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Internet of Things: Underwater routing based on user's health status for smart diving

Sarah E. Shukri[a], Rizik Al-Sayyed[b*], Hamed Al-Bdour[b], Esraa Alhenawi[c], Tamara Almarabeh[b] and Hiba Mohammad[b]

[a]Luminus Technical University College, Abdul Aziz Al Ghurair School of Advanced Computing, Amman, Jodan
[b]The University of Jordan, King Abdullah II School for Information Technology, Amman, Jordan
[c]Software Engineering Department, Al-Ahliyya Amman University, Amman, Jordan

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ABSTRACT

Technological advancements affect everyday life; they benefited our daily routines, habits, and activities. Underwater diving is one of the most interesting and attractive activities for tourists worldwide but could be risky and challenging.When paths are not clear, diving might take additional time and effort leading to some health problems. Thus,providing divers with proper direction information to surf underwater can be useful and helpful. Also, monitoring diverse health statuses and alerting them in caseof any undesirable condition can increase their safety. Smart devices such as mobiles, watches, sensor devices, cellular networks along with the Internet of Things (IoT) can all provide location-based services. Such services can help in providing the best path for the divers and monitor their health status during diving.This paper proposes a new underwater routing approach, called Underwater Routing for Smart Diving "URSD", which provides divers with routing information tovisit underwater cultural or natural resources and monitors their health status during the diving period. The URSD approach was simulated and compared with theshortest path. Results showed that the URSD helped divers to route within paths that have a larger number of nodes, furthermore, it could enhance and improve divers experience and help them mitigate underwater risks.

1. Introduction

In recent years, tourism sector has experienced rapid and continuous growing, it has experienced increasing in total arrivals from 25 million in 1950 to a total of 1.186 billion Arrivals in 2015, making it one of the most growing (Glaesser et al., 2017) and most providing jobs (Buhalis & Law, 2008) sector worldwide. In 2022, the number of international tourists who travelled, exceeded 900 million, these numbers were according to the World Tourism Organization; abbreviated as UNWTO1. In 2021, however, twice this number was recorded, and it is expected that the number will reach 1.8 billion in the year 2030. Tourism activities are an essential part that attract the tourists and encourage them toward visiting some cities. Underwater diving is one of the most attractive tourism activities for tourists all over the world, where they can visit cultural and natural resources underwater. Providing an underwater guided route for the diver can be very useful (Rangel et al., 2014), and it has been in use before (Delgado, 2011) and (Claudet et al., 2010). The quality of tourism experience plays an essential role in the retention of tourists. Thus, it is important to deliver new Information and Communication Technologies (ICTs) to enhance the quality of tourism experience. The development of ICTs have dramatically changed the structure of the tourism sector in recent years (Porter, 2001), where in the 1970s Computer Reservations Systems (CRSs) have been developed; in the 1980s Global Distribution Systems; abbreviated as GDSs, have been established, and then came the Internet development late the 1990s (Paraskevas & Buhalis, 2002). Providing new technologies for underwater routing can enhance the divers' experience remarkably,

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* Corresponding author.
E-mail address: r.alsayyed@ju.edu.jo (R. Al-Sayyed)

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where divers can find and visit the resources (s)he prefers in a shorter period of time. Also monitoring his/her health status while (s)he is diving can be safer, since some problems might occur with him/her underwater and alerting him/her to avoid these problems might enhance his/her experience and save his/her life in some scenarios. The rapid improvement in ICTs brings out new technologies, one of them is the Internet of Things (IoT), it refers to the interconnection network of every day's objects, which are often equipped with intelligence (Xia et al., 2012), IoT builds a distributed network of internet, devices interconnecting with other devices and with human (See Fig. 1). This brings out huge and vast opportunities for new applications that might improve the quality of our lives.

