



ORIGINAL ARTICLE

# Reliable data deliveries using packet optimization in multi-hop underwater sensor networks

Muhammad Ayaz <sup>a,\*</sup>, Low Tang Jung <sup>a</sup>, Azween Abdullah <sup>a</sup>, Iftikhar Ahmad <sup>b</sup>

<sup>a</sup> CIS Department, Universiti Teknologi PETRONAS, Malaysia

<sup>b</sup> SE Department, CCIS, King Saud University, Saudi Arabia

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2H-ACK

**Abstract** A fundamental challenge in underwater wireless sensor networks (UWSNs) is that acoustic links are subject to high transmission power with high channel impairments. These channel impairments result in higher error rates and temporary path losses which restrict the efficiency of these networks. Besides this, the availability of limited resources and continuous node movements are major threats for reliable data deliveries. With these constraints, it is a difficult task to design a protocol which has the ability to maximize the reliability of these networks. In this paper we provide a reliability model in order to insure reliable data deliveries from sensor nodes to surface sink. For this purpose, we propose an algorithm which determines the suitable data packet size for efficient data transfer. It uses a two-hop acknowledgment (2H-ACK) model where two copies of the same data packet are maintained in the network without extra burden on the available resources. The findings on the relationship between data packet size, throughput, bit error rate (BER), and distance between both communicating nodes are also presented.

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## 1. Introduction

Underwater wireless communications, more specifically the underwater acoustic (UWA) communications, require the

employment of acoustic signal in order to exchange the information below water (Stojanovic, 1996, 1999; Ayaz et al., 2011). Many novel studies of underwater acoustic networks, communications and routing protocols, have the potential for applications in off-shore oil industry, naval missions and the environmental domain. Acoustic signal is considered as the only feasible medium that works satisfactorily because radio waves do not propagate well underwater and optical waves are affected by severe scattering.

UWSN consists of a number of sensor nodes that depend on the area of deployment, used to sense any event occurring in the surroundings and after some required processing, will route this sensed data toward surface sink. An important fact about these networks is that, an individual node can be resource constrained, but a collection of these nodes can cover large areas, first sensing and then forwarding this useful data toward the

\* Corresponding author. Tel.: +605 3687421.

E-mail address: ayazsharif@hotmail.com (M. Ayaz).



surface sink with an acceptable degree of accuracy. In some applications like submarine detection, the sensed data can be time critical and have to be delivered within the appropriate intervals (Domingo, 2009). Therefore, such applications require not only a guaranteed data delivery, but also within tolerable end-to-end delays. However, these sensor nodes are responsible for transferring the sensed data within the network, and this can cause congestions in different parts at different time intervals due to their multi-hop nature (Liu, 2008; Ayaz et al., 2009). The degree of congestion starts to increase as data packets are forwarded toward the surface, especially the nodes around the sinks are seriously affected. The available resources like buffer space are limited, unless these congestions are detected and some appropriate avoidance techniques are implemented, a significant amount of data packet loss can occur. The occurrence of such packet losses requires retransmissions, which not only causes the loss of a significant amount of energy, but also can lead to large end-to-end delays.

Lucrative benefits of UWSNs are not without costs. The challenges present in these environments like continuous node movements and 3-d topology are other than, that acoustic channel impose including multipath propagation delay, fading, limited bandwidth and severe energy constraints of battery-powered sensor nodes (Akyildiz et al., 2004). Sound waves propagate five orders of magnitude lower than electromagnetic waves, at a speed of 1500 m/s. Furthermore, reflection, refraction and ambient noise of the underwater channel are the reasons for high packet loss rates. Thus, identification of channel parameters which have profound implication on UWSN performance is needed. Although studies related to these areas are increasingly attracting the attention of researchers, still a comprehensive resource on techniques or algorithms for choosing the best packet size for efficient data transmission is not yet readily available. This research focuses on finding the optimal data packet size for UWA data transmission with energy efficiency as the optimization metric. As (Basagni et al., 2009) indicates the network performance sensitivity in relation to the choice of packet size, this study investigates the effects of packet size on energy consumption too.

The rest of the paper is organized as follows. Section 2 provides an overview of the reliability and its importance for UWSNs as well as, relevant issues are highlighted. Section 3 gives the idea about our previous model, from where we have enhanced this work. In Section 4, we present the explanation for how 2H-ACK reliability model works while further its algorithm and calculation of waiting time is provided in Section 5. Section 6 covers the evaluation of the proposed model where simulation results are provided with different performance metrics. Finally, Section 7 briefly concludes this article.

