Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online): 0493-2137
E-Publication: Online Open Access
Vol:55 Issue:01:2022
DOI 10.17605/OSF.IO/QDXFM

EXPERIMENTAL ANALYSIS OF VECTOR BASED FORWARDING AND DEPTH BASED ROUTING PROTOCOLS IN UNDERWATER ACOUSTIC SENSOR NETWORK (UW-ASNS) BY VARYING NETWORK SIZE

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Abstract: Underwater Acoustic Sensor Networks (UW-ASN)is a special branch of Wireless Sensor Networks (WSN) that exhibit distinct characteristics than WSN due to the differences in nature of medium of operation. Underwater sensor networks (UWSN) are the network of autonomous sensor aided devices called sensor nodes deployed over a region of water for collaborative execution of a specific task. Sensor nodes use acoustic signals as transmission medium that operates at low frequency as radio frequency (RF) signals cannot penetrate in deep water. Acoustic signals are largely affected by underlying noises like the sound of aquatic animals, continuous drifting of nodes due to water movements and noises of underwater vehicles. So data collection phase demands high energy due to packet losses and higher delay. Sensor nodes are battery operated devices, so optimal use of energy adds to achieve longevity of network. Network lifetime can be improved by thoroughly investigating challenges in UWSN, architecture and protocols designed for UWSN. This paper presents architecture of UWSN and experimental analysis of two popular routing protocols Vector Based Forwarding (VBF) and Depth Based Routing (DBR) by implementing in ns-3, Aquasim NG.
Keywords: UWAN, UWSN Architecture, Network Layer protocol, Cross layer approach, VBF ,DBR, AquaSim NG , ns-3

INTRODUCTION

Under Water Sensor Networks (UWSN) is considered the most promising technology for oceanographic data collection. To enable this system, it's necessary to build efficient communication among underwater sensor nodes. Underwater Sensor Networks consist of sensors that are deployed to perform a collaborative task over a given volume of water. To achieve wireless communication, optical waves are considered the first mode because of their presence in terrestrial networks. Properties of optical wave reveal that propagation of signals in water at very low frequencies (30-300Hz) requires large antennae and high transmission power. Furthermore optical waves are affected by scattering. Thus optical waves are not suitable for large UWSNs. Acoustic link is one of the feasible solutions for underwater wireless communication. Acoustic communication channels come with unique characteristics such as limited bandwidth capacity and high propagation delays. These characteristics of acoustic channels imply the design and implementation of new communication protocols for transmission.

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As UWSN can be considered as a special branch of WSN, the following points represent a key difference between WSN and UWSN.
Power: Because of the different physical layer technology (acoustic and optical), higher distances and complex receiver signal processing, power requirement in UWSN is higher than WSN.
Memory: Due to high noises and irregularities in underwater channels more data caching in UWSN sensor nodes is required as compared to terrestrial sensor nodes where very little data storage is required.
Spatial Correlation: In terrestrial WSN, data are highly correlated as the network is constructed with dense sensor nodes whereas in UWSN it is very unlikely to have data correlation due to sparse deployment of sensor nodes under the water.
Cost: Terrestrial WSNs are becoming less expensive as compared to UWSN. It is due to complex transceiver design and protective shield to maintain water resistant quality cost of sensor nodes are higher.

2 RELATEDWORK

This section describes various factors that affect UWSN communication and communication architecture of typical UWSN.

2.1Factors Influencing Under Water Sensor Network

Underwater acoustic communication is largely affected by parameters such as transmission loss, noise, multipath propagation, Doppler spread, and high and variable propagation delay. These factors cause variability of temporal and spatial bandwidth of acoustic channels which result in limited bandwidth of the underwater acoustic channel and are dependent on range and frequency. Underwater communication links can be classified according to their range as very long, long, medium and short links. Table 1 shows typical bandwidths of the underwater acoustic channel for different ranges.

Table 1. UW-Acoustic bandwidth for different range[1]

	Range[KM]	Bandwidth [KHz]
Very long	1000	<1
Long	10-100	2- 5
Medium	1 – 10	10
Short	0.1 -1	20-50
Very Short	<0.1	>100

Transmission loss: It is caused due to signal attenuation and geometric spreading. The attenuation is mainly triggered by absorption of the sound signal due to the conversion of acoustic energy into heat and increases with distance and frequency. The geometric spreading denotes the spreading of sound energy as a result of the expansion of the wave fronts. It is dependent on the frequency of the signal and increases with the propagation distance.
Noise: It is classified into main two categories ambient noise and man-made noise. Ambient noise is the result of ocean currents, tides, storms, sounds of aquatic ani-

mals and noise of machines like submarines, shipping activities add to man-made noises. These noise signals provoke distortion of data carrying signals.

