Ramón Doallo
Manuel Arenaz
Patricia González (eds.)

XX Jornadas de Paralelismo

A CORUÑA · 16-18 DE SEPTIEMBRE DE 2009

Actas de las
XX Jornadas de Paralelismo

A Coruña, 16,17 y 18 de septiembre de 2009

Organiza:
Grupo de Arquitectura de Computadores
Universidade da Coruña

EDITORES:

Ramón Doallo Biempica
Manuel Arenaz Silva
Patricia González Gómez

ACTAS DE LAS XX JORNADAS DE PARALELISMO

ISBN: 84-9749-346-8

Depósito legal: C 2318-2009

Edita: Servizo de Publicacións, Universidade da Coruña
http://www.udc.es/publicaciones c/e: publica@udc.es

Imprime: Macrom. Tel. 981 135 577
http://www.macrom.es c/e: macrom@macrom.es

XX JORNADAS DE PARALELISMO

Comité de coordinación

Ramón Beivide Palacio (UC)
Jesús Carretero Pérez (UCIII)
José Duato Marín (UPV)
Inmaculada García Fernández (UAL)
Antonio Garrido del Solo (UCLM)
Emilio López Zapata (UMA)
Emilio Luque Fadón (UAB)
Pedro de Miguel Anasagasti (UPM)
Alberto Prieto Espinosa (UGR)
Francisco José Quiles Flor (UCLM)
Ana Ripoll Aracil (UAB)
Francisco Tirado Fernández (UCM)
Mateo Valero Cortés (UPC)
Victor Viñals Yúfera (UZ)

Comité Organizador (UDC)

Ramón Doallo Biempica
Patricia González Gómez
Manuel Arenaz Silva
Margarita Amor López
Diego Andrade Canosa
Iván Díaz Álvarez
Basilio B. Fraguela Rodríguez
Gonzalo Iglesias Aguiño
Guillermo López Taboada
María J. Martín Santamaría
Emilio Padrón González
Xoán C. Pardo Martínez
Gabriel Rodríguez Álvarez
José R. Sanjurjo Amado
Juan Touriño Domínguez

Entidades Patrocinadoras

Vicerreitorado de Investigación. Universidade da Coruña
Ministerio de Ciencia e Innovación. Gobierno de España
Consellería de Educación e Ordenación Universitaria. Xunta de Galicia
Concello da Coruña
Red Gallega de Computación de Altas Prestaciones
Red Mathematica Consulting & Computing de Galicia
HP España
Bull España

Entidades Colaboradoras

Facultade de Informática. Universidade da Coruña
Oficina de Cursos e Congresos. Universidade da Coruña
Turismo Coruña
Turgalicia

Entidades Organizadoras

Grupo de Arquitectura de Computadores. Universidade da Coruña
Sociedad de Arquitectura y Tecnología de Computadores (SARTECO)

Presentación

Quisiéramos aprovechar estas líneas para daros la bienvenida a las XX Jornadas de Paralelismo, que tienen lugar en A Coruña entre los días 16 y 18 de septiembre de 2009. La celebración de este evento supone una vez más, y ya van veinte, el encuentro de numerosos investigadores para intercambiar experiencias y presentar ponencias que reflejan su trabajo en el ámbito de la arquitectura de sistemas de computadores.

El número de asistentes a las Jornadas de Paralelismo ha ido creciendo con cada nueva edición. En este año se han recibido 119 artículos, y el número de participantes con el que contamos asciende a más de 170. Finalmente el programa ha quedado estructurado en más de 20 horas de trabajo, repartidas en 24 sesiones que cubren los temas siguientes: tecnologías grid y plataformas distribuidas; aplicaciones; redes y comunicaciones; arquitecturas, algoritmos y aplicaciones sobre aceleradores hardware; arquitecturas de procesador, multiprocesadores y chips multinúcleo; algoritmos y técnicas de programación paralelas; compilación para sistemas de altas prestaciones; docencia en Arquitectura y Tecnología de Computadores (ATC); y evaluación de prestaciones.

