

# Energy Efficient Congestion Free And Adaptive Mechanism For Data Delivery In Underwater Wireless Sensor Networks Using 2H-ACK

M. Baskar (✉ [baashkarcse@gmail.com](mailto:baashkarcse@gmail.com))

SRM Institute of Science and Technology <https://orcid.org/0000-0003-4655-7667>

V. Anbarasu

SRM Institute of Science and Technology

A. Balaji

VIT Bhopal University

P. Kalyanasundaram

Saveetha School of Engineering

R. Thiagarajan

Prathyusha Engineering College

T.S. Arulananth

MLR Institute of Technology

---

## Research Article

**Keywords:** Hop by hop, Congestion, Energy Efficient, Throughput, Reliability, 2H-ACK, UWSN

**Posted Date:** March 9th, 2022

**DOI:** <https://doi.org/10.21203/rs.3.rs-1400154/v1>

**License:** © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

---

# Abstract

Underwater Wireless Sensor Networks (UWSN) seems to be significant area of research as it gives out proper answer for monitoring uneven circumstances that may result and bring forth scare in human existence. The challenging process in UWSN, they have large amount of delay, easily error prone, low availability of bandwidth and high congestions control. In this paper, we propose a mechanism that addresses the reliability of the network by adapting two hop acknowledgement (2H-ACK) models. Enhancement of the model is carried out to make it energy efficient congestion free by integrating the hybrid approach into the existing protocols. By this enhanced model, it shows that the performance of the model is good when compared to the existing ones. Simulation outcomes prove that the 2H-ACK proves to be best in delivery ratio when checked with existing hop by hop acknowledgement.

## 1. Introduction

The sea in Earth what we live is tremendous as it covers around 140 million square miles; over 70% of the Earth's surface, and half of the world's populace is found inside the 100 km of the seaside territories. Not just has it been a significant wellspring of substance creation, however with time it is playing a fundamental job for transportation, nearness of characteristic assets, guard and courageous purposes. Indeed, even with all its significance to humankind, shockingly we know practically nothing about the Earth's water bodies. Just less than 10% of the entirety sea volume has been explored, while an enormous zone still stays unexplored. With the expanding job of sea in human life, finding these to a great extent unexplored regions has increased more significance during the most recent decades. On one side, conventional approaches utilized for submerged checking missions have a few downsides and on the opposite side, these cold situations are not plausible for human nearness as unusual submerged exercises, high water pressure and huge zones are significant purposes behind un-kept an eye on investigation. Because of these reasons, Submerged Wireless Sensor Networks (UWSNs) are pulling in the enthusiasm of numerous analysts recently, particularly those working on terrestrial sensor systems. Earthbound correspondence is a standard arrangement of WSN which employments radio waves. WSNs at present use numerous new strategies for better correspondence. These systems are moreover tried by specialists in the field of submerged [2]. The scope for different imaginative systems administration structures have been opened by key innovative improvements in related fields. Around 70% of the earth surface is roofed by water. This is by and large unmapped district which make people intrigued to find it. Normal or semi synthetic calamities have occurred throughout the years which incited essential consideration in watching marine condition. Submerged Wireless Sensor Networks (UWSNs) structures an idealistic advancement for engaging and improving a couple of key applications in submerged investigation. UWSNs have set up numerous applications as they are utilized in ocean investigation, information assortment, contamination observing, strategic reconnaissance, fiasco avoidance, military applications and mine studies.

Sensor systems utilized for submerged interchanges are distinctive in numerous angles from conventional wired or even earthbound sensor systems [3]. Right off the bat, vitality utilizations are

diverse on the grounds that a few significant applications require enormous measure of information, however very rarely. Furthermore, these systems as a rule chip away at a typical undertaking as opposed to speaking to free clients. A definitive objective is to augment the throughput as opposed to decency among the hubs. Thirdly, for these systems, there is a significant connection between the connection separation, number of jumps and unwavering quality. For vitality concerns, parcels over different short bounces are favored rather than long connections, as multi-jump information conveyances have been demonstrated more vitality effective for submerged systems than the single bounce [6]. Simultaneously, it is watched that bundle directing over increasingly number of bounces eventually debases the start to finish unwavering quality capacity particularly for the unforgiving submerged condition. At long last, more often than not, such systems are sent by a solitary association with efficient equipment, so severe interoperability with the current norms is not required. Because of these reasons, UWSNs give a stage that supports to audit the current structure of conventional correspondence conventions. The ebb and flow explore in UWSNs points to meet the above basis by presenting new plan ideas, creating or improving existing conventions and building new applications. While look into on submerged sensor systems has altogether progressed in late years, obviously various difficulties despite everything stay to be tackled. With the whirlwind of new ways to deal with correspondence, medium access, organizing also, applications, viable examination, mix and testing of these thoughts is foremost—the field must create basic bits of knowledge, just as comprehend what stands up by and by. Thus, we accept that the improvement of new hypothetical models (both investigative and computational) is particularly required, also, that more noteworthy utilization of test beds and field tests is fundamental; such work will bolster progressively precise execution examination and framework portrayal, which will take care of into the up and coming age of submerged interchanges and detecting. Moreover, joining and testing of momentum thoughts will pressure the creases that are regularly covered up in progressively engaged lab explore, for example, complete framework cost, vitality necessities and generally heartiness in various conditions.

Eventhough the researchers have come up with many strategies regarding this area still there are numerous challenges evolving at each of the situations. In this paper the challenges that arise due to congestion control are identified and solution are proposed to solve the same which is analyzed and compared with existing protocols that proves its best solution.

