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Modelling Underwater Wireless Sensor Networks

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1. Introduction

The study of Underwater Wireless Networks as a research field has grown significantly in recent years offering a multitude of proposal to resolve the communication between the nodes and protocols for information exchange networks. Acoustics has been used by nature for years to communicate in the underwater environment using it as a language, dolphins and whales for instance are able to use it to send information between their groups. The first reference to the underwater sound propagation can be found in what Leonardo Da Vinci wrote in 1490: "If you cause your ship to stop and place the head of a long tube in the water and place the outer extremity to your ear, you will hear ships at a great distance from you".

Years later in 1826 the first scientific studies were done by picking real data measures (Colladon, 1893). The physicist Jean-Daniel Colladon, and his partner Charles-Francois Sturm a mathematic, made the first recorded attempt at Lake Geneva, Switzerland, to find out the speed of sound in water. After experimenting with an underwater bell with ignition of gunpowder on a first boat, the sound of the bell and flash from the gunpowder were observed 10 miles away on a second boat. With this collection of data of the time between the gunpowder flash and the reception of the sound reaching to the second boat they were able to establish a pretty accurate value for the speed of the sound in water, tested with this empirical method.

In the early XX century in 1906, the first sonar type was developed for military purpose by Lewis Nixon; there was a great interest in this technology during World War I so as to be able to detect submarines. It was in 1915, when the "echo location to detect submarines" was released by physicist Paul Langévin and the engineer Constantine Chilowski, device capable for detecting submarines using the piezoelectric properties of the quartz. It was not useful for the war as it arrived too late, but it established the roots of the upcoming design for sonar devices.

The first targets in which the developing of underwater sound technology was involved were to determine the distance to the shore or to other ships. After experimenting it was quickly discovered by researchers that pointing the sound device down towards the

seafloor, the depth could also be collected with enough precision. Then, by picking a lot of values it was used for new purposes like measuring the relief of the ocean (bathymetry), seafloor shape registering, search for geological resources (i.e. oil, gas, etc.), detecting and tracking fish banks, submarine archaeology, etc.

These were the main underwater acoustic application mainly use for the exploration of seafloor and fishery with sonar devices. In the 90's the researchers became aware of a new feature applicable to underwater communications, multipoint connections could be capable of translating the networked communication technology to the underwater environment. One of the former deployments was the Autonomous Oceanographic Surveillance Network (AOSN), supported by the US Office of Naval Research (ONR) (Curtin et al, 1993). It calls for a system of moorings, surface buoys, underwater sensor nodes and Autonomous Underwater Vehicles (AUVs) to coordinate their sampling via an acoustic telemetry network.

Wireless terrestrial networking technologies have experienced a considerably development in the last fifteen years, not only in the standardization areas but also in the market deployment of a bunch of devices, services and applications. Among all these wireless products, wireless sensor networks are exhibiting an incredible boom, being one of the technological areas with greater scientific and industrial development step (Akyildiz et al, 2002).

The interest and opportunity in working on wireless sensor network technologies is endorsed by (a) technological indicators like the ones published by MIT (Massachusetts Institute of Technology) in 2003 (Werff, 2003) where wireless sensor network technology was defined as one of the 10 technologies that will change the world, and (b) economic and market forecasts published by different economic magazines like (Rosenbush et al, 2004), where investment in Wireless Sensor Network (WSN) ZigBee technology was estimated over 3.500 Million dollars during 2007.

Recently, wireless sensor networks have been proposed for their deployment in underwater environments where many of applications such us aquiculture, pollution monitoring, offshore exploration, etc. would benefit from this technology (Cui et al, 2006). Despite having a very similar functionality, Underwater Wireless Sensor Networks (UWSNs) exhibit several architectural differences with respect to the terrestrial ones, which are mainly due to the transmission medium characteristics (sea water) and the signal employed to transmit data (acoustic ultrasound signals) (Akyildiz et al, 2006).

Then, the design of appropriate network architecture for UWSNs is seriously hardened by the conditions of the communication system and, as a consequence, what is valid for terrestrial WSNs is perhaps not valid for UWSNs. So, a general review of the overall network architecture is required in order to supply an appropriate network service for the demanding applications in such an unfriendly submarine communication environment.

Major challenges in the design of underwater acoustic networks (Llor & Malumbres 2009) are:

- Battery power is limited and usually batteries cannot be recharged because solar energy cannot be exploited;
- The available bandwidth is severely limited;
- The channel suffers from long and variable propagation delays, multi-path and fading problems;
- Bit error rates are typically very high;
- Underwater sensors are prone to frequent failures because of fouling, corrosion, etc.

This chapter will give an overview of underwater wireless networks going-through all the layers with emphasis on the physical layer and how it behaves in different and changing environment conditions. Besides a brief outline of the most outstanding MAC layer protocols as the ones of the routing layer algorithms will be presented. Also the main application are presented and finally the conclusions.

In the next section, we briefly describe the main issues in the design of efficient underwater wireless sensor networks. Following a bottom-to-top approach, we will review the network architecture, highlighting some critical design parameters at each of the different network layers, and overcoming the limitations and problems introduced by UWSN environments.

2. Topology

In (Partan et al, 2006), taxonomy of UWSN regimes is outlined. They classify different UWSNs in terms of both spatial coverage and node density. For every kind of network topology, different architectural approaches have to be considered in order to improve the network performance (throughput, delay, power consumption, packet loss, etc.). So, it is important to design the network architecture taking into account the intended network topology.

3. Physical Layer: Acoustic Link

The most common way to send data in underwater environments is by means of acoustic signals, dolphins and whales use it to communicate. Radio frequency signals have serious problems to propagate in sea water, being operative for radio-frequency only at very short ranges (up to 10 meters) and with low-bandwidth modems (terms of Kbps). When using optical signals the light is strongly scattered and absorbed underwater, so only in very clear water conditions (often very deep) does the range go up to 100 meters with high bandwidth modems (several Mbps).

