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Underwater spray and wait routing technique for mobile ad-hoc networks

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The underwater mobile ad-hoc networks comprise sensor nodes that are source nodes for gathering underwater-related data. Relay nodes are the mobile nodes for collecting data from sensor nodes and achieving intermittent connectivity among source and destination nodes. Developing an efficient routing protocol for underwater communication is a challenging issue due to limitations of the underwater environment. Underwater mobile ad-hoc networks are intermittent networks where end-to-end path does not exist from source to destination. To overcome these problems a delay and disruption tolerant network (DTN) is a good solution. In the current paper, we consider the Spray and Wait (SaW) routing technique. In SaW, source and relay nodes represents the moving nodes, and they try to send data to destination nodes. Based on this, we propose the replica based underwater SaW (USaW) routing for underwater mobile ad-hoc networks. In USaW, source nodes are fixed to the bottom of the surface. Underwater sensor nodes replicate sensor data and provide maximum copies of data to the relay nodes that they encounter. In generally, relay nodes have high capability of transmitting data as compared to sensor nodes in an underwater environment. We analyze the performance of USaW with respect to delivery ratio, network throughput, energy consumption, end-to-end delay, and packet drop rate comparing with existing SaW and prophet routing protocols.

[**Keywords:** USaW; DTN; ad-hoc network; sensor node; routing]

Introduction

Underwater mobile ad-hoc networks have become an important field of research for many research groups in the recent decade. Such establishments comprise sensor nodes and relay nodes for various monitoring requirements. Sensor nodes are used to measure current intensity, direction, water temperature, salinity, dissolved oxygen, carbon dioxide, and turbidity. Relay nodes collect data from the sensor nodes and transmit the data to the sink nodes. This information is helpful for different scientific, military and industrial applications, as well as for monitoring and controlling commercial activities[1]. Underwater sensor nodes communicate via acoustic transmission, such transmission is challenging due to long propagation delay, high bit error rate, low power and limited bandwidth in an underwater network design. In an underwater environment, well-known terrestrial ad-hoc routing protocols such as AODV and DSR fail to stablish routing. Delay and disruption tolerant networking (DTN) objective is facilitate communication between challenging networks, those networks suffer with intermittent connections and whose end-to-end path does not exist[2]. When an end-to-end path does not exist, the routing protocols follows the store-carry-and-forward approach. Mobile nodes route the data from the source to destination. Underwater ad-hoc networks comprise autonomous underwater vehicles (AUVs), unmanned underwater vehicles (UUVs), or remotely operated vehicles (ROVs) that are the relay nodes used for surveillance and monitoring applications frequently suffering from intermittent connectivity. Many DTN researchers have proposed different routing protocols in a terrestrial environment. They are Epidemic, Spray and Wait (SaW), Direct Routing, Prophet, RAPID, and MaxProbetc. In the previous analysis, SaW routing shows the best performance in an underwater environment[3].

In this paper, we focus on the SaW routing protocol. SaW is a replica based routing protocol: source and binary (both techniques for data delivery) differ by the method the replicated messages are passed to other nodes. Based on that we proposed a new Underwater SaW (USaW) routing technique for underwater mobile ad-hoc networks. In USaW, source nodes are fixed at bottom of the surface and provides maximum copies of data to relay nodes. USaW will increase delivery ratio and reduce the delay time, overhead, power, cost and packet loss. A replica based USaW was designed to maximize the delivery probability of the packets. Namely, its task is to replicate data and provide maximum copies to different relay nodes so that at least one of the copy will successfully reach the destination with high probability.