Multipath Propagation: Acoustic communication signals are severely degraded due to multipath propagation as it generates Inter Symbol Interference (ISI). Link configuration plays a vital role in multipath geometry. Vertical channels are affected by less time dispersion, where horizontal channels can have long multipath spreads. Spreading is tightly dependent on the depth and distance between transmitter and receiver.

Higher delay and delay variance: The propagation speed in the Under Water acoustic channel is five orders of magnitude less than the radio channel. Such large propagation delays like 0.67s/km and variances may reduce the system throughput.

Doppler Spread: The Doppler frequency spread causes degradation signal performance. High data rate transmission from the transmitter leads to adjacent symbols interfering at the receiver. The Doppler spread produces two effects namely frequency translation and the second is the continuous spreading of frequencies. Frequency translation can be compensated at the receiver but the second one is difficult.

Chemical and physical properties of water medium such as salinity, temperature, density and variations in these causes the above mentioned effects. These variations are the root cause of acoustic channels to be highly temporally and spatially variable. Specifically in shallow water horizontal channel varies far more than vertical channels.

2.2Under Water Communication Architecture

Architecture fundamentally describes deployments of sensor nodes that are stationary but are constantly moving from their positions due to water currents. Underwater communication architecture is broadly classified as Two Dimensional architecture and Three Dimensional Architecture.

Two Dimensional Communication Architecture: Main components of communication networks are uw-sensors nodes and uw-gateways. Uw-gateways are communication network equipment. Gateways relay data from the ocean bed network to the surface station. The collection of Uw-sensor nodes is anchored to the bottom of the sea. Acoustic links are used in connecting Uw-sensor nodes with uw –gateways. Two trans receivers are deployed in uw-gateway devices. One horizontal trans receiver is used for communication with uw-sensor nodes for sending commands and control information and to collect monitored data. A vertical link is used by the gateway to send data to the surface station.

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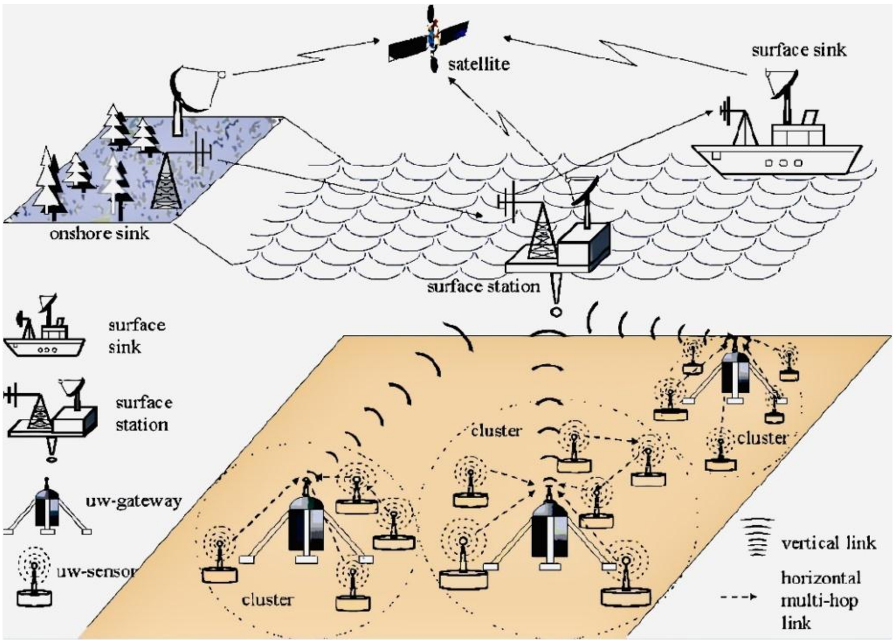

Fig. 1. Two dimensional communication architecture

Three Dimensional Communication Architecture: In three Dimensional Architecture sensor nodes are deployed at varying depths to observe the occurrences of events that cannot be observed by sensors mounted at the bottom. In this architecture, sensor nodes float at different depths. The depth of the sensor is regulated by adjusting the length of the wire that connects the sensor to the anchor, using an electronically controlled engine that resides on the sensor. Three dimensional architecture covers a larger surface area than two dimensional architecture.

