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An Extensive Single-path Communication Scheme for Submerged Sensor Networks

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Abstract: **Due to the high error rate and propagation delay in acoustic data communication channels, successful data transfer became a vital issue. Many communication methods have been proposed in recent years. But they are found to be inadequate to muddle through the unreliable submerged acoustic environment. In this paper, we propose a new communication scheme called Single path communication with retransmission (SPCR), which ensures high data rate and abridged power utilization. SPCR introduces much shorter delays and enhances the traditional one-path scheme with retransmission. Retransmission upon failures strengthens the scheme and enables to ends up the data transfer efficiently. Single path data transmission minimizes the network load and thereby avoids packet loss extensively. Exceptional buffer administration allied to the sensor nodes makes the scheme power efficient and helps to makes use of the accessible resources constructively.**

Keywords: Single-path communication, submerged sensors, retransmission, bit error rate, propagation delay

I. INTRODUCTION

Networks of submerged sensors have the potential to enhance human's ability to observe and predict the underwater environment by enabling many applications such as oceanographic data compilation, effluence monitoring, Mine detection, offshore exploration, disaster deterrence, assisted navigation, and tactical surveillance. Hence the research in submerged sensor networks has engrossed hastily rising attention in past several years. Due to the distinctive and unreliable characteristics of submerged environment, it became difficult to design and implement an efficient communication and routing scheme. Many approaches have been proposed recently. But they are not proficient to muddle through the conditions.

The role of submerged sensors in underwater applications is very significant. The information about the ocean floor and its environment can be accurately observed and evaluated with the assistance of such sensors. Submerged sensors are unable to communicate with the help of radio signals [8]. Since the submerged environment is highly error prone, the radio signals will be incident to high attenuation. This may lead to packet loss or else high bit error rate. Figure. 1 shows a typical submerged sensor network. The sensors in these networks are dealing with extremely sensitive data. So successful transmission of data from node to node must be ensured. There comes the significance of an extensive communication scheme. The proposed scheme has efficient techniques to manage the bit error and packet loss problems.

In submerged sensor networks the transmission of sensed data can be employed by acoustic signals. Acoustic signals have lower propagation speed as compared to radio signals. But still they are competent to the factors that affect acoustic channels like high bit error, packet loss, noise and Doppler spread. Hence it is very difficult to provide an efficient communication scheme for such harsh underwater networks. Since the pace of signals under the water is frail, the propagation delay will increase rapidly. Because of this reason, traditional packet retransmission from source to end cannot be applied. In SPCR, an enhanced retransmission technique has been proposed which can manage the propagation delay with minimum amount of energy consumption.

On the other hand, the error prone behaviour of acoustic channels has to be considered with much earnestness. Since the data is highly sensitive, accuracy is an important parameter. Many error detection and correction techniques have been proposed earlier. But the availability of battery power is so limited for submerged sensors. When compared to the terrestrial counterpart, the power utilization is more in acoustic networks.

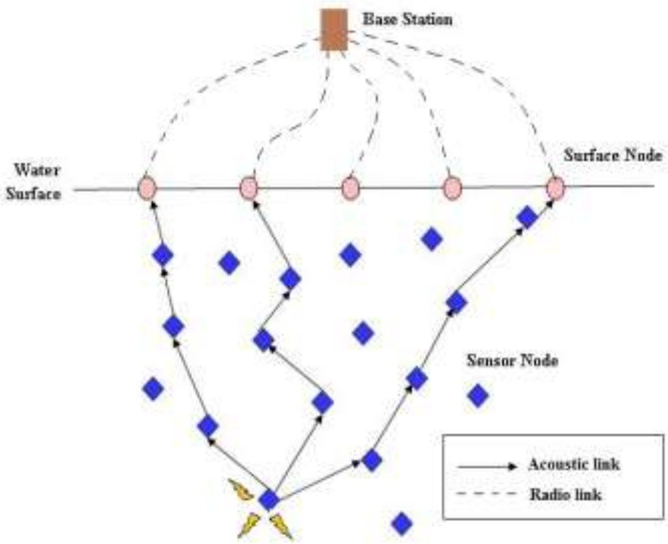

Figure 1. A Typical Submerged Sensor Network

It is not practical to recharge or replace the batteries of sensors frequently. So the design of these networks should be done such that the overall energy utilization can be minimized to the maximum. In the proposed approach, a hybrid error detection technique is used called as Hybrid Automatic Repeat Request (HARQ) [4], which is the blend of traditional ARQ technique and Forward Error Correction (FEC).

