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# Energy harvesting techniques and non-orthogonal multiple access for UASNs

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Underwater sensor networks (USNs) play a key role for applications such as underwater defense, underwater imaging, internet of underwater things, underwater navigation and so on. In USNs, acoustic waves have been referred over the radio frequency (RF) waves or optical waves to communicate between sensor nodes, buoys, and autonomous underwater vehicles (AUVs). The acoustic waves in underwater acoustic sensor networks (UASNs) have a much lower bandwidth of up to a few kHz, resulting in a lower achievable data rate. Generally, the sensor nodes have been deployed on the beds of the oceans. So, it is very difficult to recharge or replace them, once the batteries of the sensor nodes are drain off. Hence, achievable data rate and energy efficiency (EE) has to be improved simultaneously in UASNs. In this paper, we have presented different non-orthogonal multiple access techniques to improve data rate and various energy harvesting techniques proposed for UASNs to improve the EE.

**Keywords:** Non-orthogonal multiple access, Underwater acoustic sensor networks (UASN), Underwater sensor networks (USN), Piezoelectric transducer, Microbial fuel cell, Energy efficiency

## 1 Introduction

70 percent of the surface of our planet is oceans. Oceans have so many unique applications. Some of the unique applications available in the oceans are pollution control monitoring, prediction of earthquakes, chances of tsunami occurrence, underwater medical research, tactical surveillance, aided navigation, internet of underwater things, underwater imaging and much more.

USNs play a key role for the implementation of these applications. USNs consist of several sensor nodes have been placed on the bed of the ocean, autonomous underwater vehicles (AUVs) and buoys as shown in Fig. 1. Mainly, the wireless communications in USNs can achieve by using either acoustic waves or radio frequency (RF) waves or optical waves to provide communication between sensor nodes, AUVs and buoys[1].

The comparison of transmission distance, data rate, bandwidth and transmission power between acoustic waves, RF waves and optical waves are shown in Table 1.

RF waves provide high a data rate and high bandwidth (BW), but transmission power is more, require big antennas and transmission distance is up to tens of meters underwater, scattering effects also more. Optical waves have a higher data rate and BW than the RF waves. However, the transmission range between the sensor nodes has been up to very few meters due to high scattering of optical signals. Both RF and optical waves have not been suitable for long-range communications in USNs, and also, the circuit complexity has also been more for RF and optical waves. As a result, acoustic waves which have a transmission distance range up to kilometres are preferable for long-range communications in USNs. The transmission power in acoustic waves is less, and circuit complexity in UASNs are also less, but the acoustic waves have limited bandwidth, due to which achievable data rate is less, increased propagation delays and connectivity is less. To address these data rate and connectivity problems, non-orthogonal multiple access (NOMA) has been integrated with UASNs.

On the other hand, the sensor nodes have been placed on the beds of the oceans. So, they have been challenging to recharge or replace once the batteries of the sensor nodes drain off.

Improving energy efficiency has also been one of the important challenges in UASNs. In order to achieve better network life time and EE, different energy harvesting techniques have been proposed for UASNs. Accordingly, we study different NOMA techniques have been proposed for UASNs to improve the data rate. Later, we also study the different energy harvesting techniques proposed for UASNs to improve the EE.

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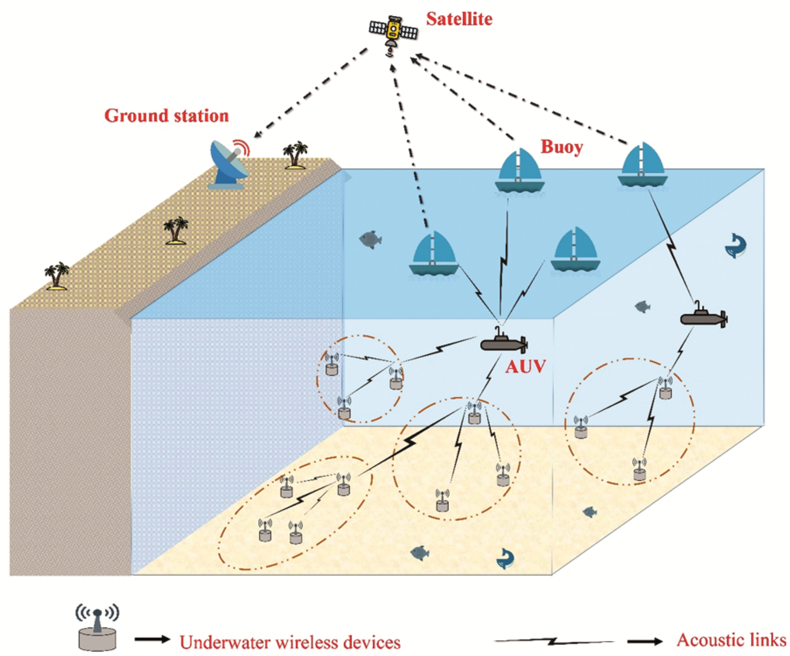


Fig. 1 — Underwater acoustic sensor network.