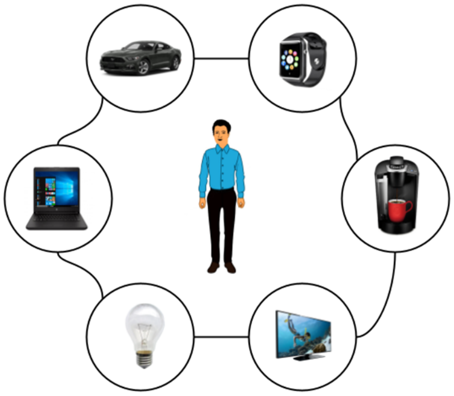

Fig. 1. Internet of Things

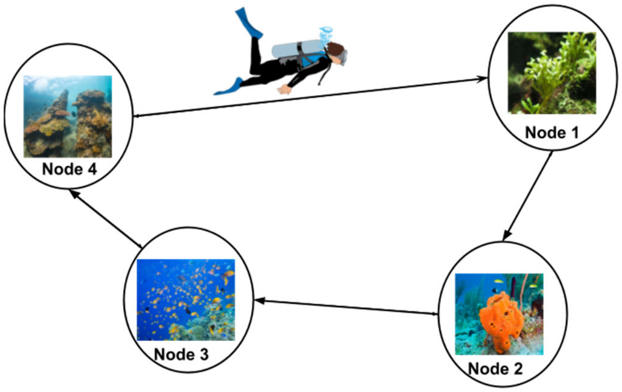

Fig. 2. Basic Components of the Proposed Approach

Geographical routing is one of the applications that can be supported by IoT using human interaction with different devices and systems (Arianmehr & Jamali, 2019) such as: mobile, GPS systems and sensor devices. Geographical routing has been implemented in different areas such as: tourism (Almobaideen et al., 2017; Stiller et al., 2006), transportation (Almobaideen et al., 2015), and healthcare (Su et al., 2013; Aravind & Maddikunta, 2022). Another application supported by IoT is monitoring health status using smart devices, such as: smart watches that can measure the heart rate and the blood pressure.

In this paper, a new approach for underwater routing called Underwater Routing for Smart Diving (URSD) is proposed. To provide the diver with routing information so (s)he can surf underwater and visit the natural and cultural resources, along with monitoring his/her health status to check the oxygen level, his/her heart rate, and other vital indicators in order to alert him in case of any undesirable condition. Fig. 2 illustrates the basic components of the approach.

This research aims mainly at proposing a routing mechanism for underwater divers. Where the route is short and contains the highest possible number of sensors. The objective of increasing the number of sensors is to maintain communication stability with a diver. To monitor his health status during diving, where his body is also attached to sensors that monitor his vital indicators. And to alert him in case of any possible danger.

The remainder of this paper is organized as follows: Section 2 presents some of the related works in underwater sensor networks. Section 3 describes the proposed approach in terms of network model, general architecture, main phases, and the simulation environment. Results are presented and analyzed in section 4, and finally the paper is concluded in sections 5.

2. Literature review

Routing is a major problem in any kind of network, and adapting the best routing protocol responsible for discovering and managing the routes of packets is also a challenge. In literature different routing algorithms have been proposed (Moshref et al., 2021; Moshref et al., 2022; Jabri et al., 2018), but by extensively reviewing the literature, no previous work for scuba divers geographical routing underwater has been found. Thus, in this section, some research is presented in underwater where sensor networks are used.

Underwater wireless sensor networks (UWSNs) can be efficiently used for exploring the underwater medium for various activities such as water pollution, environmental monitoring, oil rig maintenance, marine life monitoring, and military applications (Farooq et al., 2021). They are responsible for managing and routing data packets underwater, such networks suffer from different challenges such as: low bandwidth, high energy consumption, increased mobility of nodes (Yang et al., 2019) and they differ from other terrestrial (earthbound) networks in some manners, Table 1 lists some of the main differences between these networks.

Table 1
Main differences between Terrestrial WSNs and Underwater WSNs

Terrestrial WSNs	Underwater WSNs
High data rate (usually in MHz)	Low data rate (usually in KHz)
Dense deployment of nodes	Sparse deployment of nodes is preferable.
Routing process requires increased number of hops.	Hops numbers depend on the routingarea.
Low power consumption	High power consumption
Battery power can be easily replaced or recharged.	The power of battery is limited and hard to be replaced or recharged.
Nodes can continue working for longer period of time.	Nodes usually work for shorter period.
Nodes with less error prone	Nodes with more error prone
Nodes can communicate using radio waves	Radio waves are replaced with acousticwaves