Related works

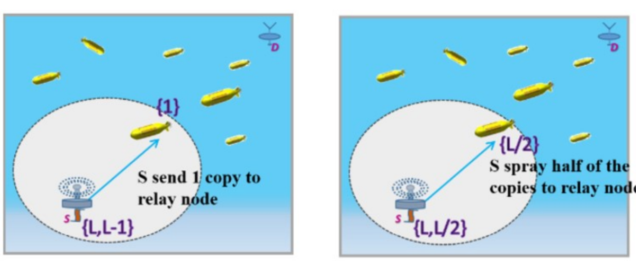
Spyropoulos et.al implement Spray and Wait efficient routing algorithm for intermittent connected mobile networks[4]. Muppalla et al. from the key factors, causes and suggested improvements in development new routing protocol is required for minimizing the delay, overhead and average latency[3]. Muhammad et al. analyze the performance of DTN routing protocols in underwater mobile networks. Binary Spray and Wait and RAPID routing protocols shows the best performance[5]. Yoon, Seokhon et al. proposing the An AURP: An AUV Underwater Routing Protocol for underwater acoustic sensor networks. He did first attempt to employ multiple AUVs as relay nodes in a multi-hop underwater acoustic sensor network to improve the network performance in terms of delivery ratio and energy consumption[6]. Sandeep Gupta et.al proposed modified spray and wait routing in underwater acoustic communication for sensor networks[7]. Chaudhary Nilam comparing existing routing protocols in delay tolerant networks[8].

Routing in DTN spray and wait

Source SaW and Binary SaW are the two types of routing techniques that exist in terrestrial environments. Source SaW is shown in Figure 1. In spray phase source node that has L number of copies transmits a single copy to all encountered relay nodes until it is left with only one copy and then enters the wait phase. In the wait phase, relay nodes transmit copies of the message destination nodes when they meet the destination. Binary SaW is shown in Figure 1. In spray phase source node that has L number of copies transmits half of the copies to the first encountered relay node. Both the source node and the first encountered relay node try to transmit half of the copies to all encountered relay nodes until they are left with only one copy, after which they enter the wait phase. Relay nodes transmit this message copy when they meet the destination. The probability of delivering data in source SaW is less efficient than the binary SaW. These two routing techniques are not suitable for underwater mobile ad-hoc networks, because source nodes are fixed at the bottom.

Routing in prophet

The probabilistic routing protocol uses the history of encounters and transitivity (Prophet) routing protocol for intermittently connected networks developed by Lindgren et. al[9] in RFC 6693. Prophet protocol uses nonrandom and contract patterns for copy the messages to other nodes in order to improve the routing performance. The PRoPHET protocol is based on the fact that if a node has visited a location or contacted with a node frequently, the probability of visiting the location and contacting the node is higher is called “delivery predictability”. The delivery predictability of node A to node B is denoted by DP (AB) and the range of delivery predictability value is defined as $0 \leq DP(AB) \leq 1$. Calculating delivery predictability in three steps. First, delivery predictability metric is updated whenever nodes encountered with in a communication range. Second, delivery predictability must age since a pair of nodes does not encounter each other for a moment of time. Finally, transitivity rule is applied[10]. In the Figure 2, source node S send message copy to first encounter node A1. If node A1 with a message to a destination node D contacts with node A2, node A1 and node A2



(a) Source Spray and Wait (b) Binary Spray and Wait

Fig. 1 — Spray and wait routing

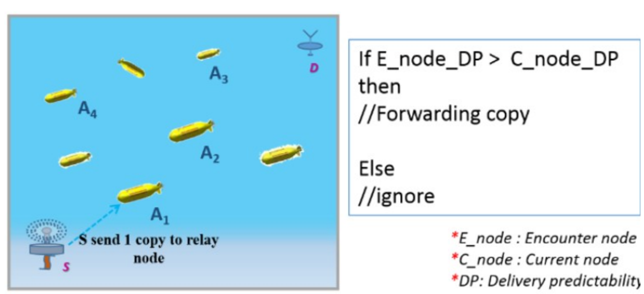


Fig. 2 — Prophet routing

exchange their delivery predictabilities. Then, node A1 compares DP (A_1D), and DP (A_2D). If DP (A2D) > DP (A1D) then the message to destination node D is copied to node A2. Otherwise, the message is not copied to node A2.

