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Modeling UWSN Simulators – A Taxonomy

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***Abstract*—**In this research article of modeling Underwater Wireless Sensor Network Simulators, we provide a comprehensive overview of the various currently available simulators used in UWSN modeling. In this work, we compare their working environment, software platform, simulation language, key features, limitations and corresponding applications. Based on extensive experimentation and performance analysis, we provide their efficiency for specific applications. We have also provided guidelines for developing protocols in different layers of the protocol stack, and finally these parameters are also compared and tabulated. This analysis is significant for researchers and designers to find the right simulator for their research activities.

***Keywords*—**Underwater Wireless Sensor networks (UWSN), SUNSET, NS2, OPNET, WOSS, DESERT, RECORDS, Aqua- Sim, Aqua- Net Mate.

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I. Introduction

OCEAN related research studies have created high interest in last few decades. Underwater Wireless Sensor Networks (UWSN) research studies have become a prime area of research, as nearly 70% of our world is covered with sea, river and oceans. Underwater Communication Studies have become popular in recent times. Several Underwater Wireless Sensor Network (UWSN) simulators have been developed for this purpose. There are many UWSN applications such as tactical surveillance, study of marine life, underwater vehicle communication, pollution monitoring, oil extraction and aquaculture. Bathymetric data [1] about sea depth and its properties help to develop underwater applications. Moorings provide an effective way to monitor ocean life by providing a platform for sensors to collect data throughout the entire water column over large temporal scales. These collected data greatly enhance our understanding of the earth's oceans and contribute in solving problems such as; predicting natural disaster and global warming**.** However many moorings do not provide data sets in real-time, as existing telemetry that connect sensors mounted along the mooring line to the surface for data transmission are expensive and limited. The main challenge for a researcher working in this domain is in choosing the right simulation environment and tool for their studies. Quite often there arises a need to compare, validate protocols, and conduct test designs using different simulators in order to arrive at a proper design. Due to high cost and increased time consumption in the deployment of UWSNs, many experimental tools and simulators are used to test the given design before actual implementation on the field. Real-time data is crucial for scientists and managers to detect important events (tsunamis, hurricanes and storms, eddies, harmful algal blooms) and to respond appropriately. Multiple unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with underwater sensors, also find application in exploration of natural undersea resources and gathering scientific data. In these applications, simulation plays a major role in testing and verifying results. To the author’s knowledge, there are many survey’s on simulators that explains terrestrial sensor networks properties and limitations whereas very few were available for underwater networks [3]-[5]. These survey articles have never addressed simulators exclusive for underwater network simulations. In this study, we analyze and report the different simulators used in UWSN, along with their properties, advantages and limitations. We also build a taxonomical reference at the end of this article. This article would serve as a base work for researchers interested in performing simulations in underwater networks, as efficient simulator aids in providing efficient results. This article will also provide information about the appropriate simulators for each protocol stack; as each simulator can be developed to work with a particular layer in the ISO-OSI network. The rest of the paper is organized as follows: Section II provides the design issues to be considered in underwater networks. Section III lists a summary of about 22 UWSN simulators widely used in underwater networking simulation. Section IV provides the taxonomy, analysis of these simulators, parametric comparisons and detailed case study of three popular simulators used for underwater sensor networks followed by the concluding factors in Section V.

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II. Design of Underwater Sensor Networks

A. Medium

Underwater networks transmit data using acoustic waves and light waves. Electromagnetic waves have very high attenuation in water, especially at higher frequencies and it requires high transmission power and larger antenna. Optical or light waves can be used to achieve ultra-high data-rate communications, but light waves are rapidly scattered and absorbed in water [2]. Optical waves are reliable only for short distance communication [6]. Acoustic waves enable communication over long range, as they have relatively lower absorption. This is the preferred medium of transmission used for underwater communications.

B. Environment

Environment refers to the Physical medium implementation [7]. Channel modeling is done based on applications and environment such as; density, depth, salinity, temperature, chemical substance, sound, optical, humidity, wind speed. And these parameters vary from sea to ocean and ocean to river [8].

