Recent Advancements and Future Challenges in Submarine Acoustic System Using Sensor and Resource Innovation Algorithm

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ABSTRACT

The past three decades, we have seen a growing interest in submarine acoustic communications because of its vast applications in marine research, oceanography, marine commercial operations, the offshore oil industry and defense. Continued research over the years has resulted in improved performance and robustness as compared to the initial submarine communication systems. We aim to provide an overview of the key developments in point-to-point communication techniques as well as submarine networking protocols since the beginning of this decade. This paper is divided into two main sections i) submarine communications and ii) Submarine networking. In this paper, we aim to provide an overview of the key developments, both theoretical and applied, in the field in the past two decades. We also hope to provide an insight into some of the open problems and challenges facing researchers in this field in the near future. We also provide an insight into some of the open problems and challenges facing researchers in this field in the near future. i) it is advantageous to obtain spatial gain using the adaptive multichannel combining scheme; and ii) the MP algorithm improves the performance of communications using PPC processing Submarine wireless sensor networks consist of a certain number of sensors and vehicles that interact to collect data and perform collaborative tasks.

Keywords: communication, time, passive-phase conjugation, decision feedback equalizer .

1. INTRODUCTION

A series of review papers provides an excellent history of the development of the field until the end of the last decade (Baggeroer, 1984; Catipovic, 1990; Stojanovic, 1996;Kilfoyle and Baggeroer, 2000). In this paper, we aim to provide an overview of the key developments in the field since the beginning of this decade. We also hope to provide an insight into some of the open problems and challenges facing researchers in this field in the near future. This paper is divided into two main sections—one on submarine communications and another on submarine networking. Section II concentrates on research on point-to-point communication issues such as channel modeling, modulation, coding and equalization. Key advances in these areas have enabled us to establish reliable high speed submarine communication links. Using these links as a foundation, submarine networks can be established. Section III focuses on research on algorithms and protocols for such networks. In this paper, we do not attempt to provide an exhaustive survey of all research in the field, but instead concentrate on ideas and developments that are likely to be the keystone of future submarine communication networks.

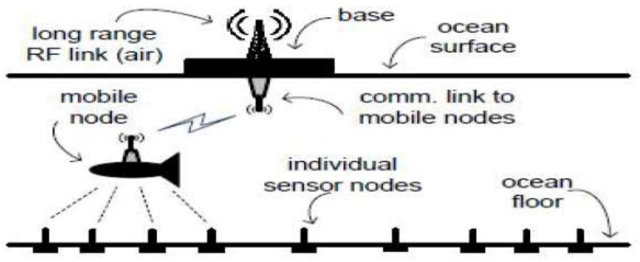

Figure1:A topology for submarine networks point to point link.

UWSN architectures can be classified in various ways. One classification discriminates between static,semi-mobile,andmobile architectures. Another popular UWSN classification method is to divide UWSNs into two-dimensional (cover ocean floor) and three-dimensional (includes depth as a dimension). UWSN can also be single-hop, multi-hop, or hybrid (single-hop individual sensors, multi-hop clusters). Architectures can be grouped into short-term, time-critical applications, and long-term, non-time-critical applications. RF, optical, and acoustic wave based architectures are another way to look at the available UWSNs. i) send commands and configuration data to the sensors. This communication will happening between submarine sink or cluster head to sensors. ii) collect monitored data. This communication will happening between sensors to cluster head or sink. Cluster heads communicate.

2. SUBMARINE COMMUNICATIONS

High-speed communication in the submarine acoustic channel has been challenging because of limited bandwidth, extended multipath, refractive properties of the medium, severe fading, rapid time variation and large Doppler shifts. In the initial years, rapid progress was made in deep water communication, but the shallow water channel was considered difficult. In the past decade, significant advances have been made in shallow water communication.

The shallow water acoustic communication channel exhibits a long delay spread because of numerous multipath arrivals resulting from surface and bottom interactions.Movement of transducers, oceansurface, and internal waves lead to rapid time variation and, consequently, a high Doppler spread in the channel. Coherent modulation schemes such as phase shift keying (PSK) along with adaptive decisionfeedback equalizers (DFE) and spatial diversity combining have been shown to be an effective way of communication in such channels (Stojanovic et al., 1993). However, the long delay spread (often hundreds of symbols) and rapid time variation of the channel often makes this approach computationally too complex for real-time implementations.

