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A balanced energy consumption-based routing protocol for efficient data gathering in underwater ASNs

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Abstract

Energy is a unique characteristic of Underwater Acoustic Sensor Networks (UASNs) which is limited in features and a basic point on which the whole network depends. On the basis of efficient energy utilization, we propose a routing protocol Enhanced and Efficient Balance energy consumption in Data Gathering (EEBDG) for UASNs. This routing scheme EEBDG, works for large scale area networks efficiently and effectively by balanced energy consumption. EEBDG removes the deficiency of previous routing scheme in which mixed routing performs all over the network which is not possible in real world when network size increases. By the increase in area of a network, we avoid the direct transmission mode using only hop by hop transmission. The contribution of our work is to extend network lifetime with large scale in the form of increased nodes and dimension, minimize energy utilization by balanced energy consumption, increased number of packets transfer. Our trade-off is packet drop ratio when number of nodes is small in sparse networks, but when the number of nodes increases our packets drop is also improved.

Keywords: Energy consumption, underwater acoustic sensor networks, lifetime, packet drop ratio

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1. Introduction

In UASNs, protocols are configured in a way so that an area where sensor nodes are deployed can generate data or obtain data from neighbouring nodes and transmit sensed data to sink and base station. Large number of sensor nodes are deployed in order to transmit data to sink and base station. The transmissions are of two types; direct transmission mode or hop by hop transmission mode and multi hop transmission mode. When nodes are in line of sight to sink, thenthey directly send data towards sink otherwise hop by hop transmission method is used. Sensor nodes are named as node or mote and designed for sensing and receiving data from neighboring nodes and can perform operations on a sensed and received data [1]. In UASNs acoustic signal is used because of the reasons being reliable, costfree, omnidirectional in nature, and dispersed network access with tolerable signal attenuation [1]. Acoustic signals have certain weak points that attract researchers to design routing protocols that can mitigate these weaknesses. These limitations include large propagation delay, finite battery, transmission and path losses, limited bandwidth and noise. The 3/4 part of the world is occupied by water. All over the world, researchers are getting more and more interest in developing applications for underwater acoustic environment and feasible topological deployment for UASNs. Some of the applications of UASNs are:

– Underwater toxic waste monitoring

– Underwater atmosphere monitoring including climate change, disaster recovery, preserving marine resources
– Lively fluctuations monitors
–Data collection from oceanographic
– Water transportation – Navigation Control (the route of boat)

In EEBDG, using concentric based division, nodes are randomly deployed using concentric circle-based division. Static sink is deployed at the center of concentric circles for data gathering process. Radius of the concentric circle is increased from 100 meters to 1000 meters; using hybrid transmission (direct transmission mode or hop-by-hop transmission mode). When nodes are at 250 meters range, direct transmission is achieved because sink is in range of all nodes, packet loss ratio is close to zero. When distance of nodes increases from 250 meters then nodes use hop-by-hop transmission mechanism and packet loss ratio increases. Acoustic signal has limited range, nodes deployed near the sink can directly send data. By avoiding redundant data transmissions of nodes which are in line of sight to sink we can save energy. This can be achieved by using nodes with distances greater than 250 meters to perform hop-by-hop transmission and avoid direct transmission mode. In EEBDG, using hop-by-hop transmission mode with transmission radius more than 250 meters energy can be preserved with balanced energy consumption with minimum transmission rate. More packet delivery ratio can be achieved with increased network stability. Rest of paper is arranged in following order, section II represents the related work and comparison table of different technologies. Section III presents proposed scheme with aggregation and energy models. Section IV explains performance evaluation of proposed and existing schemes using simulation. Section V illustrates trade-off between our proposed and existing schemes. Finally, conclusion is given in section VI.