The theory of the sound propagation is according to the description by Urick (Urick & Robert, 1983), a regular molecular movement in an elastic substance that propagates to adjacent particles. A sound wave can be considered as the mechanical energy that is transmitted by the source from particle to particle, being propagated through the ocean at the sound speed. The propagation of such waves will refract upwards or downwards in agreement with the changes in salinity, temperature and the pressure that have a great impact on the sound speed, ranging from 1450 to 1540 m/s.
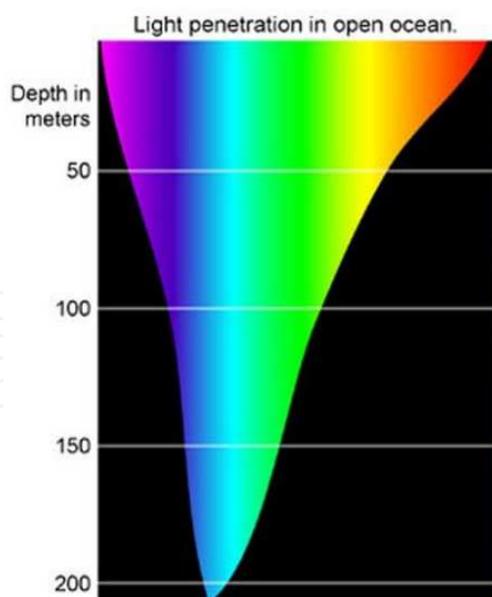
Fig. 1. This diagram offers a basic illustration of the depth at which different colors of light penetrate ocean waters. Water absorbs warm colors like reds and oranges and scatters the cooler colors
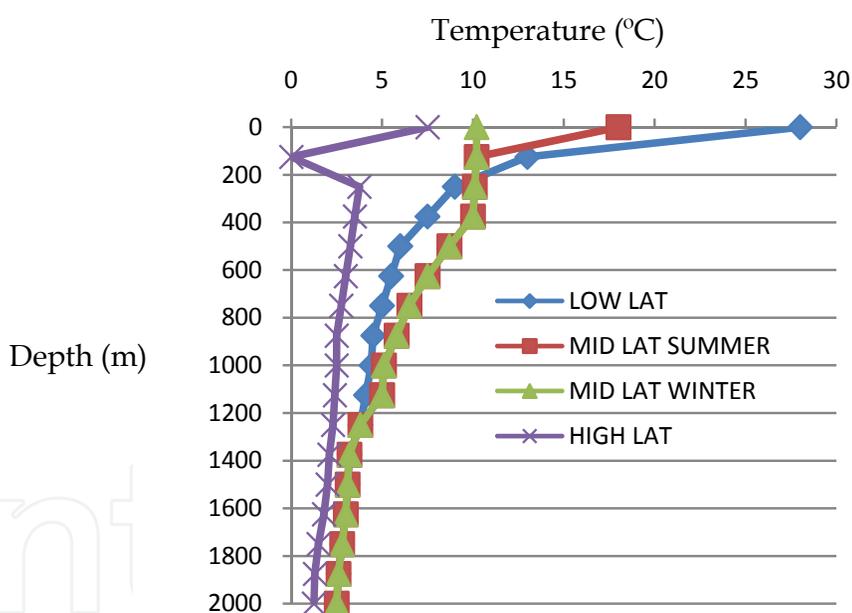

Fig. 2. Temperature variation depending on latitude and season

Depth (m)	Salinity (ppm)
0	37.45
50	36.02
100	35.34
500	35.11
1000	34.90
1500	34.05

Table 1. Salinity depending on the depth

The transmission loss (TL) is defined as the decrease of the sound intensity through the path from the sender to the receiver. There have been developed diverse empirical expressions to measure the transmission loss. Thorp formula (Urick & Robert, 1983) defines the signal transmission loss as:

$$\propto = \frac{0.11\,f^2}{1+f^2} + \frac{44\,f^2}{4100+f^2}\,[db/Km]$$

$$SS = 20\log r$$

$$TL = SS + \propto x\ 10^{-3}$$

(1)

where f is frequency in kHz, r is the range in meters; SS is the spherical spreading factor and α is the attenuation factor. Then a more accurate expression for the attenuation factor was presented, the one proposed in the Thorp formula in (Berkhovskikh & Laysanov, 1982):

$$\propto = \frac{0.11\,f^2}{1+f^2} + \frac{44\,f^2}{4100+f^2} + 2.75\ x\ 10^{-4}f^2 + 0.003$$

(2)

Since acoustic signals are mainly used in UWSNs, it is necessary to take into account the main aspects involved in the propagation of acoustic signals in underwater environments, including: (1) the propagation speed of sound underwater is around 1500 m/s (5 orders of magnitude slower than the speed of light), and so the communication links will suffer from large and variable propagation delays and relatively large motion-induced Doppler effects; (2) phase and magnitude fluctuations lead to higher bit error rates compared with radio channels' behaviour, this makes necessary the use of forward error correction codes (FEC); (3) as frequency increases, the attenuation observed in the acoustic channel also increases, which is a serious bandwidth constraint; (4) multipath interference in underwater acoustic communications is severe due mainly to the surface waves or vessel activity, that are an important issue to attain good bandwidth efficiency.

Several works in the literature propose models for an acoustic underwater link, taking into account environment parameters as salinity degree, temperature, depth, environmental interference, etc. Other physical aspects of the ocean as noise in the medium (Coates, 1989), the wind, thermal noise, the turbulence and the ship noise are included by these formulas, depending on the frequency and this factors:

$$10\log N_t(f) = 17 - 30\log f$$
$$10\log N_s(f) = 40 + 20\,(s-0.5) + 26\log f$$
$$10\log N_w(f) = 50 + 7.5\,w^{\frac{1}{2}} + 20\log f - 40\log(f+0.4)$$
$$10\log N_{th}(f) = -15 + 20\log f$$

(3)

where N_t is the noise due to turbulence, N_s is the noise due to shipping, N_w is the noise due to wind, and N_{th} represents the thermal noise. The overall noise power spectral density for a given frequency f is then:

$$N\ (f) = N_t(f) + N_s(f) + N_w(f) + N_{th}(f) \tag{4}$$

In (Xie & Gibson, 2006) the authors present the Monterey-Miami Parabolic Equation to describe the behavior of the propagation of the sound. In (Porter & Liu 2010) Bellhop, a ray tracing tool shows how the physical environment conditions and terrain shapes have a great impact in the sound attenuation.

