CHAPTER 3

OPTIMIZATION MODEL

3.1 Introduction

This chapter purposively presents the formulation of the data packet size optimization model for UWA communications. The model is inspired by the understanding of the UWA channel, the channel characteristics, the related channel parameters, and the works described in the preceding chapters. The concepts and approaches/techniques described and reviewed in Chapter 2 shall be taken as the basis for the proposed model. In brief, the proposed model shall combine the data packet size optimization findings in both the UWA and the terrestrial wireless communications.

The author adopted this hybrid approach in the view that a number of UWA wireless communications concepts overlapped with the terrestrial wireless communications counterpart. Some of their similarities include data loss due to packets collision; efficiency depends on good signal-to-noise (SNR) ratio, bit error rate (BER), and transmission range; transmission power requirements are related to source-sink distance; and hardware devices typically have half-duplex transceivers. These similarities allow the author to adopt the matured concepts and basic theories developed over the past decades in the terrestrial wireless communications into his model formulation for the UW environment. However, the unique characteristics found only in the underwater acoustic channel demand an adaptation (rather than direct adoption) of the previous techniques into the new model aimed to improve the performance of the UWA communications so that it is at least on par with its terrestrial counterpart.

The rest of the chapter is organized as follows. In Section 3.2 the background related to the concepts of stop-and-wait ARQ protocol is given as the proposed model is based on this protocol. This protocol is used in an analysis described in the subsections of 3.2 in which Subsection 3.2.1 presents an analysis of throughput efficiency in ARQ protocol and the method of linking optimal packet size to this protocol which could lead to optimal throughput. Subsection 3.2.2 analyzes a relationship between data packet size and the bit error rate and Subsection 3.2.3 explains a method to link data packet size to energy efficiency in the context of energy per useful bit (EPUB). The proposed model is discussed in Section 3.3 and Section 3.4 concludes this chapter.

3.2 Background

Underwater acoustic channel in fact is always associated with high bit error rate (BER) due to the poor qualities of physical characteristics such as time-varying multipath propagation, motion-induced Doppler distortion, long delay, absorption losses, etc. Therefore to establish a stable and reliable communication over UWA channel some kinds of automatic repeat request (ARQ) procedure need to be put in place. Despite the types of MAC protocol used in the MAC layer, ARQ procedure is always needed as a handshaking procedure between a sink and a source before data packets are transmitted. This ARQ procedure frequently is in the form, or in a variant of stop-and-wait protocol. In wireless communications the ARQ procedure can be implemented on the data link layer or on the transport layer of the network architecture. However, ARQ in general is implemented in data link layer in UWA infrastructures in which the quality of the physical link is poor and the demand for retransmissions of packets is frequent. The main task of ARQ protocol is to organize retransmission of erroneously received packets. Retransmission of the original packet can be performed as many times as necessary until it is declared correct. In practice, a limit however is imposed on the maximal number of retransmissions to prevent communication link “hang up”.

The basic procedure of stop-and-wait ARQ protocol starts with the source transmitting a data packet to a targeted sink and afterward waits for the acknowledgment (ACK) frame from that sink. If the ACK does not arrive in a predefined interval of time, (time-out) the packet is automatically retransmitted. In the event of the source receiving a negative ACK (NACK) before the time-out indicating that an erroneous packet was already received by the sink, the original packet is retransmitted. Effectively, NACK is a request from the sink for a packet retransmission. When the ACK arrives at the source before time-out (meaning that the data packet was correctly received at the sink) the source transmitter then can continue to transmit, if any, other data packets. Figure 3.1 below shows the simplified timing diagram illustrating the basic concept of stop-and-wait ARQ protocol. The operational details for variants of ARQ are readily available in many literatures on communication protocol.