Contamos en esta edición con dos conferencias plenarias, impartidas por los profesores Mark Baker, de la Universidad de Reading (Reino Unido), sobre Cloud Computing y sus servicios, y Enrique Quintana-Ortí, de la Universitat Jaume I, sobre técnicas superescalares en la construcción de bibliotecas numéricas para procesadores multinúcleo y GPUs. Además tendremos la oportunidad de asistir a dos sesiones técnicas impartidas por HP España y Bull España, y a la asamblea de la Sociedad de Arquitectura y Tecnología de Computadores (SARTECO).

El programa de las Jornadas incluye también dos mesas redondas sobre asuntos que actualmente están provocando un intenso debate entre la comunidad universitaria. La primera de ellas trata sobre cómo trasladar las fichas del Grado y Master en Informática a los nuevos planes de estudio. La segunda mesa redonda abordará el tema de la transferencia de conocimiento universidad-empresa.

No queremos acabar esta presentación sin mostrar nuestro agradecimiento a todos los organismos y entidades, públicos y privados, que han colaborado en el desarrollo de estas Jornadas, en concreto, a la Universidade da Coruña, al Concello de A Coruña, a la Xunta de Galicia, al Ministerio de Ciencia e Innovación, a la Red Gallega de Computación de Altas Prestaciones, a la Red Mathematica Consulting & Computing de Galicia, a las compañías HP y Bull, y finalmente a todos los miembros del Grupo de Arquitectura de Computadores de la UDC que han brindado su apoyo para la organización de este congreso.

Finalmente, queremos agradecer vuestro interés y participación en estas XX Jornadas de Paralelismo, que esperamos cumplan con vuestras expectativas.

Comité Organizador de las
XX Jornadas de Paralelismo
A Coruña, 16-18 de Septiembre de 2009

Índice

Algoritmos y técnicas de programación paralelas

Aplicaciones

Arquitecturas de procesador, multiprocesadores y chips multinúcleo

Arquitecturas del subsistema de memoria y almacenamiento secundario

Arquitecturas, algoritmos y aplicaciones sobre aceleradores hardware

Compilación para sistemas de altas prestaciones

Computación de altas prestaciones sobre arquitecturas paralelas heterogéneas

Docencia en ATC

Evaluación de prestaciones

Redes y comunicaciones

Tecnologías grid y plataformas distribuidas

Analyzing the behavior of acoustic link models in underwater wireless sensor networks

Jesús Llor, Esteban Torres, Pablo Garrido, and Manuel Pérez Malumbres[1]

***Abstract*—In the last years, wireless sensor networks have been proposed for their deployment in underwater environments where a lot of applications like aquiculture, pollution monitoring and offshore exploration would benefit from this technology. 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). So, the design of appropriate network architecture for UWSNs is seriously hardened by the specific characteristics of the communication system. In this work we analyze several model proposals of acoustic channels for their use in underwater wireless sensor network architectures. For that purpose we have implemented the acoustic channels using the OPNET Modeler tool in order to perform an evaluation of their behavior under different network scenarios. Finally, some conclusions are drawn showing the impact on UWSN performance of different elements of channel model and particular specific environment conditions.**

***Keywords*—Underwater acoustics, Acoustic channel model, Wireless sensor networks, Network simulation.**

I. INTRODUCCIÓN

WIRELESS networking technologies have experienced a considerably development in the last fifteen years, not only in the standardization areas but also in deployment and commercialization of a bunch of devices, services and applications. Among this plethora of wireless products, wireless sensor networks are showing an incredible boom, being one of the technological areas with greater scientific and industrial development pace [1]. Recently, wireless sensor networks have been proposed for their deployment in underwater environments where a lot of applications like aquiculture, pollution monitoring and offshore exploration would benefit from this technology [2].

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) [3].

Major challenges in the design of underwater acoustic networks 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.

Basically, an UWSN is formed by the cooperation among several nodes that establish and maintain a network through the use of bidirectional acoustic links. Every node is able to send/receive messages from/to other nodes in 2 the network, and also to forward messages to remote destinations in case of multi-hop networks. The most common way to send data in underwater environments is by means of acoustic signals, just like dolphins and whales use to do for communicating between them. Radio frequency signals have serious problems to propagate in sea water as shown in [4], being operative for radio-frequency only at very short ranges (up to 10 meters) and with low-bandwidth modems (tens 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) and blue-green wavelengths.