A very popular digital modulation scheme, binary phase shift keying (BPSK), shifts the carrier sine wave 180° for each change in binary state. BPSK is coherent as the phase transitions occur at the zero crossing points. The proper demodulation of BPSK requires the signal to be compared to a sine carrier of the same phase. This involves carrier recovery and other complex circuitry.

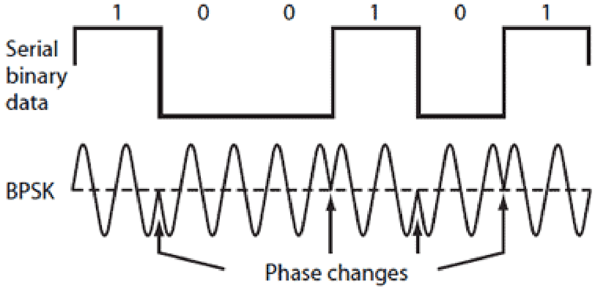

Figure2**:** Binary Phase Shift Keying (BPSK) And Quadrature Phase Shift Keying (QPSK)

3. SUBMARINE SENSOR NETWORK SERVICES

Providing scalable and efficient routing services in submarine sensor networks (UWSNs) is very challenging due to the unique characteristics of UWSNs. Firstly, UWSNs often employ acoustic channels for communications because radio signals do not work well in water. Compared with radio-frequency channels, acoustic channels feature much lower bandwidths and several orders of magnitudes longer propagation delays. Secondly, UWSNs usually have very dynamic topology as sensors move passively with water currents. Some routing protocols have been proposed to address the challenging problem in UWSNs. However, most of them assume that the full-dimensional location information of all sensor nodes in a network is known in prior through a localization process, which is yet another challenging issue to be solved in UWSNs. In this paper, we propose a depth-based routing (DBR) protocol. DBR does not require full-dimensional location information of sensor nodes. Instead, it needs only local depth information, which can be easily obtained with an inexpensive depth sensor that can be equipped in every submarine sensor node. A key advantage of our protocol is that it can handle network dynamics efficiently without the assistance of a localization service. Moreover, our routing protocol can take advantage of a multiple-sink submarine sensor network architecture without introducing extra cost. We conduct extensive simulations. The results show that DBR can achieve very high packet delivery ratios (at least 95%) for dense networks with only small communication cost.

4. PREVIOUS IMPLEMENTATION

Evolution of modulation technique				
Type [kHz]	**Year**	**Rate Range**	**[kbps] km/a**	**Band**
FSK	1984	1.2	5	3s
PSK	1989	500	125	0.06d
FSK	1991	1.25	10	2d
PSK	1993	0.3–0.5	0.3–1	200d–90s
PSK	1994	0.02	20	0.9s
FSK	199 7	0.6–2.4	5	10d–5s
DPSk	1997	20	10	1d
PSK	1998	1.67–6.7	2–10	4d–2s

Figure3:The subscripts d and s stand for deep and shallow water.

5. PROPOSED WORK NETWORK MODEL AND ENERGY CONSUMPTION

We consider that 3D UWSNs are composed of a certain number of sensor nodes uniformly scattered in monitoring fields. We present a generic model for a 3D UWSN that is represented by with sensor nodes. Each sensor node is assigned with a triplet of coordinates . We also assume that all sensor nodes know their own locations through a certain localization service [24]. Such assumption is justified in submarine systems where fixed bottom-mounted nodes have location information upon deployment. In fact, the submarine localization is a nontrivial task for which relatively very few options are available. Many researchers have proposed a variety of localization schemes and techniques to address this issue specially [25, 26]. It is not always feasible to deploy anchor nodes at the sea floor for deep water environment. In this case, mobile beacon nodes such as autonomous submarine vehicles (AUVs), which are equipped with internal navigation systems, are exploited as reference nodes to assist in corresponding distributed localization algorithms. This paper takes advantage of these research results as existing preconditions.

Definition 1. The function defines the distance between two nodes and in a 3D Euclidean space as Submarine wireless sensor nodes are equipped with sensing devices. They collect data from the external environment and transmit these data by one or multihop to the sink node. Sink node is the node that generates data aggregation results and also the target location of the data transmission. Each sensor node can either transmit or receive data packets. All sensor nodes can tune their transmission radius ranged from (minimum transmission radius) to (maximal transmission radius).