## **2. Background Work**

Before proceeding with the detailed proposed method for the challenges of UWSN we first need to have the understanding of Underwater Wireless Networks and what all are the basic terms and needs that need to be focused when designing the solution. Underwater Acoustic Networks (UANs) as a platform for oceanic research have gained much attention during the last decade and a strategy is required for the development of different potential applications. Monitoring the aquatic environment and dynamic changes of the ocean is not an uncomplicated assignment. To preserve marine resources and obtain a sustainable development, changes occurring in the marine environment have to be monitored effectively. The threat of climate changes and increased water-borne activities may have great impacts on oceanic

life and ecosystems. A rapid change in the marine environment may have great influence on terrestrial life and environment.

## 2.1 Communication

The acoustic signal is the only medium that is feasible for communication for underwater situations. Eventhough considering the electromagnetic waves, optical waves, and the need of the underwater cases have made those things not suitable for these situations. These waves inspite of having high frequency it is not able to sustain due to the high absorption and attenuation in underwater [15]. Hence in these cases it is need to improve the electromagnetic modems that thereby increase communication among them. When we have dense underwater sensor network where the medium is dynamic then it seems to that Acoustic signal is more suitable. Through this we are able to address the communication in omnidirectional and the channel are distributed with high attenuation of signal. In spite of its advantages, there are numerous challenges for communication when it comes to underwater sensor. One of such problem is the path of communication getting lost. Along with these challenges it has error rate at high proposition including a large amount of delay due to less bandwidth. Due to these low bandwidth the data are transferred at lower rates thereby relies on range of communication and frequency [13]

Using of optical link seems to be good in this type of communication. It fixes point to point communication only when the water present is very clean. But the same suits impossible for good when it comes to distributed network even though if its short range [Huang and Ma].

To be precise it can be said that these are not suitable for shallow water that is when water is not clean and also for long range of distance that is long distance of communication.

## 2.2 Deploying of Nodes

The numbers of nodes deployed are not static and it keeps changing which can be considered to be a variable to have a good cooperative communication for a high volume of data. In [14], author work is considered to be the start of for this process of deploying the nodes in underwater sensor. The method proposed was 2 different communication architectures: two and three dimensional manner. In the first case, at the bottom the sensor nodes are fixed that are grouped into clusters organized by more than one gateway with the help of acoustic links. These gateways are the source of transmission of data from underwater to the surface. In second case, sensor nodes are made to float at each level of depth which will be able to cover all levels. In this type of methods the nodes are attached with wires to the surface so that it can be adjusted to any level when and where needed. But due to this process the cost effect is very high when it comes to a larger region with greater depth.

At one more method is proposed [12], where the above said methodology is been followed but instead of having it at a floating level in surface buoys here they are fixed at the bottom level. They are fixed with a pump so that it positions itself to the surface then returns back to the position to and fro. Due to this

advanced methodology the deployment of network is said to be reliable, but it makes high cost when there is need to focus on large areas monitoring.

Enhanced method of fixing the radio enabled surfaces can increase the efficiency and performance of the network. One same method is proposed by Ibrahim et al. who suggest that network efficiency can be increased if the gateways are fixed at the suitable positions. But to our disappointment this method is applicable only for two dimensional ocean surface and seems to be difficult in case of 3D ocean surface area.

## 2.3 Localization

The collected data seems to be not useful in some cases when the time and position information are not present. This is the next critical challenge faced in this UWSN research area. This localization terms refers to be important critical factor to be considered for some information processing. In paper implemented by Erol [11], he coined the term “catch up or pass”. This method combines and helps each one to perform the task successfully. The underwater sensor node which are fixed are utilized and their velocity along with position is retrieved and based on that it can be decided to carry the data to nearby gateway. This can be done at either of the way like slow or fast. In general during this phase all the researchers have a thought or fix that each nodes deployed are synced with time for all along the network. But this fixes can be carried out for application that are for short term and prone to be a failure for long term applications. Some cases ToA is been proposed, where advancement of techniques are used. But still the accuracy part there is lag when it comes to long distance communication.

Kai Chen and He [9] put forth a concept of DNR (Dive and Rise) which are used for positioning the system's at correct place. Instead of going for more dynamic DNR they proposed to take use of four different nodes: sensor nodes that are ordinary, Detachable Elevator Transceivers (DETs), anchor nodes and surface buoys. By using these enhanced methods, certain assumptions are made. They are, pressure value fixed with all sensor nodes so that information are provided to the most depth level. Finally when the structure of network is fully known it can be referred to be static. In spite of this advancement, still there are challenges which are ought to be sorted out. The study of simulation among nodes, mobility of nodes is still not clear therefore the ridiculousness of arrangement of nodes to carry out long term applications is difficult thereby increases the overall cost of the network.

## 2.4 Reliability

The most challenging and critical feature or factor of the communication network is said to be this one, reliability. This is a major one when it is a terrestrial network which makes us clear how much difficulty in underwater sensor networks. In this common type of network when there are many number of paths from source to destination and redundancy of data then it is said to be not reliable. But coming to our scenario, various researchers have come up with different methods to say that the network is reliable. But the factors are still more difficult and are not that much clear what has to be carried out. In general, we refer that the data to be communicated properly without any delay and packets must not be lost. Trying to

satisfy these needs it ultimately results in traffic and more amount of delay in receiving the information that is data packets.

