ISSN XXXX XXXX © 2019 IJESC

Research Article Volume 9 Issue No.3

Underwater Wireless Communication

Kulkarni S.R.[1], Rajmane M.S.[2], Mulani S.A.[3]
Diploma Student[1, 2, 3]
Department of Electronics & Telecommunication Engineering
Vishweshwaryya Abhiyantriki Padvika Mahavidhalaya, Almala, India

Abstract:
One of the main problems in underwater communications is the low data rate available due to the use of low frequencies. Moreover, there are many problems inherent to the medium such as reflections, refraction, energy dispersion, etc., that greatly degrade communication between devices. In some cases, wireless sensors must be placed quite close to each other in order to take more accurate measurements from the water while having high communication bandwidth. In these cases, while most researchers focus their efforts on increasing the data rate for low frequencies, we propose the use of the 2.4 GHz ISM frequency band in these special cases. In this paper, we show our wireless sensor node deployment and its performance obtained from a real scenario and measures taken for different frequencies, modulations and data transfer rates. The performed tests show the maximum distance between sensors, the number of lost packets and the average round trip time. Based on our measurements, we provide some experimental models of underwater communication in fresh water using EM waves in the 2.4 GHz ISM frequency band. Finally, we compare our communication system proposal with the existing systems. Although our proposal provides short communication distances, it provides high data transfer rates. It can be used for precision monitoring in applications such as contaminated ecosystems or for device communicate at high depth.

Keywords: TX/RX, TTL, SOC, EM, CTS/RTS, RF, CMOS

I. INTRODUCTION

Nowadays, there is extensive ongoing research activity relating to underwater communications and underwater sensor networks. On one hand, the main research lines are based on increasing the distance and bandwidth, and, on the other hand, the attempt to reduce the energy consumption of underwater devices, with the aim of increasing the network lifetime. Underwater communication research is primarily focused on the use of optical signals, electromagnetic signals and the propagation of acoustic and ultrasonic signals. Each technique has its own characteristics, with its benefits and drawbacks, mainly due to the chemical characteristics and physical constraints of the medium. Systems based on optical communication are able to reach very high propagation speeds. However a strong backscattering is caused by suspended particles and they are affected by the turbidity of the water, so they are not good options for long distances .Systems based on acoustic waves are less sensitive to fine particles suspended in the water and to the water turbidity, than the optical waves. Moreover, they are the most used methods, since they are able to reach large distances. Although acoustic communication is a proven technology, it presents some main drawbacks, like the low data rate , which is limited by some factors, such as low carrier frequency, strong reflections and attenuation when the communication is performed near the surface, as well as poor performance in turbid water with large particles, sensitivity to varying environmental characteristics and the salinity. In acoustic and ultrasonic communications, researchers usually work on varying the type of modulation and communication protocol, in order to minimize the effects of reflections, and on achieving as high a communication data rate as possible. When higher data rates are needed, we should make use of radio frequency (RF) methods, which are able to reach communication data rates of up to 100 Mb/s in very short distances, apart from presenting substantial immunity from the environmental features. Electromagnetic (EM) waves, in the RF range, can also be a good option for underwater wireless communication systems. EM waves are less sensitive to reflection and refraction effects in shallow water than acoustic waves. In addition, suspended particles have very little effect on them. The speed of EM waves is higher (150,000 times greater) than that of acoustic ones The speed of an EM wave mainly depends on permeability (μ), permittivity (ε), conductivity (σ) and volume charge density (ρ). These parameters change with the type of water and the electrical conductivity value associated with the medium often varies, thus the wave propagation speed and absorption coefficient, which are directly related to the working frequency, also vary. Conductivity presents different values for each case, seawater has a high conductivity average value, which is around 4 S/m (obviously it changes with the salinity and physical properties of each kind of sea water), but in fresh water the typical value is 0.01 S/m and drinking water presents a conductivity between 0.005 and 0.05 S/m. Moreover, the permittivity of seawater changes as a function of the frequency, the temperature and the salinity. In authors provided a relationship model of this dependency in the water. Thus, the main problem for underwater communications based on EM waves is the high attenuation due to the conductivity of the water. This attenuation increases when the EM wave frequency increases. Hence, the higher frequencies will register greater signal losses. In this paper, we perform a practical study of the behavior of EM signals (in the 2.4 GHz ISM frequency band) in underwater environments, using devices compatible with the IEEE 802.11 standard. We have analyzed other technologies that also work on this frequency. This is the IEEE 802.15.4 standard. A priori, we think that, due to the low-power consumption of IEEE 802.15.4, it would be better to use these devices as sensor nodes. However, our application needs data transfer rates higher than the ones offered by IEEE 802.14.5. For this reason, we should sacrifice a little power consumption in favor of improved data transfer rates. The paper shows the tests performed at different frequencies and modulations in order to measure several parameters such as minimum depth, distance between devices and signal transmission characteristics. These tests were performed in a swimming pool filled with fresh water. We set up an underwater point-to-point link between two sensor nodes. These underwater sensor nodes were developed by us. We used two computers connected to each sensor node via serial in order to monitor the activity of the underwater point-to-point link between sensors. We have used the echo request and echo reply packets in order to perform our tests. From the point of view of applications, it is easy to think that underwater communication in the 2.4 GHz band is unhelpful and impractical because water has a high attenuation of these frequencies. However, as we shall see at the end of this paper, there are many applications where the use of EM waves brings many benefits. The rest of the paper is structured as follows: Section 2 reviews some published works on underwater wireless transmission based on RF and acoustic communications. Section 3 summarizes the main issues to be considered in underwater communication in fresh water when electromagnetic waves are used. It also shows the most important features of each modulation used in our research. The fourth section shows the deployed sensor node and its consumption. The used topology and the measurement strategies are also explained in this section. Section 5 shows the results obtained as a function of the working frequency and the distance between devices. The analytical models obtained from the real measurements are shown in Section 6. In Section 7, we compare our 2.4 GHz communication system proposal with the communication proposals published in the related literature. Finally, Section 8 contains the conclusions and future work proposals.