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 underwater sound propagation speed is around 1500 m/s (5 orders of magnitude slower than radio signals), 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' behavior, being mandatory the use of forward error correction codes (FEC); (3) as frequency increases, the attenuation observed in the acoustic channel also increases, being this a serious bandwidth constraint; (4) multipath interference in underwater acoustic communications is severe due mainly to the surface waves or vessel activity, being a serious problem to attain good bandwidth efficiency. In this work, we are

---

[1] All authors are with the Dept. of Physics and Computer Engineering at the Miguel Hernandez University (Spain). E-mails: {jllor, esteban.torres, pgarrido, mels}@umh.es

going to study an analyze underwater acoustic link models proposed in the literature in order to understand and evaluate the communications constraints related to the special characteristics of communication medium (ocean) and acoustic signals.

In this work, we are going to study an analyze underwater acoustic link models proposed in the literature in order to understand and evaluate the communications constraints related to the special characteristics of communication medium (ocean) and acoustic signals. We have chosen the OPNET simulation tool to develop the corresponding models. After validating our implementations with the results published by the authors of those models, we have analyzed the contributions that each model has introduced, in order to propose a more detailed one.

The paper is organized as follows: In section 2, we perform a review of related work about underwater acoustic link modeling. In section 3 we describe step-by-step the proposed acoustic model based on the fundamentals of underwater acoustic theory and proposals extracted from other authors. In section 4, we describe the model implementation, network scenarios and the simulation results obtained. And, finally, in section 5 some conclusions and future work are drawn.

II. RELATED WORK

Several works in the literature propose models for an acoustic underwater link taking into account several environment parameters as salinity degree, temperature, depth, environmental noise, etc. with different detail levels. Most of these proposals are validated by means of simulation tools, being some of them publicly available for common simulation tools like NS-2 [5] and Opnet Modeler [5][6]. However, other proposals only give some hints about the complete model, so we have to build the model from scratch and validate it by means of the simulation results provided by authors.

One of the first implemented models was proposed by Sozer et al [9]. They propose a simple physical acoustic model based in the Opnet radio model but using the fundamentals of underwater sound physics found in previous works [7][8]. In this work some parameters like node depth were not considered.

In Coelho [10], a simple physical layer model was proposed to evaluate the performance of UWSN considering two different MAC protocols: a contention based with collision avoidance (CSMA-CA), and a contention free one (ALOHA). The physical layer does not consider any propagation loss, neither the influence of node depth. On the other hand, Leopoldo [11] proposes a more detailed physical layer model based on the Monterrey-Miami Parabolic Equation (MMPE) [13] in order to better predict the underwater acoustic propagation.

One of the most complete models is described in [12], in which features not implemented in the previous works are introduced so as to calculate the transmission loss, such as (1) variable sound propagation that depends on the environmental conditions, (2) the influence of the waves or wind drift the and objects that can be found in the surroundings (e.g., ship, biologic activity, seafloor shape, etc.).

Most of the works enumerated above, include an upper layer (MAC protocol) and one or more traffic generators in order to verify the correctness of the physical model and also measure its impact on network performance metrics (throughput, end-to-end delay, etc.).

As the result of reviewing and comparing the referred methods, lack of accuracy has been found out when modeling the real world conditions. Obviously, this have a strong influence in the results obtained, leading to serious differences between the different works. The most noteworthy reasons are: (1) do not consider the depth of the nodes, this which is an essential factor at the time of when calculating the transmission loss; (2) do not consider the movement of the nodes, which is not real in the underwater environment due to the continuous movement of the sea water. Adding mobility to the nodes has an increase of the computational time in calculating the list of reachable nodes all the time of the communication; (3) do not consider that the environmental conditions are very variable. The underwater network is a highly dynamic environment as many features can have an effect on it, like underwater biology (whales, fish banks, etc.), the changing climate of the surface, the sea tides, ship and human activity, etc.

All of these factors should be considered whenever a node tries to make a communication to another node. As in the case of mobility this implies a greater computational load each time we run the simulations, the solution brought to date is to calculate the list of reachable nodes at the beginning of the simulation and assuming that the conditions will not change during the period that the simulation lasts.