C. Node Mobility

Underwater sensor nodes are equipped on surface-level buoys. Some special purpose underwater sensor nodes have medium mobility due to water current and other underwater activities [9]. Based on the traditional empirical formulas and bathymetric chart data, underwater objects move at speed of 3-6 km/h in a typical underwater condition. Based on these parameters efficient protocols are needed to be implemented in the protocol stack.

D. Physical Layer

Acoustic channel modeling is given prime importance, as acoustic waves are best suited for physical layer communication [10]. Only efficient Channel modeling supports the upper layers protocols like MAC and Routing. Parameters like signal fading, receiver power, propagation loss, propagation delay, transmission loss, background noise, node depth, density, mobility should all be considered for efficient channel modeling.

E. MAC Protocol

Development of MAC Protocols for acoustic UWSNs shall include the use of modem features, wake-up systems that can reduce power consumption. Synchronization and localization are important requirements for MAC Protocols.

F. Network Protocol

Network protocols proposed for ground-based sensor networks are not applicable for underwater communication. UWSN have unique features and new research at almost every level of the protocol suite is required.

G. Application Layer

The Application layer protocols must support the following features in underwater networks like; reusability, performance, scalability, availability and support for rich-semantic scripting languages to define experiments and to process results [11].

III. Underwater Sensor Network Simulators

A. SUNSET

SUNSET stands for Simulation, Emulation and Tool for Real-life Testing of Underwater Wireless Sensor Networks (UWSN). It was developed in the Department of Information in La Sapienze University, Italy. Sunset works in implementing MAC and Routing Protocols for UWSN's. It can simulate and emulate Sea Communication Protocols [12]. SUNSET is a Framework to seamlessly Simulate, Emulate and Test (at-sea) a variety of Communication Protocols. It validates and evaluates the real time acoustic devices like Modems, Environmental Sensors, Autonomous Under Water and Surface Vehicles.

Key Features: SUNSET represents a more mature, flexible and robust framework. Protocols performance tested through NS2 Simulations can directly be emulated for Real Time Sea testing without any code re-writing. It supports five different types of acoustic modems and several types of sensing devices. It also supports Underwater Acoustic Channel Models like Empirical Formulas (URICK's Formula), Bell Hop ray tracing. It has modules for Packet Conversion, Event Scheduling that results in higher scheduling accuracy, higher efficiency and flexibility.

Limitations: SUNSET needs each node to run an instance of NS2 and this creates an overhead on resource limited underwater embedded Systems. SUNSET also limits parallel operations and impairs real time features of the system.

B. SUNRISE

SUNRISE is a Sensing, Monitoring, and Actuating Environment for UWSN developed in the Department of Information in La Sapienze University, Italy. SUNRISE provides an Interface over the SUNSET Platform to easily Design, implement, validate and evaluate Communication Protocols for UWSN [13]. It has a Software defined open architecture modem that will empower open collaborative developments.

Key Features: SUNRISE is a software-defined open-architecture modem and protocol stack that will guide open collaborative developments. It supports application domains, data analysis, and scalability. It allows seamless integration of additional platforms and devices made available by partners or third parties. SUNRISE supports security, privacy and trust by providing an environment in which solutions for underwater security can be developed and tested.

Limitations: SUNRISE project is helpful in developing underwater Robot's for numerous applications. The main limitations are the battery life for the Underwater Robot's doesn't long too much for its applications.

C. DESERT

DESERT is a NS-Miracle Based Framework to Design, Simulate, Emulate and Realize Test-beds for underwater network protocols. It was developed in University of Padova, Italy. DESERT Protocols support the Upper layers (Application and Transport) through the Network, Data Link and Physical Layers [14]. DESERT is a useful tool to develop and test Underwater Real World Applications. DESERT implements a simple communication and networking architecture that allows heterogeneous nodes to communicate reliably in the underwater environment. This helps in protocols investigation and validation.