## 2. Reliability

It has been shown that Transmission Control Protocol (TCP) and other congestion control mechanisms like this are highly problematic for wireless multi-hop networks (Rahman, 2008; Scheuermann et al., 2008; Domingo and Prior, 2008; de Oliveira and Braun, 2002). TCP is a connection oriented protocol, that requires 3-way handshake between the sender and receiver before actual data packet transmission starts. In UWSNs, where actual data might be only a few bytes, the 3-way handshake process will definitely be a burden for such a small volume of data.

Moreover, UWSNs are considered as multi-hop where each inter-hop link is characterized by its pathetic and error prone acoustic channel. So the time required to establish a TCP connection between two end nodes that are a significant number of hops away from each other, might be very high. For reliability concerns, TCP requires an end-to-end ACK and retransmission strategy, which can result in a poor throughput and longer transmission time. On the other hand, when we talk about UDP, it does not offer any flow control and congestion control mechanisms. In the case of congestions, UDP simply drops the packets without providing any scope for recovering these lost packets.

It is well known that, packet size directly affects the reliability as larger packets suffer higher loss rates, while shorter packets face greater overhead. It is accepted that longer packets help to increase the collisions in the networks but also these are preferred only when a sufficient link quality is available. This optimum choice also depends on erroneous characteristics of the link and number of control bits required for packet transmission, as experiments have shown that error probability is proportional to the data packet length. When we talk about multi-hop wireless links, the quality of these links depends on the end-to-end routes available in the network. Moreover, successful data deliveries also depend not only on the characteristics of the acoustic channel but also on the techniques being applied for error control mechanism. These issues, which belong to different layers of the communication stack, are the main reasons that urge the researchers to work for packet optimization especially for wireless environments.

Dynamic packet sizes are determined according to different properties of the wireless channel, e.g. shorter packets and error correction methods are selected for bad channel conditions while packets with larger sizes are suggested for good channel conditions. Not only is it accepted that longer packets help to increase the collisions in the networks but also these are preferred only when a sufficient link quality is available as well as when collisions alone are considered. Also, it has been seen that, increase in packet size directly affects the channel access rate and hence the traffic on the channel, and then the traffic rate affects both the number of collisions and probability of successful carrier sense. Now, when we talk about underwater fragile conditions, usually the possibility of path breakage is pretty high and a more practical design for adaptive packet length can ensure that packet can get through with some tolerable outage probability.

## 3. Previous work

In (Ayaz and Abdullah, 2009), the authors presented Hop-by-Hop reliable data delivery scheme for UWSN. In this architecture, sensor nodes are deployed at different depth levels from surface to bottom and multiple surface buoys are used as sink. Floating nodes get assigned dynamic addresses with the help of hello packets, broadcasted by the surface sinks. Nodes near the surface sinks have smaller addresses and these addresses start to increase as nodes go down toward the bottom. When a sensor node has data packet, it will forward this packet toward the nodes in the upper layers, i.e. nodes with the smaller addresses than its own address, in a greedy fashion. This proposed protocol has many advantages such as, it does not require any specialized hardware, no dimensional location information

required and node movements can be handled easily without maintaining complex routing tables. Nevertheless, it still requires some reliability mechanism to handle the problem of node failure or packet losses so that more precise results can be obtained.

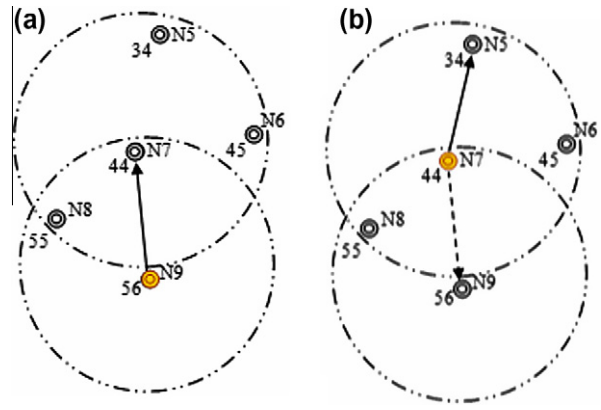
In this paper, a cross layer solution for reliable data deliveries in underwater wireless sensor networks is presented. We highlight how this cross layer approach can affect different parameters like single-hop and multi-hop routing, end-to-end error probability and packet reception rate. The relationship between data forwarding and packet size, and effects of different packet size on different performance metrics like effective throughput, latency and success rate are also investigated.