Architecture of underwater mobile ad-hoc network

In underwater mobile ad-hoc networks, sensor nodes represent the fixed nodes and sense underwater environment data. Relay nodes are responsible for collecting the data from sensor nodes and sending it to the sink node. Here we are considering the relay nodes that are either AUV's, UUV's, or ROV's. Figure 3 shows the underwater mobile ad-hoc network scenario. Here sensor nodes are fixed at the bottom and relay nodes are moving nodes. When designing a USaW routing to manage an underwater environment efficiently as depicted in Figure 3, there are 6 main points to consider. They are transmission speed, network throughput, end-to-end delay, energy efficiency, cost, and packet drop rate.

Transmission speed: The propagation speed of underwater communication is 1500 m/s. Water changes effect the data speed. In general, AUVs have high data transmission capabilities as compared to sensor nodes. In USaW routing, maximum copies are assigned to relay nodes, which increases the transmission speed.

Network throughput: In an underwater harsh environment, packet transmission is a challenging issue due to the intermittent connectivity, low bandwidth, long propagation delay and path loss, etc. USaW is replica based routing, instead of fixed sensor nodes many relay nodes are trying to send data to the sink node as soon as possible. This ensures increased delivery rate and network throughput.

End-to-End delay: In an underwater harsh environment, the data delay time is very high due to the intermittent connectivity, low bandwidth, and path loss etc. In USaW, there exists a replica based routing, instead of fixed sensor nodes, many relay nodes are trying to send data to sink node as soon as possible. Such a notion will reduce the delay time.

Energy efficiency: In the context of underwater communication, it is difficult to replace batteries, and each battery has a restricted capacity. In USaW routing, AUVs needs more energy for data transmission rather than the sensor nodes. We can easily pickup and recharge the relay nodes on the surface. In this routing reducing power, usage in fixed sensor nodes can be expected.

Cost: This is one of the largest issues with the underwater communication. The usage of memory and energy increases, which seriously affects the cost.

Packet drop rate: The packet drop rate in an underwater environment is very high due to the limitation of connection failures. In USaW routing, many relay nodes have the same copy, which turn decreases the packet drop rate.

Proposed USaW routing

In USaW routing, source nodes are fixed at the bottom. Source node will only have one copy each and will assign the remaining copies to the first relay node they encounter. In such environment source nodes are fixed to the bottom, hence it is easier to assign maximum copies to encountered relay nodes. Overall, relay nodes have high probability for data transmission (for storing, carrying, and forwarding). It will lead to an increase in the transmission speed, throughput. This relay node transmits half of the copies to all encountered relay nodes until it is left with only one copy. It will reduce the delay time and packet drop rate. Relay nodes transmit the message copy to the destination when they meet. USaW routing algorithm is shown in Figure 4.

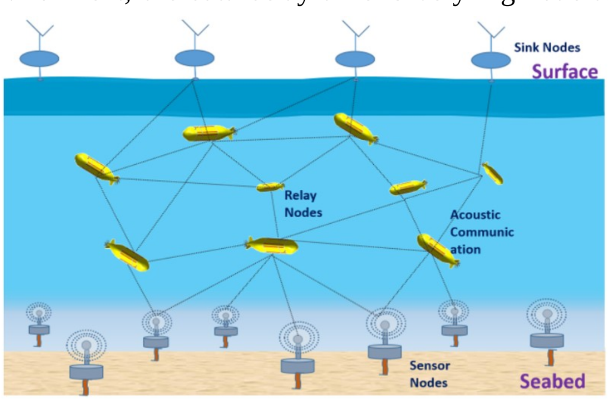


Fig. 3 — Underwater mobile ad-hoc network

Algorithm1: USaW Routing

Step 1: Source node generates L copies of gathered data
Step 2: In the spray phase S transmits L-1 copies to encountered relay nodes
Step 3: If a relay node encounters the destination,
  It transmits data to the destination and
  Enter into the wait phase
 Else
  If a relay node has more than one copy
   It transmits half of the copies to the encountered relay node
  Go to step 3
Step 4: Relay nodes delete existing copies

