Modeling the Acoustic Channel for Simulation Studies

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LONG-TERM GOALS

Underwater acoustic communications, especially from a single point-to-point link perspective, have been studied extensively in the past few decades. Underwater networking issues have begun to attract the interest of researchers as well, and represent a fertile research area which can be expected to grow in the future. Bringing the study of acoustic communications systems to the networking level has the potential to open up new directions and to provide a means to make them much more powerful and useful. Many military and naval applications can be expected to greatly benefit from this paradigm shift.

The main goal of the proposed work is to develop channel modeling techniques to enable more detailed studies at the networking level. To this aim, we propose to start from existing data sets for point-to-point communications, in order to try and extract fundamental behaviors and model them in a way suitable for the simulation of more complex systems. This includes the integration of existing (as well as new) acoustic propagation modeling techniques into network simulators, the search for synthetic statistical models based on measured data, as well as the development of trace-based simulation techniques, and their validation and assessment.

OBJECTIVES

As the project started on 04/01/10, the reporting period covers the first five months of the effort. The main objective for the first six months was to gain a detailed understanding of the propagation phenomena that most affect underwater acoustic systems, and to identify the main sources of available experimental data that can be used for our purposes. This preliminary investigation is instrumental for the core research activities of the project, to be carried out during the rest of the first and through the second year, in which data analysis techniques will be used in order to identify key behaviors and to provide synthetic models for the acoustic channel, to be thoroughly validated against measured data.

APPROACH

The objective of the proposed research work is to develop simulation models able to correctly capture the behavior of acoustic propagation in underwater communication networks, while containing the proper level of detail that makes them realistic while still sufficiently lightweight for use in networking simulations.

The technical approach we proposed to adopt in the overall effort includes the following points: (i) deep interdisciplinary understanding of acoustic propagation environments and networking capabilities/requirements; (ii) identification and evaluation of the main PHY metrics that need to be used in networking studies; (iii) development of comprehensive simulation models that accurately reproduce the propagation characteristics of underwater channels, while also being suitable for use in networking studies; (iv) validation of the proposed models in the performance analysis of advanced communications and networking functionalities through detailed analysis, simulation, and experimentation.

In this first part of the project (five months), we mostly focused on point (i) above, and on starting some interactions with other research groups who can give us access to experimental datasets.

The current project team includes Prof. Michele Zorzi (PI), Prof. Gianfranco Pierobon (co-PI), Dr. Paolo Casari (post-doctoral researcher) and Ms. Beatrice Tomasi (Ph.D. student).

WORK COMPLETED

The focus of the work in these first five months of the project has been the following: (i) to develop some detailed understanding on acoustic propagation; (ii) to further develop our WOSS simulation framework; (iii) to interact with groups who may be able to give us access to experimental datasets which we can analyze.

Point (i) required some literature study as well as observations based on real data and on the output of detailed propagation software tools, e.g., Bellhop [BH]. Although we of course cannot claim we have become experts in ocean acoustics, which is an exceedingly complex topic, we are confident that our understanding of acoustic propagation phenomena is adequate for the tasks we need to accomplish in this project.

As to point (ii), we have rounded up a version of the World Oceans Simulation System (WOSS) [WOSS], which provides a handy interface to mediate between the well-known network simulator ns2 and the propagation simulation tool Bellhop. In general any network simulator takes care of managing high-level node behavior (adherence to protocol rules, mobility, on/off periods, position updates, and so forth), while delegating the management of transmission/reception events to a different part of the code or to external modules. In any event, the network simulator itself expects an output from channel signaling as to whether a transmission was successful or not, how much interference it created to (or received from) other nodes, and which node could correctly receive or overhear it. This entails a characterization of the attenuation that signals incur as they travel throughout the network.

