Macrothink Institute™

Network Protocols and Algorithms
ISSN 1943-3581
2016, Vol.8, No.4

Simulation Tools for Underwater Sensor Networks: A Survey

Anjana P Das

College of Engineering, Trivandrum, India

LBS Centre for Science and Technology, Trivandrum, India

E-mail: anjanapdas@gmail.com

Sabu M Thampi

Indian Institute of Information Technology and Management-Kerala India

E-mail: smthampi@ieee.org

Received: November 8, 2016 Accepted: December 30, 2016 Published: December 31, 2016

DOI:10.5296/npa.v8i4.10471 URL: http://dx.doi.org/10.5296/npa.v8i4.10471

Abstract

In underwater sensor network(UWSN) research, it is highly expensive to deploy a complete test bed involving complex network structure and data links to validate a network protocol or an algorithm. This practical challenge points to the need of a simulation environment which can reproduce the actual underwater scenario without the loss of generality. Since so many simulators are proposed for UWSN simulation, the selection of an appropriate tool based on the research requirement is very important in validation and interpretation of results. This paper provides an in-depth survey of different simulation tools available for UWSN simulation. We compared the features offered by each tool, pre-requirements, and provide the run time experiences of some of the open source tools. We conducted simulation of sample scenarios in some of the open source tools and compared the results. This survey helps a researcher to identify a simulation tool satisfying their specific research requirements.

Keywords: Aqua-glomo, Aqua-Sim, AUVNetSim, Simulation Tools, SUNSET, Underwater sensor Networks

1 Introduction

Underwater Sensor Network (UWSN) is the key technology that aids underwater exploration and it becomes a hot area of research recently because of its environmental, scientific, commercial, and military significance. But still, this area has not been explored well enough to exploit all the resources and their potential applications. Even though the Wireless Sensor

Network (WSN) technologies have evolved a lot, there are practical difficulties in incorporating the state of the art WSN technologies into UWSN because of the obvious domain characteristics such as constrained environment, error prFone acoustic channel, and mobility of nodes [1, 2, 3, 4, 5]. Hence, these unique features of underwater environment have motivated research activities in UWSN.

Network simulation is one important area of focus for any researcher who attempts to verify and validate a protocol or an algorithm in any kind of network without actual deployment. In UWSN research, it is highly expensive to deploy a complete test bed to repeat the experiments and to validate the results in an iterative manner. Hence, in most of the research activities, the UWSN need to be simulated effectively. The existing simulators of wired or wireless networks cannot be used for the simulation of UWSN without modification because of the unique characteristics of underwater environment. For UWSN simulation, modeling the features of acoustic channel, three-dimensional deployment, and the mobility of nodes into the existing simulators are not so easy. These features point to the need of a simulator which can effectively simulate the underwater environment by incorporating all domain specific characteristics.

Because of the global interest in UWSN research, there are so many simulators proposed so far for simulating UWSN. But, most of them are either application specific or configuration dependent, which need to be configured for simulating UWSN scenarios. One of the critical issues faced by UWSN researchers is the selection of an appropriate simulation platform according to research requirement. The lack of globally accepted standard simulator for UWSN research makes comparison of results impossible. The identification of the most appropriate simulation tool satisfying the specific research requirement plays a vital role in the validation and interpretation of results. To select an appropriate tool, the awareness about the features offered by each tool, their pre-requirements, scalability, and availability is required. Hence, in this paper, we present an overview about various simulation tools available for UWSN studies. Lopez et al. [6] discussed simulation tools available for Wireless Sensor Networks (WSN). Korkalainen et al. [7] compared the suitability of five popular simulation tools for WSN planning and verification. Neves et al. [8] performed comparative study on simulation tools for WSN in medical applications. Dhivya and Arthi [9] did a comparative study on some of the UWSN simulation tools. Raj and Sukumaran [10] provide a comprehensive overview on UWSN simulators. In this paper, we surveyed various simulation tools that can be used to simulate UWSN and compared the features offered by them. We conducted simulation of UWSN in some of the open source tools, compared the results and provide the run time advantages and difficulties faced. So that, researchers can choose the best simulation tool suited for their research work.

The rest of this paper is assembled as follows. Section 2 provides the description of various simulation tools and their taxonomy. Section 3 includes the discussion and results of the simulation experiments conducted in NS2, NS3 and Aqua-Sim. Section 4 summaries the work and explore the future research directions.

2 Simulation tools

A brief description of simulators that can be used for simulating underwater sensor networks are presented in this section. Figure 1 depicts the hierarchy of various simulation tools. Among them, some are exclusively developed for underwater scenarios, while others are primarily developed for terrestrial applications, but can be configured further for use in the underwater environment. Some simulators can be used only for software testing and validation,