For underwater sensor networks, it is believed that multi-path communication schemes are favourable for load balancing and to manage the network traffic. But the power utilization of such schemes is not affordable. So it's more beneficial to stick on to the traditional single path scheme. A power efficient error management and retransmission method has to be clubbed with the single path propagation that maintains the transmission reliable. In the proposed approach, all the sensors in the network are assumed to be the source and destinations at times. That means, the source node will be changed with time. The retransmission of packets is managed by a method called

Recent Packet Retransmission (RPR). If retransmission is needed, the immediate sensor will be able to resend the packet. An efficient buffer management system is integrated with all sensors for managing the same.

In SPCR, we propose a power efficient single-path communication scheme for submerged sensors with which the unreliable behaviour of underwater environment can be managed beneficially. Our contribution is strengthened by integrating highly efficient error detection and correction methods. Also in case of failures, the retransmission scheme incorporated with SPCR will manage the network load and end to end propagation delay. We conducted comparative studies and observed that the enhanced single path transmission scheme provides power efficiency and high accuracy. The implementation of proposed scheme can guarantee successful source to destination propagation of sensitive data that the submerged sensor networks observed.

The rest of the paper is organized as follows. In the section II we review and investigate some of the recent works on communication of underwater sensors. Section III gives the detailed explanation of our proposed scheme and finally in section IV we conclude the paper.

II. Related works

Zhong *et.al* [1] proposed a multi-path communication scheme which played an important role in design of our proposed approach. The approach was termed as Multi-path power control transmission scheme (MPT). In this scheme, multiple numbers of same packets will be transmitted through different paths. This will increase the load in the network and also the end to end propagation delay. The sensors will transfer the sensed data to the surface node though several intermediate nodes. When the packets reach the destination, a probabilistic method of error correction is performed. Since the data handled by the submerged networks are highly sensitive, the probabilistic error correction method is not sufficient. Figure. 2 shows the implementation of the concept. Our proposed approach overcomes all the disadvantages of the above mentioned scheme.

Chitre *et.al* [2] reviewed a number of papers and analysed the design challenges and issues for underwater sensor networks. The paper pointed the challenges posed by the communication channels like low bandwidth, Doppler shifts, fading, bit error rate etc. The underwater networking protocols and their comparative examination were also performed by them. They enhanced the DFE algorithm with efficient error correction coding and iterative algorithms. Hence the performance of the network improved.

Zaihan *et.al* [3] proposed a cross layer approach for the communication of submerged sensors. The cross layer approach focuses on low bandwidth, poor channel stability, high propagation delay etc that the submerged network suffers from. Several implementation issues in such networks are raised, that ranges from power efficiency, physical and MAC layers, network topologies etc. Comparative analysis of underwater and terrestrial sensor networks in the paper provides a comprehensible scheme for communication of sensors.

Babiker *et.al* [4] proposed an efficient error correction method called adaptive hybrid error correction technique (AHECT). As the underwater environment is highly error prone, traditional error correction methods may not be sufficient. AHECT automatically adapts with the circumstances. That is, if the network suffers low bit error rate, then it enables usual retransmission (ARQ). On the other hand, it enables the hybrid method, that is the blend of ARQ and FEC in case of high bit error rates. The power utilization of the proposed technique was comparatively high.