2. Related work and motivation

In UASNs, nodes have energy constraints and operate on limited non-replaceable battery power. Energy preservation is vital for all routing protocols in order to sustain network for long time. Balanced energy consumption is always desirable in underwater sensor nodes. Some of the recent research on energy based techniques are discussed below: In [2] authors present their achievement to extend network lifetime and energy efficiency with the help of balanced energy consumption in UASNs. The technique presented in this paper is Balanced Transmission Mechanism (BTM). This mechanism uses two kind of algorithms. Both algorithms use balance energy consumption to achieve longer network lifetime. However, building the route structure is static, it cannot adopt dynamic topological changes of underwater environment. Once the structure for nodes in the network is built it is fixed and can not be changed with passage of time. In [3] the achieved parameter is balanced energy consumption per node which is the primary reason for an extended network lifetime. Proposed technique is applied in sparsely 2D environment by presenting two types of schemes for balanced energy consumption. First monitoring the network and secondly, giving balanced energy scheme in dense and shallow water through Energy Based Hybrid (EBH) and Differential Initial Battery (DIB) mechanisms. Main objective of [4] work is to achieve prolong network lifetime and enhanced throughput through balanced energy consumption. This paper introduces two protocols, Efficient and Balanced Energy consumption Technique (EBET) and Enhanced EBET (EEBET). Both schemes avoid direct transmission mode for balancing energy consumption in rings whereas EEBET balances energy in whole network. Relay node selection in EBET is on the basis of optimal distance and in EEBET number of hops minimization is on the basis of depth threshold. Special routing scheme results in overhead for neighboring nodes to share their residual information and depth with each other. Energy Hole Minimization with field division for energy-efficient routing in WSNs is presented in [5]. In this paper, authors investigated factors affecting network lifetime which contribute to energy hole creation due to unbalanced energy consumption. The performance evaluation shows that network is stabile for longer time, therefore, packet delivery ratio is improved as compared to existing schemes. Although in order to achieve extended network lifetime, some packets are dropped. On the avoidance of coverage hole area and energy hole in underwater networks [6], gave solution by coverage repair algorithm and balanced energy consumption techniques. This scheme suffers from packet delivery ratio to achieve prolong network life time, energy consumption and throughput. End to end delay is increased because of time spent on removing coverage hole in network. An Energy-Efficient Reliable Data Transmission Scheme for Complex Environmental Monitoring in UASNs [7], maximizes network lifetime with the help of effective energy operation. Technique used in this paper is data transmission scheme known as Energy-efficiency Grid Routing based on 3D Cubes (EGRCs).

In EGRC, energy efficiency and prolong network life-time is achieved on the basis of maximum residual energy and localization (minimum distance to sink) of sensor nodes to select the optimal cluster heads. Additionally, consistency of the data transmissions is maintained by searching the next hop neighbor on the basis of residual energy, location and end-to-end delay. In [8], the goal is to minimize energy consumption, increase reliability and achieve low communication cost. The technique used is a novel Layered Multipath Power Control (LMPC) by taking the noise attenuation in deep water, to organize the transmission power and control the data rate across whole network. Optimum network lifetime by balanced energy consumption in [9] is use of multiple number of sinks and threshold of energy by introducing in the network by multiple number of sinks and nodes which are randomly deployed. This is known as Lifetime Optimization of a Multiple Sink (LOMS) for wireless sensor network through energy balancing. Single hop with multiple sinks is used throughout the network. Gao, et. al [10] presents Selection of Transmission Range in UASNs, denoted as (OSTR). Nodes are deployed randomly. To achieve goal of efficient energy utilization or minimum energy consumption, network uses help of transmission power of all nodes. Transmission power of node is defined for two cases. Firstly when a node has higher transmission power, it will have a large transmission distance and deliver a packet to destination by involving a fewer relay nodes. In [11], optimizing number of hops and retransmissions for Energy-Efficient Multi-hop UASN communications achieve minimum energy consumption. It saves energy in some other conditions and also in small trials of retransmission. In this paper authors have analyzed and studied that how much energy is required for multi-hop transmissions in order to successfully deliver data. Optimum number of hops, retransmissions, code rate and Signal-to-Noise Ratio (SNR) are considered. This scheme achieves minimum energy consumption suffering from higher end-to-end delay. Complex Network Approach to Topology Control Problem in UASNs is presented in [12]. Objectives of this work is coverage, connectivity, optimized energy consumption and propagation delay as much as possible. A scale free model is applied in 3D environment. Topology Control Strategy based on Complex Network theory (TCSCN) is used to design double clustering structure selecting cluster heads. Scheme does not work on self-adaptive solution like transmission rate.