Due to high energy requirements for communication in UWSN, optimal usage of it is of prime importance. Efficient routing algorithm designs are of prime concern in achieving optimal power usage of battery operated sensor nodes. A review of various algorithms is described in further section.

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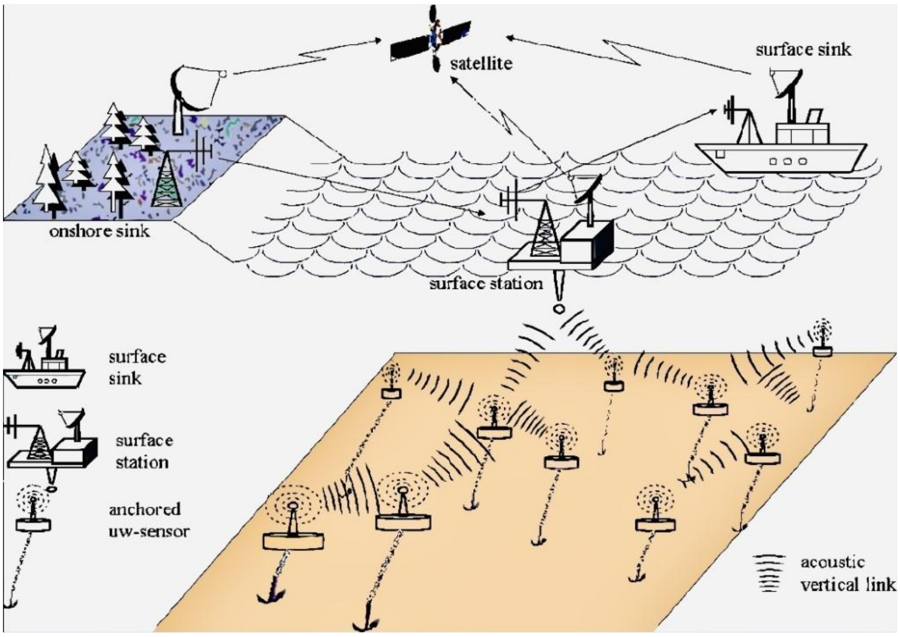

Fig. 2. Three dimensional communication architecture

3 NETWORK LAYER PROTOCOLS

Developing a new routing layer protocol is always of great interest for WSN. Routing protocols for WSN are broadly classified as flat, hierarchical and location based. Merits and comparisons of each are presented in[2].To decrease energy consumption, an efficient clustering algorithm is discussed in [3]. However, there are several drawbacks concerning the suitability of these protocols for UWSN. Ad hoc network focuses on broadcasting and multicasting strategies using flooding. But these methods have higher energy requirements as flooding of packets may generate collision if the number of nodes in a network is lesser.(GFG[4],PTFK[5]) are efficient for limited signal power requirement and their scalability feature for terrestrial communications. Global positioning system (GPS) radio receivers, which are used to accurately estimate the location of sensor nodes, do not work properly in the underwater environment as GPS uses waves in 1.5GHz band that does not propagate in water. So low frequency acoustic signals are useful. There are a few protocols specially designed for underwater networks that fall under the category of greedy algorithm designs.

In [6] Protocol is source based routing protocol. The algorithm designed is a greedy type and assumes all sensors know their positions through localization services. Vector Based Forwarding (VBF) operates by creating a virtual pipe by using the Radius parameter field in the packet. This parameter specifies the predefined threshold used by sensor nodes to determine if they are close enough to the routing vector and are eligible for packet forwarding. The efficiency of the protocol is determined by the size of the radius of a virtual pipe. Nodes forward the packets by broadcasting them to nodes residing in a constrained pipe of a given width in the direction of the sink. If the radius is too large many nodes might receive the packet that increases interference, if the radius is too small, few or no relays can be found.