2. BLOCK DIAGRAM

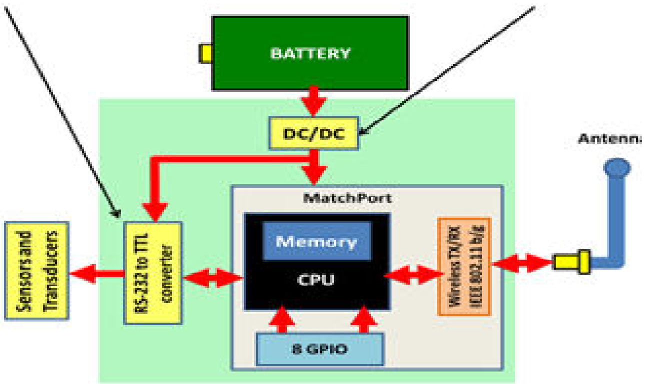

Figure.1 Block diagram of the underwater wireless sensor node.

2.2 EXPLANATION

(1) a power unit, consisting of a battery and a number of DC/DC converters; (2) a processing unit, which usually consists of a small processor and memory; (3) the physical sensors and (4) the transceiver circuit that is formed by a transmitter and a receiver system. In order to provide a wireless interface card to the sensor node we used the Match Port b/g [27], from Lantronix, Inc. It is an embedded system that acts as a gateway between a wireless network, based on IEEE 802.11b/g standard, and a 10/100 Ethernet-based wired data network. Two sets of pins are incorporated to implement two transistor–transistor logic (TTL) ports (but can be converted to RS-232 or RS-485 interfaces) and eight GPIO (which are configurable from its graphical interface) that allow controlling sensors based on ON/OFF operation systems. The device uses CMOS technology with 3.3 V logic levels. The operating speeds range from 300 bps to 921 Kbps. The frames can be 7 or 8 bits with 1–2 stop bits. They can also be configured with even/odd parity, or no parity, and we can use flow control, using the signals (CTS/RTS) or not, and simply use the TX and RX signals. Match port works with System-on-Chip (SOC) processor with 256 KB SRAM, 2 MB Flash memory for storing web pages and the device firmware. MAX233CPP integrated circuit converts the signals from the Match Port from TTL levels to RS-232 standard logic level signals. We have used this integrate circuit, because it requires less passive components than others. Other models need several resistors to limit the current flow of its entries. This current limitation procedure causes higher power consumption. Therefore, a simpler circuit with the same TX/RX features means lower power consumption. The sensor node has lower power consumption using this configuration than using other configurations. In order to power the device with batteries, we used a LDO voltage regulator and a small capacitor 98AGL52B [28] to filter the output voltage and prevent voltage fluctuations. Figure 1 shows the block diagram of the circuit. We can see that the Match Port includes the main elements of a sensor node, such as CPU, memory and radio system. We can also see the schematic for TTL/RS232 converter, which communicates the node with the sensors via DB9 connector, and DC/DC circuit which transform the voltage of 12 volts to 3.3 volts. In our underwater wireless sensor node, the Match Port acts as a central processing unit and transmitting device. The device allows us to connect 2 sensors with RS-232, TTL or RS-485 interfaces, which are one of the most common interfaces in underwater sensors. Its frequency range is from 2.412 GHz to 2.472 GHz. These values correspond to the spectrum used by devices operating under the IEEE 802.11b/g standard at 2.4 GHz. The used antenna is a monopole with 2 Dbi of gain.