WOSS is an instrument which provides exactly one such output, by triggering more realistic simulation of acoustic propagation through Bellhop. Since Bellhop needs environmental data, WOSS gathers this data given knowledge of the geographic position of the nodes in the world, as well as of the period of the year where network operations are assumed to take place. Such information is readily obtained from the network simulator. After that, WOSS queries ocean databases for environmental parameters such as a seasonal average of the sound speed profile, the sea bottom and surface waves profile, as well as the type of bottom sediments, and provides this data to Bellhop, which outputs an estimate of the transmission loss incurred by acoustic waves. Optionally, the user can ask WOSS to average the transmission loss over different realizations of the SSP (random surface wave generation is in the process of being implemented). New features have been recently implemented in WOSS. These allow, among other things, to include knowledge of the emission pattern of the transducer in use. The transducer itself can be chosen among a variety of commercial models of common use, covering many possible frequency bands. All of the above has been released in the public domain under an open source licence, and can be downloaded (along with proper documentation) from http://telecom.dei.unipd.it/ns/woss/

The interactions with other research groups and the search for datasets to be used in our analysis (point (iii)) have been mostly focused in four directions, namely, SeaWeb, NUS, WHOI and NURC.

Some preliminary contacts have been made with Prof. Joe Rice (Naval Postgraduate School) and Dr. Chris Fletcher (SPAWAR), both of the SeaWeb project, and with Prof. Mandar Chitre's group at the National University of Singapore (NUS). We are still discussing the possibility to access some of the datasets they gathered through multiple sea trials in the recent past. We have met Prof. Joe Rice in Venice last July, and will be having additional interactions. We also plan to meet NUS representative at ACM WUWNET at the end of September.

We are now interacting rather closely with Woods Hole Oceanographic Institution (WHOI). We are in contact with Dr. Jim Preisig, who has given us access to datasets obtained in some of his ONR-funded efforts. Beatrice Tomasi has just started a semester at WHOI as a visiting PhD student, and will be working with Jim on channel models, data analysis, and experiment design. Michele Zorzi and Paolo Casari will also be visiting WHOI in September. We believe that this collaboration with WHOI will lead to very good results.

Finally, we have a long-time relationship with the NATO Undersea Research Centre (NURC). We have been interacting heavily with them in the past two years, and have done some collaborative work on underwater protocol design and analysis, which is related to the present project. In addition, we participated in a sea trial campaign (SubNet09) in the Summer of 2009, and again in September 2010. Some details about the experimental results and some initial data analysis efforts are described in the next section.

RESULTS

The results obtained in the SubNet09 sea trials represent a very comprehensive dataset that we have started to analyze. Even though such results were not produced as part of the current effort, they currently represent the main starting point of our investigation. In the following, we provide some information about the experimental setting and some preliminary observations.

The experiments were performed off the coast of the island of Pianosa, Italy (42.585_N, 10.1_E), and spanned a period of about three and a half months, between May and September 2009.The testbed consisted of four hydrophones arranged at different depths in a vertical array (VA), and of three acoustic modems (all Teledyne-Low Frequency models [Tele]) placed on a tripod on the sea floor at a depth of 60, 70 and 80m, at different distances from the VA (1500m, 2200m and 700m, respectively). A scheme of the testbed is depicted in Figure 1 [OCEANS10]. The three transmitters have been labeled T1 (1500m from the VA, depth 60m), T2 (2200m from the VA, depth 70m) and T3 (700m from the VA, depth 80m). The hydrophones of the VA (named H1, H2 and H4 – hydrophone H3 was not working properly unfortunately), are placed at 20, 40 and 80m, respectively. Temperature sampling in the water column close to the VA was provided by a thermistor chain and, combined with a CDT measurement, allowed to derive the sound speed profile (see Figure 2).

