Segment based Reliable Multipath Communication in Underwater Sensor Networks

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Abstract
Underwater acoustic communication is a technique of sending and receiving message below water. 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. In underwater sensor network, the main problem is reliability and low energy efficiency which is characterized by the acoustic channels. The multiple-path communications can be coupled by Forward Error Correction (FEC) and then it can achieve high performance for Underwater Sensor Networks (USNs), the low probability of successful recovery of received packets in the destination node significantly affects the overall Packet Error Rate (PER) and the number of multiple paths required, which in turn becomes a critical factor for reliability and energy consumption. It examines, a Multiple-path Forward Error Correction (M-FEC) approach based on Hamming coding is improving reliability and energy efficiency in USNs. A new approach is formulated which is termed as M-FEC and calculate the overall PER for the proposed decision and feedback scheme, which can reduce the number of the multiple paths and achieve the desirable overall PER in M-FEC. The proposed approach achieves significantly lower packet delay while consuming less energy in multiple-path in USNs. The number paths can be increased and the cost for the trajectory can be calculated using the Least Cost Any Path Routing Algorithm. Thus the minimum cost and the path can be selected and the data is transferred to the destination.

Index Terms
Underwater sensor networks, Packet error rate, Multipath communication, Forward error correction.

1. Introduction

As an emerging area, underwater sensor network has attracted rapidly growing interests in last several years. On the one hand, underwater sensor networks enable a wide range of aquatic applications, such as oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, and tactical surveillance applications. On the other hand, the adverse underwater environments pose grand challenges for efficient communication and networking. In underwater environments, radio does not work well due to its quick absorption in water, thus acoustic channels are usually employed. The propagation speed of acoustic signals in water is about 1.5 × 103 m/s, which is five orders of magnitude lower than the radio propagation speed .Moreover, underwater acoustic channels are affected by many factors such as path loss, noise, multi-path fading, and Doppler spread. All these cause high error probability in acoustic channels. In short, underwater acoustic channels feature long propagation delay and high error probability. In such harsh network scenarios, it is very challenging to provide energy efficient and reliable data transfer for time-critical applications (such as pollution monitoring and submarine detection).

There are several mechanisms to improve the performance of USNs in terms of energy efficiency, reliability, robustness, and scalability. Furthermore, existing studies have shown that the PER in the extremely unreliable area can be substantially low if the FEC scheme is employed. A segmented data reliable transport (SDRT) protocol to achieve reliable data transfer in 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.

The 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, 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 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.

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This thesis 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.

2. Related Work

To better understand of improving reliability and energy efficient, it is useful to review and examine the existing research works in literature. Therefore, recent approaches and methodologies used for improving reliability and energy efficient have been discussed.

An Energy-Efficient Mac Protocol for Underwater Wireless Acoustic Networks

It proposed a distributed, scalable MAC protocol which is suitable for underwater wireless sensor networks. It showed that the proposed scheme provides at least 95 % energy efficiency in the MAC layer, when the average number of 1-hop neighbours is about 6. Also, this algorithm is distributed, scalable and robust, as the network evolves, that is, when new nodes join or nodes dropped out.

Energy-Efficient Reliable Broadcast in Underwater Acoustic Networks

It present the design of three reliable broadcast protocols that leverage this relationship to outperform standard, radio-based broadcast approaches in terms of energy consumption and time to complete the broadcast. The three protocols are, Single-Band Reliable Broadcast (SBRB), FEC Single-Band Reliable Broadcast (FSBRB), and Dual-Band Reliable Broadcast (DBRB) each leverage the ability to use small bands to transmit long distances to alert nodes that broadcasts are to be expected.

To reducing the transmission range and selecting only certain nodes from each neighborhood to repeat the broadcast, the protocols dramatically reduce the total number of transmissions required. The extensive simulation study demonstrates that both FSBRB and DBRB yield significant gains in terms of energy consumption and time to completion, as compared to the other protocols. Additionally, DBRB performs the best when the error rates are high.

Packet Combining in Sensor Networks

In this paper, a novel scheme for error-correction that exploits temporal and spatial diversity through packet combining. Beside hop-by-hop communication, the scheme also works on multi-hop interactions present in routing or broadcasting. It is fundamentally coupled to the broadcast nature of the wireless medium, in contrast to traditional point-to-point FEC techniques that work identically in wired and in wireless networks. The performance gains shown are promising, in light of the simple design choices made. To explore systems that employ more powerful codes and that operate over more than two corrupt packets. Integrating the merging algorithm with the block combining technique may lead to improved performance on bursty channels. A software implementation has low overhead for the short codes used in this paper, more powerful coding scheme may require hardware support for fast decoding operations.