#### 4. 2H-ACK

As described earlier, it is unfeasible to achieve end-to-end reliability due to frequent network partitioning of UWSNs. We have to focus on the Hop-by-Hop reliability in order to make it more responsible for these environments. In typical Hop-by-Hop ACK (HbH-ACK) scheme; only two nodes are involved, as receiving node will reply the ACK when it receives an error free packet successfully. When the sending node receives the ACK, it can discard the current packet and continue to process the next available data packet. For stable environments like wired networks, this HbH-ACK has no problems, but for the unstable environments like underwater, where nodes can die or get lost due to many reasons, this traditional ACK method becomes less suitable. The receiving node is the only node in the network, which has the current data packet because the sending node will discard it after receiving the ACK. For UWSNs, due to continuous node movements and sparseness, it is possible that, the receiving node cannot find the next hop for long intervals in order to reach the destination and during this, it can die due to limited power or any failure can occur due to fouling and corrosion problems. In such cases all the packets held by the current node will be lost permanently because none of the other nodes maintains the backup of these lost data packets. In order to handle this situation, we proposed the 2H-ACK reliability model.

Fig. 1 presents the data forwarding and acknowledgment method followed by 2H-ACK model. Fig. 1a is showing a source node N9 that has a data packet to be sent toward the surface sink with its own *HopID* 56. In order to do that, it will ask its neighbors for their *HopIDs*. Nodes N8 and N7 will reply as both of these are in the range of N9. After comparing their *HopIDs*, N7 will be declared as the next hop as its *HopID* is smaller than N8. After receiving the data packet, instead of sending ACK immediately, N7 will try to find the next hop node in order to reach the destination, so it will repeat the same process as N9. As a result, when node N7 gets an inquiry reply from N5, then first it will send ACK toward N9 and then forward data packet toward N5. After receiving this ACK, N9 will clear the data packet from its buffer, which is shown in Fig. 1b. This process will continue till the current data packet reaches the destination.

From the whole procedure illustrated in Fig. 1 and further depicted from the algorithm, it is clear that, two nodes try to maintain the same copy of a data packet in the network. In case of an unwanted event, such as if a node is destructed,



**Figure 1** Selecting the next hop for data packet forwarding. (a) Selecting next hop. (b) Selecting next hop and replying ACK.

another copy is still available in the network and it will be forwarded after a specified waiting time.

#### 5. Algorithm

```

/* Three data sets denoted as  $F_3$ ,  $F_4$ , and  $F_5$  are obtained from
Figs. 3–5 respectively */
/* Source node and sink node are of homogeneous type */
/* Data packet ( $dp$ ) ready to send */
1. Source node: send (request HopID) to the neighbors with
predefined bit rate ( $R$ )
2. Neighbors: ACKs and return (HopIDs)
3. Source: with returned HopIDs
Sort_out and get Minimum HopID (Min. HopID)
4. If Min. HopID < Own HopID Then
5.   If Current node is not source node Then
6.     send ACK to previous Hop
7.   }
BER ( $\rho$ );
distance ( $d$ );
with  $\rho$  indexed into  $F_3$  to acquire  $N_{opt\ 1}$ ;
with  $dR$  product indexed into  $F_4$  to acquire  $N_{opt\ 2}$ ;
 $N_{opt}$  = average( $N_{opt\ 1}$ ,  $N_{opt\ 2}$ );
with  $N_{opt}$  indexed into  $F_5$  to acquire the energy efficiency ( $\eta$ );
check: difference between  $\eta$  and  $\eta_{opt}$  from  $F_5$ ;
If (difference) < (5%) then
  packetsize: =  $N_{opt}$ 
Else
  with  $\rho$  indexed into  $F_5$  to obtain packet size ( $N$ )
  corresponds to max  $\eta$ ;
  packetsize: = average( $N$ ,  $N_{opt}$ );
End If
}
8. Source: Assemble  $dp$  with packetsize
9. Source: Forward  $dp$  to Min. HopID
10. Else
11.   Source: Assemble  $dp$  with packetsize
12.   Source: Forward  $dp$  to Min. HopID
13. End If
14. Else
15.   Wait defined amount of time
16.   Go to step 1
17. End If

