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Shallow Water Acoustic Networking [Algorithms & Protocols]

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GJCST-E Classification : C.2.1

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I. INTRODUCTION

As autonomous underwater vehicles (AUVs) continue to become less expensive and more capable, they are being deployed in larger groups. As a result, the need to communicate between multiple, mobile underwater systems is growing as well. Underwater communication is best accomplished through the use of acoustic links, and interconnecting multiple underwater vehicles is best accomplished through the use of an acoustic network. Such a network, one using a shared medium and comprising mobile nodes, is called a mobile ad hoc network (MANET). It is difficult to efficiently forward data across a MANET because node mobility means network topology—the overall set of connections between nodes—changes over time. The network must spontaneously organize, learn the topology, and begin routing with a minimum of overhead traffic for route discovery and maintenance. There has been a great deal of attention paid to this problem, but almost exclusively as it applies to wireless radio networks [1–4].In a network, a node is a communication endpoint able to send and receive data.

When two nodes can communicate with one another, they are said to have a link between them. Links can be of varying quality: some links may deliver almost every message without error, others may deliver only a small fraction of the messages sent across them. In shared-medium communications like underwater acoustics, every transmission has exactly one sender but can have one or more receivers.A message may have to be forwarded across one or more links to intermediate nodes before reaching its intended destination. Routing is the process of choosing the links that will comprise the route the message will follow across the network. A routing protocol is responsible for selecting the route. Most routing protocols collect, manage, and disseminate information about the network in order to function, for example, by monitoring network topology, specifying the next hop of a message, queuing messages awaiting routes, and tracking which messages have already been processed. Unlike in a traditional, wired network, routing in a mobile ad hoc network (MANET) is complicated by the possibly rapid and unpredictable topological changes caused by movement of the nodes. A given routing protocol is typically intended for a particular type of network, and many have been developed specifically for MANETs [5–9].Little of the existing research into MANET routing protocols addresses the specific limitations of underwater acoustics [10]. While few MANETs are as drastically low-bandwidth as an underwater acoustic network, many have little bandwidth when compared with wired networks, and some MANET techniques specifically address this by reducing protocol overhead [11–13]. The greater problem is that the existing research assumes—almost without exception—that wireless networks in general, and MANETs in particular, use radio links. The particular problem is the speed of the nodes compared to the communication latency. Most advanced routing protocols need to propagate topology information throughout the network. The high latency of acoustic links means that the movement of underwater vehicles can change the network topology more quickly than updates can be propagated. This is especially a problem for protocols developed for radio MANETs, which overall assume a much slower rate of topology change compared to communication latency [11–17].This paper describes the location-aware source routing (LASR) protocol, a network routing protocol specifically designed for use in low-bandwidth, high-

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latency underwater acoustic networks of mobile nodes. LASR is loosely based on the dynamic source routing (DSR) [9] protocol and is specifically designed for use in underwater acoustic networks where the topology changes frequently. The results presented here show that, in simulated underwater acoustic networks of AUVs, LASR outperforms both blind flooding and DSR in throughput and packet delivery ratio. Note that LASR is intended for use in missions where vehicle movement dominates energy consumption, so that it maximizes successful communication rather than energy conservation. A performance comparison between protocols in terms of energy consumption is not the focus of this publication, but it is an important future study.The remainder of this paper is organized as follows. Related work is discussed in Section 2. The new LASR protocol is described in Section 3. Specifics of handling routes and messages are covered in Section 4. Section 5 presents some results of LASR in a simulated underwater network. Section 6 summarizes our conclusions.

II. SWAN COMMUNICATION ARCHITECTURE

A TWO DIMENTIONAL ARCHI for ocean bottom monitoring. These are constituted by sensor nodes that are anchored to the bottom of the ocean. Typical applications may be environmental monitoring, or monitoring of underwater plates in tectonics.