Table 1 — Comparison of Acoustic Waves with RF waves and Optical waves[1]

| Features | Acoustic waves | RF waves | Optical waves |
|---|---|---|---|
| Transmission distance | tens of km | tens of m | 100 – 200 m |
| Data rate | Kbps | Mbps | Gbps |
| Bandwidth | KHz | MHz | GHz |
| Transmission Power | tens of W | Upto 100 W | Upto 1 W |

## 2 Materials and Methods

### 2.1 Underwater NOMA

Bocus *et al.*[2] and Markled *et al.*[3] proposed NOMA for UASNs. Bocus *et al.*[2] discussed two different techniques: NOMA-orthogonal frequency division multiple access (NOMA-OFDM) and NOMA-filter bank multicarrier (NOMA-FBMC). NOMA-OFDM implied that two or more users were assigned to a single resource block (frequency/time) and that the signal transmitted by the base station was the superimposed signal of the users in that resource block. NOMA-FBMC means that the frequency is first divided into number of small subcarrier frequencies and there will be several time slots in each subcarrier frequency. Two or more users were allocated in each time slot of the subcarrier frequency, the transmitter communicated with the users allocated to that cluster for each slot. By comparing NOMA-OFDM with NOMA-FBMC, NOMA-FBMC provided better bit error rate (BER) and packet error rate (PER) than NOMA-OFDM. Markled *et al.*[3] considered a relay between buoys floating on the water and sensor nodes mounted on the ocean beds. The author contrasted non- relay full duplex-non-orthogonal multiple access (NR-FD-NOMA) with relay based full-duplex NOMA (R-FD-NOMA). Due to FD communications and NOMA, there exists self-interference (SI) and successive interference (SuI) occurred at the relay node, which significantly degraded the performance of channel capacity and increased outage probability. Further, R-FD-NOMA achieved better data rate and EE than NR-FD-NOMA, due to the assistance of the full-duplex relay node. Cheon and Cho[4] proposed a new power allocation scheme for NOMA in UASNs. In NOMA, the allocation of transmission power coefficients to a weak user and a strong user are important. Cheon and Cho[4] proposed a new power allocation scheme called equal transmission times (ETT) in which the power distribution for the weak user and the strong user is not only distance dependent but also it considers the number of packets waiting at the transmitter buffer. The total sum rate is improved by applying this scheme compared to the existing scheme. Chen *et al.*[5] introduced the NOMA in underwater visible light communication (UWVLC) where two different light emitting diodes (LEDs) are used to transmit data to two different clusters. The data rate in the UWVLC is better than UASNs, but at a very lower transmission range of only 100-200 meters whereas UASNs' transmission ranges of kilometres. NOMA for UASNs is slowly gaining popularity due to the challenges in the underwater channel. This slow progress due to the frequency-dependent channel noise, distance-dependent usable bandwidth, frequency and depth dependent path loss along with the transmission distance, makes the underwater channel more unique and complex.

## 3 Results and Discussion

### 3.1 Energy harvesting in underwater communication

On the other hand, the sensor nodes are placed on the beds of the oceans. So, they are very difficult to recharge or replace, once the batteries of the sensor nodes are drained off. Accordingly, energy harvesting techniques in UASNs is gaining importance due to the improvement of network life time and EE. Table 2 shows the literature works reported for different energy harvesting techniques.

Li *et al.*[6] explained different types of piezoelectric materials used for energy harvesting, their properties and the amount of energy harvested for the variation in density, acoustic impendence of the material. The comparison of different types of piezoelectric transducer and the irrespective filler material, density of the filler material, acoustic impedance, and source level is shown in Table 3.

Piezoelectric transducer is one of the important energy harvesting technique used in UASNs. These piezoelectric transducers transform acoustic signal pressure into electrical signal[6]. Diab *et al.*[7] suggested low power management for efficient power transfer from mechanical vibrations to electrical current. It consisted of two acrylic half-spherical glass shells between which the Pz26 piezoelectric ring was clamped. As a result, author got 175 $\mu$W harvested energy for an 8Vpp (peak-to-peak voltage) excitation voltage at a distance of 5 cm from the emitter. As the distance from the emitter increased the energy harvested decreased. Shevtsova *et al.*[8] proposed a new design with two membranes, the first consisted of porous piezoelectric ceramics and the second consisted of perforated active piezoelectric diaphragms. In this design, Pareto-based optimization was used to obtain an optimum amount of electrical energy harvested for acoustic pressure. Jang *et al.*[9] used a backscatter network consisting of a piezoelectric energy harvesting transducer, in which the circuit reflected the signal coming from the transmitter for transmission of bit one and harvested energy using that signal for transmission of bit zero. Janani *et al.*[10], the author had developed a microbial fuel cell (MFC) for energy harvesting. MFC produced electricity by using chemical action of bacteria. The MFC used in consisted of marine sediment bacteria, and two interface circuits, which were used to control the conversion of chemical energy to electrical based on the load[10]. This MFC generated a power of 6.8V which was capable of operating power instruments such as underwater sensor nodes, acoustic modems. In[11], the authors developed another MFC with ocean water or river water, sea sand, bacteria as sources of power generation. In this method, stainless steel and magnesium were used as anode and cathode respectively. The MFC in generated a power of 7.02Vwhich is capable of operating surveillance devices[11].