3.1 MMPE

Monterey-Miami Parabolic Equation (MMPE) model is used to predict underwater acoustic propagation using a parabolic equation which is closer to the Helmholzt equation (wave equation), this equation is based on Fourier analysis. The sound pressure is calculated in small increments changes in range and depth, forming a grid. If we increase the step size, we can obtain better performance. The propagation loss formula based on the MMPE model:

$$PL(t) = m(f, s, d_A, d_B) + w(t) + e() \tag{5}$$

where:
PL(t): propagation loss while transmitting from node A to node B.
m(): propagation loss without random and periodic components; obtained from regression using MMPE data.
f: frequency of transmitted acoustic signals (in kHz).
d_A: sender's depth (in meters).
d_B: receiver's depth (in meters).
r: horizontal distance between A and B nodes, called range in MMPE model (in meters).
s: Euclidean distance between A and B nodes (in meters).
w(t): periodic function to approximate signal loss due to wave movement.
e(): signal loss due to random noise or error.

The *m()* function represents the propagation loss provided by the MMPE model. According to the logarithmic nature of the data, a nonlinear regression is the best option to provide an approach to the model based on the coefficients supplied by the preliminary model. The proposed expression to calculate this function is the following one:

$$m(f, s, d_A, d_B) = \log\left(\left|\frac{\left(\frac{s}{0.914}\right)^{A0}(d_A)^{A9}s^{A7}((d_A - d_b)^2)^{A10}}{(s * d_B)^{10\,A5}}\right|\right) +$$

$$\left(f^2\left(\frac{A1}{1+f^2} + \frac{40}{4100+f^2} + 0.00275\right) + 0.003\right) * \left(\frac{s}{914}\right) + A6 * d_B + A8 * s \tag{6}$$

The *w()* function considers the movement of a particle that will oscillate around its location in a sinusoidal way. That movement is represented as circular oscillations that reduce their radius as the depth of the particle increases. The length of that radius is dependent of the

energy of the wave and is related to the height of the wave. The common waves have hundreds of meters of wavelength and have an effect up to 50 meters of depth

For the calculation of the effects of the wave we will consider:

$$w(t) = h\left(l_w, d_B t, h_w, T_w\right) E(t, T_w) \tag{7}$$

where
w(t): periodic function to approximate the lost signal by the wave movement.
h(): scale factor function.
l_W: ocean wave length (meters).
d_B: depth of the receiver node.
h_W: wave height (meters).
T_W: wave period (seconds).
E(): function of wave effects in nodes.

This function contains the elements that are resembled the node movement, first calculating the scale factor h() and then the wave effect in a particular phase of the movement. The calculation of the scale factor is as follows:

$$h\left(l_w, d_B, t, h_w, T_w\right) = \frac{\left(h_w\left(1 - \left(\frac{2d_B}{l_w}\right)\right)\right)}{0.5} * \left|\sin\left(\frac{2\pi(\text{mod } T_w)}{T_w}\right)\right| \tag{8}$$

The *e()* function represents a random term to explain background noise. As the number of sound sources is large and undetermined, this random noise follows a Gaussian distribution and is modeled to have a maximum of 20dB at the furthest distance. This function is calculated by the following equation:

$$e() = 20\left(\frac{s}{s_{max}}\right) R_N \tag{9}$$

where:

e(): random noise function
s: distance between the sender and receiver (in meters).
s_{max}: maximum distance (transmission range)
h_w: height of the wave (in meters).
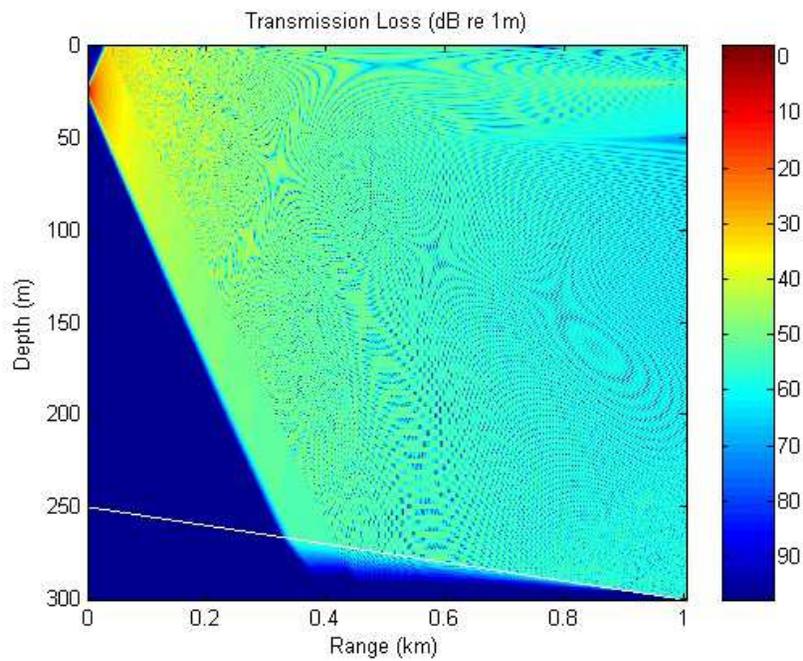R_N: random number, Gaussian distribution centered in 0 and with variance 1.