Fig. 4 — USaW routing algorithm

Communication between source node and first encountered relay node

In spray phase, for the communication between the source node and the first encountered relay node, source sensor nodes create number of copies depending on the infrastructure and number of relay nodes that exist in that network. In Figure 5, source node S creates L number of copies and sprays L-1 copies to the first relay node (A1) that it encounters. The source node keeps only one copy. Corresponding algorithm is shown in Figure 6.

Communication between relay nodes

In the communication between relay nodes, data forwarding between relay nodes follows the store-carry-and-forward approach. In this approach, data is moved from the source node to the first encountered relay node and is stored there, and waits for a chance to forward the other half of the copies. The relay nodes can carry the stored data while moving, and look for opportunities to forward the data to other encountered relay nodes. The process continues, gradually by delivering copies towards the destination. Table 1 shows the proposed USaW routing characteristics. In Figure 7, relay node A1 stores L-1 copies in its own buffer. It carries those copies and finds relay node A2 and comes in the communication range. Subsequently, A1 forwards half of the copies to A2. Now, A1 and A2 are searching for other relay nodes. If the encounter relay nodes represent the final destination, it enter into the wait phase; otherwise, process continues until there is until only one copy left. Correspinding alogrithm is shown in Figure 8.

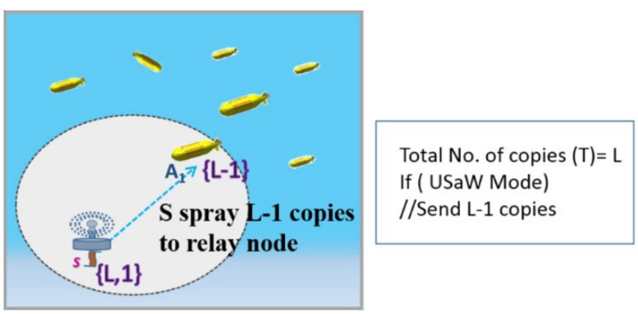


Fig. 5 — Communication between source node and first encountered relay node

Algorithm 2: Communication between the source node and the first relay node encountered //Message Creation and Sending

Step 1: Creating "L" number of message copies

Step 2: If (USaW is used) then

No. of copies = no. of copies -1

else If (binary is used) then

No. of copies = no. of copies/2

else

No. of copies = 1

Fig. 6 — Algorithm for communication between source node and first encountered relay node

Communication between relay nodes and sink nodes

In an underwater mobile ad-hoc network, sink nodes are either moving or fixed nodes. Relay nodes are the moving nodes. Identifying the location of

Table 1 — Comparison of existing localization technologies in underwater sensor network

Localization Techniques	Localization Scheme	Challenge
GIB(GPS Intelligent Buoy)	Beacon	• Only for short range • High amount of energy usage
DNR (Dive 'N' Rise) Beacon	Beacon	• High amount of energy usage due to rising and frequent update message exchange
SLMP(Scalable Localization with Mobility Prediction)	Prediction	• More powerful Anchor nodes are needed
LSL(Large Scale Localization) PL (Proxy Localization)	Range	• Suitable for large scale networks
SBL (Short Baseline System) LBL(Long Baseline System) DNRL(Dive and Rise Localization)	Range	• Suitable for large scale networks • These techniques are expensive

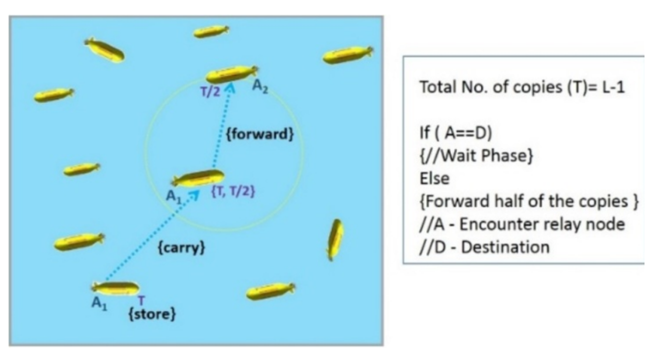


Fig. 7 — Communication between relay nodes

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Algorithm 3: Communication between relay nodes
//Message Forwarding