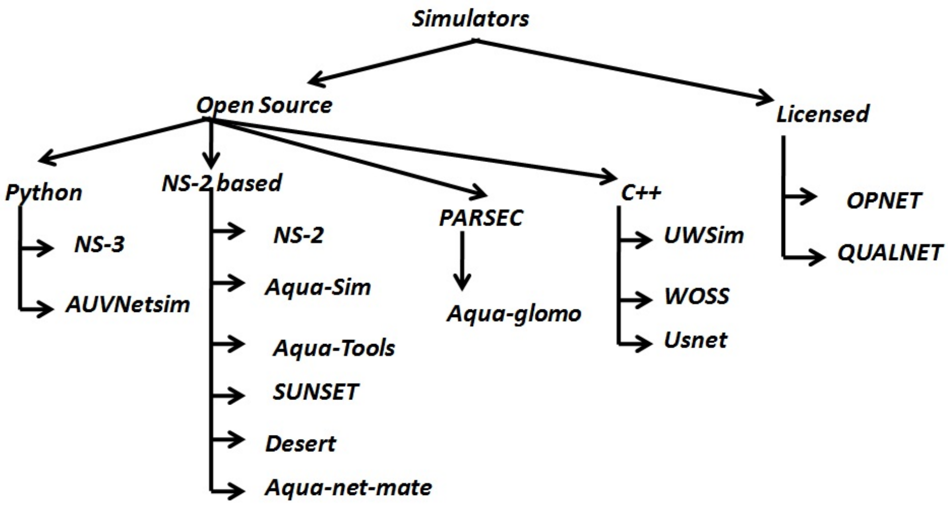

Figure 1: UWSN simulators

while some others can be used for real time testing. Figure 2 illustrates the classification of tools based on their utility.

2.1 Network Simulator-version 2 (NS-2)

Network Simulators (NS) are a series of open source discrete event network simulators. Most popular among them is NS-2. The latest version is NS-2.36. The core of NS-2 is in C++, with Object-Tcl(OTcl) based scripting. Linux is the most compatible operating system for NS-2. Windows with the Cygwin package supports NS-2. Back-end modeling in NS-2 is very complex and time consuming because of the continuous changes in the code base. Moreover, some protocols have unacceptable bugs. Even though the installation of NS-2 itself is complex and time consuming, so many well-known protocol packages are available with NS-2 package. It lacks a GUI and user should learn scripting language, queueing theory, and modeling techniques.

Moreover, there is no inbuilt packages supporting UWSN simulation except in NS-2.30. Limited tutorials and sample codes are available on NS-2.30 as it is an earlier version. Also, it is difficult to run simulation scripts written in higher versions of NS-2.30. Hence, we need to model all the underwater channel characteristics and propagation model for simulating UWSN in NS-2.35 and above. Nam is the visualizer of NS-2. Trace file is the output file generated after running a simulation. The trace file has a separate format for wired, wireless, and mobile networks. To analyze the performance of the network, data from the trace file should be retrieved and analyzed. For that, it is required to write .awk scripts of concerned performance metrics. An open source trace file analyzer software named NS-2 visual trace analyzer is available to analyze trace files.

2.2 OPNET

OPNET [11] is a high level event based network simulator, operating at packet level. It can be used for both research purposes and network design/analysis. Modeling in OPNET can be divided into three domains- Network, Node and Process. Debugging and analysis in OPNET are GUI based. Even though OPNET is one of the leading environment for network modelling

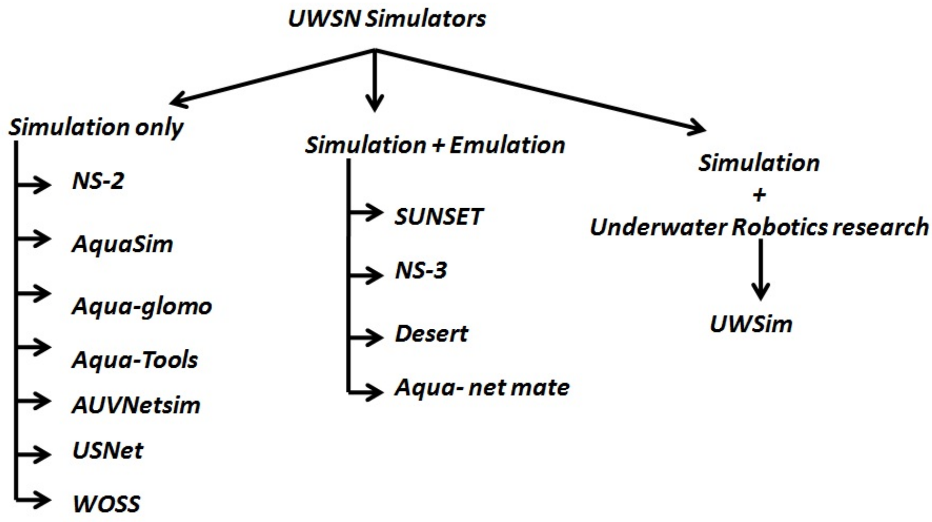

Figure 2: Classification of tools

and simulation, to simulate underwater environment, it is required to customize some of the 14 pipeline stages of OPNET. The sixth stage (for propagation delay), the eighth stage (for Receiver Power) and the tenth stage (for Background noise) of the radio transceiver pipeline need to be customized for an accurate underwater channel model [12].

2.3 Network Simulator- version-3 (NS-3)

Similar to NS-2, NS-3 is also an open source, discrete event network simulator. It was built using C++ and Python with scripting facility and supports visualization [13]. NS-3 is not backward compatible with NS-2. The NS-3 UAN framework [14] enables the modeling of underwater network scenarios. The UAN model has four parts : The channel, PHY, MAC and AUV models. The UAN propagation model facilitates the user to select an acoustic channel and the corresponding attenuation model. The propagation models supported by UAN framework are ideal channel model, thorp model, and Bellhop model. The ideal channel model assumes a zero path loss. In the thorp popagation model, Thorp's attenuation model is used to calculate path loss. The Bellhop model reads propagation information from a database. The UAN PHY Model has a PHY class, *UanPhyGen*, which is responsible for the acquisition of packets, determining errors and forwarding of successful packets. A dual PHY layer, *UanPhyDual*, can also be used which wraps two generic PHY layers together to model a device which includes two receivers. The UAN Autonomous Underwater Vehicle(AUV) model allows the user to program the AUV to navigate over a path of way-points, control various AUV parameters such as velocity, depth, direction, and pitch.