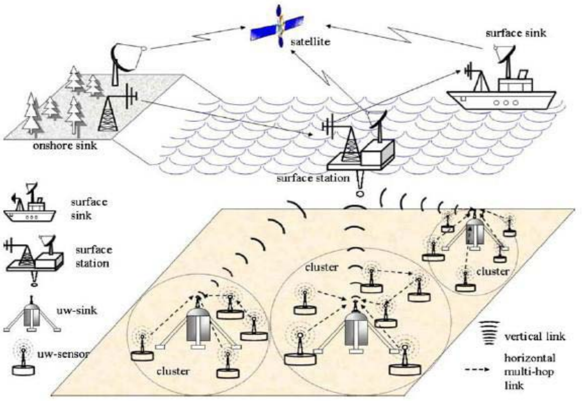

Fig. 1 : Two-dimensional underwater Sensor Networks

Reference architecture for two-dimensional underwater networks is shown in the figure above. A group of sensor nodes are anchored to the bottom of the ocean with deep ocean anchors. By means of wireless acoustic links, underwater sensor nodes are interconnected to one or more underwater sinks (uw-sinks), which are network devices in charge of relaying data from the ocean bottom network to a surface station. To achieve this objective, uw-sinks are equipped with two acoustic transceivers, namely a vertical and a horizontal transceiver. The horizontal transceiver is used by the uw-sink to communicate with the sensor nodes in order to: i) send commands and configuration data to the sensors (uw-sink to sensors); ii) collect monitored data (sensors to uw-sink)[9]. The vertical link is used by the uw-sinks to relay data to a surface station. Vertical transceivers must be long range transceivers for deep water applications as the ocean can be as deep as 10 km. The surface station is equipped with an acoustic transceiver that is able to handle multiple parallel communications with the deployed uw-sinks. It is also endowed with a long range RF and/or satellite transmitter to communicate with the onshore sink (os-sink) and/or to a surface sink (s-sink).

Sensors can be connected to uw-sinks via direct links or through multi-hop paths. In the former case, each sensor directly sends the gathered data to the selected uw-sink. This is the simplest way to network sensors, but it may not be the most energy efficient, since the sink may be far from the node and the power necessary to transmit may decay with powers greater than two of the distance.

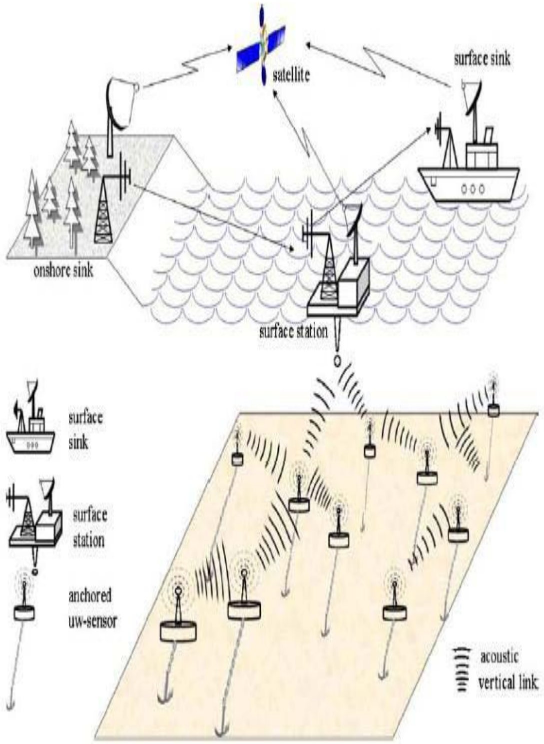

Fig. 2 : Three-dimensional underwater Sensor Network

Furthermore, direct links are very likely to reduce the network throughput because of increased acoustic interference due to high transmission power. In case of multi-hop paths, as in terrestrial sensor networks, the data produced by a source sensor is relayed by intermediate sensors until it reaches the uw-sink. This results in energy savings and increased network capacity, but increases the complexity of the routing functionality as well. In fact, every network device usually takes part in a collaborative process whose objective is to diffuse topology information such that efficient and loop free routing decisions can be made at each intermediate node. This process involves signaling and computation. Since, as discussed above, energy and capacity are precious resources in underwater environments; in UW-ASNs the objective is to deliver event features by exploiting multi-hop paths and minimizing the signaling overhead necessary to construct underwater paths at the same time [9].

Three-dimensional networks of Autonomous Underwater Vehicles (AUVs).

These networks include fixed portions composed of anchored sensors and mobile portions constituted by autonomous vehicles. Three dimensional underwater networks are used to detect and observe phenomena that cannot be adequately observed by means of ocean bottom sensor nodes, i.e., to perform cooperative sampling of the 3D ocean environment. In three-dimensional underwater networks, sensor nodes float at different depths in order to observe a given phenomenon. One possible solution would be to attach each uw-sensor node to a surface buoy, by means of wires whose length can be regulated so as to adjust the depth of each sensor node. However, although this solution allows easy and quick deployment of the sensor network, multiple floating buoys may obstruct ships navigating on the surface, or they can be easily detected and deactivated by enemies in military settings. For these reasons, a different approach can be to anchor sensor devices to the bottom of the ocean. In this architecture, depicted in the figure above, each sensor is anchored to the ocean bottom and equipped with a floating buoy that can be inflated by a pump. The buoy pushes the sensor towards the ocean surface. The depth of the sensor can then be regulated by adjusting the length of the wire that connects the sensor to the anchor, by means of an electronically controlled engine that resides on the sensor. Many challenges arise with such an architecture, that needs to be solved in order to enable 3D monitoring, including:

Sensing coverage: Sensors should collaboratively regulate their depth in order to achieve full column coverage, according to their sensing ranges. Hence, it must be possible to obtain sampling of the desired phenomenon at all depths.