3. EEBDG Protocol

3.1 Network configuration

– In our configuration, we assume a circular monitoring area A, with a radius of R starting from 100 meters and then increasing with an increment of 100 upto 1000 meters respectively.

– Whole area is divided into concentric circles, C1, C2, C3,......., Cm; where m is the total number of circles as shown in figure 1.

– Each concentric circle has the same width of r = (Radius TotalNo.ofcircles) = (R m) as shown in figure 1 [13].

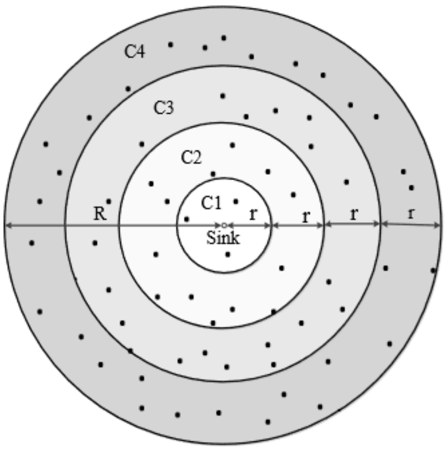

Fig. 1: Network configuration with concentric circles (m=4)

– Single static sink is deployed at the center of concentric circles.

– All nodes are homogenous in nature, randomly and uniformly distributed over a circular area of radius R and node distribution density ρ is same and all nodes have the same initial energy E0 [13].

– All nodes have the same transmission range rtrans ≤ 250. For balanced energy consumption phenomenon, for rtrans ≤ 250 meters, the nodes have alternatives to perform mixed routing (Direct transmission or Hop-by-hop transmission) and after that transmission range, they follow only hop-by-hop transmission mode

– When nodes are in transmission range rtrans, they send data directly to the sink using Direct transmission mode D; and vice versa when they are out of transmission range, they communicate with their neighbors through hop-byhop transmission mode H

– Each individual concentric circle is further divided into equal number of subcircles. For example, Circle Cj, is further divided into subcircle Cj1, Cj2, ...Cjk, where k is the total number of subcircles as shown in figure 2. For clarity, Circle 1 contains both white and grey portions, white portion represents subcircle 1 and grey portion represents 2 respectively. Likewise, all the concentric circles are divided into subcircles correspondingly [13].

3.2 Balanced Energy consumption:

According to [13] energy consumption among nodes within each circle can be balanced only if the amount of data received in each circle is balanced. Energy consumption is balanced for the Cm circle if and only if,

$E(a) = E(b)\ \forall aCj\ \forall bCj\ 1 < j \leq m$ Basic Condition:

$E(a) = D(a)*\varepsilon t(r) + H(a)*\varepsilon t(rh) + R(a)*\varepsilon r$

For any node a belonging to Cj, E is the total energy used, R is receiving energy by a in T rounds, $D(a)*\varepsilon t(r)$ is the energy spent in direct transmission mode, $H(a)*\varepsilon t(rh)$ is the energy spent in hop-by-hop transmission mode and $R(a)*\varepsilon r$ is the total energy consumption in data reception. Balanced energy consumption can be achieved in any zone based on the amount of data received. If Zj+1,k,l is the source zone and Zj,k,l is the destination zone, and hop-by-hop transmission is used, then each node in Zj+1,k,l forwards its data to the zone Zj,k,l and Zj,k,l. Both of them will receive the same probability of data by both direct as well as hop-by-hop transmission mode. Clearly the area of all destination zones as well as those of source zones are same [13].