Fig. 3. MMPE Transmission Loss (db)

3.2 Bellhop

Ray tracing requires the solution of the ray equations to determine the ray coordinates. Amplitude and acoustic pressure requires the solution of the dynamic ray equations. For a system with cylindrical symmetry the ray equations can be written:

$$\frac{dr}{ds} = c\xi(s) \quad , \qquad \frac{d\xi}{ds} = -\frac{1}{c^2}\frac{\vartheta c}{\vartheta r} \tag{10}$$

where $r(s)$ and $z(s)$ represent the ray coordinates in cylindrical coordinates and s is the arclenght along the ray; the pair $c(s)$ $[$ ξ $(s),\zeta(s)]$ represents the tangent versor along the ray. Initial conditions for and $r(s)$, and $z(s)$, $\xi(s)$ and $\zeta(s)$ are

$$r(0) = r_s \quad , \qquad z(0) = z_s \quad , \qquad \xi(0) = \frac{\cos\theta_s}{c_s} \quad , \qquad \zeta(0) = \frac{\sin\theta_s}{c_s} \tag{11}$$
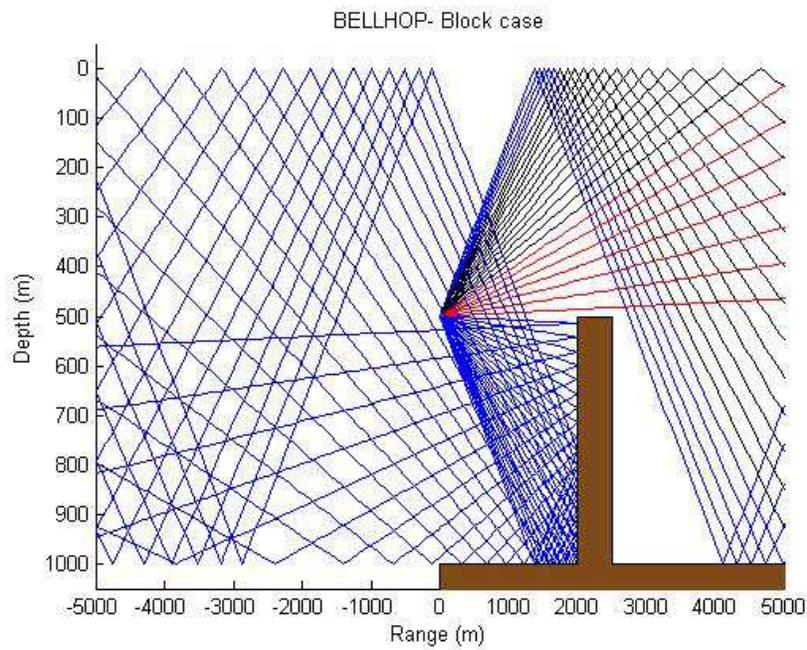
Fig. 4. Bellhop ray trace

where θ_s represents the launching angle, (r_s , z_s) is the source position, and c_s is the sound speed at the source position. The coordinates are sufficient to obtain the ray travel time:

$$\tau = \int_{\Gamma} \frac{ds}{c(s)} \tag{12}$$
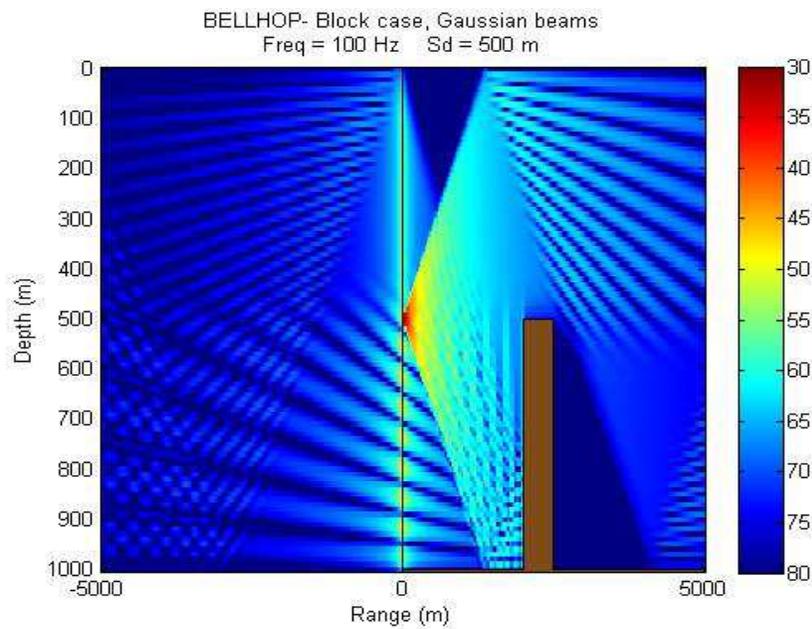
which is calculated along the curve, $[r , z_s]$.

Fig. 5. Bellhop pressure

4. Mac Layer

The main task of MAC protocols is to provide efficient and reliable access to the shared physical medium in terms of throughput, delay, error rates and energy consumption. However, due to the different nature of the underwater environment, there are several drawbacks with respect to the suitability of the existing terrestrial MAC solutions for the underwater environment. In fact, channel access control in UWSNs poses additional challenges due to the aforementioned peculiarities of underwater channels (Molins and Stojanovic, 2006).

In the MAC Layer we have different types of protocols and ones of the latest examples presented in each one of the categories. The first ones are the non handshaking protocol such as Aloha-like, an on the opposite side we have the handshaking protocols like DACAP (Distance Aware Collision Avoidance Protocol) a collision avoidance protocol based on virtual Medium Access Control carrier sensing. A number of adaptations have been proposed to adopt MACA (Multiple Access with Collision Avoidanc) (Karn, 1990), MACAW (Media Access Protocol for Wireless LAN's) (Bharghavan et al, 1994), and FAMA (Floor Acquisition Multiple Access) (Fullmer & Luna-Acebes, 1995) for underwater networks in (Molins & Stojanovic, 2006). But also new protocols such as T-Lohi (between handshake and non-handshake) are becoming more popular as they have also a great efficiency in terms of the battery use.

4.1 Aloha-like

In Aloha like mode the source node sends its data frames as soon as it receives a packet from the upper-layer protocol. It does not check the medium to see if it is busy and so it does not perform any back-off, it. The node that receives the data will answer with and acknowledge data frame, if there was no problem at the reception such as a collision or packet lost during the transmission (i.e. when there is overlapping of the receiving periods of two or more frames at the destination location, or the receiver was transmitting).

If the source, does not receive an ACK because either the frame was not correctly delivered or the ACK was lost, the sender will timeout, wait a random period (back-off) and retransmit the frame. This protocol follows the stop-and-wait paradigm. That is, the source must receive an acknowledgement for each data frame before the next frame can be sent. In addition, after a successful frame transmission, the sender will perform a back off, even if it has additional frames to send from the same packet or from a new packet.