Communication coverage: Since in 3D underwater networks there is no notion of uw-sink, sensors should be able to relay information to the surface station via multi-hop paths. Thus, network devices should coordinate their depths such a way that the network topology is always connected, i.e., at least one path from every sensor to the surface station always exists.

Sensor Networks with Autonomous Underwater Vehicles (AUVs):

AUVs can function without tethers, cables, or remote control, and thus have a multitude of applications in oceanography, environmental monitoring, and underwater resource study. Previous experimental work has shown the feasibility of relatively inexpensive AUV submarines equipped with multiple underwater sensors that can reach any depth in the ocean hence, they can be used to enhance the capabilities of underwater sensor networks in many ways. The integration and enhancement of fixed sensor networks with

AUVs is an almost unexplored research area which requires new network coordination algorithms, such as:

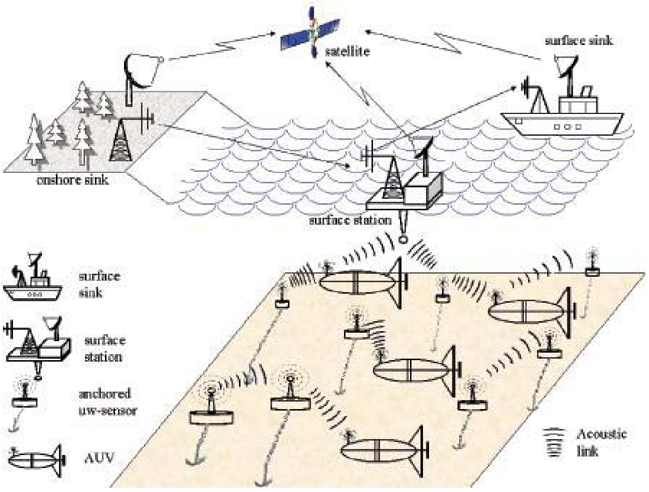

Fig. 3 : Three-Dimensional Sensor Network with AUVs

Adaptive sampling: This includes control strategies to command the mobile vehicles to places where their data will be most useful. This approach is also known as adaptive sampling and has been proposed in pioneering monitoring missions. For example, the density of sensor nodes can be adaptively increased in a given area when a higher sampling rate is needed for a given monitored phenomenon [9].

Self-Configuration: This includes control procedures to automatically detect connectivity holes due to node failures and request the intervention of an AUV. AUVs can either be used to deploy new sensors or as relay nodes to restore connectivity.

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III. Routing Issues and Protocols