Step 1: The encountered relay node is not the destination

Step 2: If (No. of copies > 1) then
2.1: ┌ If (USaW is used) then
     │       No. of copies = no. of copies/2
     ├ else If (binary is used) then
     │       No. of copies = no. of copies/2
     ├ else
     │        No. of copies = 1
     └ else
            // enter into the wait phase
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Fig. 8 — Algorithm for communication between relay nodes

mobile nodes is challenging issue due to the harsh environment. Many researchers conduct research for localization techniques for finding the location of relay nodes in an underwater acoustic communication.

Beacon based localization

GPS Intelligent Buoy (GIB), a commercial system, is designed to track underwater equipment, such as AUVs, and divers[11]. The GIB is equipped with submerged hydrophones and GPS receivers. In DNR[12], Erol et. al propose the use of mobile beacons to increase the localization coverage in 3D underwater acoustic sensor network. Beacons dive and rise to act as underwater GPS. Sink nodes broadcast their DNR beacon messages while floating above the water. Mobile sensor nodes localize themselves by listening to beacons from DNR. Instant Localization Scheme (ILS) [13]. exchanging beacon signals between the monitoring center and AUVs will indicate the distance between them.

Prediction based localization

Sweeper scheme tracks the position of the sensor nodes at regular intervals with the help of adaptive array antenna and mobility prediction scheme[14]. Zhong Zhou et. al. the scalable localization scheme with mobility prediction (SLMP) for underwater sensor networks[15]. Anchor nodes are more powerful and can estimate their locations from the surface buoys with the help of mobility prediction algorithm.

Range based localization

Range based protocols can provide a more accurate position of sensor nodes based on the distance and angle measurement. Terrestrial range based schemes time of arrival, time distance of arrival, received signal strength, round trip time, or angle of arrival is used for estimating the node distance. These schemes need additional hardware's for measuring the distance, which will affect the cost. In underwater sensor networks, acoustic channels are used. Range measurement using acoustic signals is much more accurate and cheaper when compared to terrestrial sensor networks[4]. Range-based schemes are possibly a good choice for the underwater environment. Due to unique limitations of an underwater environment, the applicability of range-based schemes is strange. Misra Sudip et. al. presents an algorithm for estimating the speed of the underwater sound at a particular location and time[16]. Different range based location techniques are put in place for underwater mobile ad-hoc network[15,11,17,18,19]. Comparisons of different existing localization technologies are shown in Table 1.

Simulation setup

We used the ONE simulator to analyze the USaW routing performance. The opportunistic evaluation system designs a simulation environment that offers a variety of tools to create complex mobility models for running different DTN related routing protocols. The shortest path map-based movement model initially places all the nodes and uses Dijkstra's shortest path algorithm to identify the shortest path to a given destination. According to this model, we designed new simulation default settings file for USaW routing related to the underwater communication. Here we considered some of the nodes as fixed nodes and some as mobile ones, and we considered communication channel limitations as the propagation speed, buffer space, battery power, noise, multi path, and fading. Moreover[20] introduces the energy consumption module for ONE simulator. In this module, we consider the three states (transmission, receive, and scan) for checking energy usage. In the transmission state, node spends an energy for sending a message; in the receive state, a node spends energy for receiving a message; and in the scan state, a node spends the energy for finding neighbor relay nodes. In this simulation, we used the Bluetooth interface. Communication range, transmission speed, and buffer size is shown in Tables 2, 3, and 4.