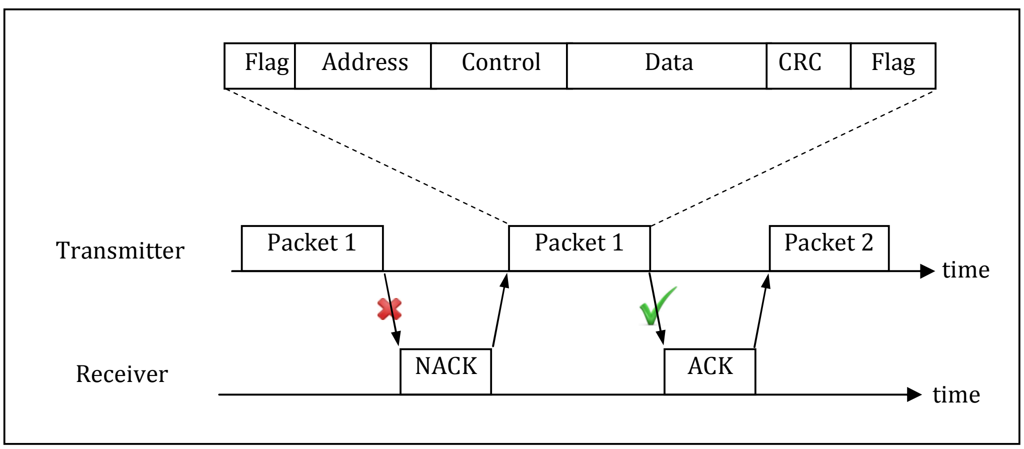

Figure 3.1: Stop-and-wait ARQ protocol

This stop-and-wait protocol is well suited for half-duplex operation and in fact it is the mode typically supported by current acoustic modem technology. It should be noted that the efficiency of an ARQ protocol is highly affected by the time spent in waiting. The efficiency can be improved if new packets are transmitted between the idle interval times of packet transmissions. Several methods have been proposed in the past [39-42] to increase the efficiency of the stop-and-wait scheme to satisfy the half-duplex requirements in the wireless underwater communication links.

These proposed methods focused on transmission of blocks of packets instead of a single packet to better utilize the time spent in waiting for the acknowledgment frames. These methods somehow indicate that the efficiency of the stop-and-wait ARQ protocol will depend on the packet size, the link delay, and the packet error rate (PER) or bit error rate (BER) in such a way that there exists an optimal packet size for which the throughput efficiency can be maximized.

In underwater acoustic channels the low speed of sound propagation (1500 m/s) often causes a long delay and poor BER, adversely affecting the ARQ efficiency. This suggests a research in data link protocol for a new optimization framework. Some of the works found in [43-45] showed a practical significance of maximizing efficiency of an ARQ scheme by controlling the packet size. They have proposed several versions of algorithms for an adaptive adjustment of the packet size in data transmission based on ARQ. However these algorithms are focused on terrestrial wireless communications where time delay is not a major problem. The main idea behind these algorithms is to estimate the instantaneous BER for an appropriate adjustment of the packet size. In this section, an analysis of protocol efficiency is conducted for a class of stop-and-wait ARQ leading to an optimal packet size which can be evaluated as a function of throughput efficiency and energy efficiency based on different BERs. It is mentioned here that energy efficiency includes the implicit component of energy per useful bit from the perspective of the transmitted data packet size.

3.2.1 Data Packet Size and Throughput Efficiency

Concerning with the stop-and-wait ARQ protocol, this subsection presents an analysis of data packet size and its throughput efficiency. Consider the data link layer packet format as shown in Figure 3.2 and assume that each data packet consists of a total of N bits where $N = N_l + N_{oh}$ in which N_l is the number of data bits (payload) and N_{oh} is the number of overhead bits. Take note that the overhead bits includes the header bits (α)and the trailer bits (τ).

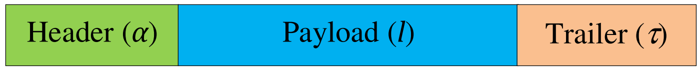

Figure 3.2: Data link layer general packet format

At a minimum, N_{oh} equals the number of bits in the packet header i.e. without the checksum (trailer). If the packet is transmitted with a bit rate of R, then the packet duration (T_p) can be evaluated as,

$$T_p = NT \quad \text{; where } T = 1/R \text{ is the duration of a single packet bit.} \tag{3.1}$$

In general the propagation delay between a source-sink pair of nodes in an underwater wireless link can be expressed as,

$$T_d = d/c \tag{3.2}$$

where,

d is the distance between the transmitter and the receiver nodes, and
c is the nominal speed of sound under water.

The nominal value of c is recognized as 1500 m/s. In practice, a synchronization preamble is normally added to the packet when it is transmitted. Let T_{syn} be the duration of this preamble. The total time needed to transmit a group of g packets and reception of the corresponding group of acknowledgments therefore can be written as,

$$T(g) = g \times (T_p + T_{ack}) + T_w \tag{3.3}$$

where,

$T_w = 2(T_{syn} + T_d)$ is the total waiting time in the stop-and-wait protocol.

It is common to see that in most of the data packet transmission the duration of an acknowledgment is usually negligible with respect to the packet duration i.e. $T_{ack} \ll T_p$. For better efficiency, the time-out of the stop-and-wait protocol in transmitting a group of g packets consequently should be equal to the round-trip time $T(g)$.