Consider two sensor nodes at minimum hop distance , there exist two values and such that the Euclidean distance between the two nodes is bounded; that is, . The quality of the bounds depends on the network density. In particular for each holds where is the minimum transmission range of the sensor nodes. Sensing devices generally have widely different theoretical and physical characteristics. Thus, numerous models of varying complexity can be constructed based on application needs and device features. However, for most kinds of sensors, the sensing ability diminishes as distance increases.

Definition 2. For a sensor , the general sensing model at an arbitrary point is expressed as where is the Euclidean distance between the sensor and the point , and positive constants and are sensor technology-dependent parameters. We assume that all sensor nodes are equipped with limited battery resources without recharging or replacing node batteries after deployment.

The network lifetime is defined as the time until the first sensor node in the network depletes its energy. The energy consumption model is the same as that in where the attenuation and the energy spreading factor (1 is for cylindrical, 1.5 is for practical, and 2 is for spherical spreading) are taken into consideration.

6. ROUTING ALGORITHM

UFCA consists of two phases: candidate discovery phase and relay node selection phase. Figure 2 illustrates the candidate discovery phase. Each frog denotes a sensor node and each number in the frog denotes the residual energy of local sensor node. Sink nodes do not have any energy constraints because they are equipped with both radio-frequency (RF) and acoustic modems and are deployed at the water surface. As for static sink nodes, they only need to broadcast their positions to the whole network one time at the initial stage of the network operation, which would not produce significant energy dissipation [31]. The sensor node that holds the data packet is the transmitter, which is similar to the gravid female frog in Figure 1. Each data packet carries the positions of the source node, the sink node, and the relay node (i.e., the node that transmits this packet). Suppose is a transmitter as shown in Figure 2 then other sensor nodes are receivers before the data packet is forwarded. At first, transmits a courtship packet with radius , which includes the positions of and the sink node . As is the nearest receiver to , it will calculate the cosine of the angle between the direction from to and the direction from to (denoted by in Figure 2) upon receipt of 's courtship packet. If the cosine value is not below zero, will transmit an advertisement packet with radius , which is calculated as

where denotes the residual energy of sensor node and denotes the maximum energy of sensor node . Thus, ranges from to . In the best case, the residual energy of is full and and equals according to formula (10), which is enough to cover 's transmission circle. In the worst case, the residual energy of is almost exhausted; it will only transmit an advertisement packet with radius in order to reach the position of . Moreover, 's position and residual energy information is included in its advertisement packet. After receives 's courtship packet and 's advertisement packet, it extracts the position and the residual energy information from these packets. As 's residual energy is less than that of 's, it chooses to enter sleep mode in order to save energy without transmitting any advertisement packet. Another receiver can also receive 's courtship packet and 's advertisement packet. But will choose to enter sleep mode because the cosine of the angle between the direction from to and the direction from to is below zero. In other words, locates in a worse place compared with other receivers. Although the receiver locates within the transmission radius of 's advertisement packet, it still keeps sleep mode since cannot receive 's courtship packet.

After receives 's courtship packet and 's advertisement packet, it extracts the position and the residual energy information from these packets. As 's residual energy is more than that of 's and the cosine of the angle between the direction from to and the direction from to is not below zero, it concludes that the probability of winning the competition is high.

Therefore, will transmit an advertisement packet with radius , which includes the information of its location and residual energy. At last, will add and to its candidate set after the receipt of their advertisement packets.

The sensor node that goes to sleep mode will wake up immediately after another sensor node broadcasts a courtship packet and the sleep sensor node locates exactly within its transmission range.

7. CANDIDATE DISCOVERY PHASE

The process of selecting a candidate as the relay node to forward the data packet is illustrated in Figure 3. After the transmitter 's candidate set is constructed, it will select the most attractive candidate as the relay node according to a certain standard, which is described as the gravity function in this paper.

8. RELAY NODE SELECTION PHASE

Given a sensor node and its neighbor node , the gravity function from to is defined as and its value is calculated as where and denote the residual energy of sensor nodes and , is the intersection angle between the direction from to and the direction from to the sink node , and is the Euclidean distance from to .At last, the transmitter computes the gravity values with every sensor node in its candidate set and chooses the candidate with maximal gravity value to be the relay node that is in charge of forwarding the data packet. describes the process of building the routing path with ultrasonic frog calling algorithm in detail. Building the routing path with UFCA.