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In[7], the Enhanced version of VBF is explained. It explains the generation of multiple vectors from each sensor node to the sink to increase the probability of finding a relay in the pipe. The method works well, especially for the sparse network. The performance of the protocol depends upon the selection of radius. In [8], DFR, While broadcasting data packets from source S to its neighbors based on directional information, the node decides whether to forward the packet or not. The decision is made by comparing the angle with a reference angle carried by the packet.
Change in reference angle at each hop facilitates varying conditions of underwater channel. Link quality of neighboring nodes is also taken into consideration. When a forwarding node has poor link quality to its neighbor nodes geographically advancing towards the sink, the protocol allows more nodes to participate in forwarding the packet. Otherwise, few nodes are sufficient to forward the packet with reliability. The exact geographic information of nodes can be difficult to find underwater, so partial information like depth can be determined easily and is used in [9], DBR. It is geographic anycast routing protocol. Packet forwarding decisions are made based on the depth field value carried in the packet at each node such that each packet is forwarded by the node if its depth is smaller than that encapsulated in the packet otherwise node discards the packet.
Hydrocast [10] is hydraulic pressure based any cast algorithm. This algorithm assumes communications are strictly vertical. Before forwarding the data packet, the node holds the packet for a time that depends upon the difference between its depth/height and that of the sender. Larger the vertical distance, the smaller the holding period. Along with holding, a node listens to transmission on the channel. If the same packet is about to be transmitted by another node then a particular node drops the packet.
While research on underwater communication protocol design so far has followed the layered approach initially developed for wired networks, network performance can be improved with cross layer design. These techniques entail a joint design of different network functionalities, from modem design to MAC and routing, from channel coding and modulation to source compression and transport layer. The main objective of the cross layer design is to enable more efficient use of scarce available resources. The following section includes a survey of various protocols based on cross layered approach.
Safdar Hussain Bouk et al.in [11]have proposed Tier-Based Cross-Layer routing protocol for the underwater Delay Tolerant Network. The network is divided into tiers with a reference from the sink node. In one tier, both transmitter and receiver should be in each other’s transmission range and the maximum range is defined as $d_{max.}$ The value of d_{max} is determined to achieve a certain level of channel capacity, as the channel capacity is highly affected by the distance between transmitter and receiver. The cross layer optimization is achieved by synchronizing MAC and routing functionalities together to minimize collision that causes delay. If a node in tier *j* wants to communicate with the sink, it sends its tier information in a request to send a message and the node(s) in the upper tier, *j*+1, reply with a clear-to-send(CTS) message. After receiving multiple CTSs from the upper tier nodes, the source node sends in-

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tent to send with the node number that acts as a next-hop routing node. The selection of the next-hop node is done based on the minimum distance that requires small transmit power. As a result, the proposed protocol has a minimum delay and a high accuracy rate and consumes less energy.

Stefano Basagni et al in [12] discusses performance evaluation of a new multi-hop routing protocol for underwater wireless sensor network, CARP (Channel aware Routing Protocol), Authors exploits link quality(L*q*) information for data forwarding, in that nodes are selected as relays if they exhibit a recent history of successful transmissions to their neighbors.

In the network initialization phase, each node calculates its hop distance from the sink. When a node x has one or more data packets to forward, it broadcasts a special packet called PING in search of a suitable relay node in the neighborhood. All nodes y have hop count (HC) such that HC(y) < HC(x) replies with PONG packet to x. Relay selection by x is done based on the link quality(lq_{xy}) from x to y and from y to z (lq_{yz}) with the formula goodness = $lq_{xy}lq_{yz}$. The node y with the highest goodness and low hop count is chosen as a relay. This protocol avoids loops and shadow zones by simple topology information as hop count.

Authors of [13], Zhou proposed an E-CARP, an enhanced version of CARP. Enhanced CARP (E-CARP) advocates caching the previous data at sensor nodes and tries to avoid the forwarding of data packets when there is a small change in the data from the previous history, thereby reducing the routing of sensory data packets to the sink node. These strategies may decrease the energy consumption when the environment to be monitored is relatively steady.

Network lifetime maximization is investigated in [14] by Hongyu Yang et al. with cross layer approach in which link scheduling, transmission power and transmission rate are used for optimization with TDMA schedules.

Optimization is achieved by computing optimal transmission power $P_i^n(l)$ and transmission rates R^n_i of a node with keeping TDMA schedules fixed at each iteration and network lifetime T*net* is compared with the previous iteration. If T*net* is increased then the TDMA schedule is updated not otherwise.

Table 2. UWSN Protocol Summary

Approach	Protocols	Implementation details
Greedy	VBF[6]	VBF operates by creating a virtual pipe by using the Radius parameter.
	An enhanced version of VBF[7]	Operate by the generation of multiple vectors from each sensor node.
Geographic Routing	DBR	Packet forwarding decisions are made based on the depth field value carried in the packet at each node.

