Energy Consumption Comparison between Acoustic Data Transmissions and AUV Data Delivery

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Abstract
Underwater sensor networks constructed in ocean are attracting many researchers’ interests for the purpose of improving underwater environmental research. In these networks, an Autonomous Underwater Vehicle (AUV) can be used to collect underwater information efficiently. An AUV has two ways to deliver sensed data; sending by acoustic waves or moving itself. In this paper, these two methods are compared to find out energy-efficient strategies by calculating formulas and carrying out simulations.

Categories and Subject Descriptors
C.2.1 [Network Architecture and Design]: Wireless communication

General Terms
Management, Performance

Keywords
Underwater Sensor Networks, AUV, Energy consumption

1. INTRODUCTION
Recently, Underwater Sensor Networks [1] is becoming an attractive topic for many researchers for the purpose of improving underwater environmental research. In Underwater Sensor Networks, Autonomous Underwater Vehicles (AUV) are used. With equipped sensor devices and acoustic modems, AUVs can act as moving nodes in sensor networks. Nevertheless, since AUVs move under the ocean, it is difficult to exchange their batteries during sensing. Therefore, when constructing Underwater Sensor Networks, it will be an important task to save AUV’s energies. In this paper, two simplest ways to restrain energy consumption, avoiding inefficient packet transmission and redundant movement of AUVs, are considered.

2. POWER CONSUMPTION BASICS
2.1 Acoustic modems
In Underwater Sensor Networks, radio waves are not suitable for wireless communications, so acoustic signals are often used. One of the typical acoustic modems is WHOI micro modem [2][3]. It has four states with different power consumption properties: Transmit, Receive, Idle, and Sleep. Though these states are the same as those of radio modems, there is a conspicuous characteristic about acoustic modems. While radio modems consume almost the same power in each state, acoustic modems consume very high power when they are in the transmit state. In [3], power consumptions of WHOI micro modems are introduced as 50W for Transmit (to achieve 185 dB re μP a with source level), 3W for Receive, and 80mW for Idle. Reference [4] gives us detailed relations between sound pressure and power consumption.

In architecture of the underwater sensor network we consider, AUVs with sensors and acoustic modems equipped are placed in the ocean to collect oceanographic information. We will call whole amount of the data DSUM. An acoustic modem is hanged down from the boat which is floating on the surface and function as a sink node. AUVs have two ways to deliver their data to the boat: sending by acoustic waves or bringing by itself. In order to calculate AUVs’ energy consumption and compare these two methods, we consider two simple scenarios which are described in Fig. 1.

In the scenario 1, an AUV which sensed data is stable and deliver data only by acoustic data transmission. If the sink node is

\[ P_T(d) = 2\pi d \times 10^{10} \times 0.67 \times 10^{-18} \]  \hspace{1cm} \text{(1)}

\[ P_T(d) = 4\pi d \times 10^{10} \times 0.67 \times 10^{-18} \]  \hspace{1cm} \text{(2)}

Where \( P_T(d) \) is the power in watts. \( d \) is the sea depth and SL is source level in dB. Because of this characteristic, to reduce the number of transmission will be important for saving energy in Underwater Sensor Networks.

2.2 AUVs
AUVs can move without any cables or remote controls, and this flexibility requires researchers to make a strict plan about energy consumption. Therefore, to calculate AUV’s power is an important process. Power consumed by an AUV [5] is given by

\[ E_{AUV} = \frac{C_p S V^3}{2 \eta} + P_{HTL} \]  \hspace{1cm} \text{(3)}

where \( E_{AUV} \) is the consumption power in Watt, \( \eta \) is AUV’s propulsion efficiency, \( \rho \) is water density, \( C_p \) is a drag coefficient between an AUV and water, \( S \) is vehicle’s surface area, and \( V \) is AUV’s velocity, \( P_{HTL} \) is the hotel load, which represents power consumption by AUV’s functions except its propulsion power.

3. ENERGY CONSUMPTIONS MODELS
3.1 Explanation of Two Scenarios

Fig. 1: Two scenarios, by which collected data is delivered by AUVs.
placed out of the range of the sender, some other nodes may try to relay the data so that packets can reach the destination. We will consider this scenario for both single hop and multi hop case. In the scenario2, only one moving AUV is considered.

