Segment Combination based Approach for Energy- Aware Multipath Communication in Underwater Sensor Networks

S. Ramya[1] R. Devi[2] R. Palanivel[3]
[1,2]M.E – CSE [3]Associate Professor
[1, 2, 3] Selvam College of Technology, Namakkal

Abstract— Underwater acoustic communication is a technique of sending and receiving message below water. There are several ways of employing such communication but the most common is using hydrophones. Under water communication is difficult due to factors like multi-path propagation, time variations of the channel, small available bandwidth and strong signal attenuation, especially over long ranges. In underwater communication there are low data rates compared to terrestrial communication, since underwater communication uses acoustic waves instead of electromagnetic waves. The data can be collected from the sensor node and transfer the data to the destination. The same source information can be send through multiple paths through the same destination. So the packet bit error rate is high and power and energy consumption for transferring data is high. The bandwidth and the energy can be consumed. And then the packet bit rate is the serious problem in the existing system. It can be overcome by using the segment combination in the hamming code technique. The packet bit rate can be overcome by increasing the number of paths. The number of paths can be increased based on calculating the cost. For calculating the cost, least cost algorithm is used. And based on the minimum cost path, the path is chosen and data is transferred to the same destination.

Keywords: Hamming code algorithm, Packet error rate, Segment combination, Dijsktra's algorithm, Feedback decision.

I. INTRODUCTION

Recent advances in networking technologies and acoustic communications have enabled the deployment of Underwater Sensor Networks (USNs) for a variety of attractive applications, such as oceanographic data collection, pollution monitoring, offshore exploration, and military surveillance. However, the high Packet Error Rate (PER), long channel latency, and low bandwidth are the inherent issues in USNs characterized by the acoustic channels. Moreover, the feature of low energy efficiency brings fundamental challenges in design of USNs. Hence, this unique characteristic motivates the research community of USNs to seek a reliable, scalable, robust, and energy-efficient approach for design and deployment of USNs. This paper attempts to address this issue by 1) integrating the Hamming Coding-based Forward Error Correction (FEC) scheme with multipath communications (MPC), 2) designing a novel packet recover technology based on segment combinations for the FEC scheme, and 3) designing a Decision and Feedback scheme for multipath communications.

USNs have attracted many research efforts from academy and industry. In industrial fields, LinkQuest, Inc., a leading manufacturer of precise acoustic instruments, has developed a series of dominant products, Underwater Acoustic Modems (UWMs), which can achieve 10^{-9}, -10^{-7} Bit Error Rate (BER). However, the transmit model power is in the range of 1-40 W and the devices are heavy and expensive. As a result, they are not suitable for deploying large-scale USNs.

However, SDRT may cause much long delay because Tornado code requires more redundant blocks and thus SDRT is not utilized in the multipath communication. It is shown that multiple-path communications can eliminate retransmission of redundant packets in high-PER networks and can perform well when the destination nodes combine these redundant packets using the bit-based majority voting scheme. On the other hand, Hamming Coding [3], especially for multiple sources, is treated as a potential solution for FEC in the high-BER networks. Moreover, the probability of recovering the original packet in the destination node is determined by the packet combination efficiency.

The traditional bit-voting-based packet combination scheme [4] in the destination node splits the packets received from multiple paths into multiple bits and then votes the bits, thus ruining the integrality of the segment in packets because the segment should be decoded as a whole unit instead of bit-to-bit if the FEC scheme is handled in the network node.

As a result, the successful probability of packet recovery for the bit-based majority voting scheme is not high, and it consumes more energy because the number of the multiple paths is the key factor of determining energy efficiency in the multipath wireless communication. To support reliable, energy-efficient communications in USNs, this thesis integrates Hamming Coding in the network nodes with multihop multipath communications, proposes a novel segment-based packet combination approach for the destination nodes, and develops a dynamical decision and feedback scheme for USNs.

The advantages of the proposed approach include:

1) The proposed segment-based packet combination FEC in the destination node can improve packet recovery efficiency to enhance reliability.

2) The developed dynamic feedback scheme can control the number of the multiple paths and achieve high energy efficiency while guaranteeing the desirable PER.

II. DESCRIPTIONS

In order to present the proposed scheme clearly, this section introduces the preliminary knowledge including 7- 4 Hamming Coding.

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A. *Hamming Coding*

When retransmissions are relatively costly or impossible, FEC becomes a suitable way for provisioning of reliable data communications. In FEC [11], [6], redundant data, also known as an error-correction code, is added to packets before transmission. The purpose is to allow the receiver to detect and correct errors without asking the sender for retransmission. FEC codes can be classified into two main categories: block codes and convolutional codes. Hamming Coding [10] belongs to the former, which can correct single bit errors and makes it possible to provide reliable communication. Specifically, 7-4 Hamming Coding contains 4-bit source codes and 3-bit error-correction codes in each 7-bit segment.