Considering reliability, TCP (Transfer control Protocol) seems to suit the best as it provides communication from one end to the other. But the same find to have problems when it is been a multi-hop wireless network structure [10]. The basic process of connection establishment in TCP is a three way handshake mechanism between the sender and the destination where the data is to be sending off. Whereas coming to acoustic network, the data to be transferred is sort of few bytes and each time if TCP need to establish this handshake mechanism then it becomes tough for TCP. This protocol addresses mainly the congestion problems since it is assumed that packet loss can happen only when there is traffic in the network. Probably this might be solution for terrestrial network whereas when coming to acoustic network the loss of data can be due to various other reasons such as failure of nodes. Hence instead of addressing the transmission rate of data and reducing it to increase the efficiency and performance of network it is needed to focus on other areas too.

After the consideration of TCP,, we focus and look into UDP (User Datagram Protocol) which enables a simple mechanism of connection instead of handshake mechanism. However having less communication process, it doesn't guarantee about reliability as it does not provide solution for congestion issues. Their method is if congestion occurs, the transmission link drops the data packet without even providing a strategy to regain it back once when traffic is settled. As said above it does not deal with ACK so obviously we are not aware whether the data is reached to the destination properly or not. Hence this seems to be not a best solution for underwater sensor networks.

The main case why the congestion is found here in UWSN is that the sensor nodes try to send their packets by the link which is common to all that is single one. So when the data packets keep travelling to the destination the traffic arises leading to congestion since the nodes in and around the end node gets affected. In this case scenario, Ayyaz and Abdullah [8] proposes a method of fixing various set of sink on to the surfaces that is more number of nodes. Due to the shortage of resources available, if the congestion is not found out at the proper time then a large amount of data packets are lost which cannot even be retrieved. Hence a proper mechanism needs to be formed out for this network to give out throughput and efficiency. If the data packets are kept on retransmitting due to loss it leads to energy loss to certain level and automatically reduces the time of packet send that is delay in receiving data packets.

To address the issues and problems of reliability in UWSN, it is needed to have proper enhanced mechanism. A protocol that addresses transport layer termed as Segment Data Reliable Transfer (SDRT) was put forth by Xie [14]. This protocol generates a set of codes called to be Tornado codes which are used during packet transmission. The data is send as block by block and hop by hop. It sends a block first waits for ACK and then sends back the second block. By carrying out this process a lot of energy is consumed. So as to keep it in hold, a window mechanism is followed which keeps transmitting the data till the window size and after that sends the data at a slower rate. With the help of the codes this will be able to do the process of recovering the data packets that are prone to error. In spite of this mechanism,

this protocol focuses on hop by hop, which makes it difficult in case of node failure. The underwater sensor networks are not fixed of proper channel of communication and due to this the retransmission of data arises thereby resulting in higher probability of error which directly affects reliability.

### 3. Challenges Present

The above section clearly mentioned the issues faced by UWSN networks in terms of communication, deployment, localization and reliability. However having a large set of protocols doesn't seem to fit enough for this type of networks. The proactive type of protocols maintains huge tables for storing the routing information to establish and develop the path between the nodes. Whenever there is a node failure or the network structure differs each time the table needs to be updated with new route. The second set of reactive protocols are said to establish the path between the nodes on demand whenever it is needed. But the problem here is there is a large amount of delay in packet transmission since the source node needs to flood information for discovering the route to destination. So there are two major problems arise: delay and flooding. Implementing these set of protocols prove at each level that reactive protocols seems to perform great than proactive but not at all times.

Now applying the same strategy to our scenario, already in UWSN the rate of transmission is slow and hence the delay is high. So using the reactive protocols to address in this case seems to be little difficult. So without the help of proactive protocol not getting information of neighbor nodes and by using flooding mechanism it is really difficult to construct a network that holds multi-hop delivery of data routing scheme. So to address this issue Global Positioning System (GPS) can be used. This can get the information of neighbor nodes and will be able to transfer the packets to the destination. When hybrid methodology is used along with GPS better solution are received. This helps our in reducing the delay and congestion between the nodes. The following table shows some of the comparisons between the terrestrial and underwater sensor networks.

Table 1  
Key feature comparison between Terrestrial WSN and UWSN

<b>Terrestrial Wireless Sensor Network</b>	<b>Underwater Wireless Sensor Network</b>
Data rate is high, MHZ	Data rate is low, KHZ
Nodes are less prone to error and keeps up the transmission for longer rate	Nodes are more prone to error and the rate of transmission are short time
Routing process includes multiple hops	The number of hops are limited depending on the area of transmission
Batteries can be used which are large and can be replaced	Limited power is present and batteries are not easy to recharge or replace
Consumption of energy is low	Energy consumption is high
Deploying the nodes in the network is directly proportional to the network performance	Nodes are deployed in random manner and not in uniformed fashion
More reliable due to advancement strategies at various levels	Reliability is the major key issue

## 4. Objectives Of The Research

In order to have a good performance in underwater wireless sensor network there are major two things that need to be addressed. They are reliability and congestion control. The rate of packet getting lost cannot be stopped but either way it can be reduced. In order to reduce the packet loss rate then network should be congestion free and reliable. The main purposed of the research are as follows:

1. Foremost functionality is to have Quality of Service which can be achieved when sustained for a longer period of transmission time
2. Increase the reliability there by reducing the multiple hop and reducing the loss of packets during transmission which in turn reduces the energy consumption
3. To maintain a congestion free area so as to avoid failure of network due to congestions
4. Address the connectivity issues by using efficient routing mechanism which takes addresses the issue of buffer overflow.

