Underwater Sensor Networks: a Feasibility Study

Diorgenes Penteado, Aloysio C. P. Pedroza, Luís Henrique M. K. Costa
UFRJ – COPPE – PEE
Grupo de Teleinformática e Automação
Rio de Janeiro, RJ, Brazil 21.945–470
Email: {diorgenes, aloysio, luish}@gta.ufrj.br

***Abstract*—Underwater sensor networks (UWSN) are considered to be feasible and suitable for several applications. However, the characteristics of the acoustic channel must be taken into account on the evaluation of the application feasibility. The acoustic channel imposes severe limitations to the communication, such as low bandwidth, low data rates and short practical transmission ranges. Applications with fixed nodes and with short data packets generated at low rates, are suited to this class of network. A possible application taking these factors into account is the sea currents monitoring. This work presents an analysis of the feasibility of this kind of application.**

I. Introduction

Although covering more than 70% of the Earth surface the oceans are not well known, due to its dimensions, difficulties of oceanographic data acquisition and the high costs of maritime operations. Nervertheless, there is an increasing interest on oceanographic data, due to its influence on the weather, fishing, navigation, biology, ecology and support for petroleum resources offshore exploration.

The traditional approach for ocean monitoring and data acquisition is based on several sensors gathered in an apparatus operated with batteries. This apparatus is deployed in the ocean bottom in the place of interest. It records data during some programmed time, which may last several months. At the end of the mission the apparatus is recovered to have its data uploaded, processed and analyzed.

This way of data acquisition is useful, has been widely applied and represents the source of most of oceanographic data nowadays available. But it has severe drawbacks: it is limited to one point of survey, prevents monitoring the health of the sensor itself and of the data quality during the mission. Moreover, this equipment has limited storage capacity, the acquisition parameters must be established at deployment time and are unchangeable until the apparatus recovery.

A way to overcome these difficulties is the use of Underwater Sensor Networks (UWSN).

II. Underwater Sensor Networks

UWSN are based on nodes equipped with sensors and acoustic modems [1]. Figure 1 shows a possible architecture. The nodes can communicate with each other to send their own data, and forward data from other nodes, to a sink node. This sink node has two acoustic modems, one to communicate with the sensor network and the other to communicate with a gateway on the sea surface. This gateway has a radio link to a land station, which may monitor and control the data acquisition of all nodes in real time [2]. If the land station is connected to the internet, the UWSN data will be available worldwide.

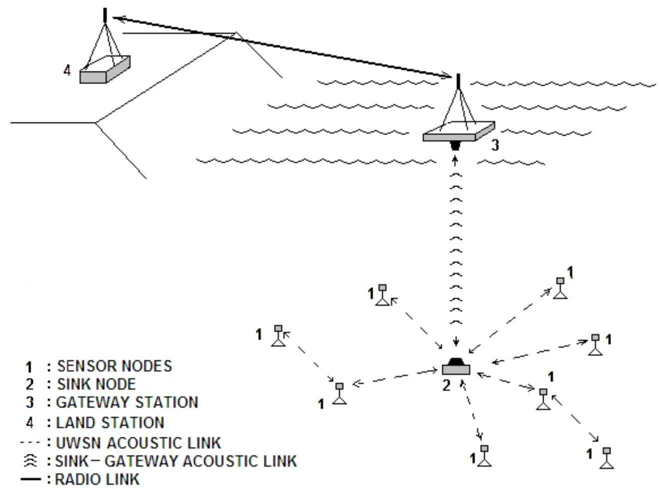

Fig. 1. An UWSN possible architecture.

Although underwater communication may be accomplished using electromagnetic or optical waves, these methods are unfeasible for practical UWSN. Due to signal attenuation, electromagnetic transmission through salty water only propagates at long distances with low frequencies. This implies on large antennas and high power consumption.

For optical transmission the limitation relies on the short range achievable, due to light absorption and scattering in water. Moreover, even at short distance, optical communication requires high precision and stable alignment source-receiver, dificult to achieve in undewater environment. Thus, the practical way to implement UWSN is through acoustic communication [3].

Nevertheless, the acoustic channel has some characteristics that limit the UWSN applications, such as low and variable propagation speed, low and distance dependable bandwidth and high power consumption. These limitations should be taken into account on the application feasibility analysis.

A. Underwater acoustic transmission

The sound speed in the water is about 1500 m/s, more than four times faster than the speed of sound in the air, but five orders of magnitude smaller than the speed of electromagnetic waves in the air. This low speed propagation implies on high latency on acoustic communication (approximately 0.67 s/km). Furthermore, the sound speed in sea water is variable, depending on pressure (depth), density, temperature and salinity [4].

Due to the sound absorption loss, the bandwidth and the center frequency of the acoustic channel are variable, decreasing with the distance. Table I shows this relationship [5]. This limitation restricts the useful source-destination distance to a few kilometers and the transmission frequencies to less than 30 kHz. This implies on low transmission rates, typically lower than 10 kbps [6].

