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Lifetime Prolonging Algorithm for Underwater Acoustic Sensor Network

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Abstract: This paper presents development of a lifetime prolonging algorithm for underwater sensor networks. The challenges faced in monitoring underwater scenarios is different the usual radio model for calculating the dissipation losses as well as the transmission losses is not applicable. Hence the constraints on terrestrial WSN's cannot be totally adopted for lifetime computations. The proposed algorithm takes into account the balanced energy consumption by nodes, with varying parameters related to the sensing field like energy, attenuation, path loss component. The aim is to prolong the node lifetime and hence network lifetime. The simulation results of the proposed algorithm is compared with the existing algorithms and found to be superior in terms of the lifetime.

Key words: Underwater acoustic sensor networks (UWA-SNs) % Energy balancing % Lifetime % Propagation delay % Attenuation loss

INTRODUCTION

Causes of inefficient utilization of resources can be very complex and their remedies may not be straightforward. To deal with these problems which require reporting of properties of a certain physical phenomena, one can make use of smart micro-electronic objects called sentinels, which go by the name wireless sensor networks (WSN) and interface the physical world with computers, thereby creating a profound flexibility for awareness and remote controlling. But the most important parameter to consider for efficient and prolonged lifetime of these nodes is energy [1].

In environment conditions such as volcanoes or ocean beds it is not possible to replace the nodes if their energy is depleted. The network lifetime which directly determines the duration of the sensing task, can be prolonged with optimal and balanced energy utilization and information can be gathered for a longer duration of time.

Sensor networks and hence UWA-SNs have emerged as an economically viable alternative to currently adopted and costly methods used in seismic monitoring, climate regulation and transportation.

A vast portion of earth is covered by oceans. Due to this vast presence of oceans, we need an economical approach to achieve our goal of underwater monitoring in a very cheap and efficient manner and underwater acoustic sensor networks (UWA-SN) can be one way of achieving this goal. The limited battery and hence the lifetime of these acoustic sensors is our biggest challenge in today's fast revolutionizing world.

The design of a UW-SN depends on factors like the bandwidth limitation, underwater corrosion that causes failure, non rechargeable batteries and the propagation delay that is not fixed unlike the terrestrial SN's. Hence UWA-SNs differ from the terrestrial both in terms of its energy costs and channel propagation phenomena. Also it is harder to recharge/replace node batteries in underwater environments. So for these networks, balanced energy dissipation becomes very important and it is highly desirable to distribute energy consumption of each node evenly, thus nodes may die together and one can change/replace their batteries through re-deployment.

Several literatures address the energy consumption in UWA-SNs. Some [2-5] estimate the battery lifetime and power costs. Whereas others [6-8] have analyzed the energy consumption considering routing protocols such as packet relaying, direct transmission and clustering. However, most of the earlier works [2-8] have just considered the total energy consumption and not the energy balance of individual nodes. The main issue of

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interest to us is to maximize the *lifetime* of such a sensor network for a given amount of energy, or equivalently, to retrieve the same data using the least amount of energy as discussed in [9]. In this paper we define the lifetime of a sensor network as the expected lifetime of any given sensor in the network. In a densely deployed sensor network this definition can be easily extended to be the time until a certain percentage of the sensors died. Thus in prolonging the lifetime of a sensor network, it is important to balance the power depletion from one sensor to another. The different ways of collecting the sensing data are *direct transmission (*DIRECT), where each sensor directly sends gathered information to the remote receiver [9], is used for comparison *multi-hop routing* (MHR) [10], which has been extensively studied for both generic ad hoc routing networks as well as wireless sensor networks, to realize goals, like, energy consumption minimization.

In this paper we propose a new alternative approach i.e. Optimized Energy Balancing (OEB) data propagation algorithmic approach where sensors balance energy dynamically based on energy of the neighbouring sensors. This approach is discussed in detail in next section and is proved to be potentially more scalable. The OEB is a hybrid data propagation algorithm. To achieve energy balance it alternately changes nodes transmit mode between multi-hop and direct transmission based on node's residual energy. We formulate the energy consumption and estimate network lifetime with varying parameters related to the sensing field.