```

### 5.1. Calculating the waiting time

The packet receiving node, in the example Node N7, will not send the ACK immediately to the packet sending node N9, but first, it will try to find the next hop. When the next hop is available, then it will send ACK to the N9. The time lapse between sending the packet and receiving the ACK known as the waiting time, can be calculated from

$$W = 4t + t_p + \alpha \quad (1)$$

The total waiting time  $W$  depends on three parameters as shown in (1).  $t$  is the propagation time,  $t_p$  is the processing time, and  $\alpha$  is the time allowed for the receiving node to find the next hop. Among these,  $t$  and  $t_p$ , can be a constant as propagation speed (1500 m/s) and processing power of the node, so both are fixed values. While the value of  $\alpha$  can vary according to the environmental conditions and it depends on network density  $d$  and speed of node movements  $v$ . The effect of  $d$  and  $v$  can be represented as follows,

$$\alpha \propto 1/d \quad \& \quad \alpha \propto v \quad (2)$$

The value of  $\alpha$  will increase with the decrease of  $d$  and vice versa, while in the case of  $v$  it is the opposite. If we assume  $v = 0$ , then the value of  $\alpha$  depends only on  $d$ .

## 6. Results and discussions

The general scenario of the underwater environment set up is shown in Fig. 2. A cluster of 100 nodes is placed in the middle of a body of water with a dimension of 2 km  $\times$  2 km  $\times$  200 m. This is to avoid reflection effects near the water surface and the water bottom. A depth of 200 m is chosen to simulate the shallow water environment. One sink is placed roughly at the center of the cluster to collect data packets from other nodes. The distance range between the sink and a source node is 100 m to 1 km. The maximum transmission range of the nodes is to be 1 km. In the simulation, two nodes are created (one transmitter and one receiver/sink) while at any one time for one hop data packet relay with one constant bit rate (CBR) module per layer. A unidirectional Module/Link connects the two nodes. The packet flow is in accordance to the ns-2 MIRACLE layered framework.

The transmitter CBR module, acting as an agent, generates data packet of the required size. The MIRACLE physical layer

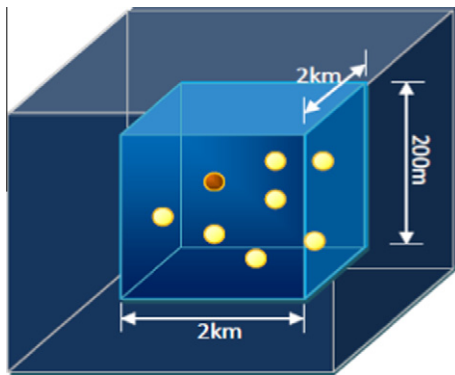


Figure 2 The general scenario.

(MPHY) uses binary phase shift keying (BPSK) modulation to send the data packet over the underwater channel to the receiver. The underwater channel is configured with Shannon channel characteristics. Our simulation has adopted the energy efficiency definition from the work of Ayaz and Abdullah (2009), Inwhae (2005) and Akkaya and Newell (2009). Some essential parameters used in the simulation are listed in Table 1.

### 6.1. Data packet size and BER

When ARQ protocol is used in relatively high BER links the communication performance is sensitive to the packet size. In our simulation we used the  $k_{opt}$  (3) which was adopted from Amato et al. (2009) and Modiano, (1994).

$$k_{opt} = \frac{-h \ln(1 - \rho) - \sqrt{-4h \ln(1 - \rho) + h^2 \ln(1 - \rho^2)}}{2 \ln(1 - \rho)} \quad (3)$$

This equation shows that the optimal packet size  $k_{opt}$  is a function of BER,  $\rho$  and packet header length,  $h$ .

Fig. 3 shows a set of graphs relating packet size to different BERs with different header length. This is one of the set of graphs to be used in the proposed optimization algorithm. Do take note that a header length of 160 bits is the standard length used in the RTS data packet for stop-and-wait ARQ protocol. It is understood that under this stop-and-wait protocol the source node will transmit an RTS packet to the sink node to establish the link between them before packets transmission. In the proposed algorithm this RTS packet will double its function as a test data packet for the source node to compute the quality of the link thus obtaining the link BER. The top most graph/line in Fig. 3 is to be used as the reference graph for the proposed algorithm. The rest of the plots are used for comparative studies purpose.

A simplified data set can be obtained from Fig. 3. For example, with a header length of 40 bits, the simplified data set is obtained as in Table 2. This simplified data set stores BERs in an incremental step of a decade. These increment steps make BER computation practically faster. For practical implementation the packet size to be composed in actual transmission can be the truncated value or a round-up value if truncation is not preferred.