## 5. Working Methodology

The sensor nodes are placed to monitor the allocated region. Both the sensor nodes along with relay nodes are allowed to be deployed at various level according to the depth of water present. The sink nodes are placed at the top of surface level. Now based on the depth level and region of monitoring these nodes can be deployed. We fix an assumption here that nodes are not allowed to modify the depth level and movement of nodes horizontal fashion is not allowed. The scenario works in a manner that sensor node transfer the information to the relay nodes. These nodes through the acoustic channel pass the

information to the sink nodes that are present at the surface through the links available. When a large amount of data transmitted continuously causes buffer overflow due to congestion. Hence at the relay node some manipulation process need to be carried out to keep the node stable thereby eliminating some data packets. Now while transferring of data between sensor node to relay or from relay through link to surface nodes there are possibilities of data loss there by affecting reliability. So to address this issue we consider 2H-ACK mechanism. Once the network seems to be reliable we use enhanced protocol to make it congestion free thereby increasing the performance of network.

## **5.1 Reliability – 2H-ACK**

It is very difficult to achieve the reliability in UWSN due to the high rate of error prone and partitioning of network. Hence we adapt to send transmission of data hop by hop so as to ensure that at each hop the data is safe. So when data is send from source node to nearby node, it sends back ACK to the node where it has received the data. Once ACK is received the data from the send node is removed and it starts in process of the next block of data. This seems to be working well and good incase of environments that are said to be stable. Whereas in this scenario its highly risk that network environments are not stable as the nodes have high rate of failure. In this case the receiving node when holding the data, due to energy limitations not able to withstand and gets failed, then data also goes down along with the node. Hence we don't have any other mechanism to retrieve back the data. Hence we adapt 2H-ACK such that data till it receives the second ACK keeps in hold of the data packet.

In the above figure, Node N9 is said to be source node holding the data. It broadcast the nearby nodes for HopId and the range of nodes in transmission range of this particular node is N8 and N7. Based on minimum hopping count the node selects the next subsequent node. So based on the value N7 is chosen to be the next node. Data transferred to N7 and ACK send to N9. Similarly N7 checks for its nearby nodes in transmission range and finds out N6 and N4 among which it chooses N4. Now this process is carried out until the packet reaches the destination.

### **5.1.1 Delivery Guaranteed**

To increase the performance of a network, then it should be reliable. To achieve this goal we implement the mechanism of using 2H-ACK to avoid packet loss during transmission. To maintain this sort of strategy, making one node to hold the data to be send we make one more nodes to acquire a copy of transmission data. Hence two nodes will be having a same copy of data. This process can be acquired by 6 steps as mentioned in the below diagram. N represents the node along with its number. N4 is said to be node4 and node7 as N7 and N9 as node9 etc. To establish the connection and get in hop details the source node sends Inquiry request through which it can get the next hop location. The neighbouring node receiving the request checks if it has the minimal hop count. The node which has the minimum value replies back to the source node with Inquire reply. In Figure 3, the source node is said to N9 and it needs to transfer the data packet to the destination. First step N9 sends broadcast to get in HopId to know their hop count value with the help of Inquire Request. In the next step it is found that N7 is available and it sends the reply of its hop count in form of Inquire Reply. Now the data packet is transferred to node 7

from N9. Now once the data is received the N7 sends the first ACK to N9. Further now the node N7 does the same process as like N9 and finds out N4 is close by as it gets its HopID in form of Inquire Reply. Now the data packet is transferred to N4 and again now N7 sends the second ACK to N9 stating that it has a transferred a copy to next node.

Once this acknowledgement is received the node N9 clears its buffer by removing the data present. This is the process of 2H-ACK as the data is removed only when the second acknowledgement is received ensuring that one more copy of data is present with other node. Hence it is clear that two nodes simultaneously maintain the data so that when a network failure or node failure occurs its been retrieved from other node holding the data.

### Algorithm for 2H-ACK

---

Packet of data to be send to destination is ready

1. Send request to neighbor nodes for HopID
2. Received HopID stored in an array  
    Array is sorted to get the minimum HopID
3. **If** min HopID < current HopID **Then**
4.     **If** current node and source node are different **Then**
5.         Send ACK to previous hop node
6.         Forward the data packet to the node with min HopID
7.     **Else**
8.         Forward the data packet to the node with min HopID
9.     **End If**
10. **Else**
11. Waiting time enabled for given time
12. **Goto** step 1
13. **End If**

### 5.2 Congestion Control

The next important and critical feature to consider is congestion control. Here due to the hop by hop process there is proper handling of bandwidth since each data is processed and taken forth in front towards the destination. Instead of making use of end to end methods we go step by step process and data is not removed until or otherwise ACK is received. It works in an idea of per-contact routing rather than existing routing methodologies. This methodology handles a way such that each node is not prior known about the next hop node and thereby moves step by step getting the information of HopID and Hop Count. Hence the nodes surrounding the source node or node which has data packet send Inquire Reply to the current node. So that it will be able to manage the congestion and bandwidth process without any complications.

The node holding the data packet send the message represented in Fig 5, which holds two fields node ID and HopID. Once the message is received by the surrounding nodes they send the reply back in the format mentioned as Inquire Reply, Fig 6. This contains 4 fields stating the node ID along with HopID, buffer size of the node which means the maximum capacity that node can store data packets and finally the energy level of the node.

