**Gravel**	**Sand**	**Limestone**
2	3015	2908	2829	3040
6	2487	2047	1924	2177
10	1856	901	930	948
14	946	1712	1687	1730
18	1708	1730	1686	1716
20	1695	1716	1688	1721

So, next will be presented the results obtained by simulating the ocean bottom made of four most custom materials. We have simulated the improved algorithm DEADS for these four materials in the presence of a network with different % of link failure (LF) It is studied also the delay and the network lifetime for different number of reflections. Apparently, building a detailed geo-acoustic model for a particular oceanic area is a rather a difficult task and the amount of information approximated (in doses of inaccuracies) are the main limiting factor for totally accurate modeling of the interaction of sound during its transmission with the bottom part in underwater environments. Compositions of the different materials and the stratification of the materials encountered in the bottom parts of the oceans are indicative of the fact that there is a need for a specific geo-acoustic model for each area geographically considered (large or small). However, achieving an accurate information obtained from the measurements field, prediction on the propagation of an acoustic signal, when this propagation is dominated by losses at the bottom, can be quite accurate. According to [12], if it is transmitted at high frequencies, the details regarding the composition of the bottom part would only take into account only the first few tens of meters of sedimentary layer while in the case of transmission at very low frequencies (<10 Hz) we would need a complete information over the entire column of the sedimentary layers up to the qualities of the rocky layers located under it. The delay measured for sand (Table 5) and gravel (Table 6) when the network has different % of link failure (LF), is decreased by increasing the number of reflections, for both materials. As the nodes of our network that have different % of link failures and it is in the continuous movement, we find at high importance to present also the lifetime and the delay of the network of the four bottom materials considered for two cases of the network: with a 5% and 50 % of link failures (Table 7- Table 10). It is not of interest to simulate further on this values because the network is not connected anymore [16]. Each bottom material has its owns values of results, but in both cases it results that the network lifetime decreased by increasing the number of reflections, but the values are much lower in the network with 50 % of link failure.

5. CONCLUSION

The geo-acoustic model here considered can be defined as a good model that simulates in a realistic way the bottom of the oceans. It is based on measured values and those extracted by extrapolation of materials qualities which are of importance for the sound propagation modeling. Such model can also be developed further for helping to give details about the thickness and qualities of sedimentary or rocky layers below the bottom of underwater areas up to a depth called the effective depth of acoustic signal penetration. Our study is a novelty in this process for helping to get close to the problems that can be meet during the process of monitoring with UWSN.

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