As the reliable communication between underwater sensor nodes is considered a critical challenge, many researchers addressed such a point. As an example, researchers in (Khasawneh et al., 2020) proposed a new localization free shortest path routing that is reliable, efficient energy, and pressure-based (SPRE-PBR). The proposed approach considers three main parameters: (1) Node energy, (2) Pressure, and (3) Link quality to determine the next node in the path. SPRE-PBR also uses the route cost calculation and shortest path to remove unnecessary nodes from the path and reduces the complexity of the selected path. UWSNs are suitable for applications such as: military applications for monitoring and submarine detection. Target localization on the other hand, is a very important process in submarine detection. In (Shakila & Paramasivan, 2020), the researchers proposed a new nodes localization method based on the range of the nodes supported with Spider Monkey Optimization Algorithm (SMOAL). The nodes are located using the direction and time of arrival of propagated waves. The location status is also forwarded to the monitoring scheme using another proposed approach called Energy-Aware-Depth-Dependent-Routing-Protocol (EADRP). The proposed approaches outperform the traditional approaches in terms of different evaluation metrics such as: coverage, error in the localization, delivery ratio, consumption of energy, delay, packet drop, and throughput. USWNs suffer from different transmission problems, such as: the high energy consumption, limited bandwidth and long propagation delay. Such problems affect the performance of underwater networks. Thus, researchers in (Mahato et al., 2020) proposed a new routing technique that overcomes previously mentioned problems, using a combination of cuckoo search algorithm and Ant Colony Optimization Algorithm. Some researchers proposed a cooperative efficient energy routing protocol (CEER) to increase the network's lifetime and reliability (Ahmad et al., 2022).

Another approach that was proposed by (Ismail et al., 2020) called Reliable Path Selection and Opportunistic Routing (RPSOR) for UWSNs, they based it on three major factors: Advancement factor (ADVf), which employs the depth of current and next hop forwarding node; Reliability index (RELi), which employs the energy of the current forwarder and average energy in the next expected forwarding region; and Shortest Path Index (SPi), this latter factors is calculated on the basis of the number of hops to the sink, and average depth of neighbors in the next expected hop. To overcome the challenges of the USWNS, the proposed approach uses a more reliable path towards the sink by calculating RELi for each node. Finally, the proposed scheme was simulated and evaluated against WDFAD-DBR, and the results showed that RPSOR outperformed the WDFAD-DBR in terms of PDR and energy tax.

Continues movements of nodes underwater, requires methods to handle the maintenance and recovery of routing path, In order to handle this issue, a new position based routing protocol called Vector Based Forwarding Protocol "VBF" was presented (Xie et al., 2006), it is a location-based protocol; the state information of sensor nodes are not required during the packet forwarding, since the number of nodes is limited, the data packets are forwarded in a redundant and interleaved way from the source to the destination nodes, which helps in avoiding the packet loss and node failure. The main idea behind implementing this protocol is that every node previously knows its location, and every packet carries out the locations of all other nodes in the forwarding path starting from the source node, to the forwarding nodes and finally reaching out to the destination node.

In this research, the idea of vector which can be described as a virtual routing pipe was proposed, where packets are routed and forwarded through this pipe from the source to the destination, and only the nodes which are closer to the vector can forward the packet. This idea helped in mitigating the network traffic and delay and it also improved the ability to manage the dynamic topology of the network. The VBF protocol suffers from some limitations. First, the protocol is highly sensitive to the routing pipe radius threshold which may affect the routing performance. Secondly, the creation of the virtual routing pipe from the source to the destination is highly affected by the node's distribution and density.

Moreover, if nodes are originally sparsely distributed or due to their movement. It is possible that a few or no nodes exist in the routing pipe. Which will affect the efficiency of the overall network. Or it's possible that some paths will lie outside the routing pipe. Also, the same forwarding nodes might be used for routing for a certain source-destination pipe which will consume their battery power. Over these limitations VBF protocol suffers from communication overhead due to using the 3-way handshake technique. Finally, VBF was simulated with a small to medium number of nodes, and results showed that it achieved the goals of robustness, energy efficiency, and high success of data delivery.

To increase the robustness and overcome the problems in VBF protocol, an enhanced version of VBF was proposed called Hop-by-Hop Vector-based Forwarding “HH-VBF” (Nicolaou et al., 2007), it is built upon the same concept of using virtual pipe. But, instead of using one single pipe from source to destination; it defines a pipe on each forwarding node. Thus, each node makes the decision about deciding the path using its virtual pipe.

In this method, the nodes can find a path even if there is a small number of nodes in the area. But the method still suffers from the problem of routing pipe radius threshold and additionally due to its hop-by-hop nature it suffers from high signaling overhead. Finally, the simulation results showed that the HH-VBF outperformed VBF in providing a better delivery ratio. Especially in sparse areas where nodes are distributed far from each other.