Moreover, the acoustic communication is affected by noises, such as reverberations caused by the transmission reflections in the sea bottom and sea surface, wind, fishes, sea surface turbulence, and human-made noises, such as shipping and off-shore activities [5].

Also, as the underwater acoustic signal is based on mechanical waves of alternating compressions and rarefactions of the water, its transmission requires much more power than the equivalent terrestrial electromagnetic transmission. Furthermore, the power necessary to transmit the acoustic signal is much higher than the needed for the reception [7]. Table II shows typical values of acoustic and electromagnetic transmission powers [8].

These acoustic transmission characteristics imposes some challenges to UWSN implementation [9]. One of the most important is the Medium Access Control (MAC) protocol. The nodes are battery operated. The battery recharge in the sea bottom is almost unfeasible and its replacement is a very difficult and expensive operation. Therefore, transmission losses caused by message collisions must be avoided to prevent waste of energy and to provide a long term operation to the network nodes.

Moreover, due to the high latency of the communication channel, the medium access control for UWSN is a challenge. Several protocols have been proposed to overcome this limitation [10]. Several of these proposals are based on terrestrial sensor networks and are not, in general, suited to UWSN due to its dependance on high synchronization of nodes. Due to the acoustic transmission latency and to the oscillator clock drift, the synchronization of network nodes is difficult to achieve, limiting the feasibility of the proposed protocols.

Nevertheless, one of the most simple MAC protocol that may be used on UWSN is the TDMA (*Time Division Multiple Access*), as shown in Figure 2. It is accomplished by cyclic assignment of a time slot for the transmission of each network node. Each time slot must be separated from each other with a *time guard interval*, large enough to prevent transmissions overlapping. Also, for the efficiency of this protocol, a minimal level of synchronization through the network should be guaranteed.

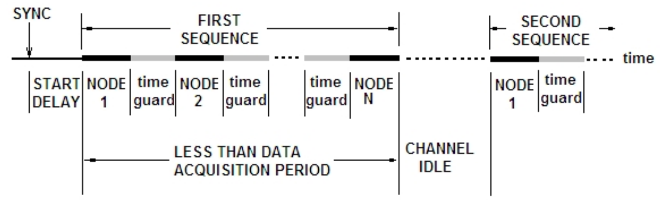

Fig. 2. TDMA scheduling.

B. Synchronization of nodes

Very precise synchronization of nodes in an UWSN is difficult to achieve. For long term network operation, the internal clock of nodes drifts and may not be used for high precision synchronization purposes. On the other hand, the high transmission latency and energy consumption restrictions prevents the development of efficient protocols to precisely synchronize the nodes of an UWSN.

A rough but stable and reliable synchronization – because based on astronomical events – may be accomplished with the periodic tides. Over a reasonably large area – tens of kilometers – one may consider that the tide variation effect is the same and may be observed with small delays from all nodes of an UWSN. This delay is due to the *tidal wave* velocity – the tide in equator travells from East to West at a velocity of approximately 40.000 km/day. Within a range of 50 kilometers close to the equator line one may consider that this delay is less than 1 minute. Anyway, this delay may be computed, taking into accounto that the nodes are fixed and the coordinates of all nodes of the UWSN are known.

The tide variation may be monitored in real time by all nodes of an UWSN through a simple pressure measurement. It is possible to accurately measure changes of 10 centimeters of tide at a depth of 1000 meters. The nodes can get a tide sample each minute to monitor the tide *tendency*. Each sample will be approximately equal to the average of several pressure measurements over one minute, to filter the waves effect. Through an algorithm using these samples, the nodes can synchronize their own clock to the events of high and low tides with a precision of approximately one minute.

TABLE I
BANDWIDTH OF THE ACOUSTIC CHANNEL AS FUNCTION OF DISTANCE.

	Range [km]	Bandwidth [kHz]
Very long	1000	less than 1
Long	10-100	2-5
Medium	1-10	approximately 10
Short	0.1-1	20-50
Very Short	less than 0.1	greater than 100

TABLE II
NODE POWER CONSUMPTION.

State	Underwater	RF Sensor	RF Computer
TX	50 W	80 mW	2.24 W
RX	3 W	30 mW	1.35 W
Idle	80 mW	30 mW	1.35 W

Most of the sea parameters (pressure, temperature, salinity, sea currents) change slowly. Thus, this precision may be sufficient for many applications of UWSN, especially for long term missions, for which the internal clock oscillator drift becomes significant.

III. Sea current measurement, a feasible UWSN application

One of the most used equipment to measure sea currents is known as ADCP (*Acoustic Doppler Current Profiler*). It is based on the analysis of Doppler effect of sound reflections on suspended particles in moving water. This equipment may be attached to the sea bottom and programmed to sample the sea current at fixed intervals, until it is recovered to have its data uploaded to be processed and analysed. An useful sampling interval for this data acquisition is one hour. Each of these samples is coded into a data packet, typically with less than one kbyte. These parameters reveals that this application is feasible using an UWSN.