In ARQ protocol, the throughput efficiency is defined as the ratio of useful packet time and the total time averagely spend for a successful packet transmission. The average time is taken over the number of retransmissions. With a probability of packet error given as p_e the average time needed to transmit one packet successfully is given by [20] as,

$$T_1 = \frac{1}{1-p_e} T(1) \tag{3.4}$$

and thus the efficiency for transmitting a successful packet can be expressed as,

$$\eta = \frac{N_l T}{T_1} = (1 - p_e)\frac{N_l T}{T(1)} \tag{3.5}$$

In the case of transmitting a group of packets the ARQ can be regarded as g stop-and-wait protocol operating in parallel. Bear in mind that each stop-and-wait has a time-out of $T(g)$ with a packet error rate of p_e. Then the average time needed to successfully transmit a packet on one of the g links can be expressed as $T(g)/(1\text{-}p_e)$. If g packets are successfully transmitted during this time, the resulting throughput efficiency can now be written as,

$$\eta = (1 - p_e)\frac{g N_l T}{T(g)} \tag{3.6}$$

From this expression it can be noticed that throughput efficiency is dependent on the packet error probability (p_e) and the data length (N_l). With a constant bit error rate (thus constant p_e) it can be inferred that a transmission of a large packet size of N_l enables the throughput efficiency to be increased. Unfortunately, it is found that transmitting a larger packet size in practice also can increase the probability of bit error. The efficiency may drop with larger packet size as a single bit error could result in a rejection of a whole packet (thus causing high p_e). However, since bit error rate is determined by the quality of the channel link and the types of modulation and coding at the physical layer, the packet size can be varied to obtain maximum throughput efficiency. This in turn leads to the point that there exists an optimal packet size for optimal throughput efficiency.

So, with a given a set of physical layer parameters (p_e, R, d) where p_e is as the probability of packet error, R as the bit rate, and d as the distance between the transmitter and the receiver nodes, the throughput efficiency can be written in the form of [20],

$$\eta = (1 - p_e)^{N_l + N_{oh}} \frac{N_l}{N_l + \mu} \tag{3.7}$$

where,

$$\mu = N_{oh} + \frac{T_w R}{g} = N_{oh} + \frac{2}{gc} lR \tag{3.8}$$

Here c is the nominal speed of sound in underwater environment. It can be seen from the η expression that it is a function of packet length N_l. Therefore the optimal value of throughput efficiency can be evaluated by differentiating η with respect to N_l and equating it to zero i.e. $d\eta/dN_l = 0$, the optimal packet size is thus obtained as,

$$N_{opt} = \frac{\mu}{2}\left[\sqrt{1 + \frac{4}{\mu\rho}} - 1\right] \tag{3.9}$$

where,

$$\rho = \ln\left(\frac{1}{1-p}\right)$$

With the optimal packet size obtained, the optimal throughput efficiency is thus given as,

$$\eta_{opt} = (1 - p_e)^{N_{opt} + N_{oh}} \left(\frac{N_{opt}}{N_{opt} + \mu}\right) \tag{3.10}$$

Do observe that the μ term contains the lR product.

3.2.2 Data Packet Size and Bit Error Rate

One of the changes that digital communication systems has brought to wireless transmission is the need for good end-to-end performance in which the reliability of the entire radio system is usually quantified by the bit error rate (BER) metric. BER begins as a simple concept with a definition of,

$$BER = N_E/N_T$$

where,

N_E is the number of error bits, and

N_T is the total number of bits sent.

Although being considered insignificant if a strong signal can be sent through an unperturbed communication link, BER cannot be ignored when the link is imperfect or noisy and a certain level of signal-to-noise ratio needs to be maintained over the link.

In ARQ, when it is used over relatively high BER links, its performance is sensitive to the packet size [30]. This implied that there is a need in choosing a correct packet size based on BER. The optimal packet size for ideal Selective Repeat (SR) ARQ scheme is given by [30,46] as,

$$k_{opt} = \frac{-h\ln(1-p) - \sqrt{-4hln(1-p) + h^2\ln(1-p^2)}}{2\ln(1-p)} \tag{3.11}$$

where,

p is the known BER, and

h is the overhead bits per data packet (equivalent to N_{oh})

The plot of the above equation for h = 40 is shown in Figure 3.3 illustrating the non-linear drop of packet size with increasing BER (high BER means poor link quality).