Segment is, Ŝ, is obtained from the 4-bit source codes, S, following the linear operation:

$$\hat{S}=SG;$$

where G is the generator matrix of the code for 7-4 Hamming Coding. At the receiver side, the decoding process is to check which bit encounters error according to the encoding principle so as to correct the error bit.

B. *Bit-Based Packet Combination*

Generally, in multiple-path communications, after the destination node receives all the copies of the original packet from multiple paths, it will combine these copies using bit based majority voting scheme [12], [13]. Suppose there are l copies of the original packet received in the destination node, the *i*th bit, b*i*, in the final combined packet is determined by

$$b_i = \begin{cases} 1 & \sum_{w=1}^{l} b_{iw} \geq l/2 \\ 0 & \sum_{w=1}^{l} b_{iw} < l/2, \end{cases}$$

where b_{iw} is the i^{th} bit in the w^{th},($1 \leq w \leq l$), packet. As a result, the final packet can be combined bit by bit.

III. BIT-BASED VERSUS SEGMENT-BASED PACKET COMBINATION APPROACHES

The inherent characteristics of acoustic channels in USNs including the low bandwidth, high latency, and high BER pose many challenges in provisioning of reliable underwater communications. Without any error correction scheme, it is impossible to provide low BER transmission in the extremely unreliable area. Thus, FEC based on the Hamming Coding scheme is a useful approach to improving BER. Furthermore, the crucial performance in terms of energy efficiency is taken into account for designing USNs.

However, energy efficiency and delay are paradox typically in wireless networks. To bridge this gap, a widely used scheme, energy-efficient multipath communication [12] has been proposed to eliminate retransmission and reduce delay. MPC is utilized from the same source node to transmit the same packet along multiple paths to the destination node where these corrupted packets are combined bit-to-bit using the majority voting scheme.

In order to investigate the impact of diverse packet combination schemes on the number of multiple paths required for error correction in FEC. In these experiments, the source transmits packets to the destination communication paths. The bit-based and the segment-based packet combination approaches are deployed for recovering the original packet from the received copies at the destination.

As shown in Fig. 1, 10 corrupted copies of the original packet are received at the destination via different communication paths. Each received packet is divided into three appositional segments. Each segment is composed of 7 bits. PBC, PSC are the final packets recovered by using the bit-based majority voting scheme is treated as an integral part for 7-4 Hamming encoding.

Using MPC with the 7-4 Hamming Coding approach. The copies of the original data packets are corrupted due to the noise of the.

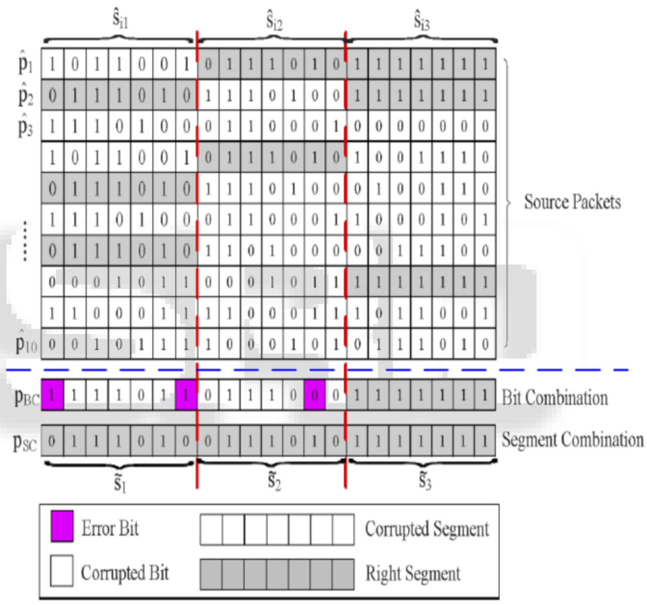

Fig.1. Comparison of Bit Majority, Vote-Based and Segment-Based Packet Combination in the destination.

decoding, but the bit-based combination scheme ruins the integrity and degrades the performance.

The above results show that the bit-based combination scheme is less efficient than the segment-based combination for the multiple paths FEC.

Due to the limitation of the traditional MPC in USNs, the current bit-based FEC schemes are neither suitable for reliable nor energy-efficient communications, nor for delay sensitive applications in USNs.

IV. M-FEC SCHEME

This section will present in detail the proposed M-FEC scheme for multiple-path communications in USNs. First, the architecture of multiple path for USNs is presented and then the encoding and decoding processes for Hamming Coding are introduced for M-FEC. After that we formulate the overall PER using a Markovian model and investigate

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the PER of the proposed M-FEC scheme, compared to the bit-based FEC for multiple-path communications using a set of numerical experiments. Finally the Decision and Feedback algorithm is developed for the M-FEC scheme.

A. *Network Design*

The dense node deployment makes multipath routing a natural and promising technique to cope with the unreliable network environments and large end-to-end packet delays. Thus, multipath communication enables to improve the robustness and reduce end-top-end delays for USNs.

