

# Energy Consumption Estimation in Cluster based Underwater Wireless Sensor Networks Using M/M/1 Queuing Model

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## ABSTRACT

Underwater Wireless Sensor Networks (UWSN) has attracted significant attention recently. One of the most important issues in these networks is the energy constraint. Battery power in UWSN is limited and usually batteries cannot be easily recharged or changed. Therefore energy saving in this type of networks is vital. Network life time can be estimated by estimating energy consumption of nodes. In this paper, first we propose an analytical model for energy consumption estimation in cluster based underwater wireless sensor networks using M/M/1 queuing model. To the best of our knowledge, this is the first analytical model that represents the underwater cluster head's behavior based on M/M/1 queuing model. We can use this model to investigate the network performance in terms of average energy consumption. Then, we propose an analytical scheme to reduce energy consumption of cluster head nodes by reducing number of transitions between the idle and active states of cluster head nodes based on the number of data packets in the queue. Our analytical model is suitable for delay-tolerant aquatic applications. We validate our analytical model using simulations.

## General Terms

Energy consumption in underwater wireless sensor networks.

## Keywords

Underwater Wireless Sensor Networks, M/M/1 queuing model, Energy Consumption Model.

## 1. INTRODUCTION

Underwater Wireless Sensor Networks (UWSN) consists of a number of spatially distributed underwater sensor nodes that communicate with each other using acoustic signal. UWSN are suitable for aquatic applications such as distributed tactical surveillance, disaster prevention, mine reconnaissance, environmental monitoring and water quality monitoring [1, 2, 3, 4, 5]. There are many differences between the underwater environment and the open ground environment. The main restrictions of the underwater sensor networks are the salinity, temperature, pressure, humidity and changes in underwater environment. Since electromagnetic signal has high attenuation in water environment; it isn't suitable for underwater communication [6]. Instead UWSN use acoustic signal for transmitting data. Acoustic signals have extremely limited bandwidth, travel slowly (approximately 1500 m/s)

and have high bit error rate due to the noise, refraction and multipath interference [7]. Because of corrosion and fouling in underwater environment, underwater sensors may fail. In UWSN, power management is very important issue because of limited battery power and also batteries cannot be recharged or changed when depleted [8]. In this paper, we propose an analytical model using M/M/1 queuing model to estimate energy consumption of each cluster head. For more energy saving, we proposed an analytical scheme to reduce number of transitions between the idle and active states.

The rest of this paper is organized as follows. In section 2, we discuss some of the energy conservation techniques in wireless sensor networks. We discuss clustered network architecture and system model in section 3. In section 4, we present the proposed analytical model to estimate the energy consumption in clustered based UWSN. In section 5, we present the simulation results which validate the proposed model. In section 6, we propose an analytical scheme to reduce energy consumption of cluster head nodes by reducing number of transitions between the idle and active states of cluster head nodes based on the number of data packets in the queue. We conclude the paper in section 7.

## 2. RELATED WORK

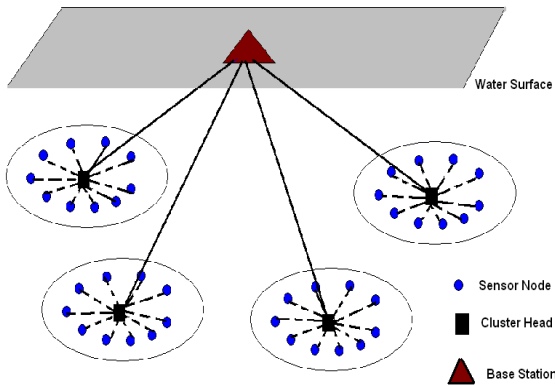
In this section, we review some related work on energy conservation techniques in wireless sensor networks. In most UWSN, network lifetime depends on battery lifetime. Therefore by reducing energy consumption, network lifetime can be prolonged. In many cluster based UWSN, cluster head nodes consumes more energy than ordinary sensor nodes. Therefore estimating energy consumption for each cluster head can help to estimate the network lifetime. R. Maheswar and R. Jayaparvathy [9] developed an analytical model of a cluster based sensor network using M/G/1 queuing model. The authors have analyzed the system performance in terms of energy consumption and the mean delay.

One of the best techniques for minimizing energy consumption in wireless sensor networks is switching between the active and sleep state [10]. In this technique, when a sensor node has packet to send, it turns on and switches to active state and sends packet. When sensor hasn't any packet to send, it switches to sleep state and turns off. If the number of transitions between the active and sleep state is high, energy consumption is high. Also in idle state, sensor nodes consume less energy than active state. R. Maheswar

and R. Jayaparvathy [11, 12] introduce an energy minimization technique using BUSY and IDLE states where the energy consumed is minimized based on queue threshold using M/M/1 queuing model. An analytical model also presented in [13] to analyze the system performance in terms of power consumption, data delivery delay and network capacity against the sensor dynamics states in on/off modes.