All data packets at relay nodes should have limited lifetime, which are controlled by TTL (time-to-live) information carried in the packet header. At first, the routing path is created as an empty queue structure after initialization as described in line 1. While TTL value is bigger than zero and the sink node is not reached, the process of building the routing path is repeatedly executed. And then, the source node resets its candidate set and transmits a courtship packet with the minimum transmission radius in order to find some candidates as described from line 3 to line 4. After that, all sensor nodes that locate within the covering space of ’s transmission radius will check their positions. Suppose is the first receiver with . If the cosine of the angle between the direction from to and the direction from to is below zero, then chooses to enter sleep mode for saving energy. Otherwise, adds to its candidate set and transmits an advertisement packet with radius according to formula . And then, all sensor nodes that locate within the covering space of ’s transmission radius will compare their residual energy with that of ’s. Suppose is a sensor node that receives ’s courtship packet and ’s advertisement packet. If ’s residual energy is less than that of ’s, it will choose to enter sleep mode without competing with . Otherwise, will add to its candidate set. The operation is iterated until all candidates are discovered as described from line 5 to line 17. During the phase of relay node selection, calculates the gravity In many proactive routing protocols, the active sensor nodes must send periodic update packets to other nodes even when the routing information is similar to the previous one. Moreover, the storage overhead for routing table maintenance also grows quickly as the size of the network increases. Although some reactive routing protocols can avoid the overhead incurred by routing table maintenance, the periodic flooding messages for the routing path discovery is another deadly cost in resource-constraint submarine wireless sensor networks. In UFCA, the update of candidate set is evoked only when this sensor node is selected as a transmitter. After that, it can determine where to forward a data packet without the need of routing table maintenance or any flooding mechanism

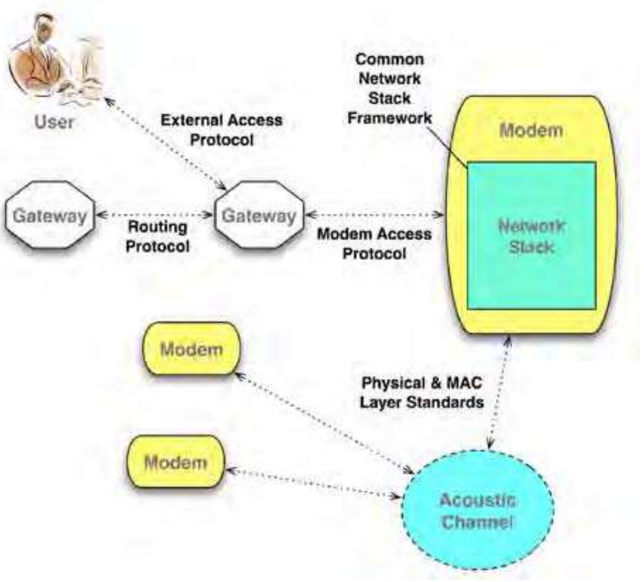

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Figure4: submarine communication

9. PERFORMANCE OF EVALUATION SIMULATION SETTINGS

We use Aqua-Sim as simulation framework to evaluate our approach. Aqua-Sim is an -2 based submarine sensor network simulator developed by submarine sensor network lab at University of Connecticut. To simulate acoustic channels, we extend Aqua-Sim with spherical path loss and Thorp attenuation. We use a 3D region with size 1000m × 1000m × 1000m and different number of sensor nodes varied from 100 to 600. Six sink nodes are randomly deployed at the water surface, which are assumed stationary in all simulations. The sensor nodes follow the random-walk mobility pattern. Each sensor node randomly selects a direction and moves to the new position with a random speed between the minimal speed and maximal speed, which are 0m/s and 4m/s, respectively. The data generating rate varies from one packet per second to 6 packets per second with a packet size of 50 bytes (i.e., from 400bps to 2.4kbps). The communication parameters are similar to those on a commercial acoustic modem and the bit rate is 10kbps. TTL (time-to-live) value is set to 30 hops for each data packet. Each result is obtained from the average run of 40 times.

As the long propagation delay and limited bandwidth of acoustic channels make the existing MAC protocols widely used in radio networks unpractical for UWSNs, this paper adopts R-MAC protocol as the underlying MAC protocol in order to avoid data packet collision. R-MAC schedules the transmission of control packets and data packets at both the sender and the receiver to avoid data packet collisions. Therefore, we do not distinguish courtship packet and advertisement packet from each other in MAC layer. In fact, we only need to make certain that which node is the sender and which node is the receiver in this session.