An FEC based Reliable Data Transport Protocol for Underwater Sensor Networks

The Segmented Data Reliable Transport (SDRT), is a reliable data transport protocol for underwater sensor networks. SDRT segments data packets into blocks and encodes using SVT codes. The application of SVT codes increases channel utilization, reduces the number of packets transmitted in the network, and relieves both of the sender and receivers the burden of lost packet management. Therefore, SDRT is energy efficient and lightweight. Furthermore, the appropriate block size enables SDRT to effectively address the dynamic network topology problem. Setting appropriate block size depends on the expected number of needed packets. It developed a model to estimate the number of packets actually needed for data recovery. It evaluated the accuracy of the model and the performance.

Efficient Multipath Communication for Time-Critical Applications in Underwater Acoustic Sensor Networks

It proposed a novel Multi-path Power-control, Multipath Transmission (MPT), for time-critical applications in underwater sensor networks. MPT combines the power control strategies with multi-path routing protocols and packet combining at the destination. Without retransmission at the intermediate nodes, MPT can achieve low end-to-end packet delay. With power control at the physical layer, MPT can achieve relatively high energy efficiency. MPT is a promising transmission scheme for a good balance between packet delay and energy efficiency.

3. Descriptions

3.1 Hamming Coding

When retransmissions are relatively costly or impossible, FEC becomes a suitable way for provisioning of reliable data communications. In FEC, 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 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. The 7-bit segment Ŝ is obtained from the 4-bit source codes, S, following the linear operation: Ŝ = 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.

3.2 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 bitbased majority voting scheme. Suppose there are l copies of the original packet received in the destination node, the ith bit, bi, 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 biw is the ith bit in the wth, (1 ≤ w≤ l), packet. As a result, the final packet can be combined bit by bit.

4. 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.FEC based on the Hamming Coding scheme is a useful approach to improving BER.
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 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 as to recover the original packet. In order to investigate the impact of diverse packet combination schemes on the number of multiple paths required for error correction in FEC.

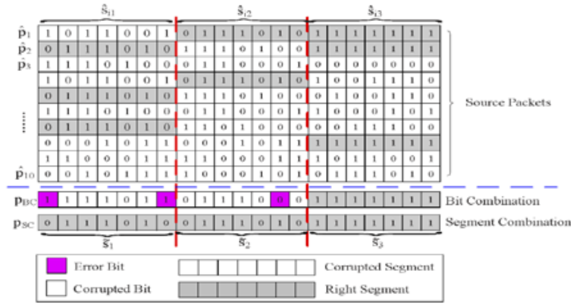

Fig. 1.Comparison of bit majority vote-based and segment based packet combination in the destination

5. The Proposed M-Fec Scheme

5.1 Network Architecture

The multiple-path communication is high efficient and feasible in the deep underwater area. Multipath routing has drawn extensive attention in the research community of wireless sensor networks. 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.

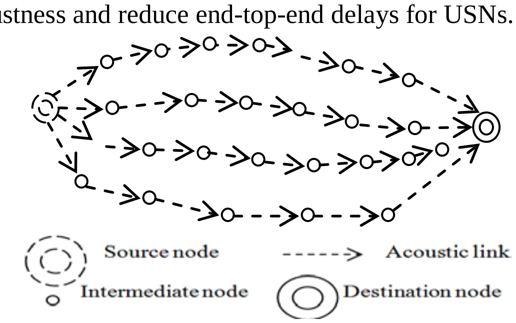

Fig. 2. Network Architecture for Multi Path Communication

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) protocol to establish multipath routing through the intermediate nodes.

In each intermediate node, the data packet will be dropped without any further processing if any error occurs in its header. Otherwise, the decoder of Hamming coding used to recover some corrupted segments into the original one. If there are some errors in the corrupted packet, and then the packet will be transferred to the next intermediate nodes until it reaches the destination.

At the destination, the decoder first corrects some errors encountered during transmission in the acoustic channel for all received packets. Then, the received packets are classified according to the packet ID.

5.2 Segment-Based Combination

The M-FEC scheme accesses all the segment sets$\{\hat{S}k \mid 1 \leq k \leq v\}$, compares them in turn and chooses the segment that appears most frequently as the final data segment in its position. If two or more segment in the same position has identical count, the one appearing earlier is selected as the winner. Especially, if the domain "Flag" equals 1 after CRC checking in the packet header, all the segments in the packet are right and are regarded as the final ones. Thus, the kth final segment in the data packet is expressed as

$$\hat{S}_k = \begin{cases} \hat{S}_{lk,} \text{ "Flag = 1" in lth received packet} \\ \hat{S}_{lk,} \text{ VCount}(\hat{S}_{ik},\hat{S}_k) \geq \text{Count }(\hat{S}_{ak},\hat{S}_k) \end{cases}$$

Where$\hat{S}_{ak}$is an arbitrary segment in,$\hat{S}_k$, and Count($\hat{S}_{ik}$,$\hat{S}_k$)is the function of counting the number of$\hat{S}_{ik}$in$\hat{S}_k$. All the final segments and the original header are combined and encapsulated into a new packet. Furthermore, this procedure applies to all the packet sets.