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	Hydrocast[10]	Assumes communications are strictly vertical. Node holds the packet for a time that depends upon the difference between its depth/height and that of the sender.
Cross Layer	Safdar Hussain Bouk et al.in [11]	The cross layer optimization is achieved by synchronizing MAC and routing functionalities together to minimize collision that causes delay.
	CARP[10]	Exploits link quality(L*q*) information for data forwarding.
	E-CARP[11]	Caching the previous data at sensor nodes.
	Hongyu Yang et al[12]	Optimization is achieved by computing optimal transmission power $P_i^n(l)$ and transmission rates R_i^n of a node with a fixed TDMA schedule.

Two popular protocols namely Vector Based Routing(VBF) and Depth Based Routing(DBR) are implemented and obtained results are discussed in the next section.

4 SIMULATION SETUP

ns-3 is a discrete-event network simulator for Internet systems.*ns-3* has an emulation mode, which allows for the integration with real networks. Aqua-Sim Next Generation is an ns-3 based Simulator for Underwater Sensor Network[16]. Implementation of Vector Based Forwarding (VBF) and Depth Based Routing (DBR) is performed using Aqua-sim ng *ns-3* based simulator. It supports 3D networks and mobile networks.

Aqua-Sim supports the simulation of underwater acoustic channels with high fidelity. It also facilitates the implementation of a complete protocol stack from the physical layer to the application layer[17].

Following network setup parameters are identified and their initial values are declared as shown in the table below.

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Table 3. Simulation Parameters

Sr No	Parameter	Value
1	Network Size	250 x 250 x 250
2	Deployment	Random Uniform
3	Initial Energy of nodes	50J
4	Packet Size	40 bytes VBF 50 bytes DBR
5	Transmission range	100meter
6	Transmission Power con-sumtion	1.6W
7	Receiving power consumption	1.2W
8	Idle power consumption	0.008W
9	Frequency	3 kHz

In network setup, sensor nodes are varied with a range of 100,200,300,400and 500. Numberof Sink node are considered 1 and 3 respectively. The following graph shows End to End Packet delivery ratio.