There different version called Aloha-based protocols, a couple of proposals modification for underwater networks of the protocol can be found in (Chirdchoo, 2007) that presents Aloha with Collision Avoidance (Aloha-CA) and Aloha with Advance Notification (Aloha AN).

- Aloha-CA: Pays close attention to every packet it overhears, picking the information of who are the sender and receiver. With this information it can easily calculate the busy duration due to the packet at every one of the nodes. Each node will store in a database table the information of the monitored packets with the busy durations of every node of the neighbourhood.

- Aloha-AN: This protocol has all the features of Aloha-CA and adds the sending of a small advanced notification packet with the necessary information to let the other nodes build the databases tables. The sender will wait after this packet for a lag time before sending the actual data packet. Whenever a node has a packet to transmit, it will check the database table to ensure that the packet does not result in a collision at any other reachable nodes.

4.2 DACAP

DACAP is a handshaking protocol Distance Aware Collision Avoidance Protocol (Peleato & Stojanovic 2007) for Ad Hoc Underwater Acoustic Sensor Networks. This protocol is a non-synchronized data access that uses control messages to decide when to start the communication Request-To-Send (RTS) / Clear-To-Send (CTS) handshake. If a collision happens during the handshake, the transmitter will not receive a CTS that enables him to send the data packet.

The protocol is describe in Figure 6 and Figure 7 and explained in the following steps:

- RTS reception: After this event, the node sends a CTS to the sender, and waits for a data packet. If another RTS is received the node sends a warning short packet to give and advice to the sender of the last one that the medium is in use.
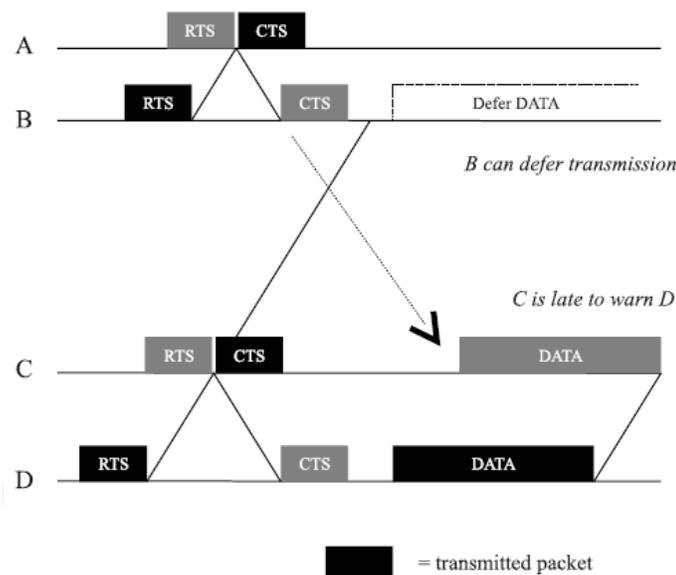

Fig. 6. Transmission in DACAP

- CTS reception: When the transmitter receives this message it waits for those nodes whose transmissions are still happening to avoid any collisions. If it happens to receive another CTS or a warning packet reception the current data packet to send will be deferred for a random back-off time, if the waiting time expires the transmission proceeds normally.
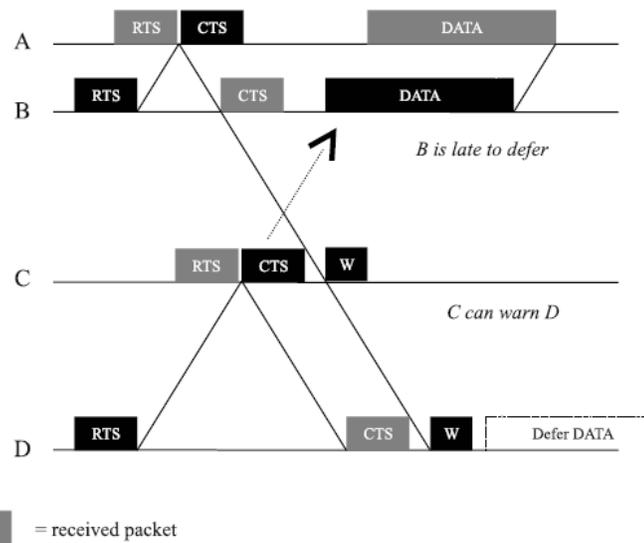
Fig. 7. Reception in DACAP

DACAP is a collision avoidance protocol with an easy scalable adaptation to big networks involving more nodes and a greater area. The protocol is aware of power consumption by avoiding collisions at the same time that maximizes the throughput. It minimizes the handshake time using the tolerance to interference of the receiver node, when this one is close to the limit of the range reception range. It works with a half-duplex communication link, the nodes do not need to be synchronized and it supports mobile nodes.

The throughput with this protocol is several times higher than the one achieved with Slotted FAMA, while offering similar protection to collisions, i.e. savings in energy. Although CS-ALOHA offers higher throughput in most cases, it wastes too much power on collisions.

4.3 T-Lohi
Tone-Lohi is a contention-based Mac protocol that uses short packet as wake up tone to reserve the medium. It is a full distributed reservation process and one of its main features is the power consumption, the nodes will be in an idle mode with low energy requirement until it receives the wake up tone.
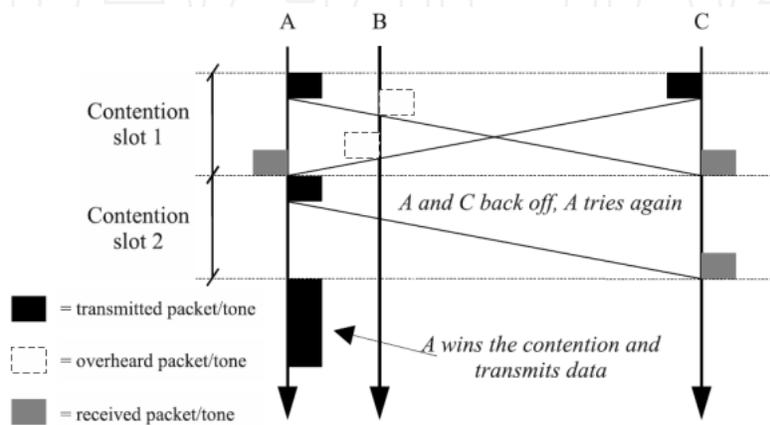

Fig. 8. T-Lohi Protocol Scheme

The main goals of T-Lohi are to make an efficient use of channel utilization, achieve a stable throughput, and save as much energy as possible without having an impact in the performance. This energy conservation is approached in two ways: (1) the reservation to prevent data packet collisions or at least reduce them, (2) and the usage of wake-up tones for the receivers to keep them in low power while in listening mode.