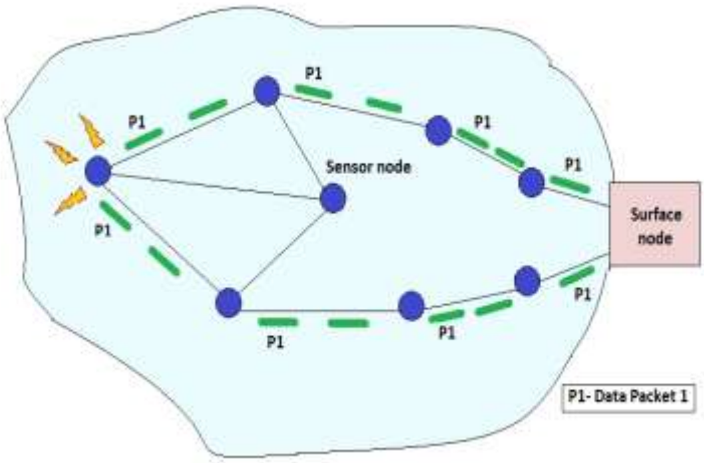

Figure 2. Multi-path Communication Scheme

Our proposed communication scheme called as SPCR is capable of managing the anecdotal nature of underwater conditions. Conventional single-path propagation is enhanced with efficient error detection and rectification techniques which makes the scheme more sophisticated. The scheme is highly compatible for error prone manner of these networks. The data rate of the network is maintained by buffer system integrated with each sensor nodes. The power utilization of this scheme is found to be feasible and the retransmission method proposed reduces the end to end delay in the network.

III. PROPOSED SCHEME

In this section, we present our communication scheme that can overcome the unreliable behaviour of submerged environment. Single-path communication with retransmission (SPCR) is the enhancement of conventional one-path data propagation method. In this scheme the sensor nodes in the network are assumed to be scattered over a large area under the water. The sensor node which is submerged in water will sense some environmental data and sends to the receiver which is on the surface. The proposed approach is demonstrated in the Figure. 3. SPCR is a power efficient communication scheme for the sensor nodes in which the different data packets will be sending through different paths. Hence the data rate of the network can be increased accordingly.

When the first node receives the packet from the source, it checks the packet for errors using an efficient error detection technique called as Hybrid Automatic Repeat Request (HARQ). HARQ is the combination of conventional ARQ and Forward Error Correction (FEC). HARQ error correction is observed as the most energy efficient method of error rectification for acoustic sensor networks [4].Once if the packet reached next node, the receiver node will send back an acknowledgement (ACK). The received packet is then copied to the buffer of the sensor node and forwarded to the next node [5]. If the packet has been damaged or lost, it has to be recovered or retransmitted. The traditional approach of retransmission, which is from the source node itself, will not be worthy here due to the limited battery power and high propagation delay.

The design of a Submerged sensor network is not that much undemanding. Many momentous challenges have to face. Some of them are stated below [6], [9]:

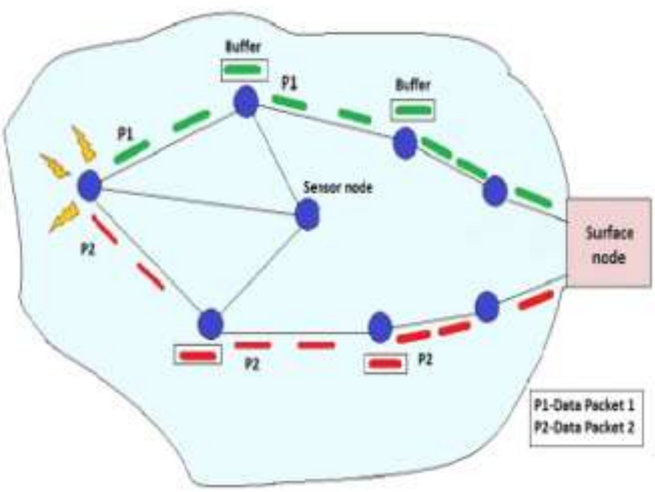

Figure 3. Single-path communication with Retransmission (SPCR)

- Acoustic channel bandwidth is dreadfully limited.
- Fading and Doppler shifts makes the channel impaired.
- Rate of propagation under water is five orders of magnitude lower that that in terrestrial networks.
- Channel will frequently experience high bit error rates and temporary loss of connectivity.
- Since batteries cannot be recharged usually, available power is limited.
- Due to fouling and corrosion, submerged sensors are prone to failures.