Without prior knowledge of the location’s information of sending and receiving nodes; large number of broadcast queries will encumbrance the network which may reduce its overall throughput. In order to reduce the flooding a new protocol was proposed called Focused Bream Routing “FBR” (Jornet et al., 2008), this routing technique pre-assumes that every node in the network knows its location information, and every source information knows the information about the final destination. Other than this information, the information of intermediate “forwarding” nodes are not required.

Routes establishing processes done dynamically during sending the data packets for its destination. Also, the decision about the next hop is performed at each step, when the appropriate nodes are found. However, the FBR protocol seems to be suffering from some performance problems. First, if nodes due to their movements in water become sparse, it is possible that no one node will lie within the forwarding path. Also, nodes which are available as candidates to be chosen for the next hop, may exist outside the forwarding path. In this case, when it is unable to find the next hop, the broadcast query will be resent, which will affect the overall performance and increase the communication overhead. Second, it assumes that the sink is known and fixed, which reduces the flexibility of the network and makes it more rigid.

It is commonly known that the water movement makes the underwater environment more dynamic, but in this research (Chen et al., 2008) a new protocol called Reliable and Energy Balanced Routing Algorithm “REBAR” was proposed, which assumes that the node mobility due to water movement can be taken as a positive factor. Which can help in balancing the energy depletion of the network. The reason they provided is that when nodes move then they start to alternate around the sink, this brings an effect of a kind of balance in energy consumption in the whole network.

As nodes closer to the sink have a tendency to perish more quickly than other nodes, they solved the portioning problem by frequently moving the nodes. owing to their participation in the routing procedure. They make the same assumption as (Jassim et al., 2013) and (Khasawneh et al., 2020) that each node is aware of its location and that of the sink location. However, they suggested an adaptive strategy by specifying the data propagation range, in order to balance the network's energy consumption. This protocol uses geographic information to direct nodes to broadcast within a restricted range between the source and sink because wide broadcasting uses a lot of energy.

Specifically, depending on how close a node is to the sink, each node has a chance of taking part in communication. In order to reduce their involvement in the routing process and equalize the energy consumption across all nodes, nodes that are close to the sink are set to lesser values. Their approach assumes that the sink is permanent and stationary in the middle and that each node has a particular range and a unique ID. Although node mobility was seen favorably in this case, it still has significant issues. First, the network may become sparse as a result of their moves. Second, because the nodes must regularly update the information about their locations, their movement can lower overall performance. Additionally, it is believed that both the horizontal and vertical directions of the movement are dynamic. However, since only horizontal movements are typical in real-world situations, that might not be practical. Furthermore, the end-to-end delay resulting from different nodes' movements was not taken into account in their simulation results, which solely considered delivery ratios and energy consumption using varied node speeds. Finally, their simulation findings demonstrated that the delivery ratio increased when node motions increased relative to static nodes.

It is necessary to know all the nodes' positions for location-based protocols. Something sees itself as difficult. A new technique called Depth Based Routing “DBR” was suggested in place of the full location’s information needed (Yan et al., 2008). This simply needs to know the nodes' depth information. The authors recommended employing low-cost depth sensors for each node to get the nodes' depth information.

Their model assumes that there are several sinks positioned at the water's surface that are utilized to gather data packets from other sensor nodes. Data packets are forwarded from higher to lower sensor nodes by DBR after making a judgment on the depth information. A node senses a packet's depth from the surface when it gets it, records it in the “Depth” packet header, and broadcasts it to other nodes. The receiving node will now determine its depth in relation to the surface and only transfer the packet if its depth value is less than the one written in the header. If not, the packet will be discarded. The data packet will be forwarded until it reaches one of the data sinks. Since these data sinks have larger bandwidth and stronger communication capabilities, the delivery of data packets to any one of them can be regarded as successful. However, DBR protocol still suffers from some major problems. First of all, it has only greedy mode, which it can’t itself reach high delivery ratio in sparse areas.

It might be possible that no node can act as a forwarding node since they have a higher depth value than the sending node. And the sending node will keep sending more repeated attempts, which will decrease the overall performance. Second, sending the broadcast packets can decrease the overall performance. Also, these broadcast packets require the receiving nodes to calculate their depth every time which consumes the limited available energy.

For UWSNs, geographical routing is preferable because it is stateless. How- ever, it requires distribution of sensor nodes. Which might be expensive in terms of energy and time to converge. To provide an alternative to geographical routing, a new protocol called Haydrolic Pressure based Routing Protocol “HydroCast” was proposed (Lee et al., 2010). HydroCast uses the anycast routing to forward the data packets to the surface, by exploiting the pressure levels. Moreover, it is stateless, and it can complete its tasks without requiring high distribution of sensor nodes.