In addition to the default visualizer, another visualization package called Netanim is developed, and it is integrated with the NS-3 package itself. Software known as Tracemetrics is developed to analyze the trace files. In NS-3 simulation, .pcap files can be generated and they can be imported to the well known packet analyzer software wireshark.

2.4 Aqua-Sim

Aqua-Sim [15] is an open source NS-2 based simulator. It was developed by UWSN Lab for underwater sensor network research. The attenuation of acoustic signal, propagation model, and packet collisions are effectively handled by Aqua-Sim. It follows an object-oriented design style and supports three-dimensional deployment. The attenuation model adopted is Thorps model. Aqua-Sim is parallel and independent of the CMU wireless simulation package (Figure 3). Thus, changes in Aqua-Sim does not interfere other packages in NS-2.

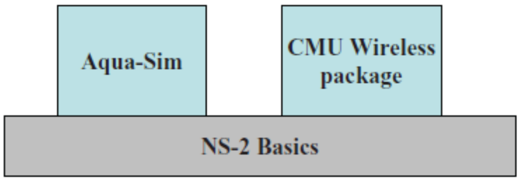

Figure 3: Aqua-Sim and wireless packages [15]

The entire functionality of Aqua-Sim is divided into four main folders. The uw-common folder has scripts related to underwater sensor nodes and traffic. MAC protocols and acoustic channels are included in uw-mac and routing protocols in uw-routing. The OTcl scripts to validate Aqua-Sim are contained in the uw-tcl folder. The *UnderwaterNode* object is the precis representation of an UWSN node. The *UnderwaterChannel* object indicates the acoustic channel.

2.4.1 Aqua-3D

Aqua-3D is Aqua-Sim's animator, which supports three-dimensional visualization[16]. Installation of Aqua-3d requires either NVIDIA or ATI graphics card. It has a simple GUI controllable with a mouse. Appearance of the environment can be customized, saved, and loaded for later recall. It has good control over speed and timing of animation. Node positions can be retrieved in Aqua-3d visualizer. Packet collisions at nodes can be detected with the help of built-in procedures.

2.5 SUNSET

SUNSET can be used for underwater network simulation, Emulation and real-time testing [17]. It was developed by Sapienza University. SUNSET is based on NS-2. During simulation, SUNSET uses different acoustic channel models. SUNSET can be interfaced with real external hardware in emulation mode.

Advantages

- It uses multiple threads in emulation mode.
- It can be used as a real time scheduler.
- It has improved interference model.
- The timing module provides information on device and packet transmission delays, which are not usually considered in simulation. This reduces the gap between actual and simulation results.
- It has utilities module

- It has debug module
- The statistics module is used to collect statistical information to evaluate performance.
- It has packet converter module
- It has generic and application driver modules to integrate with acoustic modems, sensors, and AUV.

2.6 Aqua-glomo

Aqua-Glomo[18] is an upgraded version of GLOMOSIM (Global Mobile Information System Simulator), a simulator developed for large communication networks. In Aqua-Glomo, GLOMOSIM's physical layer and network layer packages are upgraded to build it suitable for UWSN. The implementation language used is PARSEC (Parallel Simulation Environment for Complex Systems), a C-based language. Acoustic communication is implemented at the Physical Layer and the attenuation model used is Thorp's model [19], which is dependent on distance and frequency. In network layer, RMTG (Routing and Multicast Tree based Geocasting)[20] is implemented, which is a geocast protocol developed specifically for UWSN. The mobility model adopted is Random-Waypoint.

2.7 Aqua-tools

The AquaTools toolkit [21] is based on NS-2. The channel and physical layer operations are divided into four major components such as Propagation, Channel, Physical and Modulation. The respective components are to be modified to make it suitable for the requirement. The AquaTools package allows the user to choose the appropriate underwater propagation and channel models using the respective names. The availability of three different channel models enables the simulator to consider the distance between nodes, ambient temperature, depth, acidity, salinity, and transmission frequency.

2.8 USNet

Underwater Sensor Network Simulation Tool (USNeT) [22] has a user friendly front-end with support for three-dimensional deployment which provides a real time process based simulation for under water sensor networks. In USNet, all network features are implemented as classes in C++. The support of threads allows the system to handle multiple tasks in parallel, which is not possible with simulators such as NS-2. It is most suitable for handling cluster-based routing protocols.

2.9 WOSS

In World Ocean Simulation System (WOSS) [23], Bellhop ray tracing [24] software is used to incorporate the acoustic propagation effects of UWSN. The world databases for environmental parameters are integrated with WOSS. So that, a user can choose the desired geographical location of the network, and the desired time for running simulation. The network design in WOSS is a complex process which limits the simulation to small network density scenarios.

2.10 QualNet

QualNet is a well popular simulation tool, which provide a platform to plan, test and train network behavior of a communication network of any type. It has a very good GUI with so many inbuilt options to design a network. QualNet is considered as the state of art simulator for designing large heterogenous networks. The main components offered by QualNet are as follows

- QualNet Architect- It is the visualization tool
- QualNet Analyzer consists of statistical tools to analyze the network performance
- QualNet packet tracer is a graphical packet trace analyzer
- QualNet File editor is an editing tool
- QualNet Commandline interface provides command line access

QualNet provide a flexible platform to design and test network protocols. It is compatible for parallel processing. It is good for localization related studies as it supports both Cartesian and Geographic coordinate systems. In the case of mobile networks, it supports only Random-waypoint mobility model and users need to design other required mobility models. QualNet has an inbuilt statistical propagation model. QualNet is developed for both wired and wireless radio networks. Most of the inbuilt channel properties, protocols, network components, and propagation model are related to radio networks. To simulate UWSN in QualNet, it is required to model all the domain characteristics and channel properties, which is a hard job.