### 6.2. Data packet size and throughput efficiency

In stop-and-wait ARQ protocol, its throughput efficiency is defined as the ratio of useful packet time and the total time spent on the average for a successful packet transmission. The average time is taken over the number of retransmissions. With a probability of packet error given as  $\rho$  the average time needed to transmit 1 packet successfully is given by Schwartz (1987) as,

$$T_1 = \frac{1}{1 - \rho} T(1) \quad (4)$$

with this the efficiency for transmitting a group of  $g$  successful packets can be expressed as,

$$\eta = \frac{gN_f T}{T_g} = (1 - \rho) \frac{gN_f T}{T(g)} \quad (5)$$



**Table 1** Essential simulation parameters.

Parameter	Setting
Payload length	10–1000 bits
Header length	10, 40, 160 bits
Distance	100–1000m
Frequency	8.2 KHz
Bandwidth	6 KHz
Protocol	ALOHA
Constant bit rate (CBR)	0.01 s, 0.03 s, 0.05 s

where,  $N_l$  is the payload length, and  $T$  is the bit duration. So, with a given set of physical layer parameters ( $\rho, R, d$ ) where  $\rho$  is the probability of packet error,  $R$  is the bit rate, and  $d$  is the distance between transmitter and the receiver; the throughput efficiency can be written in the form of,

$$\eta = (1 - \rho)^{N_l + N_{oh}} + \frac{N_l}{N_l + \mu} \quad (6)$$

$$\mu = N_{oh} + \frac{T_w R}{g} N_{oh} + \frac{2}{gc} dR \quad (7)$$

where,  $T_w$  is the total waiting time in the stop-and-wait protocol,  $c$  is the nominal underwater acoustic sound speed of 1500 m/s, and  $N_{oh}$  is the header length. The optimal packet size can now be evaluated by differentiating  $\eta$  with respect to  $N_l$  and equating it to zero. From which the optimal packet size,  $N_{opt}$  is given by,

$$N_{opt} = \frac{\mu}{2} \left[ \sqrt{1 + \frac{4}{\mu\rho}} - 1 \right] \quad (8)$$

with  $N_{opt}$  evaluated, the optimal throughput efficiency can be written as,

$$\eta_{opt} = (1 - \rho)^{N_{opt} + N_{oh}} + \left( \frac{N_{opt}}{N_{opt} + \mu} \right) \quad (9)$$

Take note that  $\mu$  is related to  $dR$  (range-rate) product where  $d$  denotes the distance in meters between a source-sink pair and

**Table 2** Simplified data set.

BER	$k_{opt}$	Truncate
$10^{-2}$	39.86605	39
$10^{-3}$	178.9482	178
$10^{-4}$	612.1234	612
$10^{-5}$	1979.8950	1979
$10^{-6}$	6304.5221	6304

**Table 3** Simulation parameters for packet size and throughput efficiency.

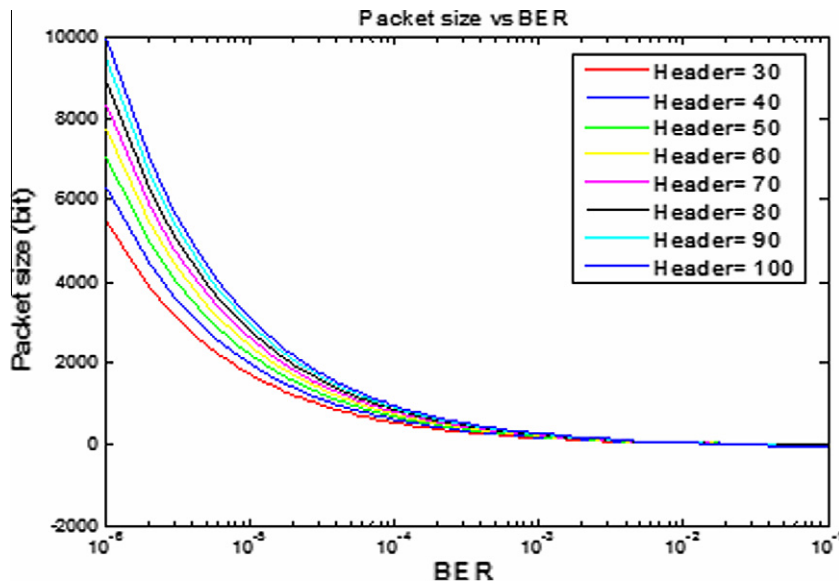
Link delay	0.01 s
BER ( $\rho$ )	$10^{-3}, 10^{-4}$
Distance	500 m to 5 km
Rate ( $R$ )	100 to 1000 bps
Header ( $N_{oh}$ )	160 bits
No. of group ( $g$ )	1