The fundamental concept of HydroCast is comparable to DBR in that the forwarding choice is based on the depth information or the pressure level. The node among its neighbors with the lowest pressure level is where the data packet is transmitted. Local maximum, which occurs when the forwarding node can't discover the next hop with a lower depth than its neighbors, is a significant difficulty for the DBR protocol. DBR is unable to manage the situation and come up with a solution in such void regions. HydroCast manages the scenario by keeping a recovery route for each local maximum node; nevertheless, the route transfers the data to neighbors with a deeper depth than itself. The route can exit the void region and return to the greedy mode after one or more forwarding. The void regions issue has been effectively resolved by HydroCast.

The wireless channel's quality for simultaneous data packet reception by neighboring nodes has also been considered by the authors. A minority of the receiving nodes can forward data opportunistically thanks to these simultaneous receptions, which improves the delivery ratio. Additionally, opportunistic routing may result in the sink receiving several copies of the data packet, which could put a strain on the network's resources. No information was provided regarding the energy consumption by the depth sensor nodes, despite the simulation results showing a high delivery ratio with a little end-to-end delay.

3. Underwater routing for smart diving (URSD)

The underwater network model is presented in section 3.1 of this part, followed by Section 3.2's discussion and illustration of the overall URSD architecture. Section 3.3 describes the key stages of the URSD protocol, while Section 3.4 describes the simulation environment.

3.1 Network model

URSD aims at directing the diver in underwater network model to a desired destination node, the directing process is done using virtual paths and directions sent to the diver, it also aims at directing him within the path that has the greatest number of sensor nodes, to be able to monitor his health status during the diving period, and to do not lose the communication with him. Network model of URSD can be viewed as a graph with nodes representing the visiting resources, edges representing the virtual paths, and each edge has several intermediate nodes representing the sensor nodes. The components and their description are listed below (Fig. 3):

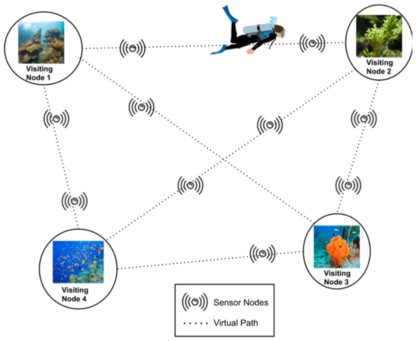

Fig. 3. Network Model of the Proposed Approach

1. Underwater attraction sites (UAS): Represents the underwater nodes in which the divers aim at visiting. They can be any natural or cultural resource. These nodes contain sensors within their area, in order to be able to locate them.

2. Underwater sensor nodes: sensor nodes are distributed between visiting nodes, in order to direct the diver between a specific source-destination, and to periodically communicate with the diver and track his health status.

3. Virtual path: is an unreal path between any source-destination visiting node used to direct the diver toward his desired destination.

3.2 General architecture

The architecture of URSD is illustrated in Fig. 4. This architecture can be generalized to be applied in different applications and domains, in which the main components of the architecture and the network model are applicable. Many examples of different applications could be found to be applied using this architecture, such example is the ambulance car; when an alert is sent for the Emergency Department (ER) of certain medical institution to move an ambulance car for a certain destination to pick up a patient with undesirable condition, it which to arrive as fast as possible using the shortest path without losing the cellular connection or any other type of connection with the ER department, in such application the URSD architecture is applicable where the sensor nodes are considered as the connection points, the sink node is the ambulance car, and the visiting node is the ER department. Another application where the URSD architecture can be applied is mining or mine clearance. Demining is referred to the process of removing land mines from an area. Such application is very sensitive and might threaten the life of the workers. In such application finding a safe path for the worker to reach the land mine and keep on the connection with him is highly recommended and the threat of any failure is very dangerous. Thus, the URSD architecture can be equipped to avoid such failures, where the land bombs are considered as the visiting nodes, the safe points and connection points are the sensor nodes, and the worker is the sink node. URSD architecture built upon the general architecture proposed by (Al-mobaideen et al., 2017) with some modifications in the components. In our proposed architecture. The diver should be equipped with smart watch device, and it is assumed to be GPS enabled. And he must be also equipped with sensor nodes that track his heart rate, blood pressures and oxygen level. The smart watch allows the diver to send a packet describing what he wants to see and his health status and get back a direction that shows him the virtual path leading towards the intended destination.