So, despite of all the previous works, there is still the need to seek a complete model to simulate and define more realistic results for underwater data communications.

III. UNDERWATER ACOUSTIC LINK MODEL

In this section we are going to summarize the fundamentals of underwater acoustic propagation and, at the same time, introduce the main blocks of the acoustic link model reusing or adapting parts of other models, in order to build a more detailed underwater acoustic link model.

The sound, according to the description by Urick [7], is 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 has a great impact on the sound speed, ranging from 1450 to 1540 m/s [8].

The transmission loss (TL) is defined as the diminution 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. In [7] [8], the signal transmission loss is defined as:

$$\alpha = \frac{0.11 f^2}{1+f^2} + \frac{44 f^2}{4100+f^2} [dB/Km]$$
$$SS = 20 \log r$$
$$TL = SS + \alpha r \ x \, 10^{-3} \qquad (1)$$

Where f is frequency in kHz, r is the range in meters, SS is the spherical spreading factor and α is the attenuation factor. We will use a more accurate expression for the attenuation factor, the one proposed by Sozer [9]:

$$\alpha = \frac{0.11 f^2}{1+f^2} + \frac{44 f^2}{4100+f^2} + 2.75 x 10^{-4} f^2 + 0.003 \qquad (2)$$

On the other hand, the Monterrey-Miami Parabolic Equation (MMPE) [13] has been introduced in the model to better predict the underwater acoustic propagation. With the MMPE model, the underwater sound propagation is modeled taking into account all effects of surface waves, seafloor and salinity changes are considered to calculate the underwater sound propagation. This model can be considered as an approach to the Helmholtz's equation (wave equation), which is based on a Fourier algorithm.

The obtained coefficients from MMPE are used for a more realistic prediction of the transmission loss. It is necessary to be aware that calculating these coefficients has a high computational cost. So, network simulations would require too much time to complete, being necessary to perform simplifications to the way those coefficients are computed. In order to determine the expression for the propagation loss we choose the one based on the MMPE model, introduced in [11]:

$$PL(t) = m(f, s, d_A, d_B) + w(t) + e() \qquad (3)$$

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 data generated by MMPE model [14].
f: frequency of transmitted acoustic signals in kHz.
d_A: sender depth in meters.
d_B: receiver depth in meters.
r: horizontal distance between A and B nodes (called range in MMPE model).
s: Euclidean distance between A and B nodes.
w(t): periodic function to approximate signal loss due to wave movement.
e(): signal loss due to random noise or error.

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 [7] and is modeled to have a maximum of 20dB at the furthest distance [3]. This function is calculated by the following equation:

$$e() = 20\left(\frac{s}{s_{\max}}\right) R_N \qquad (4)$$

Where:

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

Taking into consideration the environmental conditions introduced by Harris [12], an improvement has been introduced when calculating e(), in order to reduce the randomness and introduce more realistic noise sources. Based on [12] we propose that the major factors contributing to the underwater environmental noise are ship activity, and thermal noise. Notice that in Leopoldo's model [11] the wind and the turbulence is already considered when introducing the wave effect. So, the ship activity and thermal noise sources are added to the physical layer, and as a consequence, we reduce the high degree of randomness of expression (4). So, in order to model the environmental noise, we propose the following expression:

$$N(f) = N_t + N_s$$
$$10 \log N_s(f) = 40 + 20(ship - 0.5) + 26 \log f - 60 \log(f + 0.03)$$
$$10 \log N_{th}(f) = -15 + 20 \log f \qquad (5)$$

Where N_s is the noise due to shipping activity, ship parameter indicates the noise due to ship activity (ranges from 0 to 1) and N_{th} refers to the thermal noise. So, finally, the function e() stands as follow:

$$e() = 20\left(\frac{s}{s_{\max}}\right) R_N + N(f) \qquad (6)$$

After completely defining the proposed propagation loss, we have also to determine another characteristic parameter of underwater acoustic links: the sound propagation speed. There are several proposals to model the underwater sound propagation speed which is affected by several others like temperature, salinity and depth. For our purpose, we use the expression proposed in [7]:

$$c = 1449 + 4.6 \cdot t + 0.055 \cdot t^2 + 0.003 \cdot t^3 +$$
$$(1.39 - 0.012 \cdot t)(S - 35) + 0.017 \cdot d \qquad (7)$$

Where

t: temperature of water in Celsius degrees.
S: salinity of water in parts per million.
d: depth of node in meters.