Energy conservation is required since the network is solely based on the performance of a certain number of energy-constrained nodes. Apart from energy, lifetime also depends on factors like the observation region, the source behaviour within that region, base station location, number of nodes, path loss characteristics, efficiency of node electronics and the energy available on a node [11]. This allows architects of sensor networks to focus on factors that have the greatest potential impact on network lifetime. By employing a combination of theory and extensive simulations we show that after balancing the energy in all data gathering scenarios presented, there exists a more balanced network which achieves a longer lifetime.

The paper is organized as follows. Section II presents the network model under consideration, related assumptions and algorithm designed. In Section III results have been discussed with respect to average lifetime of a sensor network. We also discuss related energy allocation issues in this section. We conclude the paper with a summary and discussion of future work in Section IV.

MATERIALS AND METHODS

Network Model: A typical mooring oceanic monitoring system [12] is used to transmit data underwater. This mooring system is equipped with acoustic modems and sensor nodes for data sensing and transmission. A basic network lifetime prolonging algorithm [14] discusses improvement of the network lifetime but fails to consider the underwater communication constraints completely. Our approach considers the acoustic equations for lifetime computation including acoustic modems characteristics and underwater communications mainly influenced by path loss, noise, multi-path, Doppler spread and high and variable propagation delay. All these factors determine the temporal and spatial variability of the acoustic channel.

The OEB algorithm assigns a unique ID to each node. This node ID gives the position of the sensor as well as the no of packets a node will need to send to the sink. The Node ID also depicts *Acknowledgement*, since it also confirms that the data is coming from the preceding node only, Packets include sensed data such as temperature, pressure, salinity, etc. We first consider each sensor sends the packet hop by hop (MHR) to the sink via the linear sensor network. After the first iteration, the energy consumption for the nodes in the chain is different. Considering two adjacent nodes: S_i and S_{i-1}, S_{i-1} not only transmits its own sensed data towards the sink, but also relays the data it receives from S_i, similarly node S_{i-2} will also relay two packets, one of node S_{i-1} and one of its own (hence S_{i-2} transmit three packets which is equal to its assigned ID, reason why ID depicts node position) which leads to uneven energy consumption. As a result, the nodes near the sink will deplete more energy and eventually die out first.

Now, considering each node sends sensed data directly to the sink (DIRECT Transmission). The nodes far from the sink deplete energy more quickly and eventually die out first.

From the above discussion it can be summarized that the root cause for unbalanced energy consumption problem is the different communication distances to the sink and the way of data transmission. To overcome this uneven energy consumption the node may transmit data via multi-hop route to the sink; say in *MODE*0 or directly to the sink with suitable transmission power, in MODE1 as discussed in [13].

Our Approach first categorises the various levels of sea into channels based on the transmission loss and the attenuation factors. The nodes are arranged on these different strata of the sea based on their energy requirements and energy losses.

Optimum Energy Allocation for Linear Network: Assuming the sensor nodes are equipped with a transmission power control module which adjusts transmission power enables the nodes to use a hybrid transmission strategy for data propagation. In OEB, when node's energy changes after transmitting, the node changes the working mode based on the energy comparison with its immediate neighbours. By alternately changing node's working mode based on the residual energy, the nodes dissipate energy evenly, thereby prolonging the network lifetime.

However, to allocate the energy to nodes so as to maximize the network lifetime we need to consider the signal attenuation at the different levels and number of optimal no of hops to the sink. [13, 2]. Uneven consideration of above stated parameters may lead to frequent switching between states *MODE*0 and *MODE*1, which consumes tremendous energy. Therefore, finding the appropriate energy, keeping in mind all the factors affecting like noise and hence attenuation of signal becomes very important.

Under Water Acoustic Propagation: In this section, we review the energy consumption characteristics and the factors affecting lifetime.