Considering a transmission rate of 5 kbps – a typical acoustic modem data rate – each node needs only 1.6 seconds of the channel time to transmit its data packet (1 kbyte). As the data packet interval is 1 hour, there is enough time to schedule a TDMA with *time guard interval* large enough to avoid collisions. The acoustic channel may be idle most of the time. Also, this high ratio between packet interval generation and packet transmission time allows great scalability for the application and large margin for the routing protocol overhead.

A possible architecture for this application is a sink node receiving data from nodes deployed around it. The sink node communicates acoustically with the underwater network and with a sea surface gateway. The gateway makes the connection between a land station and the UWSN nodes. The nodes are attached to the sea bottom in fixed positions and transmit their data sequentially, in a TDMA scheme, directly to the sink node, if close enough, or through a multi-hop routing protocol, if needed. The synchronization of the UWSN nodes may be accomplished with the scheme of tide monitoring described before.

As the bandwidth decreases with the distance, short range transmissions with multiple hops are more efficient than larger one-hop transmission [11]. This implies on the necessity of routing protocols. The issue of UWSN routing protocol is still an open question. Nevertheless, due to energy saving restrictions and to the low rate of changes expected in the architecture, the routing protocol for this class of network must be based on the reactive ones, such as AODV (*Ad hoc On-demand Distance Vector*) [12] or DSR (*Dynamic Source Routing*)[13]. This kind of routing protocol only searches for a new path when a message must be forwarded to a node with unknown route, saving energy avoiding unnecessary route discoveries and frequent routing table maintenance.

IV. Conclusion

This work presented some important issues to be taken into account on a feasibility analysis for UWSN applications. We showed the feasibility of this class of network to monitor/register sea currents using ADCP equipments. The short length packets and the low data rate generated from this application make it suited to UWSN, even taking into account a conservative transmission data rate, such as the nowadays available acoustic modems (5 kbps). The high ratio between packet interval generation and packet transmission time allows the use of a TDMA scheme as Medium Access Control protocol. We have also proposed a method to get a rough, but stable and reliable synchronization scheme with tide monitoring.

Acknowledgment

The authors would like to thank to Petroleo Brasileiro SA for its support with Diorgenes Penteado's travel expenses and CAPES and CNPq for partially funding this research.

References

[1] E. Sozer, M. Stojanovic, and J. Proakis, "Underwater acoustic networks," *Oceanic Engineering, IEEE Journal of*, vol. 25, no. 1, pp. 72–83, 2000.

[2] I. F. Akyildiz, D. Pompili, and T. Melodia, "State of the art in protocol research for underwater acoustic sensor networks," *SIGMOBILE Mob. Comput. Commun. Rev.*, vol. 11, no. 4, pp. 11–22, 2007.

[3] L. Lanbo, Z. Shengli, and C. Jun-Hong, "Prospects and problems of wireless communication for underwater sensor networks," *Wirel. Commun. Mob. Comput.*, vol. 8, no. 8, pp. 977–994, 2008.

[4] R. Urick, *Principles of Underwater Sound*. McGraw-Hill, 1983.

[5] I. Akyildiz, D. Pompili, and T. Melodia, "Underwater acoustic sensor networks: research challenges," *Ad Hoc Networks*, vol. 3, no. 3, pp. 257–279, 2005.

[6] M. Stojanovic, "Underwater acoustic communications," in *Electro/95 International. Professional Program Proceedings.*, 1995, pp. 435–440.

[7] J. Partan, J. Kurose, and B. N. Levine, "A survey of practical issues in underwater networks," in *WUWNet '06: Proceedings of the 1st ACM International Workshop on Underwater Networks*. New York, NY, USA: ACM, 2006, pp. 17–24.

[8] I. Kurtis B. Kredo and P. Mohapatra, "A hybrid medium access control protocol for underwater wireless networks," in *WuWNet '07: Proceedings of the second workshop on Underwater networks*. New York, NY, USA: ACM, 2007, pp. 33–40.

[9] J. Heidemann, W. Ye, J. Wills, A. Syed, and Y. Li, "Research challenges and applications for underwater sensor networking," in *In IEEE Wireless Communications and Networking Conference, Las Vegas*, 2006.

[10] H. Doukkali and L. Nuaymi, "Analysis of MAC protocols for underwater acoustic data networks," *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, vol. 2, pp. 1307–1311 Vol. 2, May-1 June 2005.

[11] M. Stojanovic, "On the relationship between capacity and distance in an underwater acoustic channel," in *Proc. First ACM International Workshop on Underwater Networks (WUWNet), Sept*, 2006.

[12] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *WMCSA '99: Proceedings of the Second IEEE Workshop on Mobile Computer Systems and Applications*. Washington, DC, USA: IEEE Computer Society, 1999, p. 90.

[13] D. Johnson, D. Maltz, J. Broch *et al.*, "DSR: The Dynamic Source Routing Protocol for Multi-Hop Wireless Ad Hoc Networks," *Ad Hoc Networking*, vol. 5, pp. 139–172, 2001.