IV. VALIDATION AND EXPERIMENTAL RESULTS

The implementation of the model described in previous section was mainly based on the models proposed by Coelho [10] and Leopoldo [11] with add-ons from other proposals, like Harris [12] that improves the environmental noise modeling, and [6] that provides a more accurate expression for calculating the sound propagation speed. We employed the OPNET Modeler Release 14.0 PL3 simulation tool to implement the model and defining the network scenarios to perform the corresponding simulation tests.

Firstly, we implemented the original proposals [10] and [11] so we could validate its functional behavior with the simulation results provided by the authors. After that, we introduced some changes in the model (as explained in previous section) in order to perform a global evaluation of our proposed model. For that purpose several network scenarios were defined and, also, we have implemented two simple MAC protocols (upper layers) to analyze the impact of acoustic links model parameters in the UWSN global performance.

A. Model Validation

With respect MAC protocols, we will use the Aloha (with explicit ACK) and CSMA-CA (a simple RTS-CTS-DATA –ACK with a contention back-off) versions found in [10] and [11].

We define a UWSN (shown at figure 1) topology with a group of sensor nodes generating background and non-periodic traffic. The relay nodes are responsible to forward the traffic from sensor nodes to the gateway node (also known as sink node), which receives the information from all sensor nodes in order to store or retransmit it to the offshore control station. In Table I, the spatial location of every node is defined.

In order to obtain reliable results we run every experiment 30 times. In Table II we summarize the default parameters used in simulations.

To validate the model, we perform several simulation tests from which we show the number of collisions and the average end-to-end delay. The results obtained in our implementation (figures 3 and 5) are very similar to the ones obtained by original author (figures 2 and 4), so we validate our implementation.

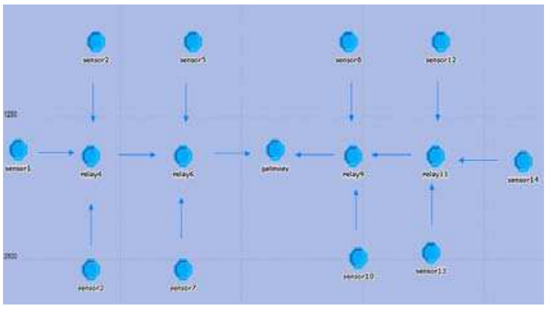

Fig. 1. Topology with several sensors, relays and one sink node.

TABLA I

NODES 3D POSITION.

Node	Depth	Pos X	Pos Y
Sensor 1	20	200	1550
Sensor 2	20	1000	600
Sensor 3	25	950	2600
Relay 4	10	950	1600
Sensor 5	25	2000	600
Relay 6	30	1900	1600
Sensor 7	15	1900	2600
Sensor 8	10	3600	600
Relay 9	15	3650	1600
Sensor 10	10	3700	2500
Relay 11	35	4500	1600
Sensor 12	12	4550	600
Sensor 13	5	4450	2450
Sensor 14	14	5400	1650
Gateway	5	2850	1550

TABLA II

DEFAULT SIMULATION PARAMETERS.

Parameters	Value
Data Frame Payload Size	1024 bits
Packet Time Generation	48,65,80,102,120,144,180,240,360,720
Propagation Threshold	80 dB
Propagation Speed	1500 m/s
Data Rate	1000 bits/s
Node Frequency	20 kHz
waveHeight	4 meters
waveLength	100 meters
wavePeriod	5 seconds

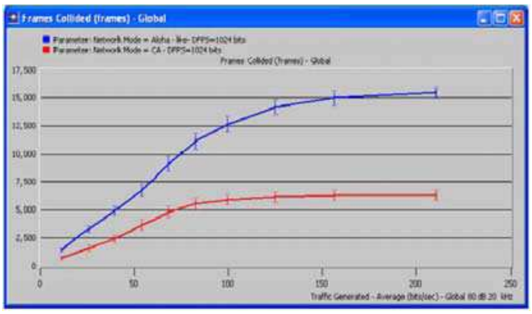

Fig. 2. Collisions vs. Load: Results from original authors.