2.11 AUVNetSim

AUVNetSim [25] is an open source simulation tool developed using python. It has most of the state of art acoustic networking protocols and parameters as packages, which can be directly applied or modified. The physical layer is inbuilt and based on the Thorp model. Hence, modeling different environmental conditions are not possible, leading to simulation results, drastically different from real network deployment.

2.12 Desert

Desert [26] is based on ns-miracle framework. It supports simulation, emulation, and test bed experiments. It has c/c++ libraries to support the design of new protocols. It supports cross layer protocol design and experiments. In application layer, desert has two modules to handle traffic flow between nodes: *uwcbr* as constant bit rate and *uwvbr* as variable bit rate. The two modules of transport layer (*uwudp* and *uwtcp*) provide multiplexing, demultiplexing, error control, and flow control. In network layer, desert has modules for static routing, dynamic routing, flooding, and to assign IP addresses to nodes. In data-link layer desert provides modules for six major MAC protocols. Desert offers three hardware platforms for emulation and test-bed experiments. Moreover, it provides different modules for simulating node mobility in both 2D and 3D scenarios.

2.13 Aqua-net mate

Peng et al. introduced Aqua-net [27], which is a networking kit for UWSN research. It is suitable for designing embedded systems. Zhu et al. put forward Aqua-net-mate [28], that is coupled with aqua-net and provides simulation functionality also. It offers the switching between simulation mode and emulation mode. The detailed documentation on aqua-net and aqua-net-mate is not available online.

2.14 UWSim

UWSim [29] is an open source underwater simulation tool developed using C++. It makes the use of *OpenSceneGraph* [30] and *osgOcean* [31] libraries. UWSim has good configurable interface. It has network interfaces to interface sensors, robots and actuators with external software. It supports multiple robots also. Moreover, UWSim supports dynamic simulation of rigid body motion by using the state-space dynamic mode.

3 Simulation tests and Discussions

To analyze the performance and difficulties of simulating UWSN, we conducted simulation of sample UWSN scenarios in open source tools such as NS-3.26, NS-2.35 and Aqua-Sim. The nodes are deployed in random locations and random traffic flow is designed. The simulation parameters are listed in table 1.

Table 1: Simulation parameters

Number of nodes	10, 50, 100
Area	$500 \times 500 \times 500\ m^3$
Simulation time	500 s

3.1 Simulation using NS-3

A small UWSN scenario is simulated in NS-3.26. Figure 4 shows the visualizer output of the simulated scenario. Node mobity and traffic flow can be visualized in the NS-3 visualizer. Figure 5 shows the simulated network in Netanim animator. The orientation of nodes at different times, its coordinate details, and IP addresses can be analyzed. Figure 6 displays the analysis of the pcap file in wireshark packet analyzer. The entire path of traffic flow can be retrieved and analyzed using packet analyzer.