Table 2 shows common settings simulation parameters related to underwater environment. Figure 9 shows the simulation screen shot. Table 3 depicts specific setting parameters for sensor and relay nodes. In the energy consumption module, we assumed that scan process consumes more than ten times the amount of energy consumed for sending or receiving a message. Similarly, the consumed energy for transmitting is two times higher than the receiving energy. Table 4 list the parameters settings for calculating the energy consumption.

Performance metrics

When designing a USaW routing technique to manage an underwater environmental monitoring system efficiently, we consider the following five factors.

Delivery ratio: Delivery probability is defined as the number of delivered messages divided by the number of generated messages.

Packet loss/ drop rate: Packet loss is defined as the percentage of dropped messages with respect to packets generated.

Packet loss and energy consumption: It is evaluated as the total amount of energy used for transmission multiplied by the energy used for packet loss.

EPL = Packet loss × (TxE + RxE + SxE).

Where TxE, RxE, and SxE are transmit, receive and scan energy respectively for the data transmission.

Network Throughput: The average rate of a successful packet delivery over a communication channel.

Table 2 — Specification of simulation parameters

Parameters	Value
Simulation time	4320s (1.2h)
Interface	Bluetooth
No. of nodes	1000~1200
Movement	SPMBM
Number of copies	50

Table 3 — Specification parameters of sensor node and relay node

Parameters	Sensor Node	Relay Node
Transmit Range	10m	100 m
Transmission Speed	200kbps	10Mbps
No. of nodes	800	200~400
Buffer Size	10MB	20MB
Moving Speed	fixed	0.5~1.5 M

Table 4 — Energy parameters for Relay nodes

Parameters	Settings
Battery Capacity	4.8 Joules
Scan Energy	0.92 mW/s
Transmit Energy	0.08 mW/s
Receive Energy	0.04 mW/s

End-to-end delay: The average delay between the message creation and its delivery at the destination.

Results and Discussion

We estimate the USaW routing's performance in an underwater communication with respect to delivery ratio, end-to-end delay, packet loss, average hop count, network throughput and energy consumption. In the first simulation, we consider that 800 nodes are fixed nodes, i.e., source nodes, 200-400 nodes are the mobile relay nodes, and 10 nodes are the destination nodes. Based on the simulation results, USaW displays the best performance as compared to existing SaW and prophet routings. As shown in Figure 10, When increasing the number of nodes, the probability of delivery ratio is increased as relay-nodes have high probability for transmitting data. As shown in Figure 11, the packet loss decreased as most of the real nodes have the same copy. Moreover, as shown in Figure 12, the network throughput increased. Figure 13 depicts the packet loss and energy consumption. USaW consumed less energy as compared to existing SaW routing. In the second simulation, we consider 800 nodes as fixed nodes, i.e.,