## **6. Results And Discussion**

The simulation is carried out by NS2 to prove the proposed methodology increases both reliability and reduces congestion thereby increasing the throughput of the network performance. The underwater MAC layer protocols are considered that helps out to show the breakage of link occurring in transmission region to the network layer. The packet size taken for simulation is made to keep varying from 50 bytes to 300 bytes. Initially the packet size is said to be fixed as 50 and keeps multiplying in multiplies of 50 by using AquaSim. The transmission area is said to be considered as 600X600 meter square by having setting the simulation time to be 50 seconds. Among these sensor nodes around 20 nodes initially are fixed at the bottom and remaining 30 nodes will be forming the layers of five with a distance of 90m starting from the top level of surface until the bottom most node. It keeps moving with 5-6m/sec in horizontal manner. To make available of the movements of nodes mobility model is adapted making it gradually move at a slower rate

The buffer size of for every node is said to be 30 packets. Traffic sources utilized are CBR (Constant bit rate) each holding the 512bytes of packet size.

### **6.1 Performance Metrics**

Evaluation of the proposed algorithm is carried out in terms of measuring various metrics. We consider packet delivery ratio compared to the number of nodes, compared to the time intervals. Also the rate of packet loss and duplication of packets at frequent time intervals. Packet drops are evaluated as total packets not able to reach destination due to various reasons. The delay is evaluated by the total time taken by the data packets to start from source and to reach the destination. Finally energy consumption

of nodes and overall network is calculated by consumption of energy of nodes involved in transmission and their sum gives the overall consumption of energy by the network.

Parameters that are considered for the simulation are listed in the table below:

Table 2  
Parameters for Simulation

Parameter	Value
Transmission Range	600 X 600 m <sup>2</sup>
Node count	75
MAC	UnderwaterMAC
Simulation Time	50 seconds
Channel	Underwater Channel
Capacity of Channel	2Mbps
Traffic Source	CBR
Size of Packet	50,100,150,200,250 and 300 Bytes
Energy at Initial Phase	10000J
Transmission Power	2.0W
Propagation Usage	Underwater Propagation
Traffic Rate	50Kb
Node Range	100m

The proposed algorithm shows that packet delivery ratio is not affected as the number of nodes is increased rather the ratio of transmission increases proving that it makes our network reliable. In UWSN the energy consumed is high in general, but when we go with our proposed methodology of step counting method the energy is consumed and is sustainable without any network failure, mentioned in Fig. 9. Finally in Fig. 10, the overall network performance throughput is achieved high inspite of difficulties in underwater wireless sensor network which proves that the proposed methodology works out a better way when compared to the existing algorithms.

## 7. Conclusion

An underwater wireless sensor network is not seemed to be reliable due to various reasons addressed earlier. The main two factors are reliability and congestion which is been addressed here. Our proposed methodology proves that by using 2H-ACK the rate of packet loss is very much reduced. Along with these issues the congestion process is been tackled which makes the network congestion free and free prone to

data failure. The simulation results proves that better outcomes are received even in case of mobility been set at simulation level. The various metrics are analyzed which proves it to be a better solution. In any case of underwater sensor network, generally the packets need almost minimum of 5 to 7 hops to reach to the prescribed destination. Hence it makes it clear that packets reach the destination without causing any extra burden to the network. Various parameters are taken to evaluate our final results.

## Declarations

### Funding

Not applicable

### Availability of data and material

Not applicable

### Code availability

Not applicable

## References

- [1] Ahmed, Sheeraz, Nadeem Javaid, Saqib Shahid, FazleHadi, and M. Qaiser Azeem. "RACE: Reliability andadaptive cooperation for efficient underwater sensornetworks." In Open Source Systems & Technologies(ICOSST), 2016 International Conference on, pp. 122-128.IEEE, 2016.
- [2] Dong, Tao, Wenjie Hu, and Xiaofeng Liao. "Dynamics ofthe congestion control model in underwater wireless sensornetworks with time delay." *Chaos, Solitons & Fractals* 92(2016): 130-136.
- [3] Jain, Shalini, Emmanuel S. Pilli, M. C. Govil, and D. VijayRao. "Performance evaluation of congestion-aware routingprotocols for underwater sensor networks with multimediatechnology." In Underwater Technology (UT), 2015 IEEE, pp. 1-6.IEEE, 2015.
- [4] Ding D , Qin X , Wu T , Wang N , Liang D . Hopf bifurcation control of congestion control model in a wireless access network. *Neurocomputing* 2014;144:159–68 .
- [5] Akyildiz IF , Pompili D , Melodia T . Underwater acoustic sensor networks: re- search challenges. *Ad Hoc Netw* 2013;12:257–79 .
- [6] Manjula, R. B., and Sunilkumar S. Manvi. "Issues inunderwater acoustic sensor networks." *InternationalJournal of Computer and Electrical Engineering* 3, no. 1(2011): 101.
- [7] Zheng Y , Wang Z , Stability and . Hopf bifurcation of a class of TCP/AQM net- works on *Nonlinear Anal* 2011;11:1552–9 .