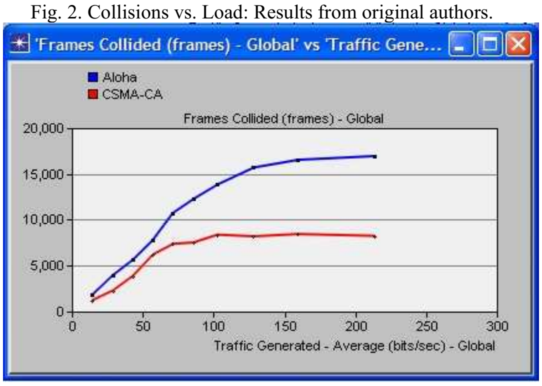

Fig. 3. Collisions vs. Load: Results from our implementation

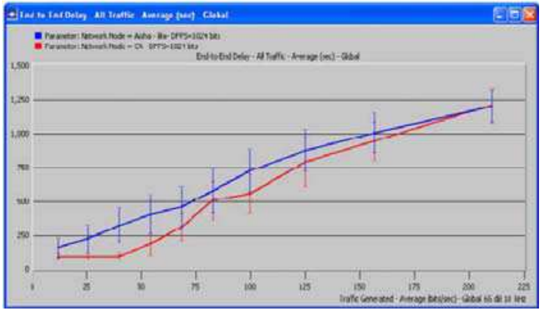

Fig. 4. Delay vs. Load: Results from original authors.

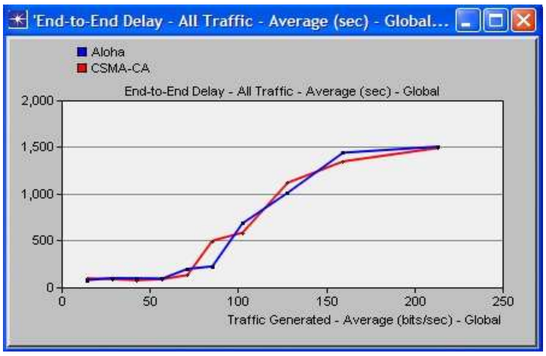

Fig. 5. Delay vs. Load: Results from our implementation.

In figures 2 and 3, the behavior of ALOHA and CSMA-CA protocols is the expected one, showing the effectiveness of CSMA-CA in reducing the number of collisions. In figures 4 and 5, CSMA-CA protocol gets better end-to-end delay from low to moderate traffic loads.

B. Proposed Model Evaluation

After running simulations, the new model performance evaluation results are compared with the Leopoldo's ones. The ship interaction is especially highlighted keeping constant the new parameters included for the new expressions. The rest of the parameters are the same of the previous simulations, except propagationSpeed that is obtained with the expression (7) and the following values: Salinity: 35 ppm, Temperature 10º C, the actual node depth value.

Firstly, we reproduce the same statistics that have been used in the validation. The MAC protocols are separated into two different graphs to emphasize the effect of shipping activity. The average end-to-end delay is not affected by the modeled ship activity interference, showing results very close to those shown at figure 5.

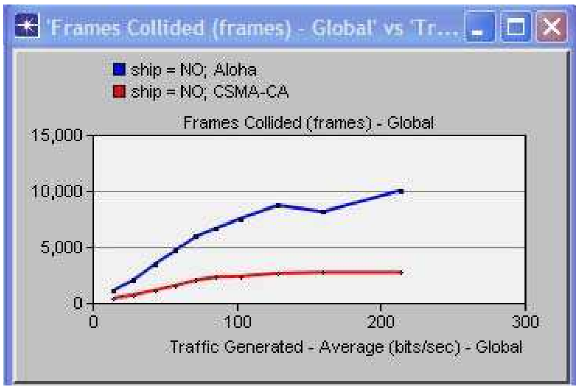

Fig. 6. Collisions vs. Load with no ship noise.