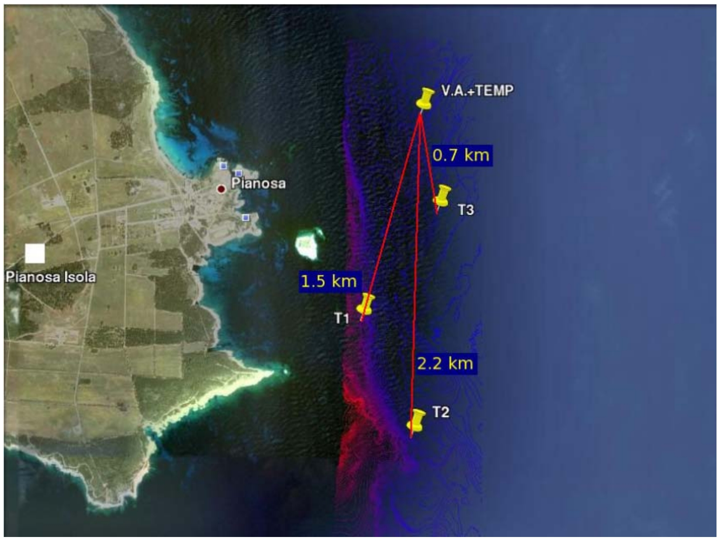


Fig. 1: A scheme of the testbed deployment off the coast of the Pianosa Island.

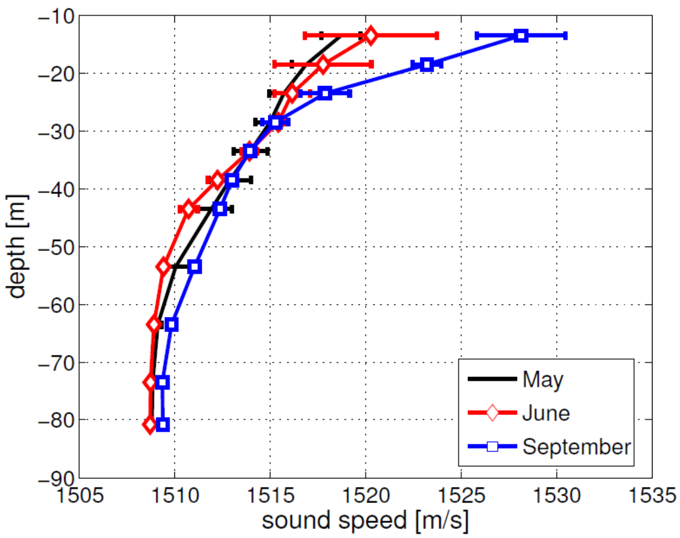
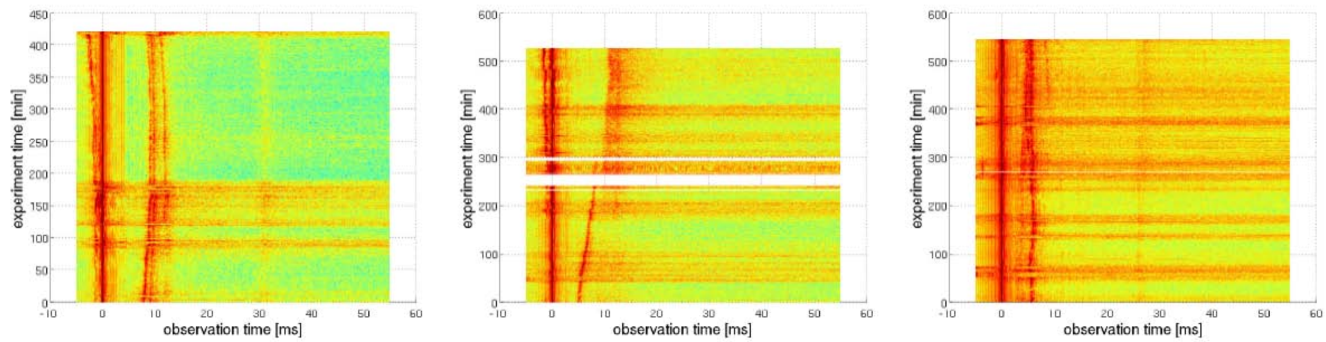


Fig. 2: Average and standard deviation of SSP during experiments on May 30, June 5 and September 2.