Inter Circle Energy Consumption When balanced energy consumption is achieved in Cj among all nodes, all the nodes in Cj send their Hj data through hop-by-hop transmission mode. They transmit the same data Dj through direct transmission mode and receive the same amount of data Rj from the Cj+1 [13]:

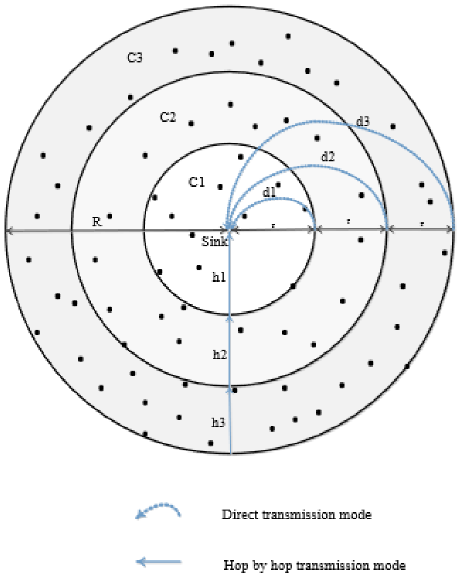

Fig. 2: Plotting the network onto a aggregation model

Data Transmission For any node in the network, data is communicated with other nodes by mixed routing. If the nodes are at smaller distance to the sink, then direct transmission is used and when the nodes are far from the sink, then hop-by-hop transmission used. In existing system EBDG, mixed routing is apply on 100 m to 1000 m, but the transmission range after 250 m does not work for direct. Hence, after the threshold defined range, nodes use hop-by-hop transmission for better balanced energy consumption.

4. Performance Evaluation

\We compare our proposed scheme EEBDG with the existing scheme EBDG via simulations. Considering a network area of 100 to 1000 meters with all the other network parameters in both schemes as same. Size of the packet sensed by sensor nodes and transmitted to the sink is 400 bits. Density of the number of nodes in both scheme is 0.04 per meter square. The network field consists of concentric circles and the static sink is deployed in the center of concentric circles. Simulation runs of the network are taken upto 15000 rounds and each circle has same radius $^{Radius}{}_{totalNo.ofcircle.}$ We compare our scheme EEBDG with existing EBDG on five metrics i.e, energy tax, network lifetime, packets received, packets dropped and network stability period.

Performance Matrics

1. Network lifetime: Network lifetime is the duration from the start of the network till 10% dead nodes in the network. Dead nodes in the network are those which do not have enough energy for the process.

2. Network stability: Stability period of the network cab be defined as the start of the network till the first node dies.

3. Energy tax: Energy tax is the average energy spent by per node when a packet is excellently sent to the sink. Energy tax can be defined as the total energy consumption of packets per node excellently delivered to the sink. It is quite different from the total energy consumption in a network.

$$Energytax = \frac{E_{total}}{Nodes * Packets}$$

E_{total} denotes the total energy consumption of the entire network. Packets denote the total number of receiving packets by sink successfully in the network. Energy tax per node varies with a different radius.

4.2 Simulation results of both schemes without mobile sink

Energy tax of both schemes EBDG and EEBDG is computed over the same nodes in the network i.e. 0.04 per meter square, as shown in figure 3. Energy tax increases with the increase of radius in both schemes. As Etotal in equation (1), the energy tax is on the increasing bent with the increase in Etotal value of the numerator, without involving any other factors. However, the increase of nodes or packets decreases the energy tax.