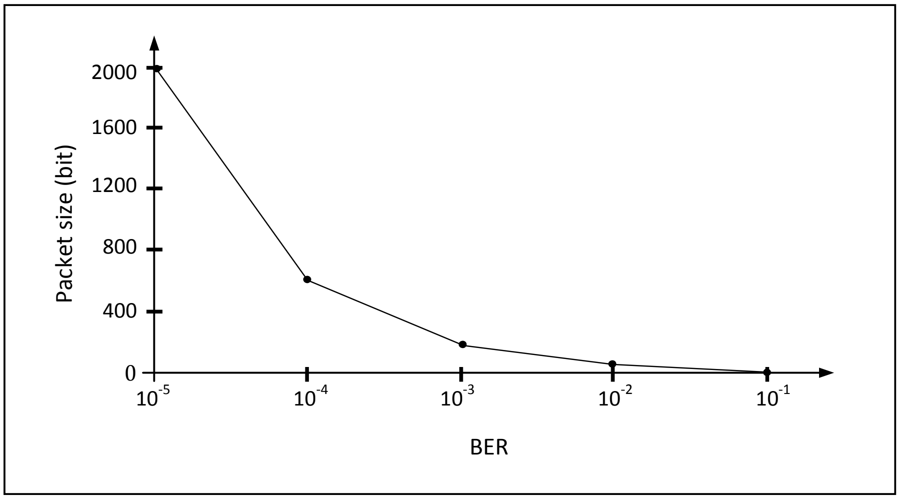

Figure 3.3: Packet size against BER for h of 40 [30]

Efficiency of ARQ protocol in delivering useful data is always a function of the block length (or the data packet size), channel error rate (or bit error rate), the number of overhead bits per block, and the round trip delay. That is, if by keeping the overhead bits per packet and the round trip delay somewhat constant, the transmission efficiency can be controlled by dynamically adjusting the packet length with respect to the error rate in the channel.

A well known equation related to the efficiency and probability of error for measuring transmission efficiency in selective repeat (SR) ARQ is given in [46] as,

$$T = \left(\frac{N-h}{N}\right)(1-p) \tag{3.12}$$

where,

$$p = 1-(1-P_b)^N \tag{3.13}$$

of which,

p	is the bit error probability/rate,
P_b	is the bit error probability,
N	is the packet size in bits,
h	is the number of overhead bits in a packet (equivalent to N_{oh})
$N - h$	denoting the actual payload.

If the efficiency equation T is differentiated by considering the actual payload and then equating the derivative to zero, the optimum payload size can thus be obtained. The plot of the throughput efficiency, the block size, and the BER based on equation T for SR protocol can be shown as in Figure 3.4 below [43]. This plot is for a header size (h) of 50 bits.

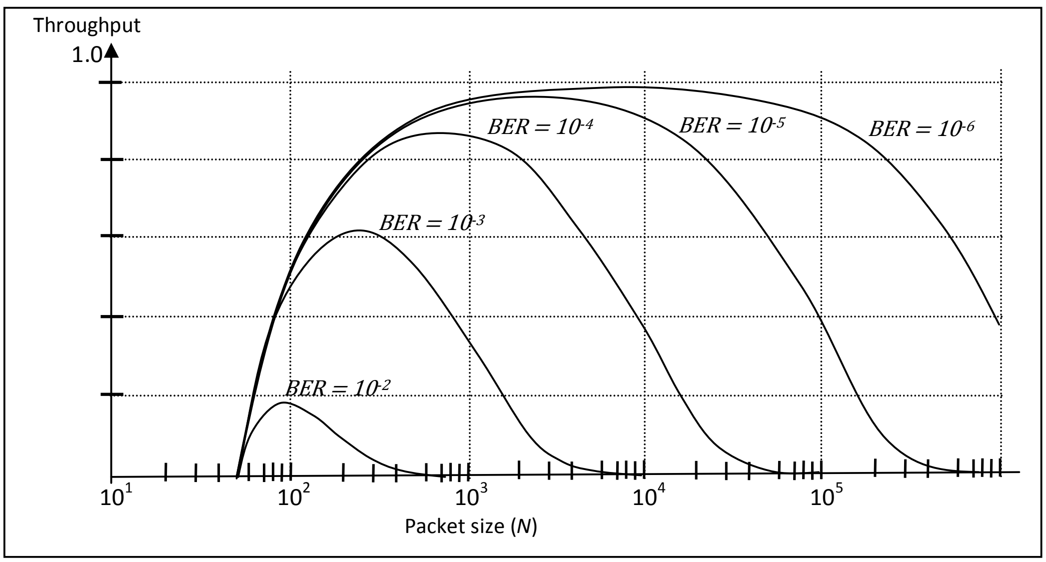

Figure 3.4: Plot of throughput against packet size with various BER [43]

Although not all of the curves in Figure 3.4 show a sharp peak, the plot indicates that for different BER, an optimal packet size can be chosen to produce an optimal throughput. In other words, as the BER increases, the transmitter can switch to the curve with lower n for the throughput optimization. It can be observed that for low BER, indicating good quality link, the optimal block size can be chosen within a wider range as compared to BER of high probability. For example, N can be chosen from a range of 1×10^3 to 1×10^5 with BER of 10^{-6} for a throughput efficiency of more than 0.9. However N can only be chosen from a range of 3×10^2 to 2×10^3 when the link quality deteriorates to BER of 10^{-4} to maintain the throughput efficiency at around 0.8 to 0.9.