Key Features: DESERT Provides an Interface between the Network Simulator and the actual Modem Hardware. It also has features to support mobility for Underwater Robot's Movements. In the data link layer six different MAC Protocols are implemented. In the network layer three different routing protocols are provided. In the transport layer two underwater transport protocol modules are provided. And finally in the application layer two modules for different bit rate traffic generations are also provided

Limitations: DESERTS implement a simpler, but less efficient solution in Field experiments when compared with SUNSET.

D. RECORDS

RECORDS stand for Remote Control Framework for Underwater Networks. It was developed in Department of

Information Engineering, University of Padova, and Italy. Its layered architecture supports MAC, Network, and transport and application layers [15].

Key Features: RECORDS is a robust, versatile and reliable solution, which gives the possibility to send and receive remote commands over multi-hop networks.

Limitations: RECORDS framework was designed, developed and implemented for static underwater networks, and it fails to implement the same feature for dynamic nodes networks.

E. SeaLinx

SeaLinx is Multi-Instance protocol stack architecture for Underwater Networking. It enables users to efficiently use the hardware by allowing applications to run simultaneously on a Modem. It was developed in Department of Computer Science and Engineering, University of Connecticut using Embedded C Language [16]. SeaLinx works in the MAC, Network, Transport and Application layers of the OSI Model. It was targeted to support simultaneous protocol that runs in various applications on a node. In SeaLinx protocols are organized into separate process and this offers flexibility and safety.

Key Features: It provides a uniform method for cross layer communication that provides safety and flexibility

Limitations: SeaLinx does not allow the user to reconfigure the networking protocols and it is unavailable to the community as of today.

F. Aqua-Net

Aqua-Net is an underwater sensor network architecture that follows a layered structure and supports various optimizations. Aqua-Net was developed by the Computer Science Department, University of Connecticut, Storrs. Aqua-Net simulator simulates the entire layers of OSI Model. Aqua-Net was targeted to work in regular embedded systems [17]. Aqua-Net has a layer based design with a core-module dispatching messages between protocols.

Key Features: Aqua-Net is a Valuable platform that will facilitate the process of application development. It has a layered structure that allows cross layer optimization.

Limitations: Aqua-Net allows only one protocol suite per modem, which means that in order to run an Aqua-Net applications, the current protocol suite must be disabled.

G.Aqua- 3D

Aqua-3D is a network animator for underwater sensor network. It was developed in the Department of Computer Science in University of Connecticut, Storrs. It supports for visual purposes like Network Animator (NAM) Window in NS2. The nodes, process events, objects can be visualized in Aqua-3D. It is a robust visualization tool with the ability to correctly visualize trace files in underwater networks.

Key Features: Aqua-3D has ability to render a simulation in 3D Graphics that is fully controllable camera for 360 degree viewing [18]. It has options to adjust the functionality, appearance, save camera angles, trace files, drawing lines for the transmission paths of the nodes, topology of the network and save some interesting events.

Limitations: Aqua-3D was tested only with Aqua-Sim trace files and packets. There is still uncertainty whether this will suit for the latest underwater simulators like DESERT, SUNRISE, SUNSET and SeaLinx etc.

H.NS-2

NS-2 is a discrete event simulator targeted at networking research. It is a variant of REAL Network Simulator in 1989 and released as an open source to the networking research. It supports all the layers of the OSI Model. Many protocols has been developed, tested and implemented in NS-2 [19]. NS-2 is an open source simulator that provides good support and has a modular approach, making it effective and extensible [20].

Key Features: NS-2 extensibility has made it so popular for sensor networks. The object oriented feature allows designing, testing and implementing new protocols in the protocol stack. It provides a graphical visualization tool called Network Animator (NAM). NAM used to view the channel link, nodes created, mobility of nodes. All the simulations are run at the packet level allowing for detailed results.

Limitations: NS-2 lacks in customization, application model and it requires advanced skills to perform meaningful and repeated simulations. The results obtained in NS-2 are not as appropriate as the results obtained in other well-known simulators like OPNET, Qual-Net, OMNET++ Simulators.