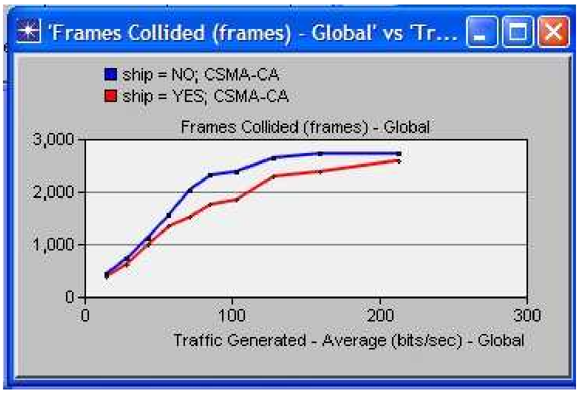

Fig. 7. Collisions vs. Load CSMA-CA

When comparing the collisions in both MAC Protocols, CSMA-CA gets better results as expected. In figure 7, we show the impact of ship activity noise in CSMA-CA collisions number. As it can be seen, there are less frames collided when the ship activity is included. This is due to the fact that as ship activity increases, the number of reachable neighbors from one node decreases (see expression (6)). Then, sensor nodes may lose their point-to-point communication with the nearest relay, so the overall network traffic load is reduced. This effect, explains the collision reduction found at figure 7.

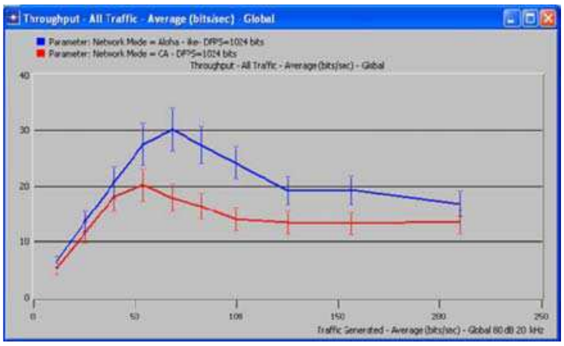

Fig. 8. Throughput vs. Load. Aloha (Blue), 1- CSMA-CA (Red) Original authors

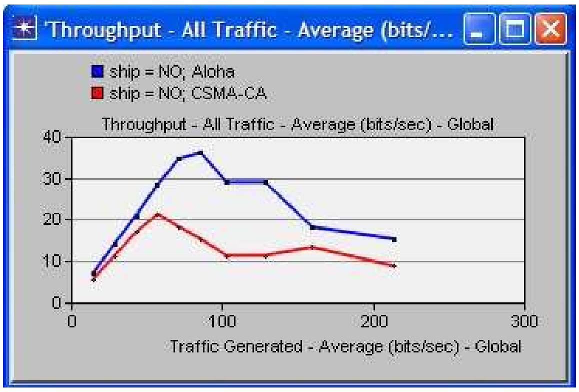

Fig. 9. Throughput vs. Load. no ship noise.

Figures 8 and 9 show network throughput results obtained by Leopoldo's model and our model proposal, respectively. The results of both models are nearly the same when there is no ship activity. These results prove that ALOHA gets better throughput performance than CSMA-CA, what it is just the opposite behavior than in terrestrial WSNs. The main reason behind this behavior is due to the signal propagation speed which is five orders of magnitude lower than radio waves, becoming inefficient protocols like CSMA-CA (RTS-CTS-DATA-ACK).

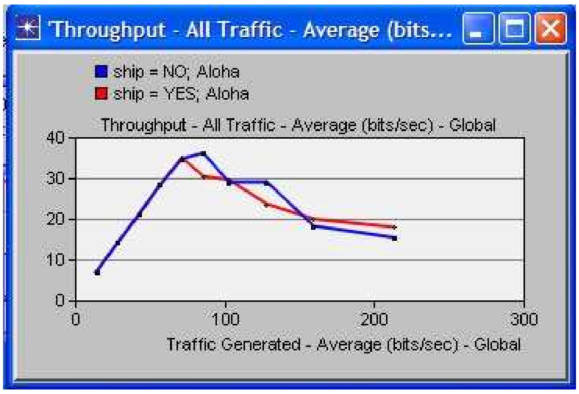

Fig. 10. Throughput vs. Load. Aloha.