- [8] Ayaz M, Abdullah A, Faye I. Hop-by-hop reliable data deliveries for underwater wireless sensor networks. In: Proceedings of the 2010 International Conference on Broadband, Wireless Computing, Communication and Applications (BWCCA); 2009.
- [9] Kai Chen YZ, He Jianhua. A localization scheme for underwater wireless sensor networks. *Int J Adv Sci Technol* 2009;4.
- [10] Scheuermann B, Lochert C, Mauve M. Implicit hop-by-hop congestion control in wireless multihop networks. *Ad Hoc Netw* 2008;6(2):260–86.
- [11] Erol M, Oktug S. A localization and routing framework for mobile underwater sensor networks. In: Proceedings of the IEEE INFOCOM workshops; 2008.
- [12] Pompili D. Efficient communication protocols for underwater acoustic sensor networks. School of Electrical and Computer Engineering, Georgia Institute of Technology; 2007.
- [13] Stojanovic M. On the relationship between capacity and distance in an underwater acoustic communication channel. In: Proceedings of the 1st ACM international workshop on underwater networks. Los Angeles (CA, USA): ACM; 2006.
- [14] Xie P, et al. SDRT: a reliable data transport protocol for underwater sensor networks. *Ad Hoc Networks* 2006a;8(7):708–22.
- [15] Akyildiz IF, Pompili D, Melodia T. Underwater acoustic sensor networks: research challenges. *Ad Hoc Networks* 2005;3(3):257–79.
- [16] I.Vasilescu, K.Kotay, D.Rus, M.Dunbabin, and P.Corke, "Data collection, storage, and retrieval with an underwater sensor network", *SenSys '05*, 2005.
- [17] Martin Hasler, Jérôme Rousselot, "Dynamical Networks: Routing Protocols for Wireless Sensor Networks", CSEM, 12.07.2006.
- [18] Bin Z, Sukhatme GS, Requicha AA. Adaptive sampling for marine microorganism monitoring. In: Proceedings of the 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004); 2004.
- [19] Wang X . Controlling bifurcation and chaos in Internet congestion control system. In: Proceedings of the 4th world congress on intelligent control and automation; 2002. p. 573–8 .
- [20] D. A. Jay et al., "A Review of Recent Developments in Estuarine Scalar Flux Estimation," *Estuaries*, vol. 20, no. 2, 1997, pp. 262–80.
- [21] Preisig, J., 2007. Acoustic propagation considerations for underwater acoustic communications network development. *SIGMOBILE Mob. Comput. Commun. Rev.*11 (4), 2–10.

[22] Quazi, A., Konrad, W., 1982. Underwater acoustic communications. IEEE Commun. Mag. 20 (2), 24–30.

[23] Schulkin, M., Marsh, H., 1963. Absorption of sound in sea-water. Radio Electron. Eng. 25 (6), 493–500.