$R$  is the data transmission rate in bps. It is explicit that  $N_{opt}$  is a function of range-rate product ( $dR$ ) and BER ( $\rho$ ) of the communication link. Some of the crucial parameters used in this simulation are in Table 3.

The simulation of this  $N_{opt}$  resulted in a set of graphs shown in Fig. 4. It can be seen here that low quality link does not permit large packet size. By keeping the distance  $d$  between the source-sink pair constant, e.g. static nodes deployment, and for a certain BER, the packet size seems to be increasing fairly linearly with an increasing  $R$ . However the packet size increases at a faster rate if the link  $\rho$  is low.

### 6.3. Data packet size and energy efficiency

In data communication systems, energy efficiency can be defined as the ratio of the amount of data transmitted and the energy consumed for that operation. Thus, minimizing


**Figure 3** Packet size vs. BERs.

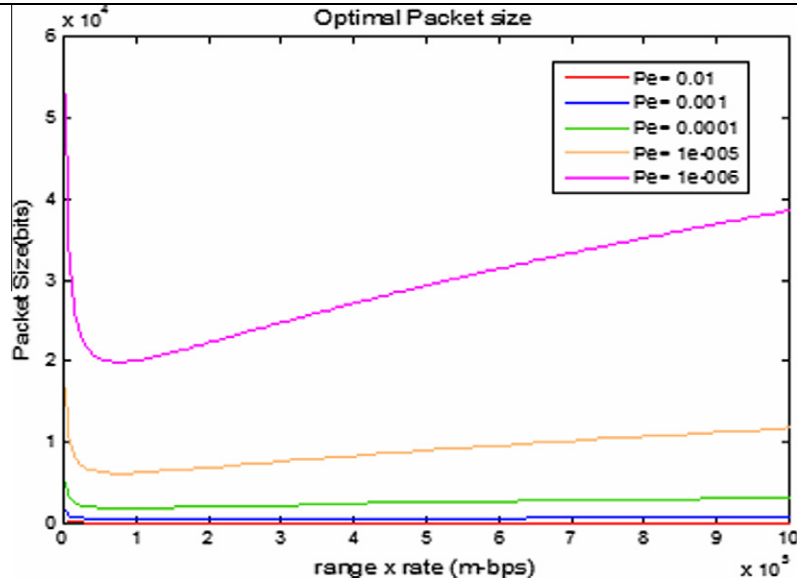


Figure 4 Packet size vs. range rate with different BER.

the total amount of energy spent on its operations is an important factor for an energy efficient system. The underwater wireless channel, being time-varying and noisy in nature, dictates the possibility of data corruption causing packet losses (discarded) at the sink which demands retransmissions of the packets resulting in a waste of valuable energy. In actual fact, a well known primary cause of energy wastage is in the retransmissions of data packets.

Our investigation focused on the physical layers (PHY) and it is assumed that nodes are able to discover each other and self-organize into a communication network with peer-to-peer communication between any pair of neighboring nodes. In this context, the energy efficiency equation by Schwartz (1988) is adopted as below Eq. (10) and would be the main reference for the simulation works on finding the relationship between energy efficiency and packet sizes. This equation is a function of packet length  $l$  and BER link,  $\rho$ .  $k_1$  and  $k_2$  are transmitter/receiver equipment constant with  $\alpha$  the header length. Implicitly, it involves the energy per useful bit (EPUB) element.

$$\eta = \frac{k_1 l}{k_1(l + \alpha) + k_2} (1 - \rho)^{l + \alpha} \quad (10)$$

In our simulation it is assumed that the source and the sink are of homogeneous type therefore they have the same equipment constants, i.e.  $k_1 = k_2$ . So the energy efficiency term in the  $\eta$  equation, i.e. the term

$$\frac{k_1 l}{k_1(l + \alpha) + k_2}$$

can be approximated to  $l/(l + \alpha)$  for  $(l + \alpha) \gg 1$ . This is acceptable since in most of the practical applications packet length is more than hundreds of bits. This is also in line with the basic definition of energy efficiency. In simulating this energy efficiency, some of the essential parameters are listed in Table 4.