In figure 10, we show the impact of ship activity noise in ALOHA network throughput. As it can be seen, the effect of ship activity noise slightly reduces the overall network throughput at high traffic loads. Similar results were obtained for CSMA-CA protocol.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have studied several underwater acoustic communication models in order to define a detailed model that emulates the characteristics of sound propagation in sea water as much realistic as possible. So, we can better define appropriate upper layer architecture for underwater wireless sensor networks as our target application.

On the other hand, we have verified that slight changes in propagation model can significantly affect the final results obtained by simulation. So, we think it is very important to determine a well-defined physical model, so simulation results of the overall network architecture may be useful for the deployment of real underwater sensor networks. In this paper we propose an underwater acoustic model based on the work of other authors in the literature. This model was validated against the original acoustic models by running experiments with the same scenarios and model parameters than those used by their authors. Also, preliminary evaluation results were shown verifying that they are coherent with the ones expected by the proposed model.

As future work, we will continue improving the model and better integrating it with the simulation tool so the dynamic of underwater environment is taken into account during the simulation. This will increase the quality of simulations and it will allow us to introduced network scenarios with node mobility patterns.

VI. ACKNOWLEDGMENTS

This work was supported by the Ministry of Science and Education of Spain under Project DPI2007-66796-C03-03.

VII. REFERENCES

[1] Akyildiz, F., Su, W., Sankarasubramaniam, Y., and Cayirci, E. Wireless sensor networks: A survey. Computer Networks, 38(4):393–422, 2002.

[2] Cui, J-H., Kong, J., Gerla, M. and Zhou, S. Challenges: Building scalable mobile underwater wireless sensor networks for aquatic applications. IEEE Network 3:12-18, 2006

[3] Akyildiz, F., Pompili, D., and Melodia, T. State of the Art in Protocol Research for Underwater Acoustic Sensor Network. Proceedings of the ACM International Workshop on UnderWater Networks (WUWNet), pp. 7-16, Los Angeles CA, September 25th, 2006.

[4] Schill, F., Zimmer, U.R, and Trumpf, J. Visible Spectrum Optical Communication and Distance Sensing for Underwater Applications. Proceedings of the Australasian Conference on Robotics and Automation. Canberra, Australia, 6-8 December 2004.

[5] The Network Simulator - http://www.isi.edu/nsnam/ns/

[6] OPNET Modeler v14.0 Reference Manual OPNET Technologies Inc. OPNET Modeler - http://www.opnet.com/

[7] Urick, Robert J., "Principles of Underwater Sound," 3rd Edition, Peninsula Pulishing, 1983.

[8] Brekhovskikh, L. and Lysanov, Yu "Fundamentals of Ocean Acoustics," Springer-Verlag Berlin Heidelberg New York, 1982

[9] Sozer, Ethem M., Stojanovic, Milica and Proakis, John g., "Design and Simulation of an Underwater Acoustic Local Area Network," Northeastern University, Communications and Digital Signal Processing Center, 409 Dana Research Building, Boston, Massachusetts, 1999

[10] Coelho, Jose, "Underwater Acoustic Networks: Evaluation of the Impact of Media Access Control on Latency, in a Delay Constrained Network," Master's Thesis (MS-CS), Naval Postgraduate School, Monterey, California, March 2005.

[11] Diaz-Gonzalez, Leopoldo, Master thesis," Underwater Acoustic Networks: An Acoustic Propagation Model for Simulation of Underwater Acoustic Networks," Naval Postgraduate School, Monterey, California, 2005

[12] Harris III, Albert F ,"Modeling the Underwater Acoustic Channel in ns2", NSTools '07, October 22, 2007, Nantes, France

[13] Smith, Kevin B., "Convergence, Stability, and Variability of Shallow Water Acoustic Predictions Using a Split-Step Fourier Parabolic Equation Model," Shallow Water Acoustic Modeling (SWAM'99) Workshop, 1999.

[14] S-Plus Version 7.0, Help Documentation, Insightful Corp. 2005.

[15] Van Dorn, W., "Oceanography and Seamanship," Dodd, Mead, New York,1974.