## Figures

Figure 1

*Overview of mobile UWSN architecture*

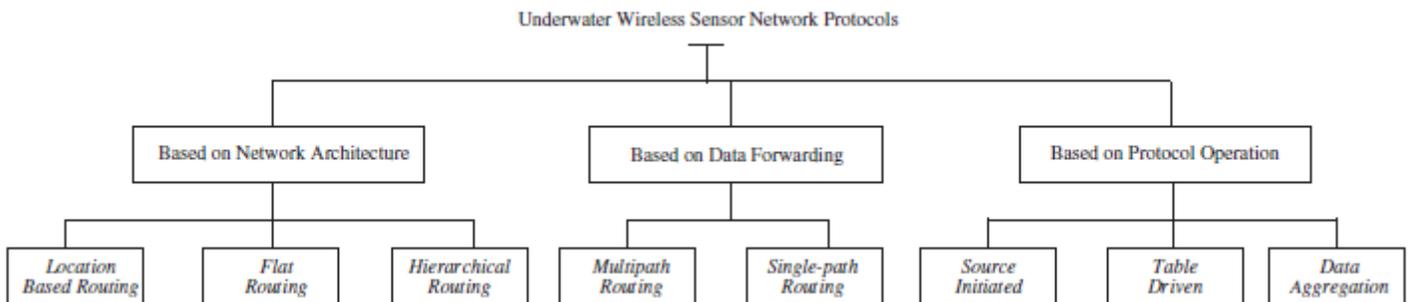


Figure 2

*Categorization of UWSN protocols*

Figure 3

*Choosing simultaneous hop for data transmission*

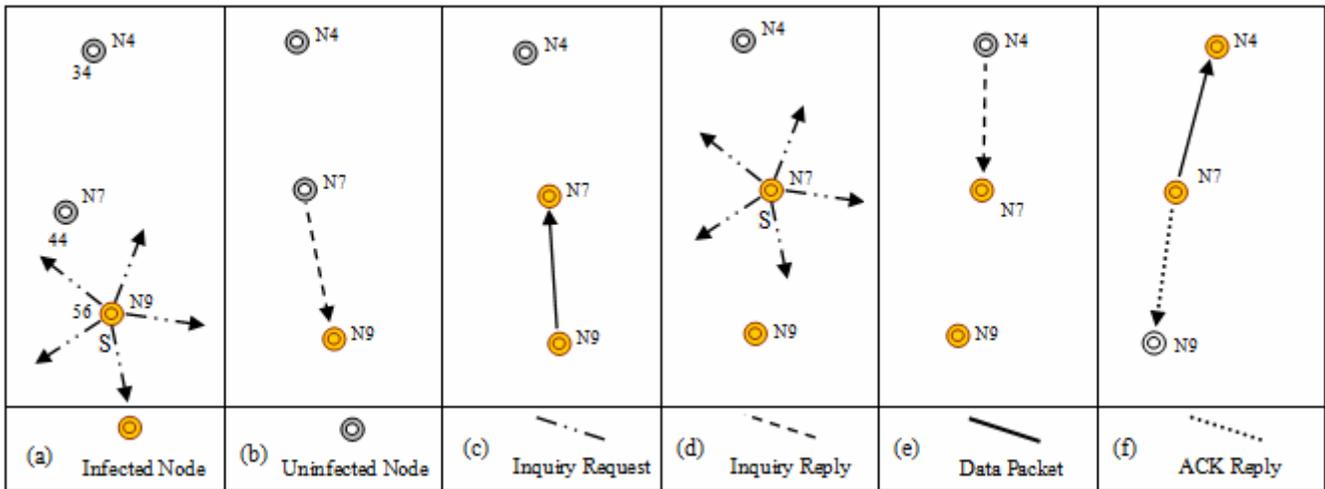


Figure 4

*2H-ACK data packet forwarding*

Node ID	HopID
---------	-------

Figure 5

*Inquire Request*

Node ID	HopID	Buffer Width	Battery level
---------	-------	--------------	---------------