In Underwater sensor networks, Acoustic communications is the typical layer technology. Radio waves propagate through conductive sea water at extra low frequencies (30-300 Hz) which requires large antennae and high transmission power. Scattering is most important factor which makes the use of optical waves inefficient. These are some reasons that acoustic communication technology is chosen for the communication in underwater when compared to the radio waves and optical waves. Acoustic modem is the most important technology used by the wireless sensor networks in underwater to communicate among them. Table 2 shows the specifications of two commonly used acoustic modems. On the basis of the above stated reasons the equations used for calculating energy consumption underwater are as follows: [7]

$$E_{MHR}=P_0*Att\ (NR)*T_p*N(N+1)/2 \qquad (1)$$

$$E_{DIRECT} = P_0*.T_p*(E_{i=1\ to\ N}\ Att\ (i*R)) \qquad (2)$$

Thorp's Expression to calculate the absorption coefficient, discussed by Urick in [14], is as follows:

Table 1: Variable Description Table.

Variables	Description (Unit)
TL	Transmission Loss (dB)
"	Path Loss Component [2,5] (dB/Km)
F	Frequency (KHz)
D	Euclidian Distance (m)
A	Transmit Amplifier (pJ/bit/m^2)
B	Transmitter/ Receiver Electronics (nJ/bit)
E	Energy (J)
L	Node ID / No. Of Packets
Att	Attenuation
P_0	Critical Transmission Power
T_p	Duration of packet transfer
R	Distance between adjacent hops
K	Energy spreading factor (K=1 for cylindrical and 2 for spherical)

Table 2: Underwater Acoustic Modem Specifications (Courtesy Link-Quest)

Specifications	UWM 2000	UWM 4000
RS-232 Data Rate	9600 bits/second	4800 bits/second
Acoustic Link	17.8k bits/second	8500 bits/second
T_x Power Consumption	4 Watts	7 Watts
R_x Power Consumption	0.8 Watt	0.8 Watt
Operating Frequency	26.775 to 44.625 KHz	12.75 to 21.25 KHz
Working Range	1500 m	4000 m
Maximum Depth	200 m	3000 or 6000 m

$$" = (0.1 f^2) / (1+f^2) + 44f^2 / (4100 + f^2) + 2.75 * 10^{G4} f^2 + 0.003 \qquad (3)$$

The energy dissipated, as discussed in [11], is minimized when, for (N-1) intervening nodes, the hop distance is made equal to (D/N); where 'D' is the Euclidean distance between the sender and the receiver. So the optimal number of hopes can be calculated by (D/d), where d can be obtained by the given equation:

$$d = (B / A\ ("-1))^{1/"} \qquad (4)$$

$$Att(NR)=(NR)^K * (10^{"/10})(NR) \qquad (5)$$

The variables used in above equations are described below in table 1 along with their units.

Algorithm: The OEB Algorithm is as follows:

```
procedure NodeInitialization
    j7n
    i72
    MODE 7 MODE0
//MHR Mode
    Energy (for i=2 to n) 7E
    Energy (i=1)7E+1
```

```
return TRUE
end procedure
procedure EnergyConsumed
 if(i<=j)
 Energy [i] 7 Energy [i]-(i-1);
 else
 Energy [i] 7 Energy [i]-(i-j);
 if (Energy [i]<=1)   // Stop Condition
 stop=1;
return TRUE
end procedure
procedure EnergyCompare
if Energy [i] < Energy [i-1]
MODE [i-1] 7 MODE1 //DIRECT
MODE [i] 7 MODE0
j 7 i-1
return TRUE
end procedure
```

RESULTS AND DISCUSSION

Simulation of the OEB is based on the values of parameters as follows: f=21 KHz, R =2 Km, K=1, T_p=1. P_0=0.8 W and N, E as variable values (based on acoustic modem specification provided by Link-Quest). Also the optimal no of hops are {5,10,15,20,25,30} for Euclidian distance {20,40,60,80,100,120}. The results of the simulations performed using equation (1 and 2) are as follows:

- For f=21 Khz, the value of absorption coefficient is 4.507 and attenuation is 15.93 using equation (3 and 5). Figure 3 shows the relationship between the no of iterations i.e. the network lifetime and the no. of nodes, keeping energy constant and varying the value of no. of nodes. Since OEB uses properties of both MHR (MODE0) and DIRECT (MODE1), its values lie between the simulated values of both MHR and DIRECT. It is observed that the average energy saved is much higher than those of MHR and DIRECT; as shown below in Figure 5 and 6.