I. UWSIM

UWSim is an underwater sensor networks simulator. It was acquired to AUV Simulator for robotic community [21]. It is based on a network component approach. It focuses on handling scenarios specific to underwater environments like low bandwidth, low frequency, high-transmission power and limited memory.

Key Features: UWSim is based on novel routing protocol and simulates the acoustic networks. While developing UWSim, various parameters for underwater networks are taken into consideration. This makes UWSim as one of the best simulators for underwater networks.

Limitations: UWSim has limited support in certain functionalities and there is need for further extensions support for a wide range of UWSN Application.

J. Aqua-GlomoSim

It is an Acoustic based communication simulator for underwater networks. Aqua-GLOMO was targeted to develop network layers protocols and physical layer protocols [22]. It works under different frequency bands in the spectrum. It is based on the popular simulator GlomoSim, where the radio channel is altered to support acoustic channel.

Key Features: Aqua-GLOMO has upgraded the GlomoSim simulators in physical and network layer models to make it feasible for underwater communication. For underwater acoustic communication, the focus is on efficient communication at the physical layer and the routing between the nodes at the network layer. These two areas present major challenges for researchers to work on. And this simulator models these two layers.

Limitations: Aqua-GLOMO was developed to work in

Physical and Network layer. Still it lacks in some features required in underwater communication as the simulation model and mathematical model are different for acoustic communication.

K. Aqua-Net Mate

Aqua-Net mate is a real-time virtual channel modem simulator for Aqua net that supports underwater networks communication. Aqua-Net Mate was developed in the Department of computer science engineering, University of Connecticut, Storrs. It supports all the layers of OSI Model [23]. Aqua- Net Mate can guarantee the real time features, since all events are triggered by system timer and each layer runs as individual process.

Key Features: Aqua-Net mate is highly extensible, configurable and user friendly. Since it is based on Aqua-Net simulator it's easy to seamlessly switch between simulation and emulation. Aqua-net mate supports real time schedule.

Limitations: Aqua-Net Mate is based on Aqua-net simulator and it modifies the Channel or Modem Simulator. Aqua-Net allows only one protocol suite per modem, which means that in order to run an Aqua-Net application the current protocol suite must be disabled.

L. Aqua-Lab

Aqua- Lab is a NS2 based simulator for underwater sensor networks. Aqua-Lab was developed in the Department of computer science engineering, University of Connecticut, Storrs. It works in the Physical layer of the OSI/ISO Model [24]. In Aqua-Lab the basic characteristics of data transmission using Micro-Modems are done. It helps in conducting a set of experiments for both field and lab environment**.** Aqua-Lab provides real channel environment being configurable, controllable, accessible and affordable.

Key Features: The goal of Aqua-Lab is to bridge the gap between real system implementation and simulation environments. A web based GUI is provided for easy access and configuration. This provides researchers the ability to test, evaluate and compare various network algorithms and protocols in a less-expensive lab based environment.

Limitations: Aqua- Lab simulator needs to incorporate many features in the acoustic environment for underwater networks. It failed to consider parameters like salinity, density of water in sea in modeling the acoustic modeling channel.

M. NS-Miracle

NS- Miracle is a NS2 Library developed to allow interlayer communications and flexible multilayer design. It was developed in SIGNET Lab in the University of Padova. NS Miracle works in all the layers of the protocol stack [25]. NS Miracle was intended to help researchers in implementing the cross-layer protocols and multi-technology solutions.

Key Features: NS Miracle library defines a standard procedure to generate a multi-layer architecture that makes cross-layer communication functionalities.

Limitations: NS Miracle, added a library in NS2 to support interlayer and cross communication for underwater sensor nodes. It failed to provide support for modeling effects of ambient oceanic conditions and node depth that can affect the channel performance.

N. Aqua- Sim

Aqua-Sim is a NS-2 Based packet level simulator for underwater networks. It follows object oriented design style and the network entities are implemented as classes. It was developed in the underwater sensor networks lab, University of Connecticut, Storrs. Aqua-Sim works fine in Physical, MAC and Routing layers of the ISO Model. Aqua-Sim simulates the attenuation of underwater acoustic channels and the collision behaviors in long delay acoustic networks. The Significant feature of Aqua-Sim is that, it gives experimental results with high fidelity and flexibility when compared with real world [26].