We use the following metrics to evaluate the performance of different routing protocols.(1)Packet delivery ratio is defined as the ratio of the number of distinct data packets received successfully at the sinks to the total number of data packets generated at the source node.(2)Energy consumption takes into account the total energy consumed in packet delivery, including transmitting, receiving, and idling energy consumption of all nodes in the network.(3)Throughput equals the total data bits received at the sink nodes divided by the simulation time.(4)Average end-to-end delay represents the average time taken by a data packet that travels from a source node to any sink node.

We compared the performance of ultrasonic frog calling algorithm (UFCA) with that of vector-based forwarding (VBF) and ERP2R (energy-efficient routing protocol based on physical distance and residual energy). In the simulations of UFCA, the minimal and maximal transmission range is set to 50 meters and 100 meters, respectively, in all directions, while the transmission range in VBF and ERP2R is fixed at 100 meters. Moreover, the routing pipe radius in VBF is set to 20 meters, which is a default value in.

10. SIMULATION RESULTS

In the first set of simulations, we compared the packet delivery ratio with the number of nodes in different routing protocols. The average speed of nodes is set to 2m/s. As shown in Figure 4, the packet delivery ratio of three routing protocols is proportional to the number of nodes. UFCA performs best among the three routing protocols in the same circumstances and VBF achieves higher packet delivery ratio than that of ERP2R.

Moreover, the curve of VBF rises faster than other protocols. This is because, with the growth of network density, more sensor nodes will fall in the routing pipe of VBF with fixed radius as the transmission range.

The packet delivery ration of UFCA is significantly improved over other protocols especially when the network is sparse as UFCA can find more routing paths for data delivery in sparse networks. Specifically, UFCA improves 34.3% of the packet delivery ratio than that of ERP2R and 11.9% of the packet delivery ratio than that of VBF on average.

11. PACKET DELIVERY RATIO VERSUS NUMBER OF NODES

The comparison of the packet delivery ratio with average speed of nodes in different routing protocols. The number of sensor nodes is set to 400 for each protocol. Overall, the packet delivery ratio of three routing protocols is inversely proportional to average speed of nodes. UFCA achieves higher packet delivery ratio than that of ERP2R and VBF when their speeds of nodes are the same. The packet delivery ratio of ERP2R decreases rapidly with the growth of node mobility. This is because the rate of updating routing information in ERP2R cannot catch up with the increase of node mobility. Specifically, UFCA improves 32.5% of the packet delivery ratio than that of ERP2R and 6.4% of the packet delivery ratio than that of VBF on average.Packet delivery ratio versus average speed of nodes.

In the second set of simulations, we compared the energy consumption with the number of nodes in different routing protocols. The average speed of nodes is set to 2 m/s. As shown in Figure 6, the energy consumption of three routing protocols is proportional to the number of nodes. UFCA performs better than other routing protocols in the same circumstances.

Moreover, the curve of UFCA has a gentler slope compared with that of ERP2R and VBF. This is mainly due to more sensor nodes entering the sleep mode with the increase in sensor nodes in UFCA. ERP2R consumes less energy than VBF because energy factor is not given in the routing determination of VBF.

As a result, UFCA decreases 26.1% of the energy consumption than ERP2R and 41.5% of the energy consumption than VBF on average.

12.ENERGY CONSUMPTION VERSUS NUMBER OF NODES

The comparison of the energy consumption with average speed of nodes in different routing protocols. The number of nodes is set to 400 for each protocol. The energy consumption of three routing protocols is proportional to the TTL value. UFCA consumes less energy than ERP2R and VBF when their speeds of nodes are the same. Moreover, the curve slopes of UFCA and VBF are rather gentle compared with that of ERP2R, which means that the factor of node mobility has slight influence on energy consumption of UFCA and VBF. ERP2R consumes less energy than VBF except when average speed of nodes reaches 4 m/s. On average, UFCA decreases 25.7% of the energy consumption than ERP2R and 36.2% of the energy consumption than VBF.

13. ENERGY CONSUMPTION VERSUS AVERAGE SPEED OF NODES

In the third set of simulations, we compared the throughput with the number of nodes in different routing protocols. The average speed of nodes is set to 2 m/s for each protocol. As shown in Figure 8, the throughput of three routing protocols is proportional to the number of nodes. The front parts of curves indicate rapid increases in throughput while the rear parts of curves show slow growth rates after the number of nodes has reached high value. The reason is that with the growth of network density, the routing paths become more crowded and downstream nodes cannot receive data packets from several of its upstream nodes simultaneously. Overall, UFCA performs better than other routing protocols in the same circumstances.