Y2.1. Medium Access Control Radio and acoustics are both shared medium techniques: multiple senders and receivers use the same medium (e.g., the water of the ocean) and there must be some sort of medium access control (MAC) to keep them from all “talking at once”. Inherent in shared-medium systems is the problem of collision—the interference among multiple, simultaneously-received signals. A large number of MAC protocols have been developed, some better suited to mobile underwater acoustic use than others [10, 18–24].Time-division multiple access (TDMA) divides the medium into time-slots [4]. Each node may use the entire bandwidth, but may only transmit according to a given schedule. LASR must use TDMA as its MAC protocol. The TDMA transmit-time information is what allows LASR to collect implicit time-of-flight information for the nodes in the network and is crucial for effective use of its tracking system.2.2. Blind Flooding Blind flooding is a network broadcasting protocol [4], and the simplest of the flooding protocols. It delivers its messages to every node in the network, and does so without knowledge of the topology. The basic operation is simple: the first time a node receives a given message, the node automatically rebroadcasts it. Because blind flooding does not require the topology to be known, many of the more-sophisticated routing protocols employ it before routes are known, for example, during route discovery. Blind flooding's advantages include operation without topological information and low end-to-end delay. The main disadvantage of blind flooding is that it can produce a significant amount of unnecessary traffic, especially as the size of the network increases.2.3. Shortest-Path Routing Flooding delivers a message by network broadcast, and every node in the network receives the message. This is very inefficient when the destination is a single node. An alternative is shortest-path routing, where a message follows the path with the fewest hops. This is much more efficient: rather than every node in the network forwarding the message to all its neighbors by broadcast, each node along the shortest path forwards the message to the next hop by unicast. However, this makes it necessary for the network nodes to have at least partial knowledge of the network topology. It is also important to avoid routing loops, which occur when mismatches in topology information across several nodes cause messages to be routed in circles. Examples of shortest-path routing include the Destination-Sequenced Distance Vector (DSDV) protocol [5], Ad hoc On-demand Distance Vector (AODV) [6], Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) [8], and the Temporally-Ordered Routing Algorithm (TORA) [7]. Of particular interest here is the Dynamic Source Routing (DSR) protocol [9], a reactive protocol which, depending on the implementation, uses either distance-vector or link-state routing. In source routing, the entire route to the destination is determined by the originator (the source) and is carried along with the message. Routes are discovered as needed via a route-request/route-reply process, and there are no periodic updates.2.4. Delay-Tolerant Routing In some networks, there may never be an end-to-end connection. Instead, individual mobile nodes must hold data until a forwarding opportunity arises [25]. For example, a protocol can exploit vehicles' nonrandom mobility patterns to improve routing performance [26]. These routing techniques are not necessarily suitable to the cooperating-AUVs problem. When cooperating, the nodes will likely actively work to stay connected, that is, each node will maneuver such that it always stays within range of the network. More importantly, certain types of data do not need to be delivered immediately and can tolerate significant delay in their delivery, but when cooperating on short time-scales, some communication is very likely to be time-sensitive and delivery cannot wait long periods for an opportune vehicle motion to put it in range.2.5. Position-Based and Location-Aware Routing A routing protocol spends most of its time determining and tracking the network topology. With communication technologies such as radio and acoustics, which links are available largely depends on the distance between the various nodes. Some routing protocols use knowledge of the location of network nodes to provide or augment topology information. These are known as location-aware or position-based protocols. Routing by absolute geographical location typically employs a locating service that is queried by nodes to look-up the current location of a destination node. Messages are routed to the neighbor that is geographically nearest to the destination. Routing by relative location typically requires both relative location (e.g., range and bearing) as well as traditional topology information. LASR routes by relative location. A protocol similar to LASR is [27], which also estimates range from one-way time-of-flight using TDMA and uses it to discover network topology for routing via DSR. However, it includes pseudo noise probe patterns as a part of each frame because localization is of primary importance in that system. The network supports only very few nodes and the overall communication rate is extremely low. The new LASR protocol has been specifically designed to address the problems of routing in low-bandwidth, high-latency underwater acoustic networks of mobile nodes. It is loosely based on the DSR [9] protocol. Like DSR, LASR is a self-organizing, infrastructureless, distributed protocol. It learns and maintains only those routes that are in use. LASR uses the source route principally as a means to communicate topology information. Each intermediate node updates the source route in every message it forwards, applying the route most likely to require the fewest transmissions (which does not necessarily correspond to the fewest hops) to reach the destination. Every message transmission is therefore routed according to the most current topological knowledge, rather than DSR's approach which routes according to the topological knowledge at the time the message was originated.3.2. Assumptions The LASR protocol is designed for small underwater networks using low-speed acoustic links. The network should not contain more than 20–30 nodes, a reasonable assumption given typical multiple-AUV operations such as [28]. This network size limitation is due in lesser part to the source route header overhead in each message.