5 EXPERIMENTAL RESULTS

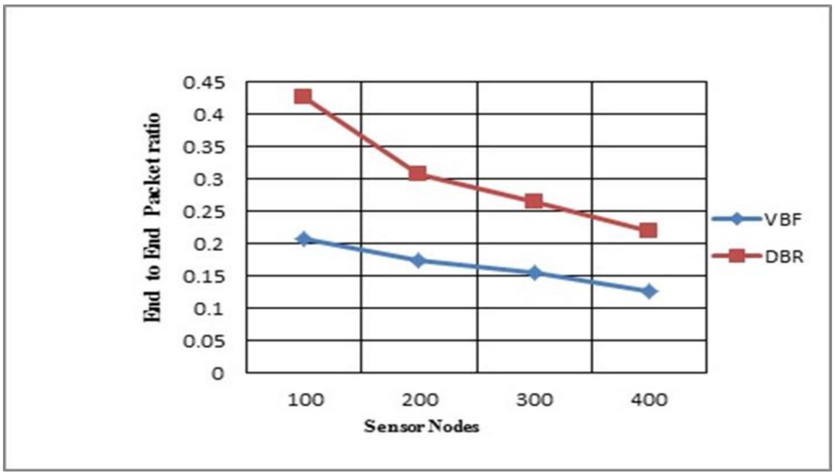

Fig. 3. End to end packet delivery ratio

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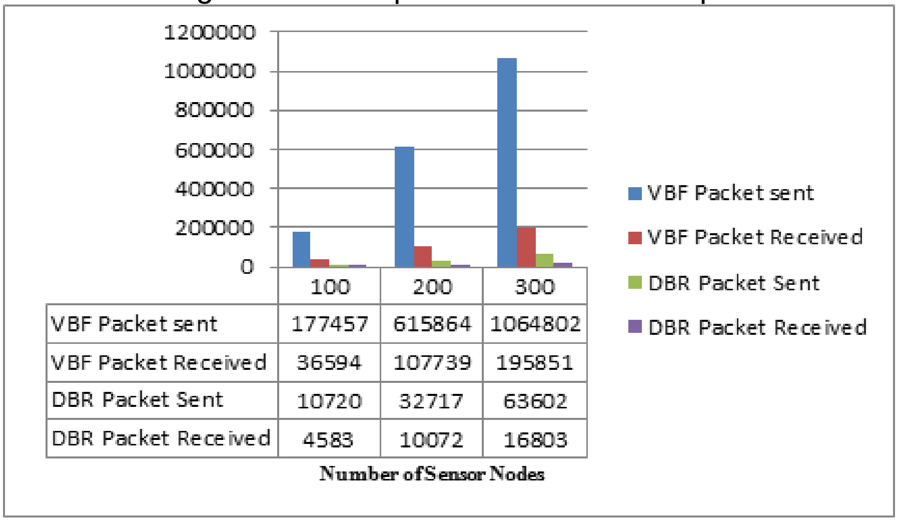
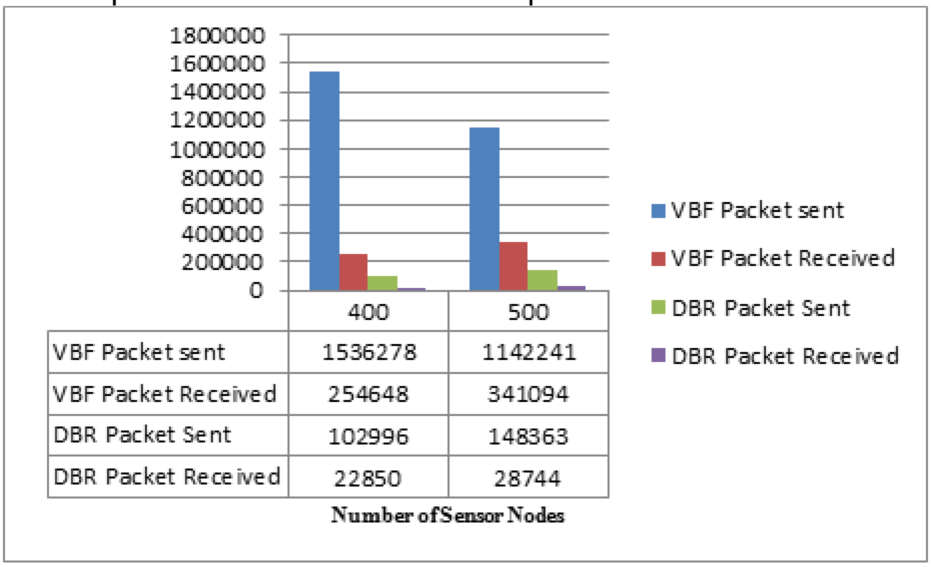
DBR performance is better than VBF because in DBR protocol, more number of neighboring nodes participate in forwarding the packets when the link quality of selected forwarder is weak. This feature adds to less packet drops whereas in VBF nodes covered under virtual pipe are the selected forwarder only.
Further graph of the number of packets transmitted when sink node =1 is displayed in the graph below. The result shows that VBF is quite expensive in terms of energy conservation due to a large number of packet losses as compared to DBR.



	100	200	300
VBF Packet sent	177457	615864	1064802
VBF Packet Received	36594	107739	195851
DBR Packet Sent	10720	32717	63602
DBR Packet Received	4583	10072	16803

Fig. 4. Packet sent and received with Sink Node = 1

Graph of the number of packets transmitted when sink node =3 is shown in Fig. 5. Graph result indicates that with an increasing number of sink nodes there is improvement in the packet losses in DBR as compared to VBF.



	400	500
VBF Packet sent	1536278	1142241
VBF Packet Received	254648	341094
DBR Packet Sent	102996	148363
DBR Packet Received	22850	28744

Fig. 5. Packet sent and received with Sink Node = 3

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Simulation result reveals that Packet losses in Depth Based Routing (DBR) protocol reduce when the number of sink nodes is increased. A little amount of improvement plays a significant role in adding longevity to network life. Packet losses are quite less in DBR when sink nodes are added in network.

CONCLUSION

This paper provides an insight into the Underwater Sensor Network (UWSN) with a discussion of terrestrial and underwater communication. Survey of protocols in UWSN for Network layer and cross layer approach is investigated. Experimental analysis of two network layer protocols VBF and DBR are implemented in ns-3 using Aquasim-NG module. Results reveal that adding sink nodes in network reduces packet losses in DBR thereby improving energy usage of sensor nodes. To obtain further more results cross-layer approach can also be investigated. Cross layer approach based protocols implementation is thought-out for future work.

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