Figure 4 show the plots between the no of iterations i.e. the network lifetime and the energy, keeping no. of nodes constant and varying energy. Again as shown in result; since OEB uses properties of both MHR (MODE0) and DIRECT (MODE1), values lie between the simulated values of both MHR and DIRECT. But the the average energy saved is much higher according to figure 5 and 6.

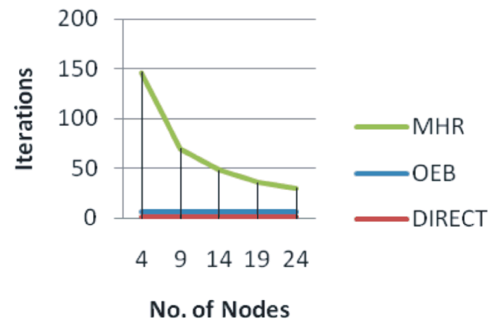

Fig. 3: No. of Nodes VS Iterations (i.e. network lifetime) keeping Energy = Constant

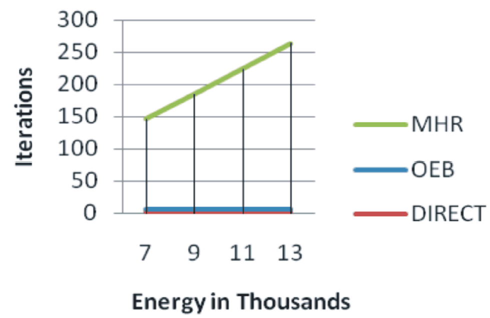

Fig. 4: Energy VS Iterations (i.e. network lifetime) keeping No. of Nodes = Constant

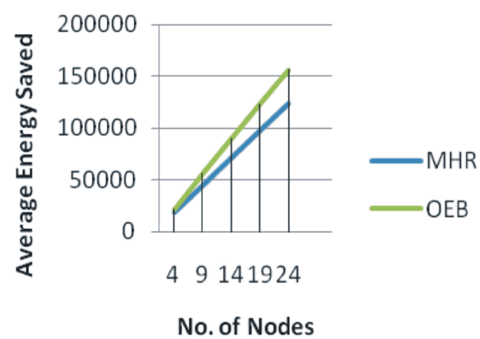

Fig. 5: No. of Nodes VS Energy Saved keeping Energy = Constant

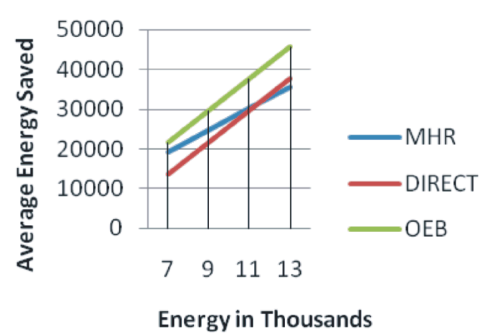

Fig. 6: Energy allocated VS energy saved keeping No. of Nodes = Constant

Figure 5 depicts the no. of nodes Vs average energy saved after any one of the deployed node dies. In this we have varied the no of nodes and kept the energy constant. Figure 6 shows the plot between energy and average energy saved, keeping the no of nodes constant and varying the energy. By examining both the graphs it can be concluded that the average enegy is saved more in OEB and hence the lifetime of network using OEB is prolonged; since the average energy saved in OEB is higher than those of nodes in MHR and DIRECT.

The above simulations are based on basic assumptions made during the designing of the OEB algorithm. The values and graphs are generated considering the actual parameter values and energy equations of a acoustic modem.

CONCLUSION

In the present work we have analyzed the energy balance consumption theoretically and proposed an energy balanced strategy: OEB for underwater acoustic sensor network for moored monitoring system. By changing modes between MHR and DIRECT, OEB achieves balanced energy consumption of individual nodes. The simulation results show that OEB strategy can achieve balanced power consumption per node throughout the network and hence maximize the lifetime of networks considering the different levels/channels of sea. By OEB we have been able to achieve bi-connectivity, k-edge connectivity and directed broadcast.

The work can be further extended for noisy channel environment.

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