The size of the source route grows linearly with the length of the longest path through the network. In greater part, this assumption is due to LASR's required use of TDMA, which does not scale well into large networks. Nodes may move at any time and in any direction. The only restriction on node motion is that speeds should be in the range 0–3 m/s; this speed range is typical for most current AUVs. This assumption is necessary to limit the rate at which node motion can change the network topology. All nodes must use identical LASR algorithms, and all must fully participate in the protocol, including forwarding the messages of others. Every node must have accurate timekeeping, for example, by means of a low-drift clock. No two node clocks may differ by more than 50 milliseconds throughout a mission, although this network time may differ from true time by any amount. This is necessary for TDMA window timing. Equipped with the optional time synchronization feature, the FAU Dual Purpose Acoustic Modem (DPAM) fits this requirement over 8 hours using low-drift clocks [29]. Also, prior work [30] has shown that for LASR, this is the minimum timekeeping precision necessary to preserve the accuracy of the time-of-flight range estimates based on TDMA window timing. The communication link endpoints should be identical acoustic modems, and these modems should be effectively omnidirectional. They must support overhearing—the reception of messages not specifically addressed to them. Overhearing is an important source of topology information. To allow the tracking system to function, each modem must report the time at which any incoming transmission is detected, regardless of whether or not the transmission can be successfully decoded. The detection time reporting must be accurate to within 30 milliseconds. As with the timekeeping precision, this reporting precision has been shown [30] to be the minimum necessary for time-of-flight range estimate accuracy. LASR's implementation of ETX assumes that network links are bidirectional (acoustic modem links are traditionally bidirectional, albeit half-duplex) and symmetrical, meaning packets can cross the link between any pair of nodes in either direction with equal probability of success. In practice, the links are not perfectly symmetrical, but symmetry is a fair assumption so long as the transducer is assumed omnidirectional and the environmental conditions (and range between nodes) do not change significantly between two transmissions. The development of a nonsymmetrical and unidirectional version of LASR is beyond the scope of this article, but constitutes a future key for development of LASR. The links are assumed to be through a shared medium. The network must use TDMA as the MAC protocol so that implicit time-of-flight range estimate is possible. The ETX implementation also assumes that a medium model exists for the modem, which can provide a reasonably accurate estimate of the frame-error rate (FER) between two modems given the distance between them. The FER is the probability that a given transmission (a frame) on the link will be received in error. All nodes must use identical medium models and the FER estimate must be deterministic: every use of the model at every node must return the same FER for a given range. Note that the FER model includes other input parameters (sea state, ambient noise, water depth, bottom type …). A complete list is provided in [31]. The FER model used in the simulation was developed from field data [32]. For simplicity, the study assumes that every input parameter is constant, with the exception of range. These other parameters impact the FER, thus the LASR performance. At fixed range, the authors showed in [33] that the LASR performance drops with ambient noise and sea state, as the FER increases with these two parameters. A range-only tracking system is assumed to be available at each node. Regular measurements of the distance from the local node to each of the various other nodes within detection range will be available from a combination of the modem's transmission detection and TDMA window timing. The tracking system must use those time-of-flight based range measurements to predict the current location of those nodes relative to the local node. Prior work [30] has shown that the tracking system must predict relative node position to within 200 m of the true relative node position. If the estimated prediction error exceeds this amount for a given node, the tracking system must cease reporting the predicted position of that node.3.3. Link Metric The expected transmission count (ETX) [34] estimates the number of times a node will have to transmit a message before it successfully receives an acknowledgment. The ETX of a route is simply the sum of the ETXs of each link in the route, and any two ETX route metrics are directly comparable. The ETX is calculated from a link's FER. The technique described in [34] to calculate the ETX uses probe messages sent periodically across a link—once a sufficient number of probe messages have been sent, it is possible to estimate the link's FER, and then to calculate the ETX. In a MANET however, node motion can cause considerable variation in link quality over short time scales. This is a problem because, while ETX outperforms hop-count in a static network, hop-count can react more quickly to link changes and outperforms ETX when nodes are moving [35].LASR uses expected transmission count (ETX), but overcomes this mobile-node measurement-delay problem by calculating the delivery ratio directly from the FER estimated by the medium model. LASR assumes symmetric links, so the probability that a message and its acknowledgement will cross a link successfully is, making the equation for ETX:

How LASR handles the ETX information is described in Appendix B.3.4. Tracking System Neighborhood topology is predicted by the tracking system based on information from both implicit and explicit communication. Combining the time-of-detection information from the modem with the current TDMA state provides both an estimated time-of-flight and the identity of the transmitter. The range to the transmitter can then be estimated using the medium model. A series of range estimates to other nodes, coupled with knowledge of a node's own motion, can form the basis for localization and tracking of the other nodes. When combined with minimal information from the other nodes about their ranges to each other, the relative, progressive location of the other nodes can usually be uniquely determined to some accuracy. A tracking system was not implemented as part of this work. The behavior of the tracking system was simulated based on the minimum established performance requirements. A recursive state-estimation filter, such as a particle filter, is expected to be able to localize and track some or all of the network nodes, depending on the amount of information available about each node. The more information that is available about another node, the more accurate tracking and location prediction can be. Even a low-order motion model (e.g., maximum, minimum, and typical speed and turning rate) will help constrain tracking and prediction uncertainty. A behavior model providing knowledge of the types of behaviors the node may exhibit (e.g., lawn mowing, line-following or hovering) can further reduce uncertainty. Information for tracking can be characterized as either explicit or implicit. Explicit information is carried as overhead in network messages. The LASR source routes, for example, carry explicit link range information. Implicit information is communicated without overhead, simply by the act of communicating. An example of implicit information is the time-of-flight measured when a message is received. Some modems, such as the FAU DPAM [31], preface each packet with a known sequence of symbols. The optional time synchronization feature of the FAU DPAM is used for TDMA communications and tracking [29]. This detection sequence is used by the receiver to identify an incoming transmission because, unlike the coded variable data in a message, the symbols in the detection sequence are known a priori, making them substantially easier to identify, even in very weak signals. It is frequently possible to correctly identify the detection sequence in transmissions from ranges far beyond the range at which there is sufficient signal to successfully decode the variable data. Under such modems, incoming transmissions fall into three categories: strong enough to decode (providing implicit range and explicit data), strong enough to detect but too weak to decode (providing implicit range only), and too weak to detect (providing nothing). Because the detection sequence can be reliably identified even across a link with an extremely high FER, the second category includes transmissions from nodes far beyond the useful explicit range of the modem. A comparison of implicit and explicit data is shown in Figure versus explicit data. Node transmits a message for node and each detect and receive it (the message is intended for but has overheard it). The detection provides an implicit range estimate to node; the reception provides all of the explicit routing information contained in the message (e.g., in the source route). Node detects but does not receive the message, thus gains an implicit range estimate to node