In the proposed scheme, a well-organized retransmission technique named as Recent Packet Retransmission (RPR) is introduced. In this technique, the node which detects the errors will send back a negative ACK first. If it is the first node in the network, then the source will retransmit the packet else the previous node will do the same. This reduces the end to end delay in propagation significantly there by increasing the data rate in the network. Both HARQ and RPR techniques are repeated for every sensor nodes till the data packet reaches the destination successfully. The network is heavily influenced by the transmission loss, high and variable propagation delay and noise.

The implementation of the proposed scheme can be alienated as four modules. Each module is having significant importance so that they have to be monitored and managed frequently. The modules are mentioned and explained in detail below.

A. *HARQ Error Control*

In the Single-path communication scheme we proposed, the error detection and rectification technique can be considered as the backbone because, the acoustic communication channels are so much influenced by the error prone behaviour of underwater environment. Since acoustic signals can travel with a speed five times lower than that of radio signals, the possibility of the packets to get damaged or lost is high. So as to cope up with this condition an energy efficient error management system is essential. HARQ which is the blend of traditional ARQ and FEC is found to be the most beneficial and efficient method.

In SPCR, the source node senses the available paths to the destination node and sends the data packets through different paths. Once the packet reaches the first node in the path, it checks for errors using HARQ technique and this process are repeated for all sensor nodes whenever they receive any data packet [4].

The average expected error rate at each sensor node can be calculated based on the distance between the source and destination nodes and It is given as:

$$e_i = \sum_{i=1}^{n} (d^c{}_{ij} - d^e{}_{ij})^2$$

where n is the number of sensor nodes other than sensing node, d^c is the calculated distance and d^e, the estimated distance.

B. *Buffer Management*

Once if the packet received by the node founds to be error free, the copy of the packet is saved in the buffer which is integrated with each sensor nodes in the network. Then the packet is forwarded to the next node. On the other hand, if there is any error, and the negative acknowledgement is received by the node, then the packet will be retransmitted from the buffer directly. This reduces the node to node packet transmission delay. The buffer is over written by other packets as the data transfer proceeds.

C. *Recent Packet Retransmission (RPR)*

Recent packet Retransmission is the newly introduced power efficient retransmission method. If any errors are there in the received packet or even the packet has been lost, then a negative acknowledgement will be send back to the previous node. As soon as the node receives the negative acknowledgment, it initiates RPR.

For a given n communication paths, the overall power utilization P, per packet, can be written as follows:

$$P = \sum_{i=1}^{n} P_i L$$

where P_i is the power utilization for a single bit along the path i, and L is the length of the packet in bits.

In RPR the recently send packet is retransmitted from the sensor node's buffer directly. This reduces the retransmission delay as compared to the traditional communication schemes. Since the packet will be retransmitted from the preceding sensor node buffer, the power utilization will be comparatively less significant.

D. Acknowledgement Management

In the network, all the sensor nodes which send any packet will be expecting an acknowledgement from the next node. In case of any errors, the nodes will send a negative acknowledgement back to the previous node. On the other hand, if there is no error or packet loss, a positive acknowledgement will be send back. All these should be monitored accurately so as to ensure the reliability of the communication scheme. The transmission of acknowledgement is also done through the same path which is taken by the packet to travel. Hence the efficient transmission of sensitive data can be ensured. The power consumption of acknowledgement transmission is insignificant.

IV. EXPERIMENTAL RESULTS

We present the simulation analysis for the proposed scheme in this section. The simulation is performed in NS-2 [10]. We have simulated a submerged sensor network, with sensor nodes dispersed arbitrarily and consistently over a large area. It is assumed that the nodes have identical and constant transmission range. In the network, communication is always made bidirectional.

A. Environment

We simulated a network consists of 200 nodes, randomly dispersed over a three dimensional area of 2000×2000×1000 m^3 and 15 surface nodes over an area of 2000×2000 m^3. CBR (constant bit-rate) traffic sources are used and the packet size is reserved as 512 bytes. 5 packets can be transmitted in a second. The maximum broadcast range of submerged sensor nodes is set to 500 m and the data rate is set to be 15 kb/s. Every data point represents an average of twenty runs with identical traffic models, but different arbitrarily generated mobility scenarios. Dynamic source routing protocol is implemented to cope up with the erroneous behaviour of the environment. Power saving mechanism of IEEE 802.11 is used to minimize energy utilization.