As illustrated in Fig. 2, the broadcast technology is handled in the source node to deliver the same packets to the same destination in multiple paths. Specifically, in the source node, the data packet is encoded using Hamming Coding approach and is delivered using Multicast Ad hoc On- Demand Distance Vector (MAODV) [13] protocol to establish multipath routing through the intermediate nodes. At the destination, the decoder first corrects some errors encountered during transmission in the acoustic channel for all received packets.

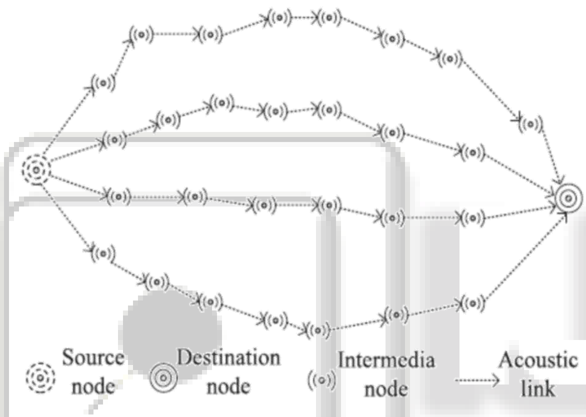

Fig. 2. Network architecture for multiple-path communications

B. *Dijkstra's Algorithm*

The general method to solve the single source shortest path problem is known as Dijkstra's algorithm. This thirty year old solution is a prime example of a greedy algorithm. Greedy algorithms generally solve a problem in stages by doing what appears to be the best thing at each stage.

Pseudo code for Dijkstra's Algorithm

```
1. void
2. Dijkstra( Table T )
3. {
4. Vertex v,w;
5. for ( ; ; )
6. {
7. V = smallest unknown distance vertex;
8. if ( v == NotAVertex )
9. break;
     a. T[ V ].Known = True;
     b. for each W adjacent to v
          i. if( !T[ W ].Known)
          ii. if( T[ V ].Dist + Cvw < T[ W ].Dist )
          iii. { /* Update W */
          iv. Decrease( T[ W ].Dist to T[V].Dist + Cvw );
          v. T[ W ].Path = V;
          vi. }
     c. }
10. }
```

V. PERFORMANCE EVALUATION

A. *Energy Efficiency*

We next investigate how the M-FEC can reduce energy consumption. The energy required for transmission is much higher than that for computation in wireless networks [7]. In USNs, this phenomenon is more remarkable.

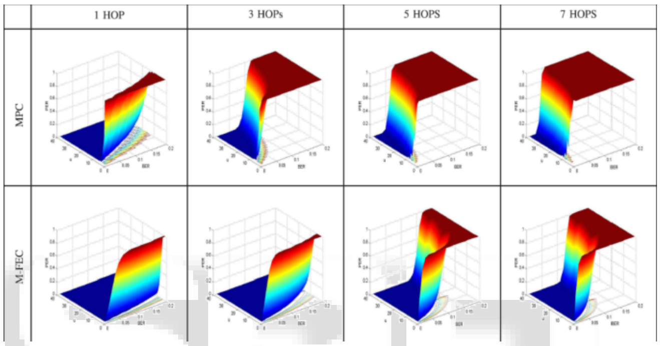

Table.1: The Achieved PER with Different BERs, Numbers of Hops and Numbers of Multipath.

Therefore, this study mainly focuses on the transmission energy consumption over the acoustic channels. Furthermore, it has been demonstrated that the number of the used multiple paths plays a dominant role in the energy consumption for transmission [9].Let E_{ij} denote the energy consumption of the j^{th} node in the i^{th} path.

The overall consumed energy, E, can be expressed by

$$E = \sum_{i=1}^{u} \sum_{j=1}^{n_i} E_{ij}.$$

We note that the overall consumed energy, E, is determined by u, ni, and Eij. Table 1, in fact, the number of paths, u, is a critical factor to affect the energy efficiency more greatly than the other two parameters, ni and Eij in multipath communications.

Hence, the M-FEC aims to adjust u according to the required PER, Preq, so as to improve energy efficiency. The energy saving solution in M-FEC consists of checking packet procedure and making decision procedure using 7-4 Hamming Coding.

VI. CONCLUSION AND FUTURE WORK

The project proposed a novel FEC approach, namely M-FEC, designed with Hamming Coding for multiple- path

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communications in USNs. To the best of the knowledge, this is the first of its kind on segment-based packet combination and recovery technology for FEC with Hamming Coding which can improve both energy efficiency and reliability in USNs. The proposed M-FEC integrates multiple-path communications and Hamming Coding to eliminate retransmission and enhance reliability.

To reduce the consumed energy of transmission, the Markovian model is used to calculate the overall PER in order to make a decision for the number of multiple paths guaranteeing the desirable PER. The proposed approach can significantly outperform conventional multiple-path communications and single- path communications in terms of an energy efficiency and reliability. Currently the scheme has a slightly less memory overhead, while in the more complex applications; the scheme may utilize more memory. The future study can be in the area of more significant memory savings.

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