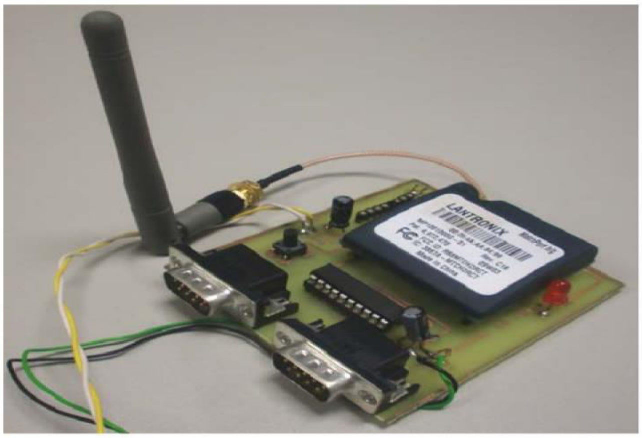

Figure.2 Image of the underwater wireless sensor node.

Figure 2 shows the model in its first phase of development to perform our tests. In order to take measurements, we used a swimming pool which has 32 m^2 surface with a length of 8 meters and 4 meters wide. It is built with brick walls that are covered with small mosaic tiles. The swimming pool depth ranges between 1.5 m and 1.80 m. We chose this position in order to avoid any reflection on the walls, ground and surface water due to the change of medium. Reflections are avoided because the measured distances have a lower order of magnitude than the dimensions of the pool.

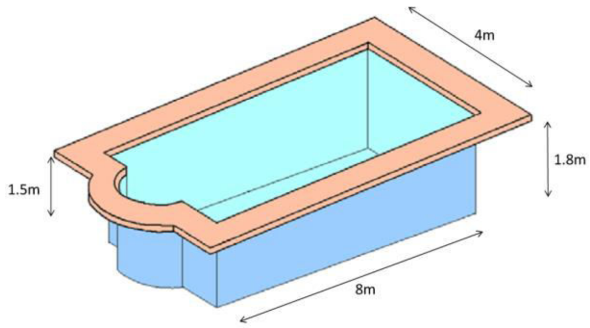

Figure.3. Swimming pool used to take measurements.

Figure 3 shows the sketch of the swimming pool used to gather the measurements. Measurements were taken in fresh water. It had a temperature of 26 °C. In addition, the pH value was 7.2 and the amount of chlorine and bromine dissolved in the water was 0.3 mg/L.

4.3. Sensor Node Preparation

In order to perform the tests, we placed the device in a sealed plastic box to make it both watertight and airtight. This also allowed communication with other devices in the network. To maintain the upright position of the device, we estimated the required ballast. It was the container volume in liters and an additional weight equal to the half value of the calculated volume. Our first step was to ensure that all measurements taken were valid, thus we had to check that the signal did not spread out of the water. Hence, we determined the minimum depth where the antennae should be placed. In order to do this, we established an ad hoc wireless connection between the node and a laptop outside the water. The wireless sensor node was introduced inside the water and we immersed it until the laptop placed outside did not receive any signal from the wireless sensor node. We lost the wireless signal when it was at 15 cm deep. This simple test ensures that there is no signal gathered from outside. The system is located in the center of the pool, about 1.8 m from the edge of the pool, to avoid any effect of reflections. To carry out the wireless communication tests, we used two wireless sensor nodes under the water. We also used two laptops, located outside the water, connected to each node via serial cable, to gather the data and monitor the network activity. Both antennae were oriented to the bottom with their radiation pattern to down. The gain of both antennae was 2 dBi. The antenna consisted of a single radiating arm vertically straight. This antenna is completed by a ground plane to operate properly. This ground plane can be natural. Hence, both sensors have identical features.

