A Tutorial on Underwater Acoustic Networking

Prof. Mandar Chitre
National University of Singapore (NUS)
mandar@nus.edu.sg

Dr. Prasad Anjangi, Dr. Shiraz Shahabudeen
Subnero Pte. Ltd. (Singapore)
prasad@subnero.com, shiraz@subnero.com

1 Overview

This is a comprehensive tutorial on the subject of underwater acoustic network (UAN) design and development. The purpose of this tutorial is to expand the audience's knowledge in the domain of practical underwater acoustic networks. The content is prepared keeping the current state-of-the-art in mind and equip the audience to be at the cutting-edge of this field at the end of this tutorial. The tutorial is not only useful for the new researchers in this domain but also to the experts in academia and relevant industries wanting to quickly develop, simulate and deploy their underwater networking solutions.

The subject matter is covered through a combination of theoretical and hands-on sessions. The audience will learn to simulate and develop underwater peer-to-peer and networking applications using the tools and techniques presented. The content outline section presents in detail the topics that are covered (see Section 5).

2 Background and motivation

Advances in the acoustic modem technology have enabled robust, reliable and high data-rate communications for a peer-to-peer link. However,

- When there are multiple nodes forming an underwater network trying to achieve an objective, what developmental tools and practices can be followed ?
- How does the current state-of-the-art acoustic modem technology provide the capabilities to the developer/user to harness and create useful underwater networking solutions ?

A comprehensive review paper in the area of UANs was published in the year 2000 [1]. The authors in [1] envisioned a UAN and presented examples of where they could prove useful. Following this work, there has been a large body of literature that was generated and the review of such work can be found in [2] in 2005, [3] in 2008, [4] in 2012 and [5] in 2016.

3 Target audience

- Engineers interested in designing, simulating or deploying underwater networks.
- Researchers interested in developing underwater networking protocols.
- Early-stage PhD students focussing on underwater networking.
- The hands-on session may also be of interest to engineers and researchers with advanced knowledge in the domain.

4 Current state-of-the-art

Platform	Release year	Institution	Laboratory
Seaweb	1995/2004	US Navy and Universities	The Office of Naval Research
Aqua-Lab	2007	University of Connecticut	Underwater Sensor Network Lab
Aqua-Sim	2009/2015	University of Connecticut	Underwater Sensor Network Lab
Aqua-Net/Mate	2009/2013	University of Connecticut	Underwater Sensor Network Lab
DESERT	2012	University of Padova	NAUTILUS Project Lab
SUNSET	2012/2013	Sapienza University of Rome	UWSN group Senses Lab
UnetStack	2014	National University of Singapore	Acoustic Research Laboratory
SUNRISE (LOON)	2014	NATO S	CMRE
SeaNet	2015	Northeastern University, Boston	Department of ECE
Ocean-TUNE (WaterCom)	2015	University of California, LA	Networked and embedded systems lab

Table 1: Selected simulation and experimental platforms [6].

This domain is expected to remain very active for years to come as the global interest in ocean exploration continues unabated. Applications include naval defence, oil and gas exploration, and a wide variety of oceanographic studies all of which require underwater acoustic networks in some form for communications and data transfer with underwater systems. Several notable underwater network frameworks and simulators have been developed over the past decade. A very comprehensive review of the simulation and experimentation platforms is presented in [6]. Some of them are listed in Table 1.

For example, DESERT [7] and SUNSET [8], are based on the popular open source networking simulation software NS2 and/or its extension NS2 Miracle. On the other hand, UnetStack [9, 10] is an agent-based network stack and simulator that was developed ground-up for underwater networking. While we take a brief look at several options in this tutorial, we adopt the UnetStack framework as the basis for demonstration and hands-on exploration. Although it is not necessary for all participants to bring laptops, we encourage participants with laptops to follow the tutorial through hands-on exercises.

5 Content outline

The content overview is presented briefly in Table 2. Each of the topic will be dealt at the conceptual and hands-on level. In the hands-on session, the participants will get a chance to apply the techniques using the tools that will be presented.