5. Network Layer

This layer is mainly responsible of routing packets to the proper destinations. So, a routing protocol is required when a packet must go through several hops to reach its destination. It is responsible for finding a route for the packet and making sure it is forwarded through the appropriate path. The way paths are selected for every source destination pair will have a direct impact on the overall network performance.

Most of the routing proposals for UWSN are based on the ones developed for terrestrial ad-hoc and wireless sensor networks. Some of the protocols designed exclusively for underwater wireless networks are:

5.1 DBR
Depth-Based Routing (Xie et al, 2008). It can handle network dynamics efficiently without the assistance of a localization service, it needs only local depth information. It is a greedy algorithm that tries to deliver a packet from a source node to sinks.
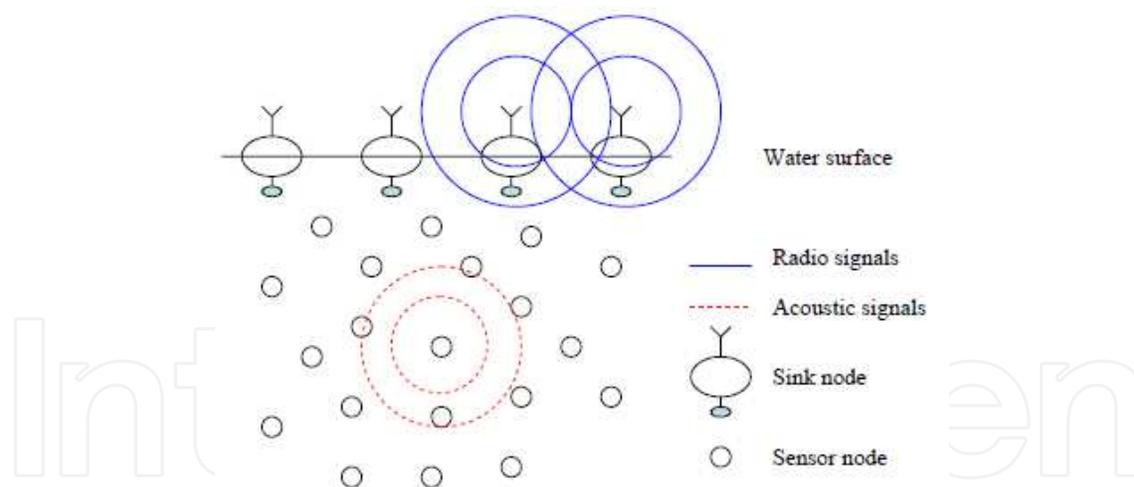

Fig. 9. Multiple sink underwater sensor network architecture

The source nodes send the data packets seeking for the sinks, in this process as the packet hops from one node to another the depth decreases as it gets closer to the final sink receiver. Finally the packet can achieve to reach to the surface. The decision that is taken in each one of the nodes during the transmission is based on its own depth and the depth of the previous sender.

When a node receives a packet it extracts the information of the depth of the previous node and compares against its own depth. After comparing the node will have two behaviours:

(1) The node is closer to the surface $d_c < d_p$ so it will forward the packet. (2) If the current node depth is greater $d_c > d_p$, it will discard the packet as it comes from a node with a better position.

Probably specially at the beginning of the transmission in the first hops, a lot of receivers of the packet will decide to forward it. To avoid the collisions that these retransmissions would bring and the high power requirements needed in the network, the number of forwarded messages must be controlled.

Also it can happen that as it is been using a multiple omnidirectional path algorithm to route the packets, that a node receive several times the same packet and in the same way forward it the same number of times. In order to save energy a node will know which packets have already sent so as not to send a packet more than one time.

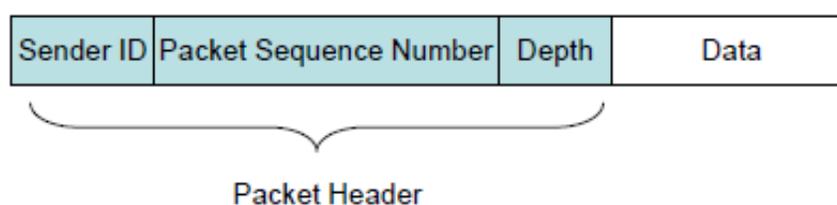| Sender ID	Packet Sequence Number	Depth	Data

Packet Header

Fig. 10. DBR Packet Format

The Packet Format will be divided in:

- Sender ID: is the identifier of the source node.
- Packet Sequence Number: is a unique sequence number assigned by the source node to the packet. Together with Sender ID, Packet Sequence Number is used to differentiate packets in later data forwarding.
- Depth: is the depth information of the recent forwarder, which is updated hop-by-hop when the packet is forwarded.

As mention before there is need to reduce power consumption forwarding only the necessary packets. To achieve this protocol uses the Redundant Packet Suppression, which consist of two features for avoiding redundant packet. One is that multiple paths are naturally used to forward packets. The other is that a node may send a packet many times. Although multiple paths in DBR cannot be completely eliminated, a priority queue is created to reduce the number of forwarding nodes, and thus control the number of forwarding paths. To solve the second problem, a packet sent buffer is used in DBR to ensures that a node forwards the same packet only once in a certain time interval.