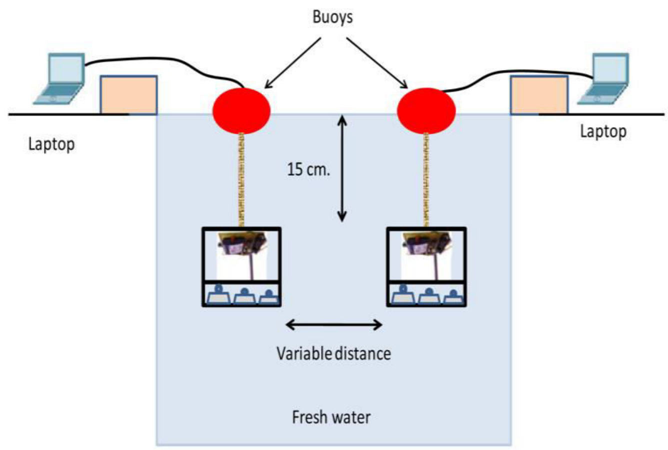

Figure.4. Topology used to take measurements

In order to perform the tests, we placed the device in a sealed plastic box to make it both watertight and airtight. This also allowed communication with other devices in the network. To maintain the upright position of the device, we estimated the required ballast. It was the container volume in liters and an additional weight equal to the half value of the calculated volume. Our first step was to ensure that all measurements taken were valid, thus we had to check that the signal did not spread out of the water. Hence, we determined the minimum depth where the antennae should be placed. In order to do this, we established an ad hoc wireless connection between the node and a laptop outside the water. The wireless sensor node was introduced inside the water and we immersed it until the laptop placed outside did not receive any signal from the wireless sensor node. We lost the wireless signal when it was at 15 cm deep. This simple test ensures that there is no signal gathered from outside. The system is located in the center of the pool, about 1.8 m from the edge of the pool, to avoid any effect of reflections. To carry out the wireless communication tests, we used two wireless sensor nodes under the water. We also used two laptops, located outside the water, connected to each node via serial cable, to gather the data and monitor the network activity. Both antennae were oriented to the bottom with their radiation pattern to down. The gain of both antennae was 2 dBi. The antenna consisted of a single radiating arm vertically straight. This antenna is completed by a ground plane to operate properly. This ground plane can be natural (a water surface to facilitate electron conduction) or artificial (a number of drivers which are joined at the base of the monopole). Hence, both sensors have identical features. Figure 4 shows the topology used to take the measurements.

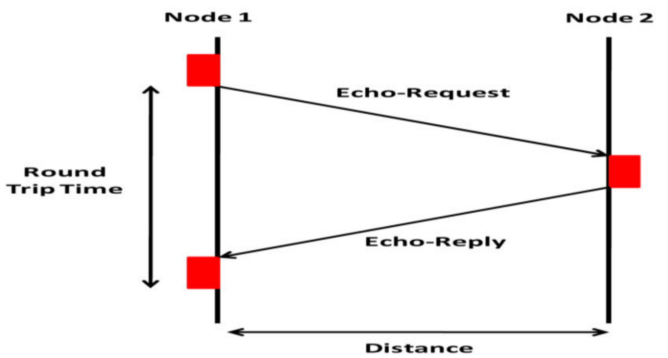

Figure.5. Packet flow diagram

2.2.1 Performance Results:

In order to analyze the performance of our system, we carried out different tests in the 2.4 GHz frequency band with different modulations and transfer rates, while we varied the distance between the antennae. These tests allow us to measure the performance of the developed nodes and characterize its behavior in terms of number of lost packets, round trip time (RTT), modulation techniques for underwater transmission, and the maximum data transfer rates that can be obtained for each modulation. We have used some common commands in the command-line shell interface that let us check the status of the network connection. Concretely, we have used the echo request and echo reply packets in order to perform our tests (see Figure 5). We sent a continuous packet flow and we collected the results. The system performance was evaluated in terms of consumption of sensor node, communication distance, data transfer rate, average RTT and % of lost packets for each frequency. The calculation of the average RTT has been done, taking into account of only the packets that performed the round-trip successfully. When a packet was not received or was received wrong, we assign the value of 3,000 ms to draw it in the graph, but this value is not taken into account in the average RTT estimation for that case. We have used a threshold value of 3,000 ms, because it is commonly used. Tests have been performed in the first seven channels specified of the 2.4 GHz frequency band in the IEEE 802.11b/g standard. These frequencies correspond to 2.412 GHz, 2.417 GHz, 2.422 GHz, 2.427 GHz, 2.432 GHz, 2.437 GHz and 2.442 GHz. We only tested these frequencies because after the seventh channel we found that the value of lost packets is around 90–100%, which is a very high value for a communications system. Table 2 shows the modulations and data rates used in our performance tests. We did not include the OFDM transmission scheme in our test performance because when we used this transmission scheme, we obtained even worse measurements and, thus worse behavior than for the other three modulations shown in Because one of the requirements to be met by a wireless sensor node is to have low power consumption in order to prolong the network lifetime our first step has been to measure this consumption.