It is considered that the plot in Figure 3.4 could suggest a scheme/algorithm that can be put in place inside the transmitter of a modem to measure the BER of the communication link consequently allowing the transmitter to dynamically adjust for optimal packet size according to the characteristics of Figure 3.4. It is also highlighted that Figure 3.4 can actually be constructed based on a certain database which may holds the various parameters of p, P_b, N, h, and $N - h$.

Now to measure P_b it is necessary to investigate the packet (or block) error probability equation p again:

$$p = 1 - (1 - P_b)^N$$

For high quality link the P_b and p are small (i.e. P_b and $p \ll 1$), thus P_b can be approximated as,

$$P_b \cong p/N$$

Then, in practice the packet error probability is defined as,

$$p = N_{be}/N_b$$

where,

N_{be} is total number of packets in error, and

N_b is total number of packets,

which gives

$$p = \frac{N_{be}}{N_b \cdot N} \tag{3.14}$$

Obviously this equation relates the p, which is directly linked to BER, to the N (packet size). In other words p refers to the function of the communication link quality. The p ratio can be computed by the rules of some error detection schemes used in the communication protocol. That is, the data packet error detection can be accomplished via the overhead bits calculated based on the rules used in the actual data transmission.

Referring to the plot in Figure 3.4, the BER and the packet size N can be tabulated in a basic format as shown in Table 3.1.

Table 3.1: BER and the packet size (n)

BER	N (bits)
10^{-6}	10,000
10^{-5}	2,500
10^{-4}	800
10^{-3}	250
10^{-2}	100

This table could be kept in the transceiver memory and indexed by the BER computed by the transceiver to obtain the optimal N. The computed BER may need to be rounded off to the nearest value in Table 3.1 to obtain the nearest optimal N. This rounding off process will affect the throughput to some extent. To reduce this effect, Figure 3.4 may be plotted with higher resolution i.e. with more BERs (finer granularities) values thus with more entries in Table 3.1. In actual implementation the size of Table 3.1 may be limited by the actual physical memory capacity available in the transceiver.

It is worth mentioned here that if the expected BER of the channel can be measured or computed by some means before the transceiver nodes are deployed into the field, a more accurate BER vs N table can be built up for better data transmission performance. The transceivers in the nodes can be configured in advance with some built-up tables (or databases) with respect to the deployment environment thus making the packet size choices more meaningful.

3.2.3 Data Packet Size and Energy Efficiency with Energy Per Useful Bit

In data communications, energy is consumed during transmission of data (energy expended at the transmitter), at the time of data packet framing, and when error correction is performed. Communication energy can be generally taken as the sum of the energy required to transmit the data and the energy needed to perform encoding and decoding of the data. In principle energy per useful bit (EPUB) refers to the energy used to transfer a data bit from a source over an imperfect communication link to a targeted sink where the transmitted bit is successfully recovered.

In practice, energy per useful bit includes the energy consumed in both the transmitter and the receiver to process all the bits in a packet in comparison to the energy consumed in the overhead bits. In information theory, the energy-per-bit quantifies the cost of reliably transmitting a large message over a noisy communication channel. Subsequently it induces that a minimum energy-per-bit concept does exists to quantify the minimum cost of reliable communication in a noisy communication channel.

In the context of a communication system, energy efficiency refers to the ratio between the amount of data transmitted and the energy consumed for that operation. By doing so, minimizing the total amount of energy spent on its operations plays an important role for a system of energy efficiency. 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 valuable energy waste. In actual fact, the retransmissions of data packets is a well known primary cause of energy wastage.

Currently most sensor nodes used in UWA communications are typically energy constrained (operated using non-rechargeable power sources) consequently leading to energy conservation to be one of the foremost priorities to have an energy efficient system. Various link adaptation techniques can be deployed to improve the link quality by dynamically adjusting the medium access control parameters such as packet size, data rate, sleep time, etc. thereby improving energy efficiency.

In terrestrial wireless data communications, it is found that the rate of packet errors is sensitive to the packet size. In other words, if the data packet size (thus the amount of data bits) can be adjusted or optimized according to the communication link quality (the error rate) there will be a possibility of reducing retransmissions that in turn can improve the energy efficiency. This brings along an added advantage in improving the throughput. In brief, when the link is noisy, the packet size is reduced to minimize the chances of packet errors and retransmissions (energy conservation) respectively, yet when the link is good the packet size is increased to improve the throughput.

This subsection investigates a relationship between data packet size and the energy efficiency in the context of energy per useful bit for shallow water UWA communications. The investigation focuses 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 communications between any pair of neighboring nodes. It is also assumed that a header or preamble is always included in front of every packet for PHY layer synchro-nization such as for timing recovery, channel estimation, transmission time slots scheduling, etc.