3.2 Energy Consumption by Scenario1
Total energy consumption of the scenario1 $C_1$ can be expressed as follows.

$$C_1 = (P_{IDLE} + P_{HTL})TN_{AUV} + (P_{TX} + P_{RX} - 2P_{IDLE})t_{TX}N_{PKT}N_{HOP} \quad (4)$$

where $P_{IDLE}$, $P_{TX}$, and $P_{RX}$ represent each state’s power consumption in Watts, respectively, and $P_{HTL}$ is the Hotel load. $T$ is the whole time of data transmission and, in this paper, it is represented by $T = \frac{D_{SUM}}{R_{APR}}$ approximately, where $R_{APR}$ is the data rate of an application. $N_{AUV}$ is the number of AUVs, and $N_{HOP}$ is the number of hops, which is expressed as $N_{HOP} = N_{AUV} - 1$. $t_{TX}$ is the time to send one packet, and $N_{PKT}$ is the number of transmitted packets. The first term represents the energy consumed in the idle phase of AUVs. The second term is the energy used while sending and receiving packets.

3.3 Energy Consumption by Scenario2
Total energy consumption of the scenario2 is expressed as below.

$$C_2 = (P_{MV} + P_{IDLE} + P_{HTL})t_{MV} \quad (5)$$

where $P_{MV}$ is the power consumption while moving, and $t_{MV}$ is the movement time.

4. SIMULATIONS
We made some experiments using network simulator NS-3 [6], to compare the two scenarios explained in previous section. To consider energy consumptions of AUVs during the simulation, we added AUV modules [7] to NS-3.

The parameters we used in the simulation are below.

- $P_{RX} = 0.158[W]$, $P_{IDLE} = 0.158[W]$, $R_{TX} = 5000[\text{bps}]$, $R_{APR} = 300[\text{bit}]$
- We chose packet size as 192 [bit], and header size as 39 [bit].
- The depth of AUV is fixed to 70 [m]. We changed velocity of AUV from 1 to 1000 [m/s]. We also changed the total data amount $D_{SUM}$ from 1000000 to 30000000 [bits], and distances between nodes. The parameters for AUV are chosen by referring to [8].

$$\eta = 0.35, \quad \rho = 1025[\text{kg/m}^2], \quad C_d = 0.04, \quad S = 0.3[\text{m}^2], \quad \text{and} \quad P_{HTL} = 100[\text{W}].$$

4.1 Single Hop Case
In this subsection, we consider a single hop case for scenario1.

In Fig. 2, relations between distance and energy consumption are shown. In Fig. 2, we can see that energy consumptions in scenario1 become very high when the distance between nodes get long. Since sending distance depends on sound pressure, we think that this exponential increase in energy consumption is caused by the formula (1) and (2). Energy consumption of scenario2 changes depending on distance. This is because movement time of AUV depends on the distance to move.

Fig. 2: Relationship between distance and energy consumption in the single hop case.

4.2 Multi Hop Case
In this subsection, we consider a multi hop case of the scenario1, where the number of hops is four at most and distance unit is 1000 m. We plot the smallest energy consumption at these distances and hop-counts, by choosing the best combination of AUV locations. Fig. 3 shows relationships between distance and energy consumption according to hop counts.

Fig. 3: Relationship between distance and energy consumption in the multi hop case for total data size as 1000000 [bit]

By using several AUVs and permitting multi hop transmission, we can avoid the exponential increase of energy consumption in scenario1 shown in Fig. 2.

5. CONCLUSIONS
In this paper, we compared two scenarios: transmitting acoustic waves and moving AUVs for data delivery. When distance to destination is short, moving AUVs perform good energy consumption and, when it is long, transmitting data performs well. Nevertheless, we can improve the performance of sending data by using several AUVs and transmitting by multi-hop. There are some remaining works about this study, to consider the hybrid version of scenario1 and scenario2 and to examine the performance of these scenarios more deeply.

6. REFERENCES