Topic	Duration	Presenter
Introduction to acoustic communication and networking a) A quick walk-through on the historic and recent developments b) Learnings from the field-trials and experiments	30 minutes	Mandar
Network protocol stacks and simulators a) Layered model b) Underwater networking architecture c) Need for cross-layer functionality d) Comparision of selected open-source underwater network simulators	30 minutes	Mandar
Introduction to UnetStack **Overview of concepts:** a) Concept of agent-oriented programming b) Framework of java and groovy agents c) UnetStack agent development d) Examples use-cases of UnetStack for application development **Hands-on session:** a) Introduction to UnetSim b) Setting up the simulator environment c) Example simulations	30 + 30 minutes	Mandar
Discussion + Coffee break	30 minutes	
Abstraction of physical layer to network simulators (PHY) **Theory:** a) Single-carrier - Phase Shift Keying/ Decision Feedback Equalizer (PSK/DFE) b) Muti-carrier - Orthogonal Frequency Division Multiplexing (OFDM) c) JANUS underwater signalling protocol **Hands-on session:** a) Measuring noise b) Transmitting and receiving packets c) Transmitting and receiving signals	30 + 15 minutes	Mandar
Lunch break	60 minutes	
Medium access control (MAC) **Theory:** a) MAC protocol design decisions for underwater networks b) State-of-the-art contention-free protocols c) State-of-the-art contention-based protocols d) Examples of popular MAC protocols **Hands-on session:** a) MAC channel reservation b) A simple MAC agent c) Simulation and performance estimation d) Example of developing and simulating contention-free MAC e) Example of developing and simulating contention-based MAC	30 + 60 minutes	Shiraz
Higher layer protocols **Theory:** a) Routing protocols b) Transport protocols **Hands-on session:** a) Route discovery b) Trace functionality c) File transfer d) Underwater chat application	30 + 15 minutes	Prasad
Coffee break	15 minutes	
Large propagation delay networks a) Challenges with large propagation delay b) Juggling-ARQ protocol c) Super-TDMA protocol	30 minutes	Prasad
Discussion / Hands-on	45 minutes	All

Table 2: Content outline and schedule.

6 Details of presenters

Mandar Chitre received the B.Eng. and M.Eng. degrees in electrical engineering from the National University of Singapore (NUS), Singapore, the M.Sc. degree in bioinformatics from the Nanyang Technological University (NTU), Singapore, and the Ph.D. degree from NUS.

From 1997 to 1998, he worked with the ARL, NUS. From 1998 to 2002, he headed the technology division of a regional telecommunications solutions company. In 2003, he rejoined ARL, initially as the Deputy Head (Research) and is now the Head of the laboratory. He also holds a joint appointment with the Department of Electrical and Computer Engineering at NUS as an Associate Professor. His current research interests are underwater communications, autonomous underwater vehicles, and acoustic signal processing.

Dr. Chitre currently is Editor-in-Chief of the IEEE Journal of Oceanic Engineering. He has served on the technical program committees of the IEEE Oceans, WUWNet, DTA, and OTC conferences and has served as reviewer for numerous international journals. He was the chairman of the student poster committee for IEEE Oceans06 in Singapore, and the chairman for the IEEE Singapore AUV Challenge 2013. He is currently the IEEE Ocean Engineering Society Technology Committee Co-Chair of underwater communication, navigation & positioning.
email: mandar@nus.edu.sg
web: http://arl.nus.edu.sg/twiki6/bin/view/ARL/MandarChitre

Shiraz Shahabudeen has held various engineering roles including at Infocomm Development Authority of Singapore (IDA), NeST Software, India etc. He was a Research Fellow at ARL, National University of Singapore (NUS) where his research interests included underwater acoustic communications and autonomous underwater vehicles. Dr. Shahabudeen holds an M.S degree in telecommunication engineering from Melbourne University (Australia) and a PhD from NUS in Underwater Communications.
email: shiraz@subnero.com
web: https://subnero.com/people/shiraz

Prasad Anjangi received his Ph.D. in Electrical & Computer Engineering from National Unversity of Singapore (NUS) in 2016. Prior to that he received the B.Eng. degree in Electronics and Instrumentation Engineering from Andhra University, Andhra Pradesh, India, in 2007 and the M.Eng. degree in Biomedical Engineering from the Indian Institute of Technology (IIT), Bombay, India, in 2009. Currently, he is a Research Fellow and part of the core team at Subnero Pte. Ltd. He worked in semiconductor industries with Atmel and STMicroelectronics as Firmware and Senior Design Engineer, respectively, from 2009 to 2012. His current research interests include underwater acoustic communications, signal processing, networking protocol design, and autonomous underwater vehicles. Dr. Anjangi has served in technical program committee of WUWNet and is a reviewer of IEEE Journal of Oceanic Engineering and IEEE Transactions on Communications.
email: prasad@subnero.com
web: https://subnero.com/people/prasad

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