B. Results and analysis

With this simulation we evaluate two important key parameters of data transmission namely end-to-end delay and throughput. (i) End-to-end delay- the time taken for a packet to travel from a source to destination across a network. (ii) Throughput- the average rate of message delivery success over a communication channel. These two parameters are significant enough to analyse the overall efficiency of the network. Comparison of these parameters of the proposed and the existing schemes are given below.

1) End-to-end delay

From Figure 4, we can see that the delay in packet transmission is comparatively less for SPCR. In the beginning the delay seems to be proportional to the packets rate. As the number of packets increases the delay goes down significantly. The buffer management in SPCR puts down the delay in the network.

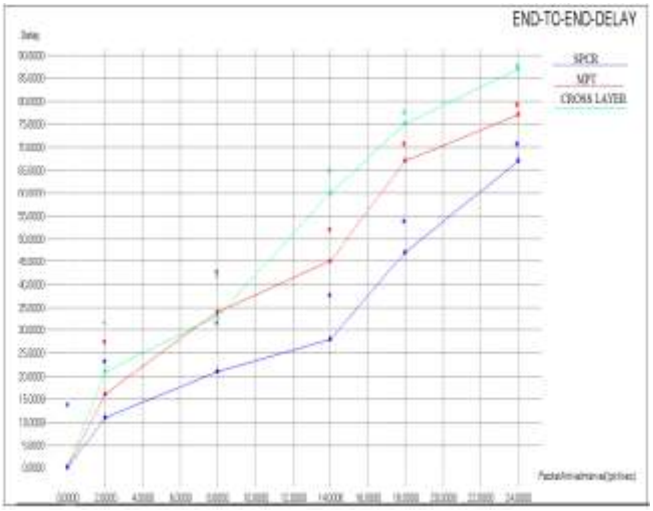

Figure 4. Comparison of End-to-end delay

2) Throughput

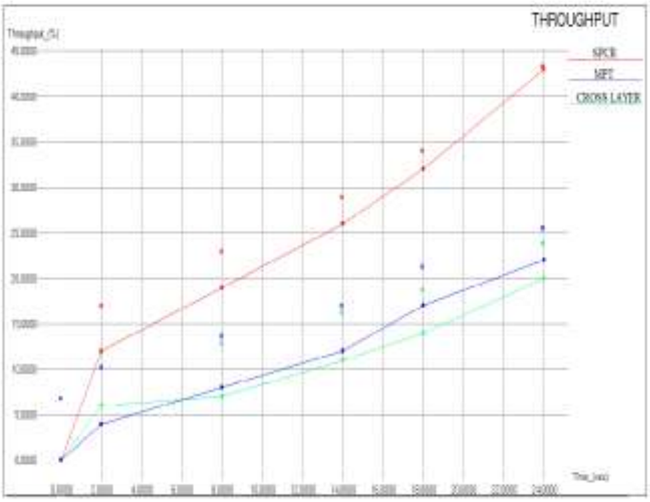

Figure 5. Comparison of Throughput

In the Figure 5, the comparative analysis of network throughput is shown. We can observe that the throughput, i.e. the message delivery success ratio for SPCR increases remarkably as time moves on. The influence of network load and the channel congestion became ignorable and thereby significant increase in throughput is obtained. Hence the proposed scheme for communication of sensor ensures the error free and successful data transmission over a large submerged sensor network.

V. CONCLUSION

In this paper, we analysed nearly all the challenging factors in the design of submerged senor networks. We presented an efficient communication scheme named as SPCR, for the sensor nodes. Integration of a power efficient error rectification (HARQ) and retransmission (RPR) method in the scheme lead us to the conclusions, the high bit error rate is minimized, the available bandwidth has been utilized beneficially and the signal propagation rate has improved with least power utilization. Also the RPR method ensures the successful delivery of sensitive data even in case of frequent network failures. Our future work will be leading to management of fouling and corrosion of sensor nodes in a much more significant way. Finally, the comparative analysis and the results ensure that the proposed scheme has more probability of success than any other communication schemes.

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