Key Features: Aqua-Sim can effectively simulate acoustic signal attenuation and packet collisions in underwater sensor networks. Aqua-Sim is a powerful tool with high fidelity and flexibility for underwater networking research.

Limitations: Aqua-Sim needs to incorporate advanced channel models with real experiments data.

O. Aqua –Tune

Aqua-Tune is the Test-bed for Underwater Networks. It is used to evaluate the algorithms and protocols developed in underwater networks. It was developed in Department of Computer Science and Engineering, University of Connecticut, Storrs. Aqua-Tune supports all the layers in the ISO Model. Aqua-Tune provides a standardized platform for testing and to bridge the gap between modeling, simulation and real world field experience [27]. Aqua-Tune provides accessibility, affordability and standardized platforms.

Key Features: Aqua-Tune systems can operate from 70 hours to 7 days without recharging the batteries. It can used to experimentally evaluate the algorithms and protocols developed for underwater networks. Aqua-Tune will not only support the research in underwater networks but also helps the maritime scientists in numerous applications.

Limitations: Aqua-Tune platform, Small Kayak needs to replace with bigger and more robust buoys. It needs to be tested with high system loads and waterproofing alternatives for the electronic devices

P. Aqua-Tools

Aqua-Tools is an Underwater Acoustic Networking Simulation Tool Kit. It was developed in Department of computer science, Jacobs University Bremen. Aqua-Tools works in Physical layer, MAC layer, routing layer and energy consumptions schemas. It was targeted to evaluate underwater acoustic communications from a networking perspective. The striking feature of Aqua-Tools simulation toolkit is ocean acidity, salinity, and temperatures are taken into consideration for simulating the acoustic channel [28].

Key Features: Aqua-Tools simulation tool kit provides support for simulating underwater acoustic networks with static and mobile nodes. It has been used to conduct the study in different channel models, climate change effects and to develop a power management scheme for underwater networks. Aqua-Tools provides a flexible scripting interface to set up the simulators.

Limitations: Aqua-Tool kit should consider for reliable data sharing in underwater sensor networks.

Q. UANT

UANT is an Underwater Acoustic Networking platform for underwater acoustic networks to address the constantly changing underwater acoustic channel by re-configurability. UANT was developed in Networked and Embedded System lab, Department of Electrical Engineering, University of California, Los Angeles. UANT supports Physical, MAC Layer of the ISO Model [29]. UANT is designed for field-deployment and prototyping, testing of PHY and MAC Layer schemes.

Key Features: UANT adapts some tools to work with underwater environments while maintaining flexibility, ultimately providing an end-to-end networking approach for underwater acoustic environment.

Limitations: UANT was developed using Tossim and TinyOS and works in these platforms. However those two platforms are well suited for terrestrial sensor networks and it's can't be an efficient simulator underwater sensor networks.

R. WOSS

World Ocean Simulation System (WOSS) is a Simulation tool for Underwater networks with Realistic Propagation Modeling. WOSS was developed in Department of Information Engineering, University of Padova, Italy. It works on the MAC Layer of the ISO Model. WOSS provides a flexible interface for protocol coding for implementing interactions among the protocols in the MAC Layer [30].

Key Features: WOSS uses BELLHOP ray tracing model to produce nearly realistic transmissions loss that includes shadow zones. WOSS incorporates bathymetry and sound speed profiles (SSPs) from Internet database to model the 3 Dimensional Underwater environments.

Limitations: WOSS, however Multipath Propagation is currently not considered and left as the future work.

S. AUWCN

Acoustic Underwater Channel and Network Simulator (AUWCN) is an underwater network simulator used to reduce the improper simplifications used, reproduce most effects existing in the physical Acoustic Underwater Channel. It was developed in Faculty of Computer Science and Electrical Engineering, University of Applied Sciences Kiel, Germany. AUWCN works in the modeling of the physical layer of ISO Model [31]. AUWCN is designed to develop and evaluate modulation schemes for use in the AUW Communication channel.