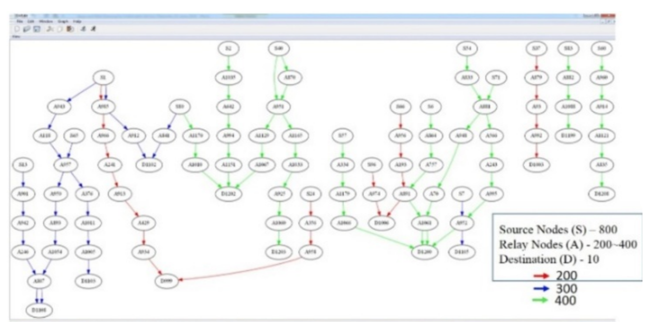

Fig. 9 — USaW adjunct graph

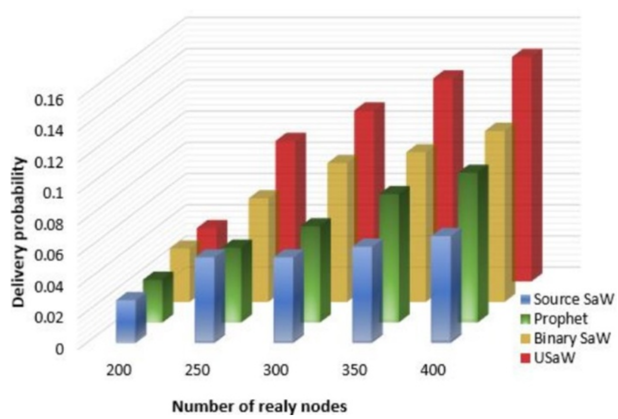

Fig. 10 — Impact of delivery ratio with increasing relay nodes

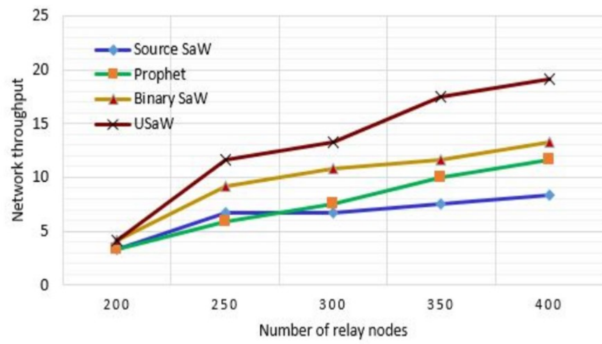

Fig. 11 — Impact of packet loss with increasing relay nodes

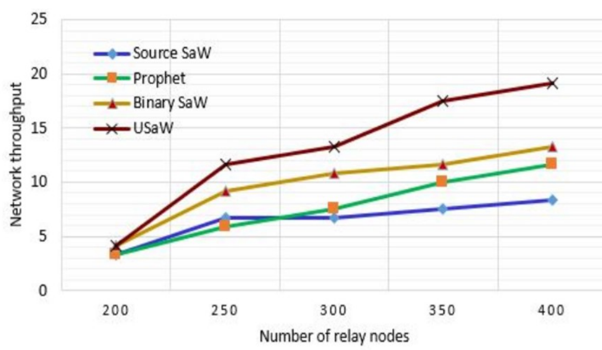

Fig. 12 — Impact of throughput with increasing relay nodes

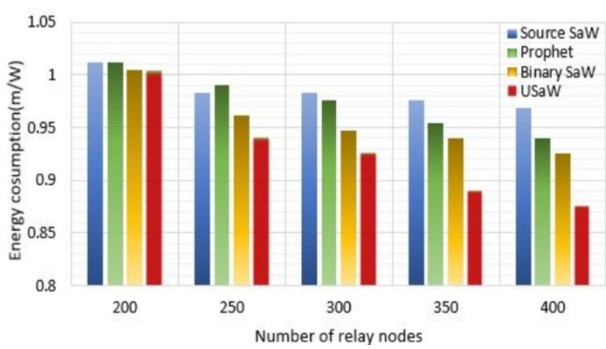

Fig. 13 — Impact of energy consumption with increasing relay nodes

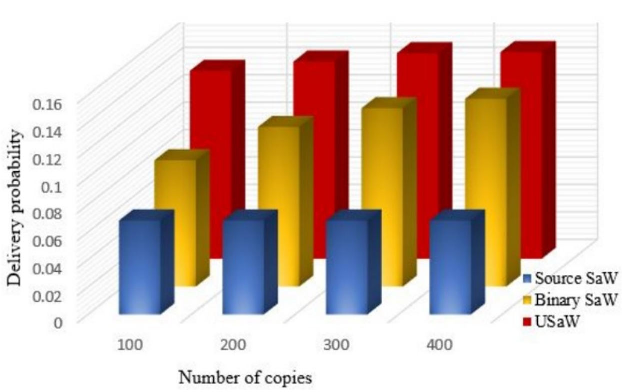

Fig. 14 — Impact of delivery probability with increasing copies

source nodes, 400 nodes are the mobile relay nodes, and 10 nodes are destination nodes. We considered number of copies as from 100 to 400.