By adopting the energy efficiency metric described in Subsection 2.3.2 and with the data packet format of Figure 2.6 in Chapter 2, the expression for energy efficiency is reproduced here as,

$$\eta = \frac{k_1 l}{k_1(l+\alpha+\tau)+k_2+E_{dec}}\left(1-PER\right)$$

where,

$(1 - PER)$ is the packet acceptance rate (i.e. the data reliability rate), and

$\frac{k_1 l}{k_1(l+\alpha+\tau)+k_2+E_{dec}}$ is the energy throughput.

For simplicity, optimal packet size is derived without error control (such as under Aloha MAC protocol) i.e. τ and E_{dec} are considered as 0 (τ is the packet trailer/checksum bits, E_{dec} is energy needed for decoding) and a packet is said to be erroneous when one or more data bits are in error. With independent bit errors, a packet can be reliably received with a probability of $(1 - p)^{l+\alpha}$ [48] where p is the raw channel probability of packet error rate. With these, the efficiency equation can now be written as,

$$\eta = \frac{k_1 l}{k_1(l+\alpha)+k_2}(1-p)^{l+\alpha} \tag{3.15}$$

This equation allows the optimal packet length l to be derived with respect to η. By taking the derivative of $d(\eta)/dl$ and equating it to 0 the optimal packet length is derived as,

$$l_{opt} = \frac{\sqrt{C_0^2 - \frac{4C_0}{\ln(1-p)}} - C_0}{2} \tag{3.16}$$

where,

$$C_0 = \alpha + (k_2/k_1)$$

It can be noticed here that the optimal packet size is effectively determined by just two parameters i.e. C_0 and p. The relationship between l_{opt} and C_0 with various values of p can be plotted as in Figure 3.5. By computing the value of C_0 from the radio equipment parameters of k_2 and k_1, and getting the p (BER) from the UW channel, this plot can provide the approximate optimal packet size for a reasonable range of radio parameters of k_1 and k_2 under certain header bit of α. For the plot in Figure 3.5 α is taken as 16 bits.

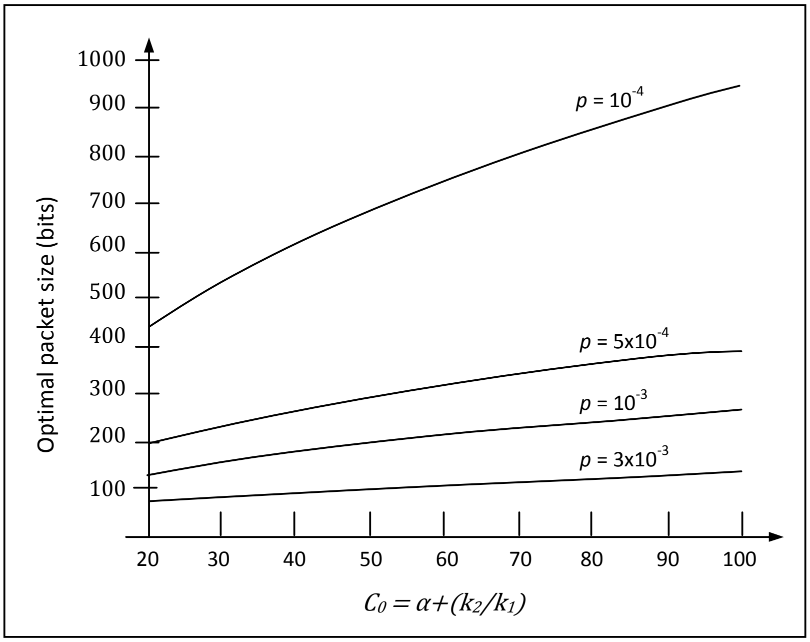

Figure 3.5: Optimal packet size as function of C_0 without error control

With the optimal packet size obtained from Figure 3.5, the optimal energy efficiency can be calculated from the η expression (3.15). Figure 3.6 in turn shows the plot of energy efficiency against the packet size l_{opt} with α of 16 bits for various values of BERs (the p).

It can be seen from the plot that the optimal energy efficiency increases with decreasing p. Interestingly, the energy efficiency suffers a steep drop for packet size smaller than the optimal size. This is mainly due to the higher overhead bits as compared to the actual payload bits in smaller packet size consequently causing high energy inefficiency.

An interesting point to note in Figure 3.6 is that for low error rate the energy efficiency declines quite slowly after the optimal peak implying that an optimal packet size can be chosen from a large optimal-packet-size range. For instance, at $p = 10^{-4}$, the optimal packet size can be chosen from a range of 200 bits to 900 bits.