The comparison between MFC is shown in the Table 4[10 & 11].

Srujana *et al.*[12], the author used hybrid harvesting technique, in which both MFC and piezoelectric transducer were used for energy harvesting. In MFC anode was immersed in water containing microbes that degraded substrates and transfer electrons to anode that was dipped into water with dissolved oxygen as electron acceptors that generate current from which voltage is produced and used by the sensors. Srujana[12] plotted graphs for how much voltage was generated in piezoelectric transducer from acoustic pressure and voltage from microbial fuel

Table 2 — Different energy harvesting techniques[6]

| Energy harvesting technique | References |
|---|---|
| Piezoelectric transducer | 6,7,8,9 |
| Microbial fuel cell | 10,11 |
| Hybrid harvesting technique | 12 |
| Ocean thermal energy | 13 |
| Galvanic cell | 14 |

Table 3 — Comparison of different types of piezoelectric transducer with their respective source levels[6]

| Piezoelectric transducer | Filler material | Density ($g/cm^3$) | Acoustic impedance (MRayl) | Source level (dB) |
|---|---|---|---|---|
| CircuitworksCW2400 | Sliver epoxy | 2.85 | Not available | 151.3 |
| EPO-TEK 301 | Non- conductive epoxy | 1.15 | 3.05 | 152.5 |
| Hot melt glue | Glue | 0.94 | 1.69 | 153.1 |
| EPDM closed cell foam | Rubber | 0.13 | Not available | 158.5 |

Table 4 — Comparison of microbial fuel cells[10,11]

| Ingredients | Power management system | Voltage | Reference |
|---|---|---|---|
| Marine sediment bacteria | Charge pump, super capacitor and interleaved boost convertor | 6.8 | 10 |
| Ocean water or river water, sea sand, bacteria | Charge pump, super capacitor and interleaved boost convertor using linear technology chip 3872 | 7.02 | 11 |

Table 5 — Voltage for different combinations of Graphite-Anode with sea water as electrolyte[15]

| Anode | Voltage |
|---|---|
| Copper | 0.2V |
| Brass | 0.4V |
| Aluminium | 0.8V |
| Zinc | 1.0V |
| Iron | 1.1V |

cell current. Chao *et al*.[13] harvested energy by using temperature shift from the surface to some depth in the ocean. This method was very useful for AUVs that collected data for a few meters and returned to the surface to relay the data to the base station on the ground. This system should dive once every 8 hours for the difference in temperature from which it can be recharged and energy recharged can be used for 8 hours. Rezaei *et al*[14]. used the theory of galvanic cell type by using zinc and brass as electrodes which are glued to the back side of sensor node and river water as electrode. This device harvested a few microwatts per $cm^3$ and extended the duration of sensor nodes up to 3 to 4 weeks. Sivakami *et al*.[15] compared the galvanic cell with graphite as cathode combined with zinc, iron, aluminium, brass, copper as anode and sea water as electrolyte. Graphite was used here as a cathode because it serves as a noble element like gold and platinum. Table 5 shows the comparison of voltage for different combinations of graphite-anode with sea water as electrolyte.

## 4 Conclusion

This paper has discussed a literature review on various non-orthogonal multiple access (NOMA) techniques based UASNs to improve the data rate within the limited bandwidth. Later, we have discussed different energy harvesting techniques available to UASNs to enhance the lifetime of the network and energy efficiency. The piezoelectric transducer has been a more important one that converts acoustic pressure into electrical energy. We saw various developments in the piezoelectric transducer that will improve the conversion of energy. We have also seen other energy harvesting techniques such as microbial fuel cells (MFC), ocean thermal energy, and galvanic cells. MFC converted chemical energy into electrical energy. We have also discussed materials used in two MFC cells and voltage generated. Ocean thermal energy technique can be used in AUVs, as it moves up and down in the oceans where there will be a difference of temperatures. Different types of anodes can be used in galvanic cells, and voltage generated has been discussed. To improve the lifetime of the sensor node, we can incorporate more than two energy harvesting techniques into the sensor node. In future work, we may implement NOMA with energy harvesting using acoustic signals in an optimal solution to improve the channel capacity and energy efficiency simultaneously in UASNs.

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