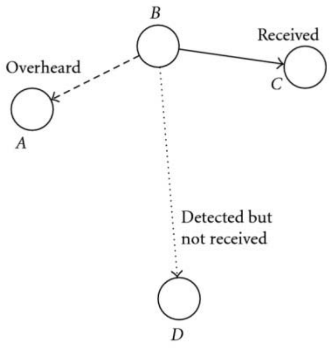


Fig. 1 : Implicite vs explicit data

But gets none of the explicit data.3.5. LASR Packet Structure Each LASR packet contains one or more messages. A message can contain user data or protocol data. A user-data message contains a source-route in addition to the user data. There are several protocol message types; these are described in Appendix A. Packets are small in a typical acoustic network, typically on the order of tens to hundreds of bytes only. This makes header overhead very expensive as even a small header can represent a large fraction of a packet. LASR uses a different header structure than DSR in order to reduce the size of the header as much as possible. LASR's header structure is shown.in

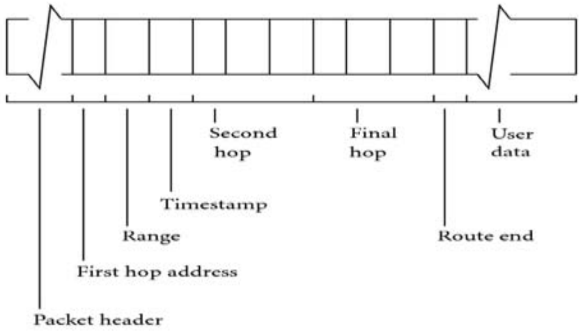


Figure 2 : Lasr header

The number of bits added to the header by a given layer can change from message to message. To accommodate this, the header is implemented as a stack of bits.7659: The LASR header is a variable-size stack of bits. This shows the source route portion of a three-hop route. A source route is structured as a series of triples followed by an end marker. Each triple is a hop in the route starting at the originator and ending one hop before the destination. A triple comprises the address of the node, the best-available estimate of the range from the node to the next hop (or the destination) and the timestamp of the range estimate. Both the range and its timestamp are quantized to conserve space in the header, see [30] for details on the quantization. The route end is the special network address zero, which is never a valid address. The network addresses are represented as the smallest number of bits that can represent the number of nodes in the network, plus one for the special zero address. For example, a 16 node network would require 17 unique addresses and would therefore require 5-bit addresses.

IV. NETWORK DESIGN CHALLENGES

a) Underwater Acoustic Sensor Networks: Design Challenges

In this section, we itemize the main differences between terrestrial and underwater sensor networks, detail the key challenges in underwater communications that influence protocol development, and give motivations for a cross-layer design approach to improve the efficiency of the communication process in the challenging underwater environment [5].

b) Differences with Terrestrial Sensor Networks

The main differences between terrestrial and underwater sensor networks can be outlined as follows:

- Cost. While terrestrial sensor nodes are expected to become increasingly inexpensive, underwater sensors are expensive devices. This is especially due to the more complex underwater transceivers and to the hardware protection needed in the extreme underwater environment [9].
- Deployment. While terrestrial sensor networks are densely deployed, in underwater, the deployment is generally more sparse.
- Power. The power needed for acoustic underwater communications is higher than in terrestrial radio communications due to higher distances and to more complex signal processing at the receivers to compensate for the impairments of the channel.
- Memory. While terrestrial sensor nodes have very limited storage capacity, uw-sensors may need to be able to do some data caching as the underwater channel may be intermittent.
- Spatial Correlation. While the readings from terrestrial sensors are often correlated, this is more unlikely to happen in underwater networks due to the higher distance among sensors.

Underwater acoustic communications are mainly influenced by path loss, noise, multi-path, Doppler spread, and high and variable propagation delay. All these factors determine the temporal and spatial variability of the acoustic channel, and make the available bandwidth of the Under Water Acoustic channel (UW-A) limited and dramatically dependent on both range and frequency. Long-range systems that operate over several tens of kilometers may have a bandwidth of only a few kHz, while a short-range system operating over several tens of meters may have more than a hundred kHz bandwidth. In both cases these factors lead to low bit rate [9].

Hereafter we analyze the factors that influence acoustic communications in order to state the challenges posed by the underwater channels for underwater sensor networking. These include:

c) Path loss

Attenuation: It is mainly provoked by absorption due to conversion of acoustic energy into heat, which increases with distance and frequency. It is also caused by scattering a reverberation (on rough ocean surface and bottom), refraction, and dispersion (due to the displacement of the reflection point caused by wind on the surface). Water depth plays a key role in determining the attenuation.