VBF achieves higher throughput than ERP2R. On average, UFCA improves 21.5% of the throughput than ERP2R and 9.3% of the throughput than VBF.

UFCA achieves higher throughput than that of ERP2R and VBF when their average speeds of nodes are the same. Noticeably, the throughput of ERP2R decreases sharply when average speed of nodes is more than 2m/s. This is because more routing cost and residual energy of the nodes as well as their neighbors along routing paths have to be recalculated with the increase in average speed of nodes in ERP2R. On average, UFCA improves 15.4% of the throughput than ERP2R and 6.5% of the throughput than VBF. Throughput versus average speed of nodes.In the last set of simulations, we compared the average end-to-end delay with the number of nodes in different routing protocols. The average speed of nodes is set to 2m/s for each protocol. As shown in Figure 10, the average end-to-end delay of three routing protocols is inversely proportional to the number of nodes. UFCA achieves less end-to-end delay than ERP2R and VBF when the number of nodes is the same. The reason is that UFCA introduces less control packets than other protocols for communicating with the related sensor nodes during the process of routing. The cost for the computation of residual energy and gravity values in UFCA is far less than that in network communication. ERP2R performs better than VBF because the highest priority node in ERP2R has a holding time of zero, which can reduce the end-to-end delay to a certain degree. On average, UFCA decreases 11.2% of the average end-to-end delay than ERP2R and 31.2% of the average end-to-end delay than VBF. Average end-to-end delay versus number of nodes. the comparison of the average end-to-end delay with the average speed of nodes in different routing protocols. The number of nodes is set to 400 for each protocol. Overall, the average end-to-end delay of three routing protocols is inversely proportional to the average speed of nodes. UFCA achieves less end-to-end delay than ERP2R and VBF when their average speeds of nodes are the same. It is worth noting that ERP2R owns a curve with rapid increasing trend. This is because more sensor nodes in ERP2R need to reevaluate their distances to the sink node with the growth of node mobility. Specifically, UFCA decreases 8.1% of the average end-to-end delay than ERP2R and 26.3% of the average end-to-end delay than VBF on average.

14. AVERAGE END-TO-END DELAY VERSUS SPEED OF NODE

Compared to algorithms such as VBF and ERP2R, UFCA is totally a different approach. In VBF, only the sensor nodes located in a predefined routing pipe are eligible for packet forwarding, and those which are not close to the routing pipe do not forward the packets no matter whether they are suitable for building a shorter routing path. Therefore, the routing performance in VBF mainly depends on the node density and it cannot benefit from the deployment of multiple sink nodes if they are not close to each other. In ERP2R, forwarding nodes are selected based on the physical distance of the sensor nodes. Each sender selects the nodes nearer to the sink node for routing decision, which is not always helpful when the node density is sparse. Although ERP2R can balance the energy consumption using a residual energy-based timer, its performance decreases dramatically with the growth of node mobility. UFCA is inspired by the calling behavior of concave-eared torrent frog. In UFCA, the process of finding an optimal routing path is similar to the process of mating with an appropriate frog with characteristics of accurate and energy-efficient. Consequently, UFCA achieves better routing performance than VBF and ERP2R regardless of node density and mobility. Moreover, different sensor nodes adopt different transmission radius according to their residual energy in UFCA and the sensor nodes that own less energy or locate in worse places choose to enter sleep mode for the purpose of saving energy. Through these means, the energy consumption is somehow equalized on the whole and the network lifetime is prolonged. Thus, the inherent adaptive nature of such algorithm is one of the main attractions in biologically inspired approaches.