5.2 VBF

Vector-Based Forwarding protocol (Xie et al, 2006) is an algorithm that allows the nodes to weigh the benefit to forward packets and reduce energy consumption by discarding the low benefit packets. One of the main factors in underwater wireless networks is to safe power so as not to let nodes run out of batteries, not being able to recharge them during long period of times. This protocol tries to focus its features in this direction. To aim this target each

packet will include the information of the location of the sender the final receiver and the one of next hop of the packet.

To be able to run this protocol it is assumed that every node have the capacity of measuring the distance and angle of arrival (AOA) of the signal. The route of the packet is compute in the sender and included in the packet. When a node receives a packet it calculates its relative position towards the target. This works recursively in all the nodes during the transmission. If the node knows that is close enough to the routing vector (it will be under the threshold value established for this purpose) it will include its position and forward the packet, in other case it drops the packet. In this way, all the packet forwarders in the sensor network form a "routing pipe": the sensor nodes in this pipe are eligible for packet forwarding, and those which are out do not forward.
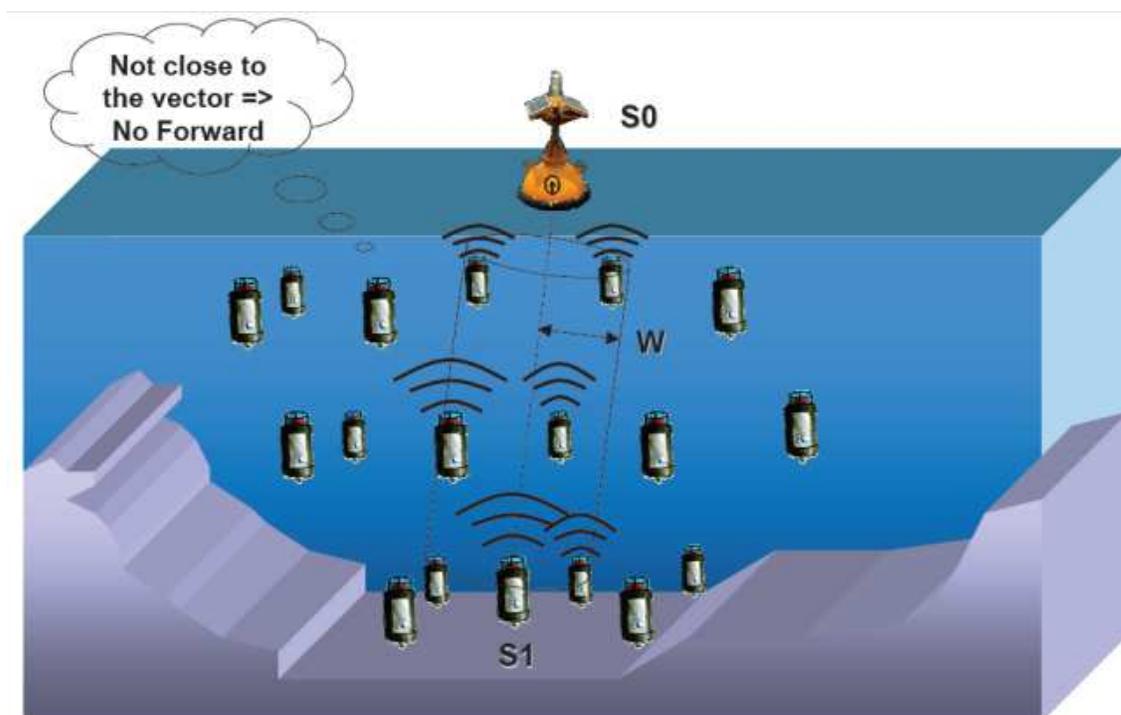

Fig. 11. High Level view of VBR for UWSN.

The figure represents the nodes that are within the routing pipe that forward the packet, "w" the threshold used to measure the width of the pipe. And the nodes that are out of this path discard the packets. This protocol is scalable to the size of the network. This kind of forwarding path (specified by the routing vector) involving nodes for packet routing has as result the energy of the network.

5.3 FBR
Focus Beam Routing, a routing protocol (Jornet & Stojanovic 2008) based on location is presented as a way to find the path between two nodes in a random deployed network. The figure 8 shows a simple two-dimensional network to explain the protocol, although it works in the same way in three-dimensional scenarios.
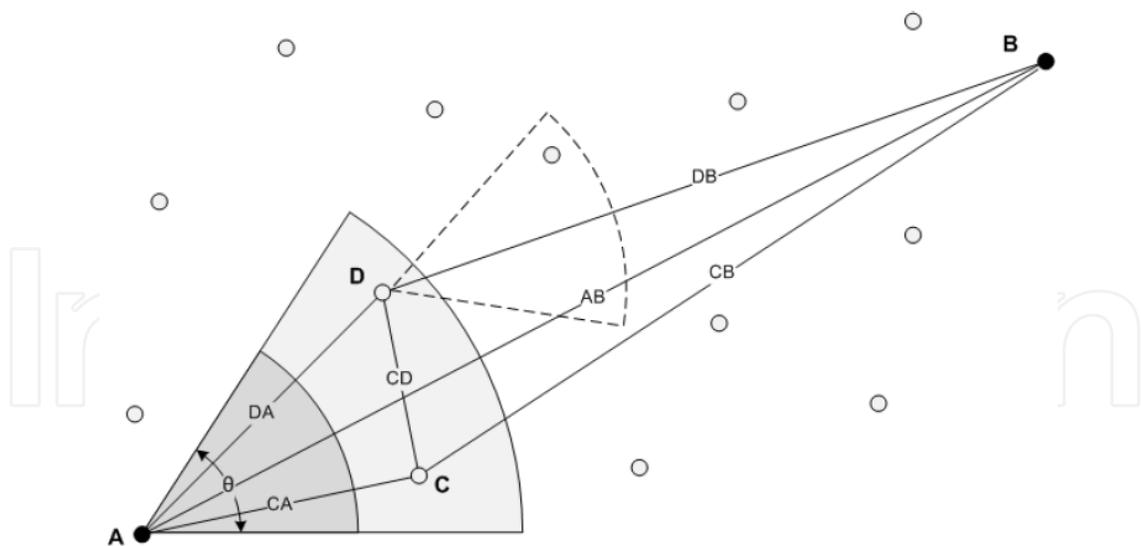
Fig. 12. Nodes within the transmitter's cone θ are candidate relays.