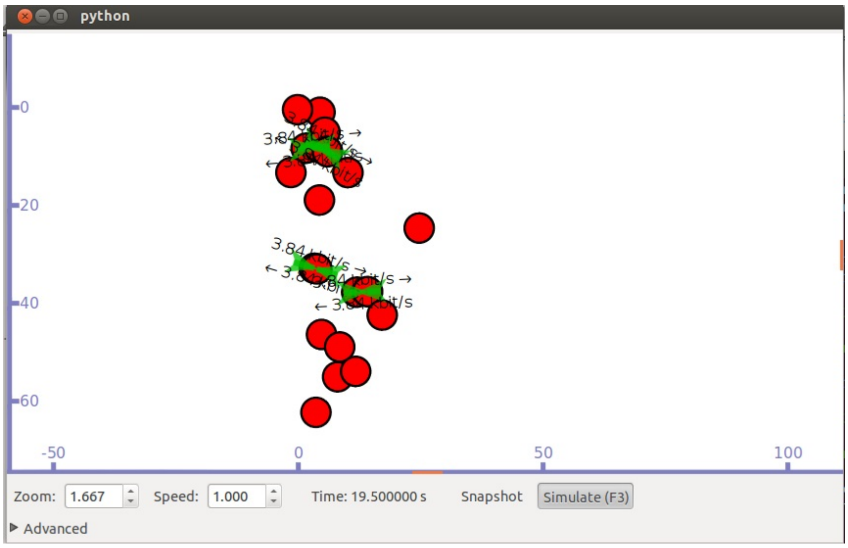

Figure 4: Network with mobile nodes in NS-3 visualizer

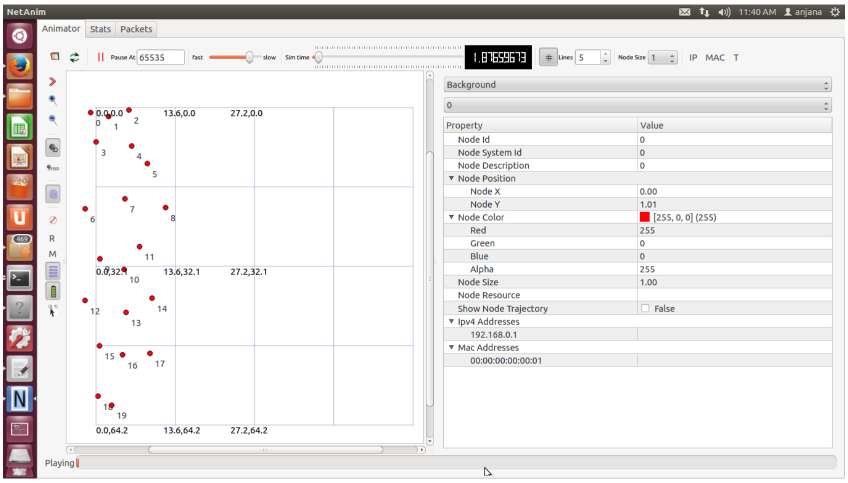

Figure 5: Simulated scenario in Netanim

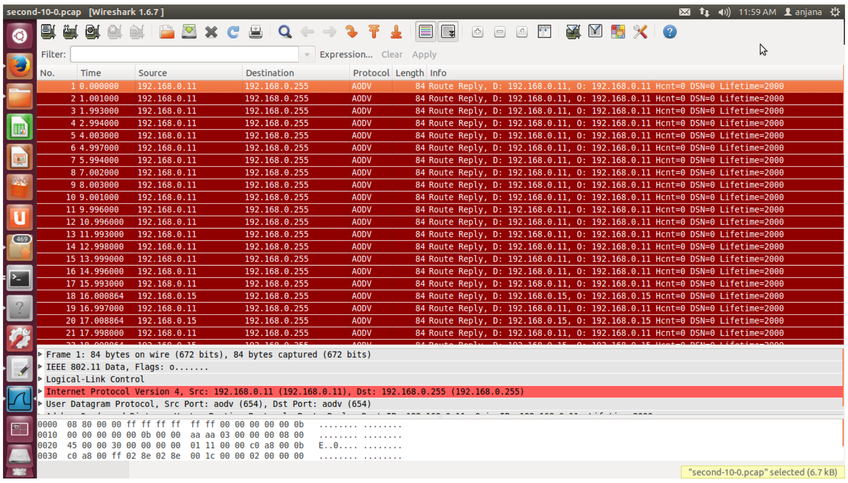

Figure 6: Analysis of .pcap files in wireshark

3.2 Simulation using NS-2

The UWSN is simulated in NS-2.35 with network density 10, 50, and 100. The nodes are deployed in random locations and random traffic flow is designed. The channel used is *WirelessChannel* with *AODV* protocol. The simulation is run for 500 s. Figure 7 shows the nam visualizer of a simulated network with 10 mobile nodes. The corresponding trace file (.tr file) of the simulated network is shown in Figure 8. The data regarding location, traffic flow, packet status (send, receive), and time delay can be analyzed and retrieved from .tr file.

3.3 Simulation using aqua-sim

A mobile UWSN is simulated in $500 \times 500 \times 500\ m^3$ space in aqua-sim simulator. The channel used is *UnderwaterChannel*, propagation model is *UnderwaterPropagation*, and routing protocol is *VBF*. Figure 9 shows the three dimensional view of simulated scenario in Aqua-3d. The simulation is repeated for different network densities such as 10, 50, and 100. Here also, the nodes are deployed in random locations and random traffic flow is designed.

We conducted detailed analysis of simulated scenarios in NS-2.35 and aqua-sim. Table 2