Geometric spreading: This refers to the spreading of sound energy as a result of the expansion of the wave fronts. It increases with the propagation distance and is independent of frequency. There are two common kinds of geometric spreading: spherical (Omni-directional point source), and cylindrical (horizontal radiation only).

d) Noise

Man made noise. This is mainly caused by machinery noise (pumps, reduction gears, power plants, etc.), and shipping activity (hull fouling, animal life on hull, cavitation), especially in areas encumbered with heavy vessel traffic.

Ambient Noise: Is related to hydrodynamics (movement of water including tides, current, storms, wind, rain, etc.), seismic and biological phenomena.

e) Multi-path

Multi-path propagation may be responsible for severe degradation of the acoustic communication signal, since it generates Inter-Symbol Interference (ISI).

The multi-path geometry depends on the link configuration. Vertical channels are characterized by little time dispersion, whereas horizontal channels may have extremely long multi-path spreads. The extent of the spreading is a strong function of depth and the distance between transmitter and receiver [9].

High delay and delay variance

The propagation speed in the UW-A channel is five orders of magnitude lower than in the radio channel. This large propagation delay (0.67 s/km) can reduce the throughput of the system considerably.

The very high delay variance is even more harmful for efficient protocol design, as it prevents from accurately estimating the round trip time (RTT), which is the key parameter for many common communication protocols.

f) *Doppler spread*

The Doppler frequency spread can be significant in UW-A channels, causing degradation in the performance of digital communications: transmissions at a high data rate cause many adjacent symbols to interfere at the receiver, requiring sophisticated signal processing to deal with the generated ISI.

The Doppler spreading generates: i) a simple frequency translation, which is relatively easy for a receiver to compensate for; ii) a continuous spreading of frequencies, which constitutes a non-shifted signal, which is more difficult for a receiver to compensate for.

If a channel has a Doppler spread with bandwidth B and a signal has symbol duration T, then there are approximately BT uncorrelated samples of its complex envelope. When BT is much less than unity, the channel is said to be under spread and the effects of the Doppler fading can be ignored, while, if greater than unity, it is overspread [9].

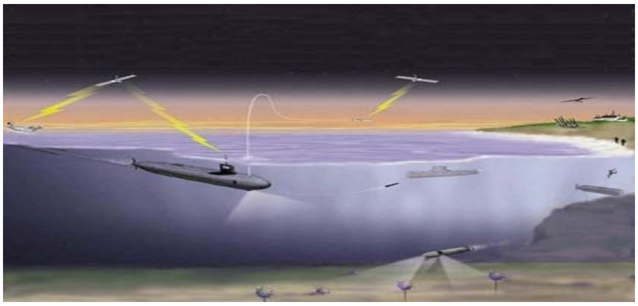
In the above sections the introduction, communication architectures and design challenges of the underwater acoustic network are discussed. Now in the further section some technologies for real-time monitoring of SWANs are discussed.

V. REALIZATION OF UNDERWATER NETWORKING

a) *Realization of Underwater Networking*

A realization of underwater acoustic networking is the U.S. Navy's experimental Telesonar and Seaweb program. Telesonar links interconnect distributed underwater nodes, potentially integrating them as a unified resource and extending naval net centric operations into the underwater battle space. Seaweb provides a command control, communications, and navigation infrastructure for coordinating autonomous nodes to accomplish given missions in arbitrary ocean environments. More generally Seaweb networking is applicable for oceanographic telemetry, underwater vehicle control, and other uses of underwater wireless digital communications. Telesonar and Seaweb experimentations address the many aspects of this problem including propagation, signaling, transducers, modem electronics, networking command-centre interfacing and transmission security. The major sea tests have included Seawebs '98,'99 and 2000[3].

Fig. 5 : Seaweb underwater acoustic networking enables data telemetry and remote control and other autonomous peripherals and Gateways