Results obtained from such experiment include for example the time evolution of the channel impulse response for the different links (see Figure 3), which makes it possible to study coherence times as well as temporal and spatial correlations of the channel behaviors.



(a) Link T2–H4, May. (b) Link T2–H4, June. (c) Link T2–H4, August.

Fig. 3: Pseudocolor plot of measured channel impulse response amplitudes for the link between T3 and H4.

Other interesting data that will be used in our study include the time series of SNR values (which is useful in studying time-correlations, see Figure 4) and the experimentally derived relationship between SNR and PER (which is important in deriving the communication performance, see Figure 5).

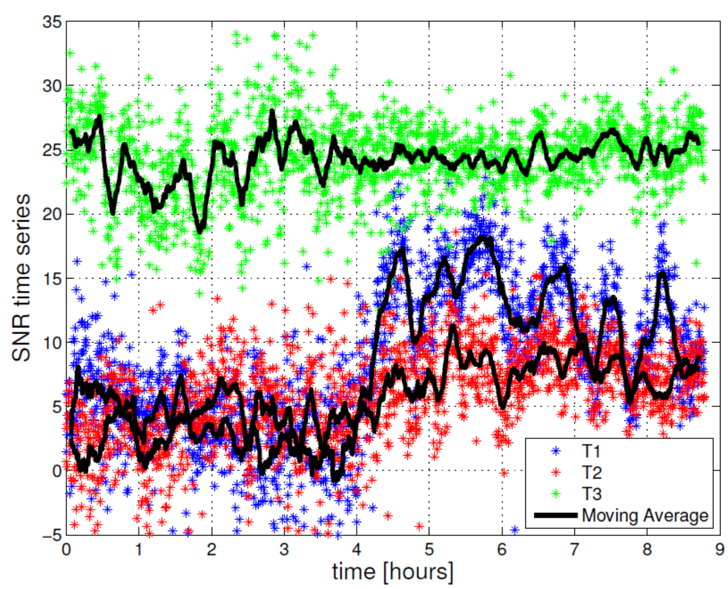


Figure 4: Measured time series of the SNR over the links from all transmitters to hydrophone H1, including a moving average taken over 25 samples.

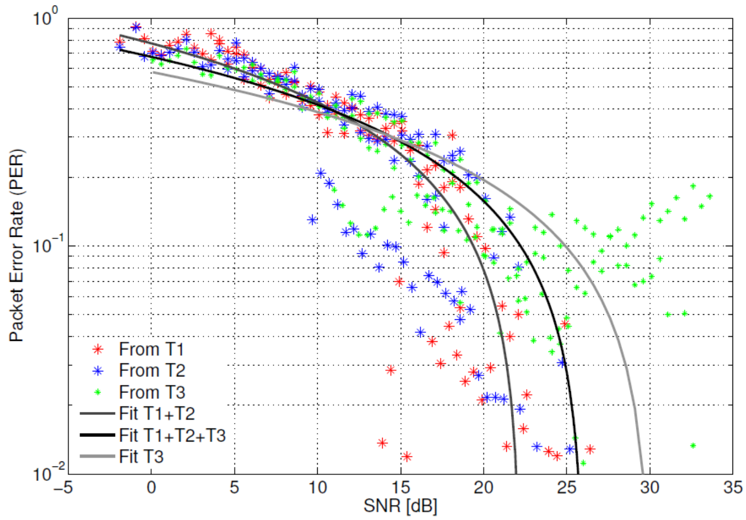


Figure 5: Log-scale scatterplot of PER as a function of SNR for varying transmitter and all receivers. Linear fits are also provided.

This large dataset will be analyzed in order to obtain useful statistical information (that will help in characterizing both qualitatively and quantitatively the channel behaviors).