According to the simulation outcome, USaW shows the best performance contrast to other routing protocols. Since SaW forwards only one copy, there is no change in the result when the number of copies is increased. When we increase the number of copies, the probability of delivery ratio is enlarged as shown in the Figure 14. Figure 15 shows the reduced delay time.

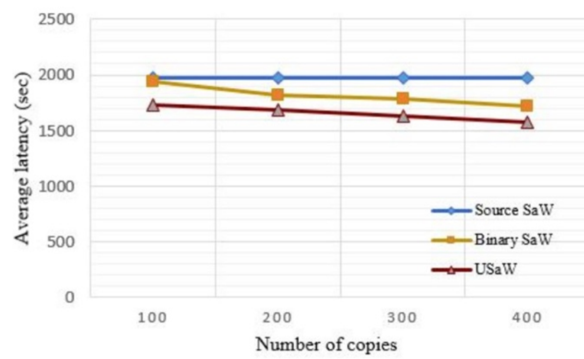

Fig. 15 — Impact of end-end delay with increasing copies

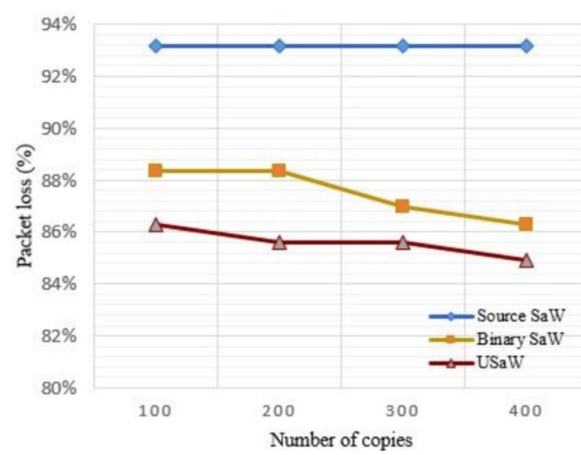

Fig. 16 — Impact of packet loss with increasing copies

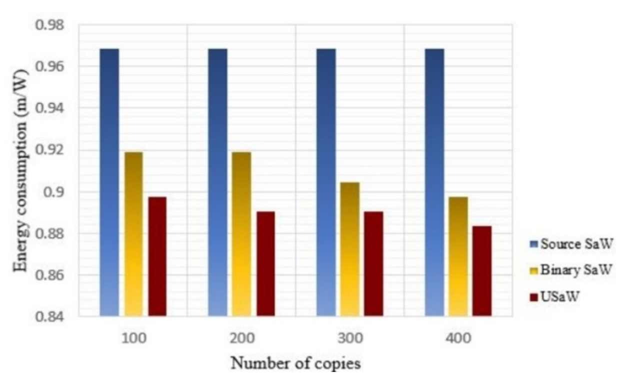

Fig. 17 — Energy consumption impact with increased copies

In Figure 16, the packet loss decreased. USaW reduced packet loss when compared to other routing protocols due to most of the relay nodes have same copy. Figure 17 shows the energy consumption impact on packet loss.

Conclusion

In this paper, the authors proposed USaW routing technique for mobile ad-hoc networks based on source and binary SaW DTN routing protocols. The work used delivery probability, average latency, energy consumption, cost, and we should packet drop rate for designing the USaW routing technique for underwater mobile ad-hoc networks. We analyzed USaW performance using ONE simulator. Based on the results, we conclude that the USaW routing shows 60% higher performance with respect to the delivery ratio and network throughput, packet loss reduced approximately 70%, and the usage of energy reduced. Increasing the number of copies of data in USaW routing led to a 50% decline of the delay time as compared to binary SaW. Finally, the authors conclude that USaW shows the best performance when increasing the number of relay nodes and copies of data compared to existing routing protocols. In my future work, we will implement communication channel model for underwater communication. Moreover, we are trying to compare bandwidth, propagation delay as additional parameters.

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