Key Features: BELL HOP Ray tracing simulates the physical channel in underwater networks. Instead of traditional modeling like transmissions loss output, it uses the CIR option to model multipath propagation. These CIRs for fixed nodes are post-processed to simulate mobile nodes. Many effects implemented in this simulator like attenuation, multipath propagation, Doppler spread, Shadow Zones.

Limitations: AUWCN environmental data need to include more complex solutions in Sound Speed Profiles, bathymetry and reflection coefficients. AUWCN needs to extend the attenuation model to broadband transmissions.

T. SAMON

SAMON is a High-fidelity Ocean sampling Mobile Network Simulator Test bed for evaluating Intelligent Control of Unmanned Underwater Vehicles. SAMON Simulator was developed at Penn State. SAMON is used to dynamically adaptive sampling techniques to significantly improve the mapping of geophysical fields by reducing temporal and spatial aliasing [32]. SAMON test bed plays important role in designing and evaluating algorithms for dynamic adaptation of sampling plans.

Key Features: SAMON simulator integrates with the real world testing and the result obtained with the simulation and real time testing is approximate.

Limitations: SAMON simulator is high cost and it is not affordable for education purposes.

U. OPNET

OPNET is a popular simulator used in industry for network research and development. OPNET (Optimized Network Engineering Tools) is a Discrete Event Driven Simulation tool, supporting modeling of communication networks and distributed systems. Alain J. Cohen along with Marc A. Cohen developed OPNET in 1986 and commercialized as OPNET Technologies Inc [33]. In 2012, Riverbed Technologies Inc. acquired OPNET. OPNET supports all the 7 layers and lots of vendors manufacturing network equipment and devices also support opnet development by providing simulations of their devices and equipment's. It can be flexibly used to study communication networks, devices, protocols, and applications

Key Features: It has a fast discrete event simulation engine that has lot of component library with source code. It is Object-oriented modeling with Hierarchical modeling environment. It supports for Scalable wireless simulations, supports 32-bit and 64-bit graphical user interface and a customizable wireless modeling and discrete Event, Hybrid, and Analytical simulation [34]. It supports 32-bit and 64-bit parallel simulation kernel and Grid computing support. It has an Integrated, GUI-based debugging and analysis with Open interface for integrating external component libraries. End-to-end visibility into application performance for organizations with ability to capture and analyze Net Flow data is also its feature

Limitations: It is commercial software with license for usage and used mostly used for accurate results suitable for real-time usage and industrial standards.

V. UsNeT

UsNeT follows the object-oriented design style. The network entities are implemented as classes in C++ encapsulating threads mechanisms. Threads have been used because the system needs to handle multiple tasks in parallel and concurrently. This cannot be achieved with discrete event simulators such as NS2 [35]. In discrete event simulators, events that affect the state of the system are chronologically ordered into event queue and event scheduler executes them one by one [36]. An event-driven simulator cannot execute multiple events at different nodes at the same time unless it uses a parallel discrete event or multithread approach

Key Features: A typical cluster based network consists of a sink and certain sensor nodes that are grouped into clusters. In this structure, each cluster has a head, which are known as head-cluster or Cluster Head (CH). A CH may be elected by the sensors in a cluster or pre-assigned by the network designer. UsNeT makes use of underwater modems efficiently

Limitations: UsNeT does not provide accurate results in emulation mode, as there is much difference in results between simulation and emulation mode.

IV. Discussion and Case Study

This section compares a few popular UWSN's simulators used in the simulation of underwater networks namely OPNET, NS2 and WOSS. As most leading industries use OPNET for simulation purposes for its striking features and provides options for modeling a network from Physical layer to Application Layer. Current simulating frameworks like SUNSET, DESERT, Aqua-Sim, Aqua-Tune have been developed using well know open source simulator NS2 and NS-Miracle. We have created a simple network with seven nodes sending packets to each other, with the following attributes in Table I.