IMPACT/APPLICATIONS

We expect the results obtained from the analysis of such a comprehensive dataset to greatly improve our understanding and modeling capabilities, which is a key goal in our project.

RELATED PROJECTS

During the reporting period, the PI has not had any active related project sponsored by ONR or the US government. He has had some related efforts funded by the European Commission, an Italian foundation, and NATO. The focus of such efforts is more on protocol design than on channel modeling and therefore those projects are complementary and non-overlapping with respect to the present one.

REFERENCES

[BH] M. Porter *et al.*, "Bellhop code." [Online]. Available: http://oalib. hlsresearch.com/Rays/index.html

[WOSS] F. Guerra, P. Casari, and M. Zorzi, "World Ocean Simulation System (WOSS): a simulation tool for underwater networks with realistic propagation modeling," in *Proc. of WUWNet 2009*, Berkeley, CA, Nov. 2009.

[Tele] "Teledyne benthos undersea systems and equipment," www.benthos.com .

[OCEANS10] B. Tomasi, G. Zappa, K. McCoy, P. Casari, and M. Zorzi, "Experimental study of the space-time properties of acoustic channels for underwater communications," in *Proc. IEEE/OES Oceans*, Sydney, Australia, May 2010.

PUBLICATIONS

Given the short time the project has been running, we have no publications that carry an explicit acknowledgement to it. However, the following recent papers contain material that is relevant to the project's objectives and have been published and/or accepted during the reporting period:

- Beatrice Tomasi, Giovanni Zappa, Kim McCoy, Paolo Casari, Michele Zorzi, "Experimental study of the space-time properties of acoustic channels for underwater communications," in *Proc. IEEE/OES Oceans*, Sydney, Australia, May 2010.
- Beatrice Tomasi, Laura Toni, Paolo Casari, Lorenzo Rossi, Michele Zorzi, "Performance Study of Variable-Rate Modulation for Underwater Communications based on Experimental Data," in *Proc. MTS/IEEE Oceans*, Seattle, USA, Sep. 2010.
- Beatrice Tomasi, Paolo Casari, Leonardo Badia, Michele Zorzi, "A Study of Incremental Redundancy Hybrid *ARQ* over Markov Channel Models Derived from Experimental Data," in Prof. of *ACM WUWNet*, Woods Hole, USA, Sep.-Oct. 2010.
- Beatrice Tomasi, Paolo Casari, Lorenzo Finesso, Giovanni Zappa, Kim McCoy, Michele Zorzi, "On Modeling *JANUS* Packet Errors over a Shallow Water Acoustic Channel using Markov and Hidden Markov Models," in *Proc. IEEE MILCOM*, San Jose, USA, Nov. 2010.

HONORS/AWARDS/PRIZES

Michele Zorzi:

- IEEE Fellow, 2007
- Member-at-Large of the IEEE Communications Society Board of Governors, 2009-2011
- Editor-in-Chief of the IEEE Transactions on Communications, 2008-present
- Editor-in-Chief of the IEEE Wireless Communications magazine, 2003-2005
- Editor for Europe of the Wiley Journal on Wireless Communications and Mobile Computing
- Keynote Speaker, European Wireless conference, Lucca, Italy, Apr. 2010. (Address was on protocol design issues and channel modelling in underwater acoustic networks.)
- Best Paper Award, IEEE MobiWac Workshop, June 2005
- Best Paper Award, IEEE CAMAD, June 2006
- Best Paper Award, IEEE GLOBECOM (Wireless Networks Symposium), November 2007
- Best Tutorial Paper Award, IEEE Communications Society, 2007
- Best Paper Award, European Wireless Conference, May 2009

- Guest Editor of several special issues, and in particular: “Underwater Acoustic Communications and Networks,” *IEEE Journal on Selected Areas in Communications*, December 2008)
- Member of the organizing and technical program committees of many conferences, and in particular: Technical Program co-Chair, ACM WUWNet’07