VI. NEW PROTOCOL RESULTS

This section discusses the simulation results for the new LASR protocol for underwater acoustic networks. The new protocol has been tested under a variety of simulated underwater missions, each in several operational scenarios. For comparison purposes, these tests are also conducted with the flooding and DSR protocols. The results demonstrate that the LASR protocol provides improved network communication performance compared to flooding and DSR.DSR is run without any of its optional features enabled as initial work demonstrated that each of the optional features negatively impacted DSR performance in an acoustic network. Three configurations of the LASR protocol are tested, which differ in number of retries and time spent waiting for acknowledgment. The LASR acknowledgment guarantee means that a receiver will acknowledge receipt within the specified time; this controls how much delay is introduced when a message, or its acknowledgment, fails to cross a link. The acknowledgment period is a multiple of the TDMA frame duration, to give each possible receiver some number of opportunities to transmit an acknowledgment (either implicit or explicit). The three LASR configurations are as follows. (a)LASR-0+3: no retries, unacknowledged messages are never retransmitted. However, receivers are still obligated to send an acknowledgment within three TDMA frames. (b)LASR-2+3: two retries, acknowledgment required within three TDMA frames. (c)LASR-2+6: two retries, acknowledgment required within six TDMA frames.5.1. Scenarios every scenario uses 16 vehicles, which is selected as an average network size for LASR. The parameters are exhaustively combined, with each combination defining a scene. Each scenario contains all scenes. Due to the stochastic nature of the communication model, each scene is run 20 times and the results averaged to smooth the performance results. The authors limit the study to 20 runs per scene due to computation time. This paper shows only a small fraction of the extensive simulation results; full results are available in [33].The vehicles originate messages containing arbitrary data and send the messages to randomly chosen destinations. Every node transmits at every opportunity. If no message is ready to be sent when the node's transmission time-slot opened, a new message is generated by either the application layer or a protocol layer. Here, we assume that there is always at least one packet in the buffer of each transmitting node, with the objective to discover the maximum possible throughput (in practice, the LASR performance is also related to the mean packet generation rate). The random selection of the destination node is according to a uniform distribution: each node (except the originating node itself) has an equal probability of being selected as the destination. This means the network had full utilization at all times: there is never a TDMA time-slot that passes without a transmission, either to forward a protocol or user-data message or to originate a new user-data message. Each vehicle is equipped with an FAU dual-purpose acoustic modem (DPAM). Every modem uses Frequency-Hopped, M-ary Frequency Shift Keying (FH-MFSK) modulation with convolutional coding [31]. Packets are fixed-size, carrying 32 source bytes each. Each transmission takes 2.65 s and has a guard time of 2.35 s, for a total TDMA time-slot duration of 5 s. The FER is determined at run-time using the FAU DPAM medium model [32], a stochastic model derived from the Nakagami model, which considers channel geometry, fading characteristics, background noise, bottom type, modulation, and error coding. The network simulation tool was developed at FAU and is described in detail in [32, 33]. The best-case conditions for communication are when Nakagami-m is 2.0 and noise PSD is -55dB/√ Hz, the worst-case when Nakagami-m is 1.5 and noise PSD is 65dB/√Hz.7.2. Graph Methodology There are two graphed network metrics: messages-delivered versus range and message success ratio. These metrics measure different aspects of the network performance: messages-delivered measures throughput, success ratio measures reliability. Note that every message size is fixed to 32 bytes, so that the message-based analysis can be easily converted to a byte-based analysis. The graphs count as delivered or successful only unique user-data messages that reach the intended destination. User-data messages which never reached their destination, duplicate user-data messages received at the destination and protocol-only messages are not counted as delivered or successful. The uncounted messages are the protocol's message overhead. The messages-delivered graphs show the total number of originated user-data messages that are successfully delivered versus the distance between the originating node and the delivery node at the time of message origination. It does not consider protocol messages (e.g., route requests and route replies) and counts only messages containing user data. The successful delivery of a protocol message is not counted towards messages-delivered, so in general, the greater a protocols message overhead, the lower its messages-delivered count. These graphs provide a measure of throughput versus range. The messages-delivered graphs should be consulted if throughput is of primary importance, especially if the loss of packets can be tolerated. The delivery success ratio graphs show the ratio of user-data messages successfully delivered to user-data messages originated. Again, only user-data messages are considered. This ratio is graphed versus the same distances as the messages-delivered graphs. Messages still in the network when the simulation ends are considered lost, and so reduce the success ratio. This metric provides a measure of reliability versus range, that is, the probability that a user-data message sent over a given range will eventually be delivered. The success ratio graphs should be consulted if assured delivery is of primary importance, especially if a loss of throughput can be tolerated. Note that it is not valid to assume that delivering a greater volume of messages implies that messages are also delivered with greater reliability, or vice versa. They are commonly inversely related because increasing the delivery reliability generally requires increasing protocol overhead, which reduces the total number of messages that can be delivered for a given network bandwidth. A protocol with little overhead may be able to send a tremendous number of user-data messages, losing most but still delivering a large number. On the other hand, a protocol with large overhead may be able to send only a few user-data messages, but may deliver almost all of them. These metrics both count messages, not bytes. Larger packets would likely increase byte throughput but are also likely slightly decrease both messages-delivered and message success ratio because larger packets would take longer to transmit, thus lengthening the TDMA window, and would probably increase the FER of the links.

VII. CONCLUSION

In this paper we discussed introductory part of Shallow water acoustic network, its different architectures-Two dimensional underwater sensor network and three dimensional underwater sensor networks. Also we compare underwater acoustic network with the terrestrial sensor network and found challenges for implementing under water sensor network. Underwater acoustic communications are mainly influenced by path loss, noise, multi-path, Doppler spread, and high and variable propagation delay. Over the next decade, significant improvements are anticipated in the design and implementation of shallow water acoustic networks as more experience is gained through at-sea experiments and network simulations.

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