Then, for each modulation and data rate shown in Table 2, we measured the RTT the amount of lost packets between both wireless sensor nodes, while varying the distance between the antennae and the working frequencies in the 2.4 GHz ISM frequency band. It let us know the wireless communication performance and the communication behavior at these frequencies. Hence, we measured the behavior of the modulation BPSK, QPSK and CCK with transfer rates up to 1 Mbps, 2 Mbps, 5.5 Mbps and 11 Mbps. Each test was 3 minutes long. We assigned the value of 3,000 ms to those packets which were not received or were received wrong. From this value, we know that no echo will be received. We know this, due to the wave propagation speed through water and the distance between transmitter and receiver.

2.2.2 POWER CONSUMPTION:

The wireless sensor node is powered with 3.3 V, with average power consumption in active mode of 460 mW. We observed that when the device is transmitting or receiving data, the power consumption increases to 594 mW, while the device consumes around the 1.1 W in its initialization phase (which is approximately 10 s long). The behavior of the device was monitored for 2.5 min since it was started. After this time, it sent broadcasts every 30 s. Figure 6 shows the energy consumption evolution and the average power consumption of this device during that time.

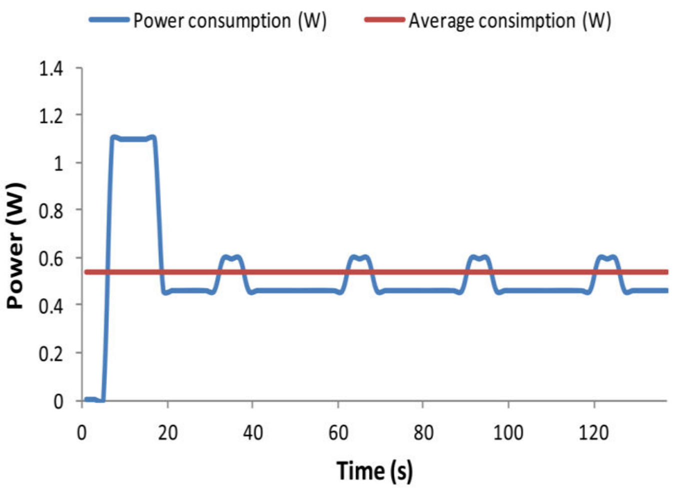

Figure.6. Underwater wireless sensor node consumption.

2.2.3 Average RTT For 1 Mbps

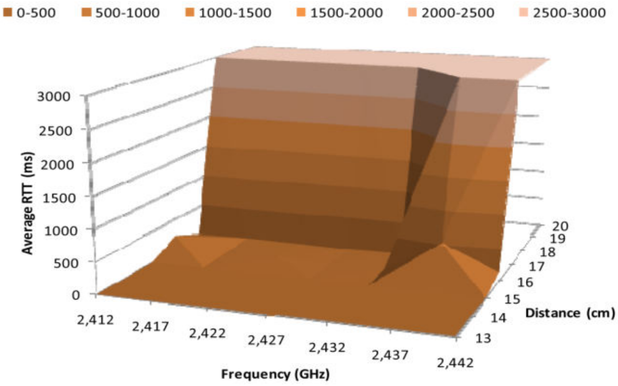

Figure.7. Average RTT for 1 Mbps.

Figure 7 shows the average RTT in milliseconds for 1 Mbps data transfer rate, when the BPSK modulation is used, as a function of the working frequency and the distance between the wireless sensor nodes. We observe that the highest variations occur between 15 cm and 18 cm. The RRT value for 15 cm is close to 3 ms, while it is 3,000 ms for 18 cm. The average RTT value for distances between 15 cm and 18 cm (at 2.412 GHz, 2.417 GHz, 2.422 GHz, 2.427 GHz and 2.432 GHz) is relatively small, around 20 ms. But at 2.437 GHz the RTT value for 16 cm increases up to 500 ms, while for 17 cm there are not registered packets, thus the obtained RTT is 3,000 ms.