Our simulation has adopted the energy efficiency definition from the work of Scheuermann et al. (2008) and Ayaz and Abdullah (2009). A database was constructed from the out-

Table 4 Essential simulation parameters.

Link delay	0.01 s
BER ( $\rho$ )	$10^{-2}$ , $10^{-3}$ , $10^{-4}$
Header ( $\alpha$ )	40 bits
Length ( $l$ )	0–1000 bits

comes of the simulation, from which the graph of packet size against energy efficiency under different link bit error rate (BER) is plotted as in Fig. 5 below.

The simulation output is shown in Fig. 5. The graph strongly depicts high energy efficiency for low BER. The energy efficiency for link with BER of  $10^{-4}$  is almost two folds than those with BER of  $10^{-2}$ . The efficiency drops very sharply for high BER when the packet length is increased beyond the peak energy efficiency. This is practically true because the probability of packets being corrupted is high and therefore the demand for retransmission increases and more energy is thus wasted. Therefore it is not surprising to observe that the energy efficiency tapered off more gently beyond the peak performance for links with low BERs. The consequence is large packet length/size in good quality link is able to attain higher energy efficiency than links with poor quality.

It is obvious from this plot that an optimal packet size  $N$  can be obtained from each BER. That is,  $N$  can be easily determined by choosing the point of maximum energy efficiency from the graph. For example, the optimal packet size for a link quality of 0.001 is given by 100 bits with the maximum energy efficiency of 84%.

It can be seen from the plot that the energy efficiency decreases with increasing BER, denoting that the more unreliable the channel is, the more energy is wasted. This phenomenon can be explained in the sense that when the link quality deteriorates, more data packets would be corrupted. In return the demand for packet retransmissions thus increases resulting in more energy being consumed for these retransmissions. It is interesting to observe that the energy efficiency for a link with low BER drops more gently after the peak than for a link with

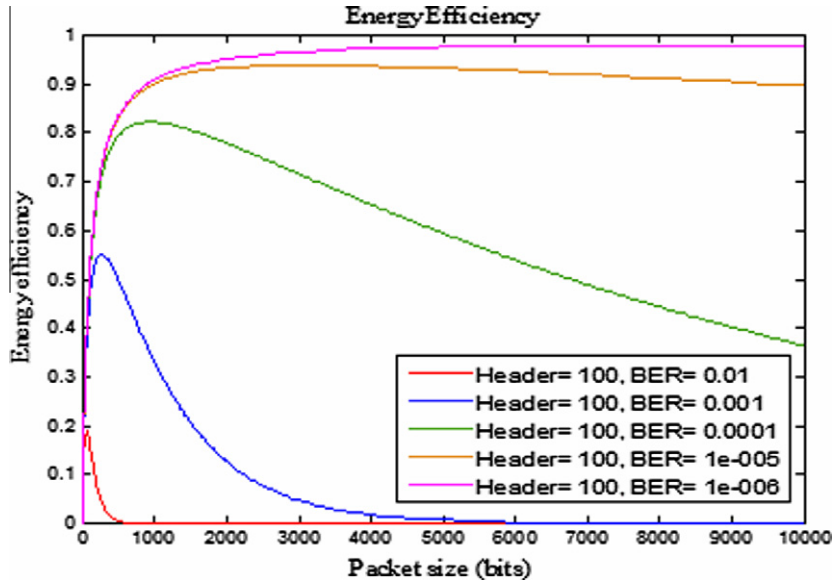


Figure 5 Energy efficiency vs. packet size under different BERs.

high BER. It brings out a point here that energy efficiency may not suffer much deterioration under good link quality even with a large packet size. For instance, with a BER of 0.0001 the optimal packet length can be varied practically from 150 bits to 900 bits with the energy efficiency maintained at/ or above 90%. This, in turn, may help to produce higher throughput efficiency with the opportunity to load the transmitted packets with larger payload. A snapshot of the database structure constructed from the outcomes of the simulation and which was used to plot the graph of Fig. 5 is given in Table 5.

6.4. Comparison with HbH-ACK

Furthermore, we present the simulation results of our proposed 2H-ACK scheme and compared with the results obtained by general HbH-ACK method. Our proposed scheme generated better results when the number of nodes starts to decrease in the network. This can be observed from Fig. 6a; with different number of nodes, delivery ratios drop with pace when HbH-ACK is used, but these ratios are less affected when 2H-ACK scheme is applied. As UWSNs are error prone and nodes can die or leave the network, which results in the sparseness of network, so 2H-ACK provides better results in such situations with small densities.