### 3. CLUSTERED NETWORK ARCHITECTURE AND SYSTEM MODEL

In this section, we present network architecture and system model. To accomplish energy consumption estimation, we consider clustered network architecture. In this network, we have three different types of nodes, cluster head, base station and sensor nodes, as shown in figure 1. In this network architecture, the whole network is divided into several clusters. In each cluster, ordinary sensor nodes will mainly be used for the sensing task. The ordinary sensor nodes are assumed to have less battery energy than cluster head nodes. The ordinary sensor nodes are cheap sensor nodes which cannot directly communicate with the base station. Typically, the ordinary sensor nodes can only connect to its one hop cluster head. Cluster heads are powerful nodes that can gather data from ordinary sensor nodes and forward it to the base station.



**Figure 1- Clustered Network Architecture**

In our UWSN model, the following assumptions are made:

- All ordinary sensor nodes are identical
- All cluster head nodes are identical
- No channel contention
- Each ordinary node sends packets to cluster head independently and identically
- The arrival of data packets to cluster head nodes is assumed to follow a Poisson process with mean arrival rate ( $\lambda$ )
- Packets are delivered from ordinary sensor nodes to cluster head nodes in each cluster
- Packets are delivered from cluster head nodes to the base station and assumed to follow a Poisson process with mean service time ( $1/\mu$ )
- The buffer capacity of the cluster head node is infinite
- Each cluster has only one cluster head

- Number of ordinary sensor nodes in each cluster are the same

Since the focus of this work is to estimate the energy consumption of cluster head nodes in UWSN, we analyze the behavior of a single cluster head node.

### 4. ENERGY CONSUMPTION ANALYTICAL MODEL

For our analytical model, we use following notations:

$\lambda$ : mean arrival rate per cluster head

$\mu$ : mean service rate in cluster head

$\rho$ : utilization of the cluster head

$P_0$ : probability that the cluster head is in idle state

$E_{TX}$ : energy consumption for sending one data packet

$E_{Idle}$ : energy consumption in idle state

$N$ : mean number of packets in cluster head per unit time

$PW$ : average energy consumption of a cluster head per unit time

$M$ : number of clusters

$Q_M$ : total energy consumption of  $M$  cluster heads per unit time

The steady state balance equations obtained for the analytical model according to the M/M/1 queuing model which are given by equations (1) to (6).

Based on M/M/1 queuing model the mean number of packets in the cluster head ( $N$ ) is determined as:

$$N = \frac{\rho}{1-\rho} \quad (1)$$

Where

$$\rho = \frac{\lambda}{\mu} \quad (2)$$

And the probability that the cluster head is in idle state is determined as:

$$P_0 = 1 - \rho \quad (3)$$

Energy required for sending a data packet can be determined as:

$$E_{TX} = \frac{\text{Packet Size}}{\text{Band Width}} \times \text{Transmission Power} \quad (4)$$

Now, the average energy consumption of a cluster head can be expressed as:

$$PW = N \cdot E_{TX} + P_0 \cdot E_{Idle} = N E_{TX} + (1 - \rho) E_{Idle} \quad (5)$$

For example, consider mean arrival rate per cluster head of 0.1 ( $\lambda=0.1$ ), mean service rate in cluster head of 0.5 ( $\mu=0.5$ ), bandwidth of 10 kbps, packet size of 1600 bytes,  $E_{Idle}$  of 0.01 and transmission power of 0.2 joule in a cluster based underwater wireless sensor network, then we have following values:

The utilization of a cluster head ( $\rho$ ) is :

$$\rho = \frac{\lambda}{\mu} = \frac{0.1}{0.5} = 0.2$$

The mean number of packets in cluster head ( $N$ ) is:

$$N = \frac{\rho}{1-\rho} = \frac{0.2}{0.8} = 0.25$$

The probability that the cluster head is in idle state ( $P_0$ ) is:

$$P_0 = 1 - \rho = 1 - 0.2 = 0.8$$

The energy required for sending a data packet is:

Energy required for sending a data packet ( $E_{TX}$ ) can be determined as:

$$E_{TX} = \frac{\text{Packet Size}}{\text{Band Width}} \times \text{Transmission Power} \quad (4)$$

Now, the average energy consumption of a cluster head (PW) can be expressed as:

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The probability that the cluster head is in idle state is:

$$P_0 = 1 - \rho = 1 - 0.2 = 0.8$$

The energy required for sending a data packet is:

$$E_{TX} = \frac{\text{Packet Size}}{\text{Band Width}} \times \text{Transmission Power} = \frac{1600 \times 8}{10000} \times 0.2 = 0.256$$

And the average energy consumption of a cluster head per unit time is:

$$PW = N \cdot E_{TX} + P_0 \cdot E_{Idle} = N E_{TX} + (1 - \rho) E_{Idle} = 0.25 \times 0.2 + 0.8 \times 0.01 = 0.058$$

Also the average energy consumption of M cluster heads can be expressed as:

$$Q_M = M \cdot PW \quad (6)$$

## 5. MODEL VALIDATION USING SIMULATIONS

Now, we use simulations to validate our analytical model. We use aqua-sim, an NS2 simulator for underwater sensor networks [14]. Simulation parameters used for the simulation model are shown in Table 1.

**Table 1- network and energy consumption specifications**

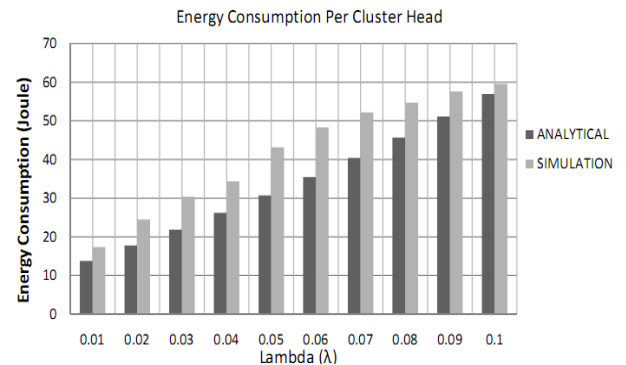
Mean service time	0.49 sec
Transmission power	0.6 watt
Idle power	0.01 watt
Number of ordinary nodes per each cluster	6
power consumption during transition from active state to idle state and vice versa	0.2 watt

Packet size	400 byte
Band width	10 kbps
Mean arrival rate per cluster head( $\lambda$ )	0.01 to 0.1 packet per second
Simulation time	1000 seconds

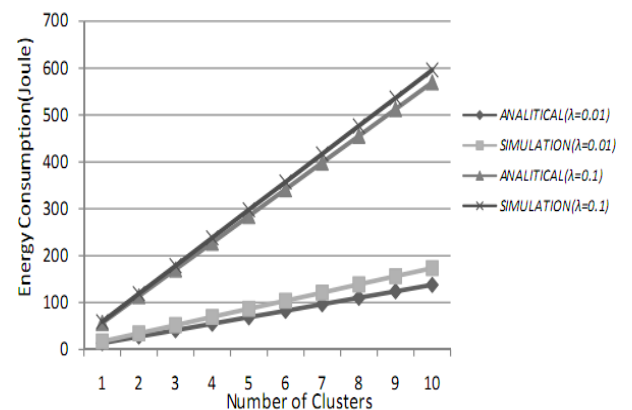
Simulations results are obtained for various scenarios by changing the mean arrival rate of cluster head and also changing the number of cluster heads. We measure the average energy consumption of a cluster head and the average energy consumption of M cluster heads. The simulations were performed for 10 runs and a confidence interval of 99% was obtained.

From figure 2, it is inferred that the average energy consumption for a cluster head increases as mean arrival rate increases because the number of packets that arrive to the cluster head increases. Also figure 2 shows that our analytical model for average energy consumption per cluster head approximately matches with simulation results. Our analytical model matches 99.91% with simulation result.

Figure 3 shows average energy consumption for various numbers of cluster heads and mean arrival rate of 0.01 and 0.1 packet per second. As shown in figure 3, the average energy consumption increases linearly as the number of cluster heads increases. Figure 3 shows that our analytical model for average energy consumption in a cluster based UWAN matches with simulation result for large number of clusters.