5.3 Decision and Feedback Scheme

The M-FEC program checks the final combined packets whether they are right or not. If all of them are right or the overall PER is even low, the destination will send feedback to the source to decrease the number of transmission paths. However, if the overall PER is high in an unacceptable range, the destination will send feedback to the source to increase the number of transmission paths. The procedure lasts until the overall PER is within a reasonable range. Thus, the number of paths can be maintained in a reasonable range.

5.4 Least-Cost Any Path Route

There are multiple possible trajectories to traverse an any-path route, and each is used with some probability P(T), which depends on a number of factors such as the nondeterministic outcome of link-layer transmissions, decisions made by link and network layer protocol mechanisms, and the topology of the network.

Least-Cost Any Path Route Algorithm

Step 1:A trajectory T in an any path route R is a sub graph of R that connects the source and the destination.

Step 2: Define the cost of a trajectory relative to the any path route it traverses.

Step 3: Find C(R) which is the cost of any path route R is the expected cost of all trajectories across that route

$$C(R) = \sum_{T€R} P(T).\ C(T|R)$$

The sum is the overall possible trajectories from the source to the destination of R.

Step 4: If the CRSs are singletons, there is only one trajectory T across an any path route (and P (T) =1), and its cost is the sum of its constituent link costs.

Step 5: Candidate relays gives each possible choice rise to a probability distribution over all possible paths between the source and destination to avoid the explicit computation of this distribution.

Step 6: The LCAR route has cost either smaller than or equal to the shortest (least-cost) single-path cost between two nodes.

Step 7: Stop the process.

6. EXPERIMENTS AND RESULTS

In underwater communication energy constrained is very important to find ways to improve the life expectancy of sensors. Segment based packet combination is proposed to improve energy efficiency and reliability of underwater sensor networks.

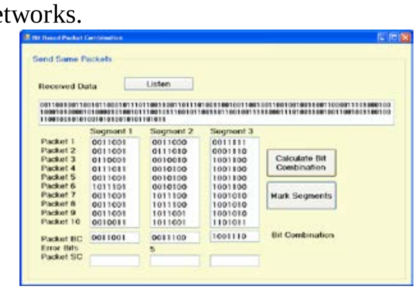

Fig. 3.Before Segmentation

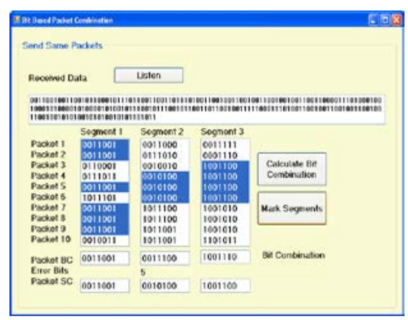

Fig. 4.After Segmentation

For segmentation, the client application sends packet data. The data is collected and displayed. The data is the combination of 1s' and 0s'. The packets are segments as segment 1, 2 and 3. The same packet data arrived in varying times is displayed. Then for each packet data, count of identical 7bit sequence is calculated and the bit sequence occurring maximum times are taken as final segment data. Suppose two 7bits sequences occurs equal times, then any one is selected as final segment data.

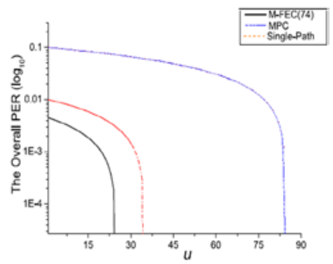

Fig. 5.The Overall PER

The above chart shows the comparison of overall packet error rate (PER) between the Multipath Forward Error Correction (M- FEC), Multiple-Path Communication (MPC), Single Path communication.

7. CONCLUSION

Energy is an essential and important factor in the lifetime of sensor network. The main purpose of network establishment is sharing of information through communication and energy is the key required for this communication. In the design of energy efficient underwater sensor networks, it is necessary to consider the resource constraints of the sensor nodes and the underwater environment. Underwater sensor networks operate in harsher conditions than TWSNs. The applications of UWSNs are also expanding into areas that represent harsher and generally more dangerous environments. Therefore, the reliability of the network is considered to be of upmost importance. Data reliability of a sensor node is described as a probability of data packet being delivered from sensor node to the sink.

In this thesis, it has proposed a FEC approach, namely M-FEC, designed with Hamming coding for multiple-path communications in USNs. To the best of the knowledge, this is the first 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, and 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.

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