2H-ACK provides the reliability by maintaining two copies of the same data packet by different nodes. Although, more than one copy of the same data packet can be received at the destination, but it happens with low probability especially when we compare them with the data packets losses. This can be observed clearly in Fig. 6b that shows the comparison of data packet duplications with the average number of data packet losses. Both the number of duplicate data packets and amount of packet losses are small when 2H-ACK is used. On the other hand, the results from HbH-ACK show that no duplicate packets are received as in this scenario only one node has the data packet in the network, but at the same time the amount of lost data packets is very high. These high data packet losses are due to node failure. As in both cases, when a node

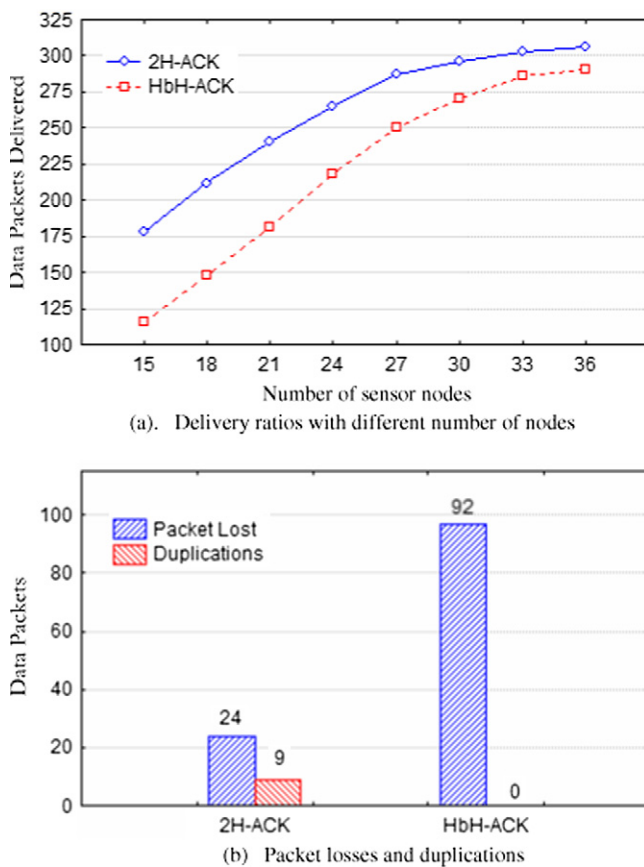
**Table 5** Snapshot of database structure for energy efficiency.

Pckt size (bits)	EPUB (mJ/bit)	BER	PER	Energy efficiency
16	1.9668	0.01	0.1485	0.4257
		0.001	0.0159	0.4921
		0.0001	0.0016	0.4992
96	1.0728	0.01	0.6190	0.3493
		0.001	0.0916	0.8327
		0.0001	0.0096	0.9079
176	1.0302	0.01	0.8295	0.1628
		0.001	0.1615	0.8004
		0.0001	0.0174	0.9379
256	1.0151	0.01	0.9237	0.0739
		0.001	0.2260	0.7499
		0.0001	0.0253	0.9443
336	1.0074	0.01	0.9658	0.0333
		0.001	0.2855	0.6975
		0.0001	0.0330	0.9439
416	1.0027	0.01	0.9847	0.0150
		0.001	0.3405	0.6469
		0.0001	0.0407	0.9408

cannot communicate with any other nodes then all the packets residing in its buffer will fail to reach the destination.

7. Conclusion and future work

For unstable underwater environments, nodes can die or get lost due to many reasons, which ultimately decrease the performance of the network. In order to handle this dilemma, the authors have proposed a 2H-ACK mechanism where two nodes maintain the same copy of a data packet, which increases network reliability. The relationship between optimal data packet size and energy efficiency in underwater wireless communications particularly to the underwater acoustic link was also investigated. The outcomes of the simulation have led to a new algorithm being proposed in this paper. The



**Figure 6** Comparison of 2H-ACK with HbH-ACK.

new algorithm can be implemented in underwater sensor nodes to determine the optimal packets size as qualified by the three metrics for efficient data transmission. An investigation on the current findings under other MAC protocols will be carried out in the future.

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