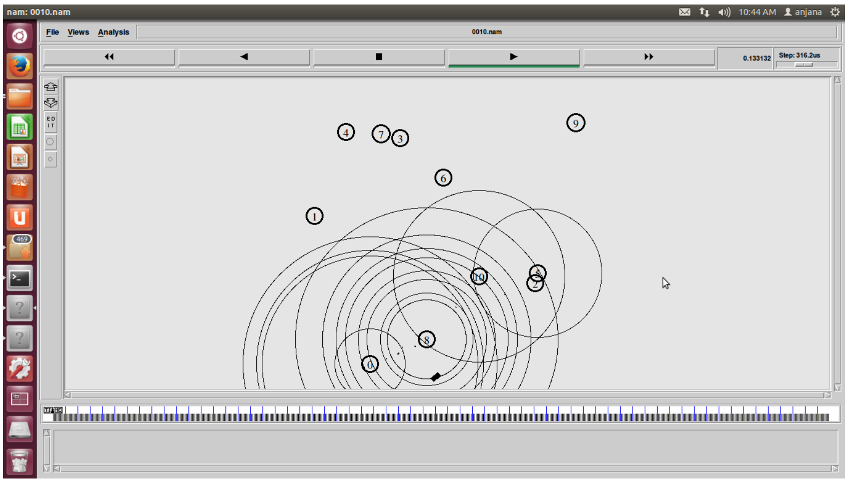

Figure 7: Network with 10 mobile nodes in nam visualizer

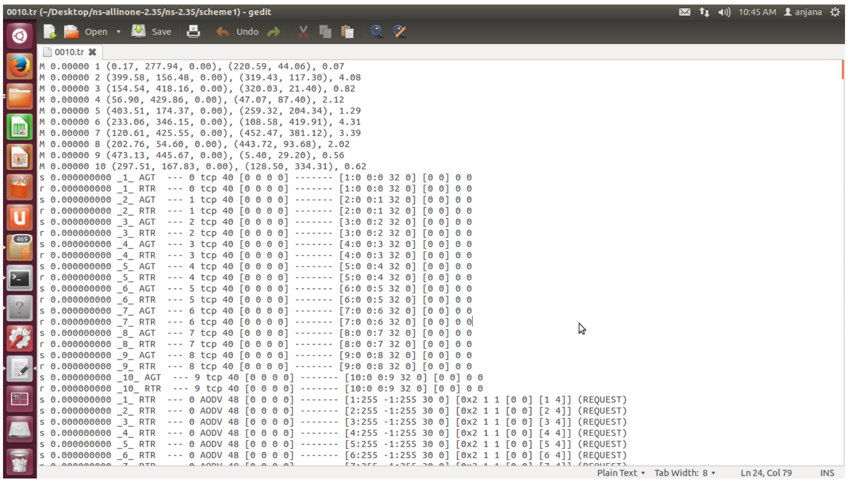

Figure 8: Trace file of a simulated network with 10 mobile nodes

shows the details of packet send and received in each simulation. The metric used for comparison is Packet delivery fraction(PDF), that is the ratio of total number of packets successfully received to total number of packets send. Figure 10 displays the variation of PDF with network density in each simulated scenario for both NS-2.35 and aqua-sim. Because of the characteristics of underwater channel and propagation model simulated, the PDF value of aqua-sim was in low range compared with NS-2.35. As so many packages for routing protocols, propagation models, and mobility models of UWSNs are associated with aqua-sim, it seems to be the best tool for soft-side research in UWSN.

We compared the features and requirements of various UWSN simulation tools described in section 2. Table 3 summarizes the comparison of simulators. The comparison shows that all the tools are characterized by some unique features, but none of them provide a perfect simulation environment to explore all domain specific characteristics of underwater environment. Different simulators incorporate different attenuation models to simulate the acoustic channel. The Thorp's attenuation model is the most popular among them, which is used in Aqua-Sim, Aqua-glomo, Aqua-tools and AUVNetSim. Most of the tools available for underwater network simulations are built on top of the popular network simulator NS-2 and are open source.

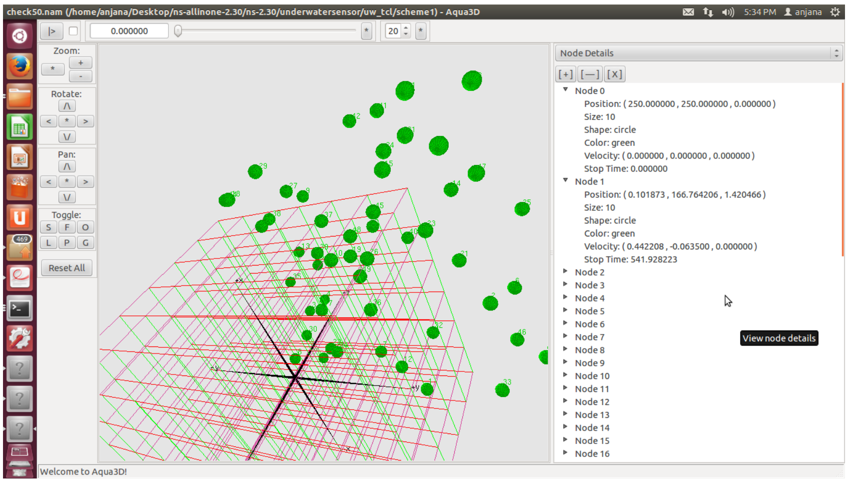

Figure 9: UWSN with 50 mobile nodes in Aqua-3d

Table 2: Traffic status

	Number of nodes	**Packets sent**	**Packets received**
NS-2.35	10	17521	16528
	50	26279	20848
	100	27824	20569
Aqua-sim	10	2023	548
	50	4022	1432
	100	12011	3463

Thus, people with good exposure on NS-2 will find it easier to use. Some of the tools such as Aqua-Sim and UWSim requires machines with good RAM capacity and graphics card to render the three dimensional underwater network. Misra et al. explored an NS-3 based simulator named ”jaltarang” for promoting UWSN research [32]. They also developed a matlab based simulation platform with GUI for simulating UWSN [33].

4 Summary and Future scope

In this paper, we provide a detailed survey on different simulation tools available to simulate underwater sensor networks. We conducted simulation tests on open source tools such as NS-2, NS-3, and aqua-sim. For each tool mentioned, its features, advantages and disadvantages are described so that a novice user can choose the best available tool to satisfy his research requirements. Moreover, this paper throws light on how to configure tools to make them suitable for use in underwater scenarios.

The detailed comparison of the available simulators shows that the problem of effective reproduction of the actual underwater environment still remains unresolved. Also, they are not updating with the current research direction. So, in future, we plan to develop an efficient and powerful open source underwater sensor network simulator with simple and intuitive GUI to allow the users to recreate the underwater environment by selectively assigning different propagation models.