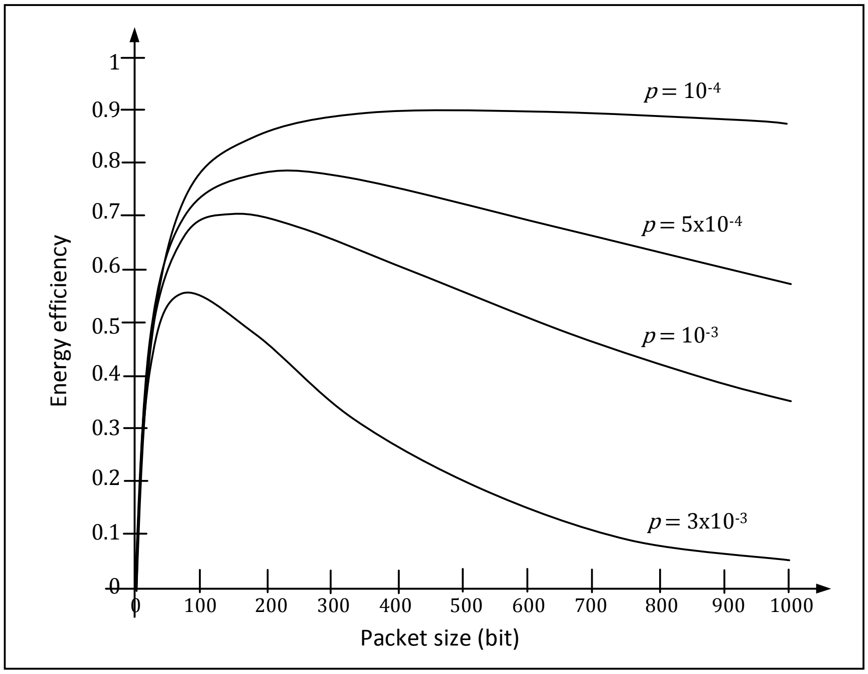

Figure 3.6: Energy efficiency as function of packet size

3.3 Proposed Model

3.3.1 Model Requirements

From the analysis and investigations described in the above sections the author can conclude that optimal packet size is sensitive to BER and can safely conclude that optimal data packet size is closely related to optimal throughput and energy efficiency under different BER conditions in UWA channel. The author would now able to propose a model or framework that can be implemented in UWA communications devices to determine the optimal packet size for effective and efficient data transmissions.

In principle, for a more practical implementation of the proposed algorithm, the author foresees a possibility of a need to conduct some necessary field data collections or measurements for the three essential parameters of BERs, throughput efficiency, and energy efficiency before the UW sensors embedded with the proposed algorithm are deployed into the designated area(s). Alternatively some simulation tools may be used to generate the necessary data for the three parameters. These collected data shall later be consolidated into some forms of databases or knowledge bases that the proposed algorithm can refer to for optimal data packet size computation. This is in analogy to conducting a land survey to collect important data before building a network of roads serving a particular area.

The consolidated databases could then be loaded into the sensor node's memory to serve as real-time references by the proposed algorithm. That is, these databases formed the knowledge about the UWA channel characteristics in that particular designated underwater environment.

Essentially, the channel BER is related to (or mathematically is a function of) the modulation scheme, the coding scheme, and the signal-to-noise ratio (SNR). Thus the proposed algorithm needs the following basic requirements:

- The SNR can be measured at the receiver node for each received test packet so that this information can be fedback to the transmitter for BER computation. That is to say, with some forms of a closed-loop feedback mechanism available in the transceiver devices, this SNR may be efficiently updated to the sender.
- For a given modulation, coding scheme, and MAC protocol, the BER can be determined by using the final p equation listed in (3.14).
- The data packet error ratio can be computed by the rules of some error detection schemes used in the protocol e.g. accomplished via the overhead bits calculated based on the rules used.
- All these equations: 3.9, 3.10, 3.14, 3.15, and 3.16 described in subsections of 3.2 would be used in the channel parameter measurements to build up the knowledge.
- The node has reasonable memory capacity to hold reasonable amount of link quality measurement results accordingly forming a reasonable knowledge bases.
- All nodes are static nodes and can be in 2D or 3D deployment.

3.3.2 Database Structure

The raw data collected from the channel measurements, as per the requirements mentioned in the above subsection, may be tabulated or consolidated conceptually in the form of Figure 3.7 below. The packet size values in the last column denote the optimal packet size evaluated from the equations described in Section 3.2. The Distance in the first column refers to the distance between a source-sink pair. It is considered that the proposed algorithm be for a single hop or nearest neighbor data transmission. CBRs denotes the constant bit rate used in sending the data bits.