TABLE I
UWSN Taxonomy

S.No	Parameters	Values
1	Number of Nodes	7
2	Area in Sea	10 X 10 metres
3	Speed of Wind in water	10 m/s
4	Speed of Sound in Water	1500 ms/s
5	Simulation Time	15 min

The simulation test case calculates the packets dropped in each simulator while sending packets to other nodes. The simulation results show the very fact that terrestrial sensor networks simulator with aquatic modeling failed to provide efficient results. So there is a need to implement new protocols in each layer of the protocol stack. We have calculated the throughput, propagation delay and number of packets dropped in each of the simulators and plotted them.

The results show that OPNET provides the best throughput. This is because of the 14 stages wireless pipeline used for both the transmitter and the receiver node. Each of these nodes can be individually modeled for each layer in acoustic communication. Whereas, most of the other frameworks are developed using the open source simulators such as NS2 and NS-Miracle have widely varying results upon testing in real-time. WOSS one of the popular open source UWSN simulator works best for MAC Layer protocols, however is not so efficient in modeling a complete network. Fig. 1 denotes the number of packet dropped amongst the simulators.

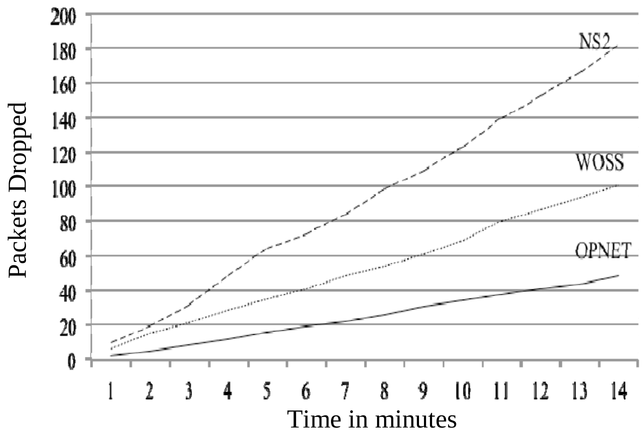

Fig. 1 Comparison of UWSN Simulation

Taxonomy for the different simulators used in UWSN is shown in Fig. 2. Each type of simulation tools in these categories possesses unique features and emphasis on some special requirements of simulation for underwater wireless network systems is provided. This is tabulated in Table II.

V. Conclusion

In this article, we study the modeling and simulation of UWSN systems. We have constructed taxonomy for UWSN simulators. A survey of existing simulation tools for UWSN is made readily available. Most of the existing simulation tools with relatively widespread uses have been studied. We believe that this survey is comprehensive enough to prove that almost all simulation tools for UWSN can be used for a particular scenario. Some simulators may be out of maintenance at this moment; however, it is worth to analyze them here so as to illustrate the evolution process of UWSN simulation techniques. This article helps underwater networks designers and researchers to find an appropriate simulator for their research. This paper will also help the underwater researchers to develop their own custom simulator for their specific applications. This article serves as an origin for learning UWSN Simulators and there is no UWSN Simulators article currently available with such information.