The transmission loss TL can be defined as the accumulated decrease in acoustic intensity as an acoustic pressure wave propagates outwards from a source. The transmission loss for cylindrically spread signals is calculated as

15. RESOURCE INNOVATION ALGORITHM

```
input: source node , sink node , TTL;
Output: routing path p;
Queue p<-¢;; //routing path initialization
while (TTL > 0) and ($s1 \neq s2$ ) do
    si.CandiSet<-¢ ;
    transmits a courtship packet with radius ;
    for all $s_j$ with < $s_k$ do
        if cos (<TIJ ) < 0 then
            $s_J$.sleep();
        else $s_i$.CandiSet.add($s_j$ );
    $s_j$ transmits an advertisement packet with radius $r_j$
            according to formula (10);
            for all $s_k$ with $\alpha(j,k) < r_j$ do
                if ($£^{yes}_{k} < £^{yes}_{j}$ ) then
                    $s_k$ .sleep();
                else si .CandiSet.add( );
                endif
            endfor
        endif
    endfor
    if$|G_{ij}|$=MAX$|G_{ik}|${($s_k £ s_i$ .CandiSet) then
        p.enqueue( $s_j$);
    $s_i$<-$s_j$ ;
        TTL—;
    endif
endwhile
if $s_i \neq s_t$ then
    p.clear(0);
    return ¢;
else return p;
endif
```

16. FUTURE CHALLENGES

Applications drive the development of submarine sensing and networking. Inexpensive computing, sensing and communications have enabled terrestrial sensor networking in the past couple of decades; we expect that cheap computing, combined with lower cost advanced acoustic technology, communication and sensing, will enable submarine sensing applications as well.

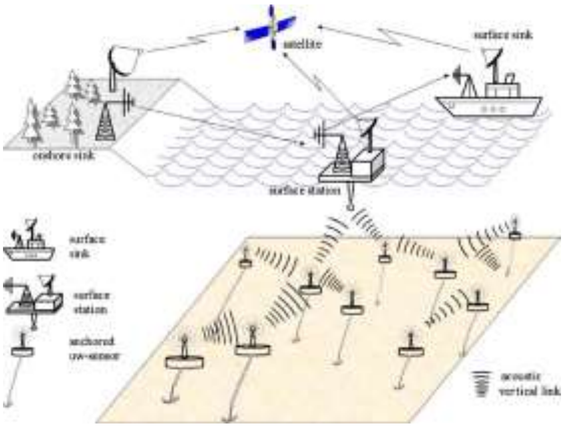

Figure 5:Average end-to-end delay versus speed of node

While research on submarine sensor networks has significantly advanced in recent years, it is clear that a number of challenges still remain to be solved. With the flurry of new approaches to communication, medium access, networking and applications, effective analysis, integration and testing of these ideas is paramount—the field must develop fundamental insights, as well as understand what stands up in practice. For these reasons, we believe that the development of new theoretical models (both analytical and computational) is very much needed, and that greater use of testbeds and field experiments is essential; such work will support more accurate performance analysis and system characterization, which will feed into the next generation of submarine communications and sensing. In addition, integration and testing of current ideas will stress the seams that are often hidden in more focused laboratory research, such as total system cost, energy requirements and overall robustness in different conditions.

In addition, we are encouraged by a broadening of the field to consider different options, spanning from high-performance (and cost) to low-cost (but lower performance), and including mobile (human-supported or autonomous), deployable and stationary configurations.

17. CONCLUSION

Finding an optimal routing path in adverse submarine environment in 3D UWSNs has always been a challenging task, especially when the factor of energy consumption is taken into consideration. Inspired by the calling behavior of ultrasonic frog in mating, this paper proposed an ultrasonic frog calling algorithm (UFCA) that aims to achieve energy-efficient routing under harsh submarine conditions of UWSNs. UFCA does not require fixed routing tables or periodic flooding messages for the discovery of routing path. In UFCA, different sensor nodes adopt different transmission radius, which can be tuned dynamically according to their residual energy. Moreover, the sensor nodes that own less energy or locate in worse places choose to enter sleep mode for the purpose of saving energy. Simulation results show the performance improvement in metrics of packet delivery ratio, energy consumption, throughput, and end-to-end delay as compared to existing state-of-the-art routing protocols.

Acoustic signal has different transmission modes in shallow water (where the depth of the water is lower than 100 meters) and deep water (where the depth of the water is above 100 meters). In shallow water, the transmission of the acoustic signal is limited to a cylindrical area from bottom to the surface, while in deep water, the transmission of the acoustic signal is mainly with spherical diffusion and the energy consumption is caused by spherical diffusion and water absorption. This paper concentrates on the shallow water scenario.

The passive sonar equation [29] characterizes the signal-to-noise ratio (SNR) of an emitted submarine signal at the receiver, which is presented by

where SL is the target source level or noise generated by the target, TL is the transmission loss, NL is the noise level, and DI is the directivity index (a function of the receiver's directional sensitivity).

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BIOGRAPHIES

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