Assuming a communication between node A and node B, node A will send and Request to Send (RTS) multicast message to all the reachable neighbours. This packet will include the information of the source (node A) and final receiver (node B). As the protocol works with power levels, the first try is done at the lowest level and it increases if there is a need because it receives no answers within a wait time established for each power level.

 This request is a short control packet that contains the location of the source node (A) and of the final destination (B). Note that this is in fact a multicast request. The initial transaction is performed at the lowest power level and the power is increased only if necessary. Power control is performed as an integral part of routing and medium access control.

Each power level will have a radius and though it will reach to a certain number of nodes. This will be the nodes that receive the RTS and its information that will be used to calculate the relative position to the AB line. This is done to know if the node is a candidate to be a relay node. Candidate nodes are inside a cone of ±θ/2 from the line AB. Every candidate node will answer to with a Clear to Send (CTS) to the transmitter; the nodes out of the candidate zone will stay in silence.

After sending the RTS the transmitter will wait to receive CTS messages from other nodes, three possible things can occur: (1) The transmitter receive no answers, the RTS has not reach any neighbour, therefore the transmitter increases the power level an tries again as it is shown in the example. (2) The transmitter receives one CTS, the sender of this message is selected as a relay for the next hop, sending him the DATA message. (3) The transmitter receives more than one CTS message, looking at the location information of the candidates included in CTS message the node that is closer to the final destination is selected as relay receiving the DATA message. After sending data the transmitter will wait for an acknowledgement message. This process will continue until we reach the final destination.

Packet collisions can happen but always will involve short packet as the link is safe for data packets which have no risk of collisions. Although the chances of collision are small, if the

source node detects a collision, it will detect signal but it will not decode the information of the data, it will resend the RTS once again, without increasing the power level.

6. Applications

As established in the introduction, underwater acoustic wireless sensor networks can be used in a wide range of different applications, as it is done by radio frequency air networks. Ones of the main places we can use UWSN are:

• Environmental Monitoring. Pollution is nowadays one of the greatest problems, oil spills from ships or broken tubes can make a lot of harm to the marine biological activity, the industry and tourist places. Monitoring ecosystems can help understanding and predicting the human and climate or weather effect in underwater environment.
• Prevention of natural disaster. By measuring the seismic activity from different remote location the sensors could alert to the coast places by detecting tsunami or submarine earthquakes alarms.
• Underwater Navigation. The sensor can be placed to make routing, identifying hazards on the seafloor, rocks or shoals in shallow water,
• Assisted Navigation. Sensors can be used to identify hazards on the seabed, locate dangerous rocks or shoals in shallow waters, mooring positions and drawing the bathymetry profile of the area.
• Underwater Discovery. Underwater wireless sensor networks can be used to find oilfields or reservoirs, locate routes for placing connections for intercontinental submarine cables. Also they could seek for shipwrecks or archaeology or lost sink cities.
• Underwater Autonomous Vehicles (UAVs). Distributed sensor in movement can help monitoring area for surveillance, recognition and intrusion detection.

7. Future Trends

A lot of advantages can be achieved by using underwater sensor networks, but a lot of research must be done in the next years. The developing of this technology will have a great impact in the industry.

It is necessary to improve the physical layer performance in terms of efficiency, building low power acoustic modem that are able to make a make best use of the bandwidth, reducing the error rate with forward error correcting coders.

Although there many proposal in the MAC layer, it seems that the collision avoidance protocols in the top for been chosen for underwater networks. In any case this decision can vary according to the application or topology type. These protocols should be also aware of power consumption, making one of their main objectives.

Currently there is a lot of works related to MAC layer proposals since this is one of the more sensible parts of the UWSN architecture. It seems that distributed CDMA-based schemes are the candidates for underwater environments, but it depends of many factors such as the

application and network topology. Also, MAC protocols should be designed taking energy consumption into account as a main design parameter.

According to the routing layer protocols, there is a need to be able to adapt to the changing conditions, to include mobility patterns and also be capable of saving energy. Most of the routing protocols need to know the location of all the nodes, geographically-based algorithms may be appropriate for underwater networks. They have to include methods to avoid errors, deal with shadow zones or disconnections or failures and mobility. Cross layer communication between the layers should be required to share the information and adjust the parameters depending on the environment condition variation.

8. Conclusions

Underwater Acoustic Wireless Sensor Networks is still growing and following the path of Radio Frequency in Terrestrial Networks, although having a very different environment with a lot of challenges to achieve in changing conditions. There are many potential research fields in which it can be applied, and needs to solve some open issues so as to be able to provide a reliable and efficient way to communicate in the network.

The development of new modem and the incorporation of companies and research to the UWSN technology will come with new commercial products and solutions to take advantage of the possibilities that underwater bring us, building and industry around submarine technologies.

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Wireless Sensor Networks: Application-Centric Design

Edited by Yen Kheng Tan

Over the past decade, there has been a prolific increase in the research, development and commercialisation of Wireless Sensor Networks (WSNs) and their associated technologies. WSNs have found application in a vast range of different domains, scenarios and disciplines. These have included healthcare, defence and security, environmental monitoring and building/structural health monitoring. However, as a result of the broad array of pertinent applications, WSN researchers have also realised the application specificity of the domain; it is incredibly difficult, if not impossible, to find an application-independent solution to most WSN problems. Hence, research into WSNs dictates the adoption of an application-centric design process. This book is not intended to be a comprehensive review of all WSN applications and deployments to date. Instead, it is a collection of state-of-the-art research papers discussing current applications and deployment experiences, but also the communication and data processing technologies that are fundamental in further developing solutions to applications. Whilst a common foundation is retained through all chapters, this book contains a broad array of often differing interpretations, configurations and limitations of WSNs, and this highlights the diversity of this ever-changing research area. The chapters have been categorised into three distinct sections: applications and case studies, communication and networking, and information and data processing. The readership of this book is intended to be postgraduate/postdoctoral researchers and professional engineers, though some of the chapters may be of relevance to interested master's level students.

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