**Figure 2- Mean arrival rate vs. energy consumption per a cluster head**



**Figure 3- number of cluster head vs. energy consumption for λ=0.01, λ=0.1.**

## 6. ANALYTICAL MODEL TO REDUCE NUMBER OF TRANSITIONS

Transitions from active state to idle state and vice versa consume most of the energy in UWSN. If we reduce the number of switches between these states, we can reduce energy consumption. If cluster head stays in idle state until receive B packets and then switches to the active state, it can reduce the number of switches between the states. To calculate the energy consumption of transitions in a single cluster head, we define the following parameters:

T: total time

$E_{Transition}$ : energy consumption during transition from active state to idle state and vice versa

$N_{Transition}$ : number of transitions during T seconds

$P_{Total-Transitions}$ : total energy consumption for transitions during T seconds per cluster head

B: buffer size of cluster head

$\lambda$ : mean arrival rate for each cluster head

The steady state balance equations are given by equations (7,8):

The number of transitions during T seconds can be expressed as;

$$N_{Transition} = \frac{T \times \lambda}{B} \quad (7)$$

Now, the total energy consumption of a cluster head can be expressed as:

$$P_{Total-Transitions} = N_{Transition} \times E_{Transition} \quad (8)$$

For example, by assuming  $\lambda=0.1$ ,  $T=1000$ ,  $E_{Transition} = 0.2$  and buffer size=5 in a cluster based underwater wireless sensor network, then we have the following :

The number of transitions during 1000 seconds is:

$$N_{Transition} = \frac{T \times \lambda}{B} = \frac{1000 \times 0.1}{5} = 20$$

The total energy consumption of a cluster head is:

$$P_{Total-Transitions} = N_{Transition} \times E_{Transition} = 20 \times 0.2 = 4 \text{ joule}$$

Our analytical model is suitable for delay-tolerant aquatic applications such as mine reconnaissance, undersea explorations, environmental monitoring, and ocean sampling. In such applications energy saving is an important issue and end to end delay isn't much important. We use equation (8) with various mean arrival rate and various B value for a cluster head with the network and power consumption parameters of Table 1. Figure 4 shows the result for T=1000 seconds. From this figure, we observe that energy consumption decreases as the B value increases. Figure 4, also shows that energy consumption decreases as the mean arrival rate decreases. From figure 4 we can conclude that, there are small differences between energy consumption for transitions for various mean arrival rate for  $B>6$ .

We also use equation (8) with various mean arrival rate and various B value for 4 and 6 cluster heads. Figure 5 shows the result for T=1000 seconds. From figure 5. it is inferred that the energy consumption for transitions decreases as mean arrival rate decreases. Figure 5 also shows that for  $B>8$ , there

are small differences between energy consumption for transitions for various mean arrival rate and various number of cluster heads. From figure 5 we observe that energy consumption for transitions can be reduced by reducing the number of transitions.

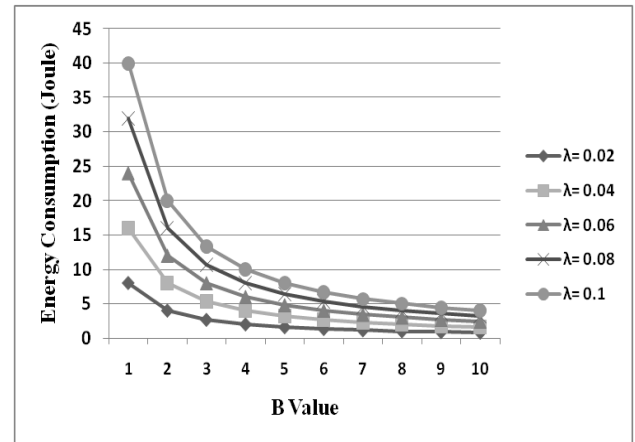


Figure 4- B value vs. energy consumption for transitions during T=1000 seconds per cluster head

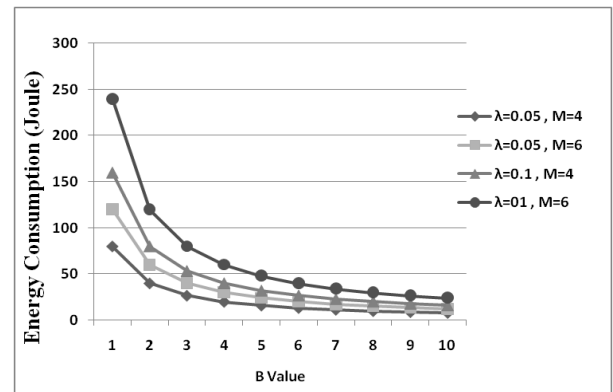


Figure 5 – B value vs. energy consumption for transitions during T=1000 seconds for various number of cluster heads

## 7. CONCLUSIONS

In this paper, we proposed a new analytical model to estimate the energy consumption in cluster based UWSN using M/M/1 queuing model. We validate this model using simulations. Transitions between idle state and active state in UWSNs consume more energy. For this purpose we have developed an analytical model for energy saving by reducing the number of transitions between idle state and active state. Our analytical model is suitable for delay-tolerant aquatic applications. The results of our analytical model show that reducing the number of transitions has a significant impact on energy saving.

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