Figure 6

*Inquire Reply*

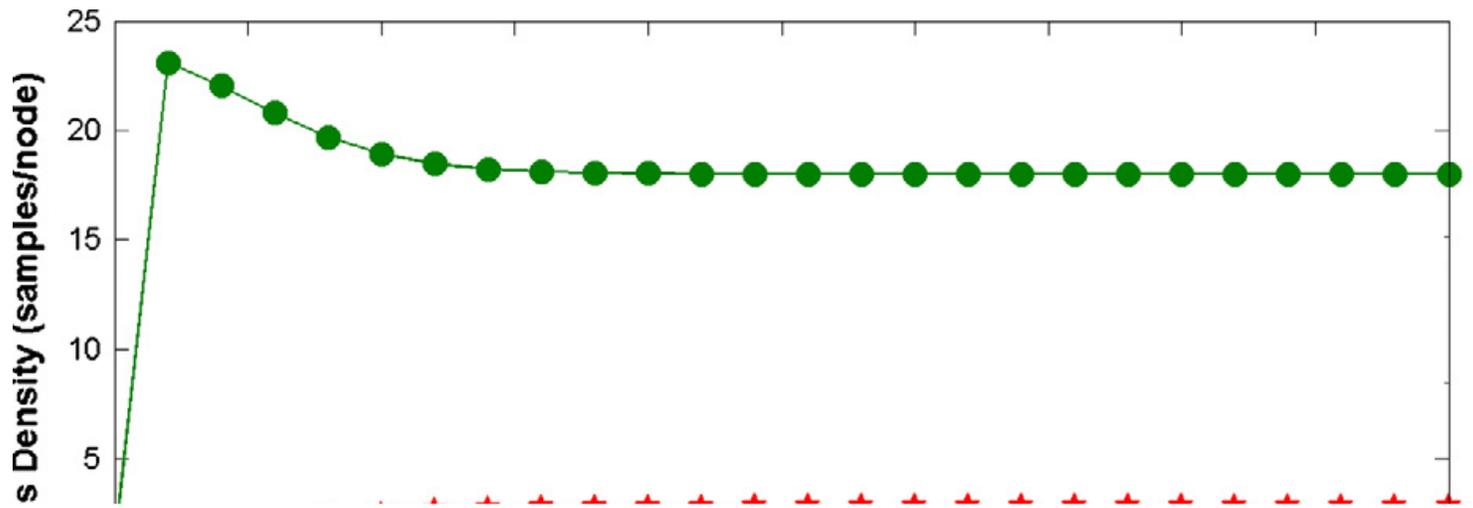


Figure 7

*Sample density of nodes duplicating for given time*

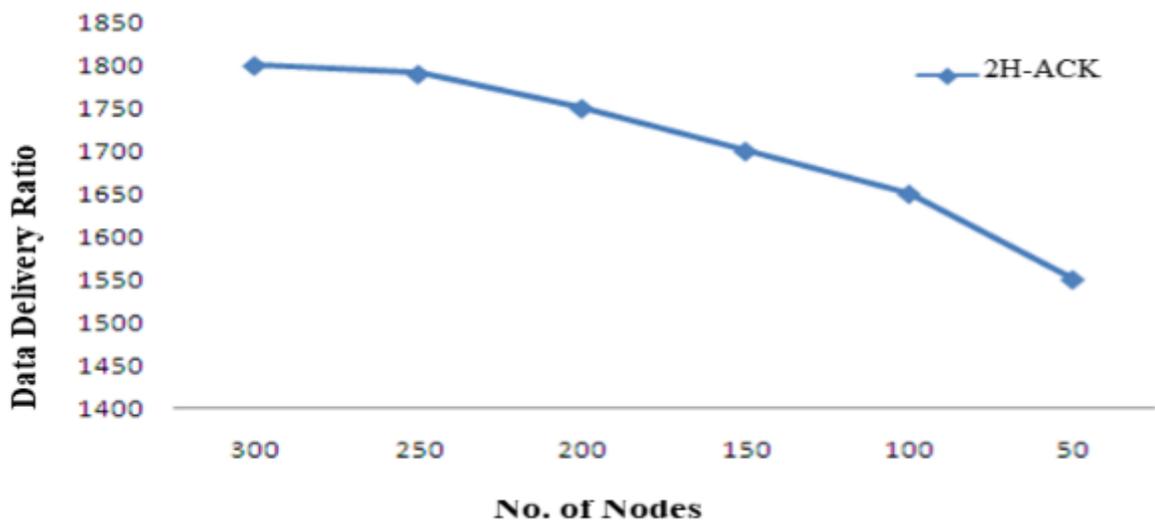


Figure 8

*Packet Delivery Ratio*

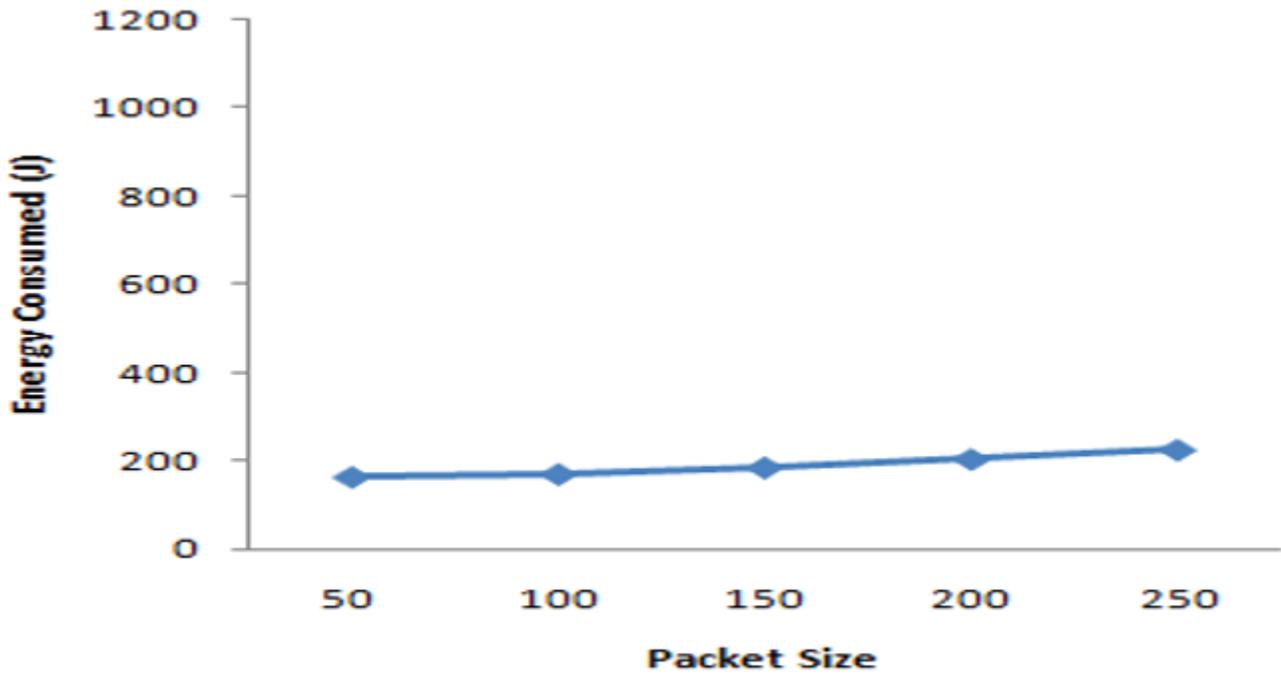


Figure 9

*Consumption of Energy*

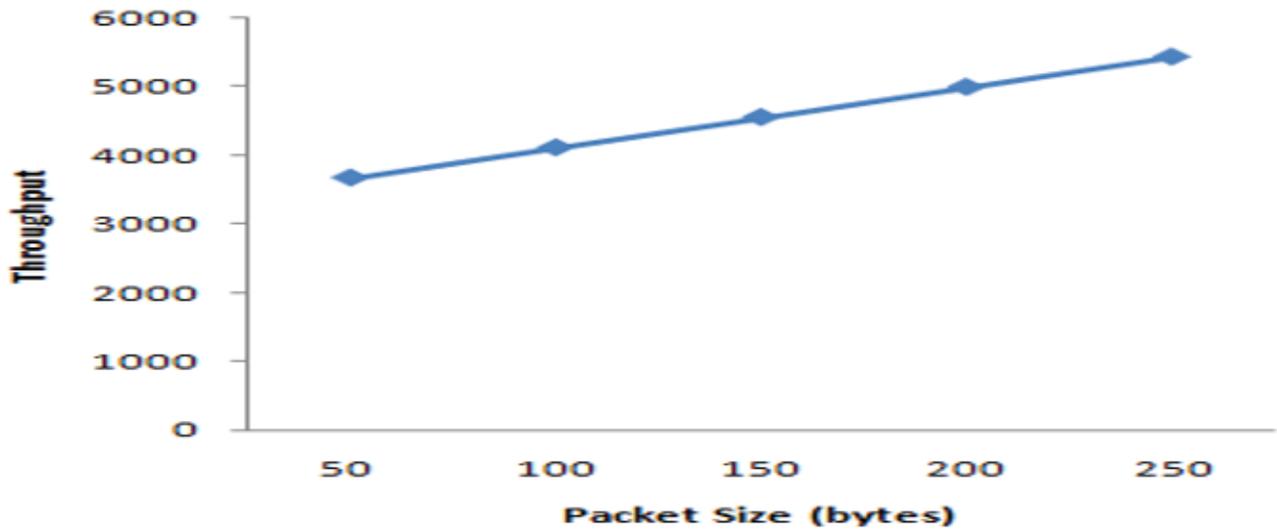


Figure 10

*Throughput of the network compared to packet size*