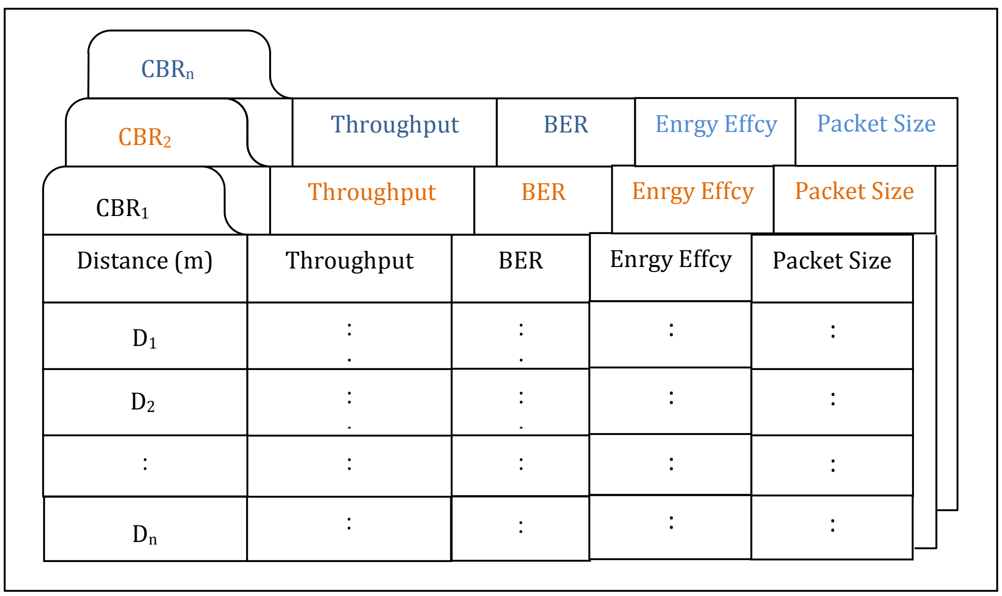

Figure 3.7: Conceptual database structure

The entries in the conceptual table are in fact arranged in the format that can be reflected by Figure 3.3, Figure 3.5, and Figure 3.6 respectively, meaning that these figures can be plotted out based on the entries in the table. The “knowledge” acquired from the communication link measurements and saved in the format of Figure 3.7 are eventually used to determine the optimal packet size for an effective and efficient data transmissions between a source-sink pair of nodes.

It is intentionally mentioned here that the size of Figure 3.7 should be adjusted according to the actual memory constraint of the sensor node. Small memory capacity node should hold a simplified version of Figure 3.7 whereas node with high memory capacity would be allowed to hold more entries for Figure 3.7. Consequently the effectiveness and efficiency of the data packet transmissions may suffer when a simplified version of Figure 3.7 is used.

The readers may also take note that the amount of BERs (and hence the throughput) needed in the table will depend on the BER resolution requirements of the UW network deployed in the particular designated environment. The range of the distance in the data structure is determined by the longest range of the reachable sink node by the sensor nodes surrounding it.

3.3.3 Optimal Packet Size Algorithm

With the data structures properly installed in each node, an algorithm to determine the optimal packet size from these databases is thus proposed as below.

```
/*three databases denoted as F33, F35, and F36 to represent Fig. 3.3, Fig. 3.5,
  and Fig. 3.6 respectively */
/* Source node and sink node are of homogeneous type */
/*test packet is essentially the RTS packet format with header length (h) of
  160 bits */
{
 Source node: send(test_packet) to the sink with
   predefined bit rate (R);
 Sink node: ack_and_return(test_packet);
 Source: with returned packet:
   {
    Computes BER (p);
    Computes distance (d);
    Computes (dR) product; //equivalent to Co
    with p indexed into F33 to acquire Nopt1;
    with dR product indexed into F35 to acquire Nopt2;
    Nopt :=  average(Nopt1 , Nopt2 );
    with Nopt indexed into F36 to acquire the energy
```

```
     efficiency (η);
    check: difference between η and η_opt from F36;
    if (difference) < (5%) then
      packetsize := N_opt
    else
    {
     with p indexed into F36 to obtain packet size (N)
       corresponding to the η_opt ;
     packetsize := average(N , N_opt);
    } end_if
   }
  Source: assemble(data_packet , packetsize);
  Source: send(data_packet);
}
```

The pseudo code for the proposed algorithm is self-explanatory. However the execution of the algorithm above will be explained in details in the succeeding chapter.

3.4 Chapter Conclusion

This chapter describes the fundamentals of stop-and-wait ARQ protocol and shows the way how this protocol to be linked to the optimization of data packet size under the performance metrics of interest: throughput efficiency, energy efficiency (with energy per useful bit as its implicit element) under the effect of different BERs. The energy per useful bit is investigated from the perspective of energy efficiency in data packet transmissions.

The analyses of these metrics were also to show the correlations between data packet size optimization and the performance of UWA communications. These analyses are aimed for finding optimal packet size computation in the context of single-hop data transmissions.

An algorithm for determining the optimal packet size with reference to the relevant databases is proposed in this chapter highlighting its requirements, formation of database structure, and application of the structures to the proposed algorithm.