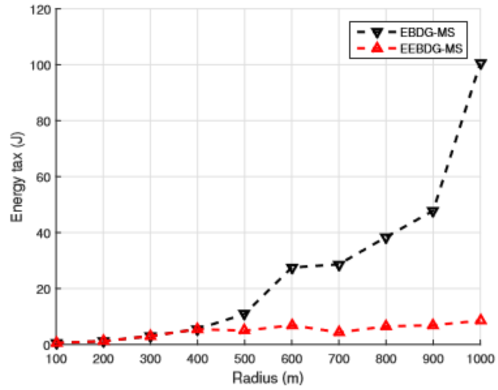

Fig. 3: Comparison of energy tax at changed network radii.

Energy tax utilized in EBDG scheme is more than the energy tax computed for EEBDG. Initially EBDG and EEBDG have same energy consumption because both schemes at the initial level perform the mixed transmission modes. EBDG continues to perform mixed transmission over the whole network with varying different radii, therefore, energy tax in EBDG is more because a large part of energy depletes by farthest nodes in the network. The farthest node sends data directly to sink, which is located at the center of area and the transmission distance between the sink and nodes is more than 250 meters. Also, in EEBDG scheme, after 250 m transmission range, it performs hop-by-hop transmission, which results in less energy consumption of the whole network. The network lifetime of EEBDG is equal to that of existing scheme EBDG as shown in figure 4. But the equal network lifetime in both schemes is achieved by difference energy tax. For example, the network lifetime end at 700 radius at 3 rounds is by using 29 energy tax but in our scheme for same network lifetime end, we use an energy tax of 4. The technique behind this low energy consumption, in EEBDG, after the 250 m transmission range we use only hop-by-hop transmission mode. In existing EBED, it uses mixed transmission over different radii which results in higher energy consumption. Network stability period of both schemes EEBDG and EBDG with different network radii is shown in figure 5. In EBDG, mixed transmission performs over the network, energy consumption is fast and occurrence of dead nodes is also quick, therefore, network stability period ends soon. Besides, in our proposed scheme EEBDG, network stability ends equally with the existing scheme but at some point we have good stability period because of our energy efficient technique.

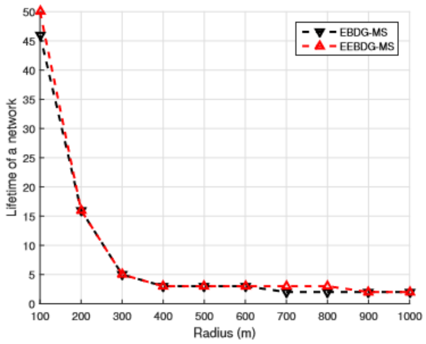

Fig. 4: Comparison of a network lifetime at changing different radii

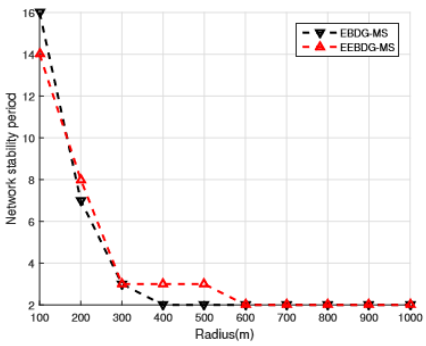

Fig. 5: Effects of changing different radius on the network stability.

5 Conclusion

In existing protocol EBDG, the concentric based division, data gathering and mixed routing performs all over the network and the area of network is increasing from 100 meters to 1000 meters. But on longer radius the directly sent packet to the sink is dropped and result is wastage of energy. Acoustic signal in underwater is of 250 meters range. It means the sink is found to all the nodes which are in a range of 250 meters, but after that the sink is not found in nodes range. Hence, by the help of transmission range we design our protocol EEBDG. Initially at 250 meters, we performed the mixed routing but after that we performed hop-by-hop transmission. Our achievements are extended network lifetime, lower energy tax, higher network stability, more amounts of packet received at the sink and lower packets dropped with the increase of radius and nodes. The feature of EBDG together with our proposed scheme EEBDG provides the effective and efficient protocol for the circular monitoring areas in UASNs.

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