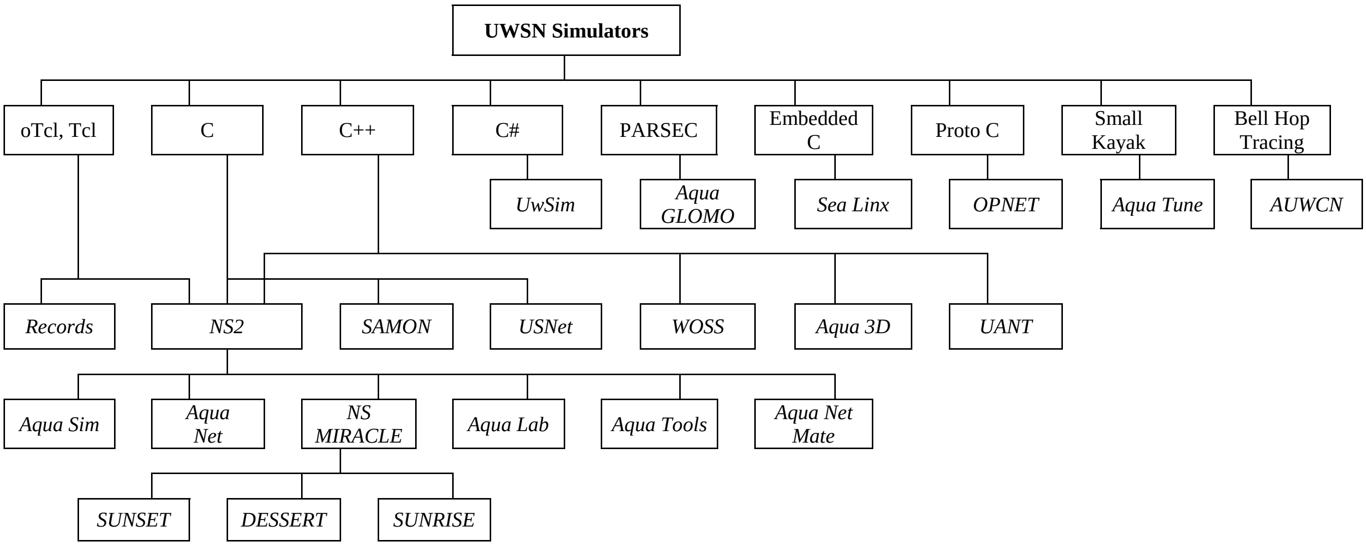

Fig. 2 UWSN Taxonomy

TABLE II
UWSN SIMULATOR COMPARISON

Simulator	Language	Specification Support	Software Modeling	Hardware Modeling	Energy Aware	Heterogeneity Support	Easy of use	Open Source
SUNSET	NS2, NS-Miracle	IEEE802.11	Yes	Yes	Perfect	Perfect	Good	Yes
DESERT	C, C++, NS2, NS-Miracle	IEEE802.15.4	Yes	Yes	Low	Good	Good	Yes
RECORDS	Scripting Languages	IEEE802.15.4	Yes	Yes	Good	Perfect	Good	Yes
SUNRISE	NS2, NS-Miracle	IEEE802.11	Yes	Yes	Perfect	Perfect	Good	Yes
WOSS	C++ Libraries	IEEE802.15.4	Yes	Yes	Perfect	Perfect	Good	Yes
Aqua-Sim	NS2	IEEE802.15.4	Yes	No	Low	Good	General	Yes
Aqua-3D	C++,wxWidgetOpenGL	NA	No	No	Low	Low	General	Yes
SeaLinx	Embedded C Language	NA	Yes	Yes	Good	Good	General	NA
Aqua Net	NS2	IEEE802.11	Yes	No	Low	Low	General	Yes
Aqua Net-Mate	NS2	IEEE802.11	Yes	Yes	Good	Good	Good	Yes
NS2	C, C++, oTcl	IEEE802.15.4	No	No	Low	Perfect	Good	Yes
UWSIM	C#. Net Framework	NA	No	No	Low	Low	General	Yes
Aqua GLOMO	PARSEC	NA	No	No	Low	Low	General	Yes
Aqua-Lab	NS2,PHP,XML Java script Ajax	IEEE805.11	Yes	Yes	Good	Good	Good	NA
NS Miracle	C, C++, oTcl	IEEE802.15.4	No	No	Low	Perfect	Good	Yes
Aqua-Tune	Small Kayak	IEEE805.11	Yes	No	Perfect	Low	Good	Yes
UANT	C++, Tiny OS, TOSSIM	IEEE805.11	No	No	Low	Good	General	Yes
Aqua-Tools	NS2	IEEE805.11	No	No	Low	Good	General	Yes
AUWCN	Bell Ray Tracing	IEEE805.11	Yes	No	Good	Good	Good	Yes
SAMON	C, C++	NA	Yes	Yes	Low	Good	General	Yes
OPNET	Proto C	IEEE805.11	Yes	Yes	Good	Perfect	Good	No
USNeT	C Language	NA	No	No	Low	Low	General	NA

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