Table 3: Comparison of Tools

	Tools	Year	Open Source	Programming Language	Propagation model	Specification	Hardware specification	Supporting Operating System	Prerequirements	Website address
Simulation	NS-2	1996	Yes	C++, OTcl	Radio model	IEEE 802.15.4, IEEE 802.11, IEEE 802.3	Minimum 512 MB RAM	Linux, Windows with Cygwin	Windows-cygwin, gcc Linux-gcc Graphic package, xorg-server, xinit, libxll-devel, libxmu-devel	www.isi.edu/nsnam/ns/
	QualNet	-	No	Visual C++	Radio model	IEEE 802.11	4 GB RAM, 1680 x 1050 screen resolution, Discrete graphics card with at least 2 GB memory, 3D acceleration	Linux, Windows	JAVA, For windows- visual C++ 6.0 or higher.	http://web.scalable-networks.com/content/qualnet
	AUVNetSim	2008	Yes	Python	Thorp's model	-	-	Windows	Python Environment, SimPy package, MatplotLib, Numpy	https://sourceforge.net/projects/auvnetsim/
	WOSS	2009	Yes	C++		IEEE 802.15.4	-	Linux	NetCDF library for C and legacy C++	http://telecom.dei.unipd.it/ns/woss/
	OPNET	-	No	C++, Python	Custamized Pipeline stages	IEEE 805.11	Minimum 512 MB RAM	Linux, Windows	System should have a GSU IP address	http://www.opnet.com/university_program/itguru_academic_edition/
	Aqua-Sim	2009	Yes	C++	Thorp's model	IEEE 802.15.4	Minimum 2 GB RAM, Graphics card	Linux	gcc/g++, automake, x11 lib	http://obinet.engr.uconn.edu/wiki/index.php/Aqua-Sim
	Aqua-tools	2010	Yes	C++, OTcl	Thorp's, Fisher & Simmons, Ainslie & Mccolm	IEEE 805.11	Build over NS-2			http://www.anujsehgal.com/publications/pdf/100114-035.pdf
	Aqua-glomo	2012	Yes	PARSEC	Thorp's model	-	Build over GLOMOSIM			http://hcis-journal.springeropen.com /articles/10.1186/2192-1962-2-3
	USNet	2013	-	C++	-	-	-	-	-	http://research.ijcaonline.org/volume71 /number22/pxc3889243.pdf
Simulation + Emulation	NS-3	2008	Yes	C++, Python	UAN model	IEEE 802.15.4, IEEE 802.11,IEEE 802.3	Minimum 512 MB RAM	Linux	Java, gcc/g++. python, qt4, mercurial, bzr doxygen, wireshark, libxml, goocanvas	https://www.nsnam.org/
	SUNSET	2012	Yes	C++, OTcl	Different acoustic models in simulation mode	IEEE 802.11	Build over NS-2		NS-2, NS-2 miracle, cross compile environment, WOSS package (For SUNSET Bellhop model)	http://reti.dsi.uniroma1.it/UWSN_Group/index.php?page=sunset
	Desert	2012	Yes	C/C++	-	IEEE 802.15.4	Build over NS-miracle	Linux	build-essential, autoconf, automake, libxmu-dev, libx11-dev, libxmu-headers, libxt-dev, libtool, gfortran, bison, flex	nautilus.dei.unipd.it/desert-underwater
	Aqua-net-mate	2013	-	-	-	coupled with Aqua-net				-
Underwater Robotic research	UWSim	2012	Yes	C++	-	-	4 GB RAM, Graphics card	Linux	NVidia or ATI Graphics card	http://www.irs.uji.es/uwsim/

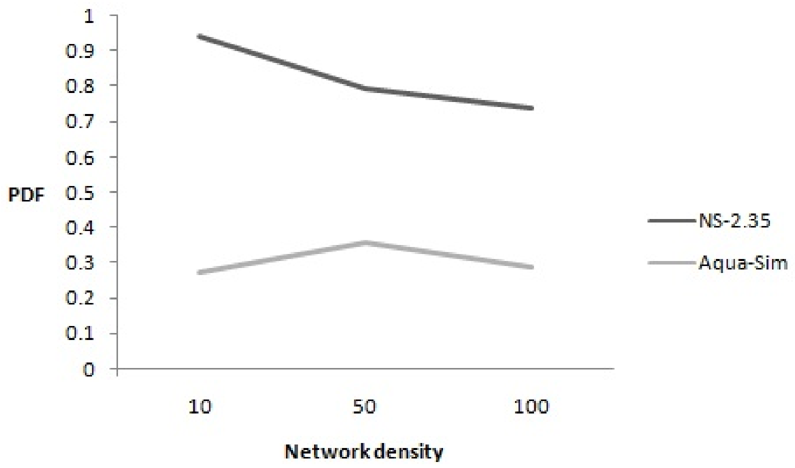

Figure 10: PDF of NS2.35 and Aqua-Sim

References

[1] A. P. Das and S. M. Thampi, "Secure communication in mobile underwater wireless sensor networks," in *Proceedings of the IEEE International Conference on Advances in Computing, Communications and Informatics, India*, September 2015, pp. 2164–2173.

[2] J. Lloret, "Underwater sensor nodes and networks," *Sensors*, vol. 13, no. 9, pp. 11 782–11 796, 2013.

[3] A. P. Das and S. M. Thampi, "Single anchor node based localization in mobile underwater wireless sensor networks," in *Algorithms and Architectures for Parallel Processing*. Springer, 2015, pp. 757–770.

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

[5] A. P. Das and S. M. Thampi, "Fault-resilient localization for underwater sensor networks," *Ad Hoc Networks*, 2016.

[6] E. Egea-Lopez, J. Vales-Alonso, A. S. Martinez-Sala, P. Pavon-Marino, and J. García-Haro, "Simulation tools for wireless sensor networks," in *Proceedings of the International Symposium on Performance Evaluation of Computer and Telecommunication Systems (SPECTS05), New Jersey, USA*, July 2005, p. 24.

[7] M. Korkalainen, M. Sallinen, N. Karkkainen, and P. Tukeva, "Survey of wireless sensor networks simulation tools for demanding applications," in *Fifth IEEE International Conference on Networking and Services, Valencia, Spain*, April 2009, pp. 102–106.

[8] P. Neves, J. Fonsec, and J. Rodrigue, "Simulation tools for wireless sensor networks in medicine: a comparative study," in *International Joint Conference on Biomedical Engineering Systems and Technologies, Funchal, Madeira-Portugal*, 2007.