3. ADVANTAGES

1) Can be use to provide early warnings of tsunamis generated by undersea earthquakes.
2) It avoids privacy leakage.
3) It avoids data spoofing.
4) Pollution monitoring.

4. DISADVANTAGES

1) Point to point communication.
2) Point to multipoint communication is not possible because of the use of led or laser.
3) System may receive from two different system but it is not possible to transmit to two different system.

5. APPLICATIONS

1) Pollution monitoring.
2) Ocean current monitoring.
3) Solar powered AUVs.
4) Equipment monitoring and control.
5) Seismic monitoring.
6) Autonomous Underwater Vechicle.
7) Acoustic navigation technology for multiple AUVs.

6. CONCLUSION

Research on underwater communications and the use of Underwater Wireless Sensor Networks is becoming a very hot topic because of the appearance of new marine /oceanographic applications. Communications based on EM wave transmission offer great benefits such as the increase of the data rate of the link to transmit more information. In this paper, we have performed several tests at different frequencies and modulations, in order to check several parameters such as the minimum depth, distance between devices and signal transmission characteristics. These tests have been performed in the first seven channels that are specified in the IEEE 802.11 standard for the 2.4 GHz ISM frequency band (which is the frequency range between 2.412 GHz and 2.442 GHz). After having gathered all these measurements, we highlight several issues. On one hand, we observe that the modulation (and thus the data transfer rates) with better performance are BPSK and QPSK. They have less than 30% of lost packets for distances shorter than 16 cm. There are also 30% of lost packets when QPSK modulation is used at 17 cm. Moreover, we observed that RTT values for 16 cm were around 25 ms when the wireless sensor nodes were working at 2.432 GHz. Thus, contrary to what we initially thought (the higher the frequency, the higher the attenuation), it seems that the communication system performance is improved slightly when it works at 2.432 GHz, compared with the results of the measurements obtained when it is working at 2.412 GHz. We have observed that the increase of percentage of lost packets is higher from 15 cm to 16 cm than from 16 cm to 17 cm and from 17 cm to 18 cm. But when we measured the average RTT, there is a substantially greater increase from 17 cm to 18 cm than from 16 cm to 17 cm and from 15 cm to 16 cm. Therefore, our underwater communication system has an optimum behavior at 16 cm, working at frequency of 2,432 GHz, with the BPSK and QPSK modulations. These modulations had also good performance at distances of 17 cm, working at 2.422 and 2.427 GHz, with a percentage of lost packets slightly above 30%.

7. REFERENCES

[1]. Akyildiz, I.F.; Pompili, D.; Melodia, T. Challenges for efficient communication in underwater acoustic sensor networks. ACM Sigbed Rev. 2004, 1, 1–6

[2]. Sendra, S.; Lloret, J.; Garcia, M.; Toledo, J.F. Power saving and energy optimization techniques for Wireless Sensor Networks. J. Commun. Acad. Publ.2011, 6, 439–459.

[3]. Garcia, M.; Sendra, S.; Atenas, M.; Lloret, J. Underwater wireless ad-hocnetworks: A survey. In Mobile Ad hoc Networks: Current Status and Future Trends; CRC Press: Boca Raton, FL USA, 2011; pp. 379–411.

[4].Liu, L.; Zhou, S.; Cui, J.-H. Prospects and problems of wireless communications for underwater sensor network Wirel. Commun. Mob. Comput.-Spec. Issue Under. Sens. Netw. 2008, 8, 977–994.

[5]. Stojanovic, M. Underwater acoustic communication. In Wiley Encyclopedia of Electrical and Electronics Engineering; John Wiley & Sons: New York, NY, USA, 1998; pp. 688–698.

[6]. Che, X.; Wells, I.; Dickers, G.; Kear, P.; Gong, X. Re-evaluation of RF electromagnetic communication in underwatersensor networks. IEEE Commun. Mag 2010, 48, 143–151.

[7]. Chakraborty, U Tewary, T.; Chatterjee, R.P. Exploiting the loss-frequency relationship using rf communication in underwater communication networks. Proceedings of 4th International Conference on Computers and Devices for Communication, CODEC 2009, Kolkata, India, 14–16 December, 2009.a