[9] V. Dhviya and R. Arthi, "Analysis of simulation tools for underwater wireless sensor networks," *International Journal of Computer Science & Engineering Technology (IJCSET)*, 2014.

[10] C. Raj and R. Sukumaran, "Modeling uwsn simulators–a taxonomy," *International Journal of Computer, Electrical, Automation, Control and Information Engineering, World Academy of Science, Engineering and Technology*, vol. 9, no. 2, pp. 585–592, 2015.

[11] J. Llor, M. P. Malumbres, and P. Garrido, "Performance evaluation of underwater wireless sensor networks with opnet," in *Proceedings of the 4th International ICST Conference on Simulation Tools and Techniques, Barcelona, Spain*, March 2011, pp. 19–26.

[12] C. Wang and Y.-j. Fang, "Channel model simulation for underwater acoustic sensor networks using opnet," in *12th IEEE International Conference on Communication Technology (ICCT), Nanjing, China*, November 2010, pp. 141–144.

[13] J. Fall, "The ns manual," http://www. isi. edu/nsnam/ns/ns-documentation, 2001, [Online; accessed on 20-Sep-2015].

[14] T. Henderson, "The uan framework," https://www.nsnam.org/docs/models/html/uan.html, 2013, [Online; accessed on 20-Sep-2015].

[15] P. Xie, Z. Zhou, Z. Peng, H. Yan, T. Hu, J.-H. Cui, Z. Shi, Y. Fei, and S. Zhou, "Aqua-sim: an ns-2 based simulator for underwater sensor networks," in *IEEE OCEANS,USA*, October 2009, pp. 1–7.

[16] M. T. et.al., "Aqua-3d," http://obinet.engr.uconn.edu/wiki/index.php/Aqua-3D, 2012, [Online; accessed 10-Oct-2015].

[17] C. Petrioli and R. Petroccia, "Sunset: Simulation, emulation and real-life testing of underwater wireless sensor networks," *Proceedings of IEEE UComms*, pp. 12–14, 2012.

[18] S. K. Dhurandher, M. S. Obaidat, and M. Gupta, "An acoustic communication based aqua-glomo simulator for underwater networks," *Human-centric Computing and Information Sciences*, vol. 2, no. 1, pp. 1–14, 2012.

[19] M. Stojanovic, "On the relationship between capacity and distance in an underwater acoustic communication channel," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 11, no. 4, pp. 34–43, 2007.

[20] S. K. Dhurandher, M. S. Obaidat, and M. Gupta, "A novel geocast technique with hole detection in underwater sensor networks," in *ACS/IEEE International Conference on Computer Systems and Applications, Hammamet, Tunisia*, May 2010, pp. 1–8.

[21] A. Sehgal, I. Tumar, and J. Schonwalder, "Aquatools: An underwater acoustic networking simulation toolkit," *IEEE Oceans, Sydney, Australia*, May 2010.

[22] K. Ovaliadis and N. Savage, "Underwater sensor network simulation tool (usnet)," *International Journal of Computer Applications*, vol. 71, no. 22, 2013.

[23] F. Guerra, P. Casari, and M. Zorzi, "World ocean simulation system (woss): a simulation tool for underwater networks with realistic propagation modeling," in *Proceedings of the Fourth ACM International Workshop on UnderWater Networks, California, USA*, November 2009, p. 4.

[24] M. Porter, "Bellhop gaussian beam/finite element beam code, ocean acoustics library," http://oalib.hlsresearch.com/Rays/index.html, 2007, [Online; accessed on 10-Oct-2015].

[25] J. M. J. Montana, *AUVNetSim: A simulator for underwater acoustic networks*. Sea Grant College Program, Massachusetts Institute of Technology, 2008.

[26] R. Masiero, S. Azad, F. Favaro, M. Petrani, G. Toso, F. Guerra, P. Casari, and M. Zorzi, "Desert underwater: an ns-miracle-based framework to design, simulate, emulate and realize test-beds for underwater network protocols," in *IEEE Oceans, Yeosu*, May 2012, pp. 1–10.

[27] Z. Peng, Z. Zhou, J.-H. Cui, and Z. J. Shi, "Aqua-net: An underwater sensor network architecture: Design, implementation, and initial testing," in *IEEE OCEANS, USA*, October 2009, pp. 1–8.

[28] Y. Zhu, S. Le, L. Pu, X. Lu, Z. Peng, J.-H. Cui, and M. Zuba, "Aqua-net mate: A real-time virtual channel/modem simulator for aqua-net," in *MTS/IEEE OCEANS, Bergen*, September 2013, pp. 1–6.

[29] M. Prats, J. Perez, J. J. Fernandez, and P. J. Sanz, "An open source tool for simulation and supervision of underwater intervention missions," in *IEEE/RSJ International Conference on Intelligent Robots and Systems, Portugal*, October 2012, pp. 2577–2582.

[30] R. Osfield, D. Burns *et al.*, "Open scene graph," http://www.openscenegraph.org, 2004, [Online; accessed 12-Oct-2015].

[31] "osgocean," http://code.google.com/p/osgocean, 2009, [Online; accessed on 12-Oct-2015].

[32] "Jaltarang: A ns-3 based underwater sensor network simulator," http://www.sit.iitkgp.ernet.in/~smisra/swan/tre/jaltarang.html, [Online; accessed on 15-Dec-2016].

[33] "Macosim: Matlab-based acoustic underwater simulator," http://www.sit.iitkgp.ernet.in/~smisra/swan/tre/macosim.html, [Online; accessed on 15-Dec-2016].

Copyright Disclaimer