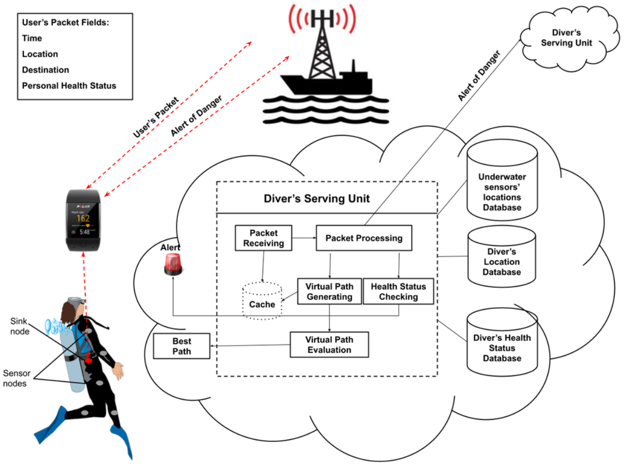

Fig. 4. General Architecture of the Proposed Approach

The following fields describe the main information sent from the user:

1. Time: The time when the message has been sent
2. Location: The current location of the diver tracked by the GPS device
3. Destination: Represents the node in which the diver wants to visit
4. Personal health status: Represents the health status details of the diver including heart rate, blood pressure and respiration

Each diver represents a potential Internet of Things object in our proposed architecture, and it is assumed that he will be outfitted with a smart watch and small wireless sensors that should be placed in various parts of his body as a Wireless Body Sensor Network (WBSN) (Yoo et al., 2009; Jassim & Almobaideen, 2013). His heart rate, blood pressure, and respiration are among the health-related data that these sensors are designed to gather. This data is then transmitted to the diver's smart watch gadget, which may aggregate it and send it to the Divers Serving Unit (DSU) via a cellular connection network on a floating ship at the surface. DSU represents the main components of architecture and it's allocated at the fog, it's mainly used to conduct computations and analyze incoming information. It's connected to Underwater Sensors' Locations database, Diver's location database and Diver's health status database, these databases are described below:

1. Underwater sensors' locations database: Maintains information about the locations of cultural and natural resources underwater, along with the locations of the sensor nodes distributed between them.

2. Diver's location database: Maintains information about the diver such as: the diver's name, his current location and the destination he wants to reach.

3. Diver's health status database: this database stores the diver's name along with his current health status in terms of: blood pressure, heart rate and oxygen level. And creates a log for his status during the diving period.

Diver's Serving Unit is located at the fog and consists of the following components:

- Packet receiving module: This component is responsible for the packet reception from the user, de-capsulation it and forwarding it to the packet processing module.

- Packet processing module: this module analyzes the received packet and contacts the underwater sensors' location database and the diver's location database to find the best virtual path for the diver, it also contacts the diver's health status database to analyze his health status and ability to stay underwater.

- Virtual path generation module: this module may find several virtual paths between the source and destination and pick the shortest one along with the best coverage of sensor nodes. This path is then sent to the route evaluation module and to the cache.

- Health status checking module: This module checks whether the diver's status allows him to stay underwater. If so, nothing happens, and the module keeps tracking his status whenever he passes in front of a sensor node. Otherwise, if his status is in danger, an immediate alert is sent to the diver to leave the water.

- Cache module: In this module a cache of source-destination routes with specific health status is kept. in case a new request of similar route has been received it will be retrieved from the cache immediately without passing through previous steps.

- Path evaluation: This module evaluates the generated path and formulates it in a way to be displayed on the diver's smart device.

- Danger alerting sub-module: If the diver felt in any kind of danger during the diving period, such as: Shark attack, earthquake or any other danger, he sends an immediate danger alert using his smart device, emphasizing that there is a danger surrounding him and threatening his life, this alert is sent over the cellular network located at the floating ship, and will be received by the serving unit located at the fog, then, this alert will be forwarded to nearby serving units' located at near fogs in order to alert divers at these locations that the risk might reach them also. also, the diver will be helped to avoid or mitigate the risk of the danger, the following (Fig. 5) illustrates the main components of this sub-module, if the diver at location A felt that there is a danger moving toward him he sends an alert using his smart device, this alert will be received by the serving unit at his location, the serving unit will send an alert to other unit at location B, and in it turns the serving unit at location B will alert the divers in the location by sending a message telling them to leave the water.

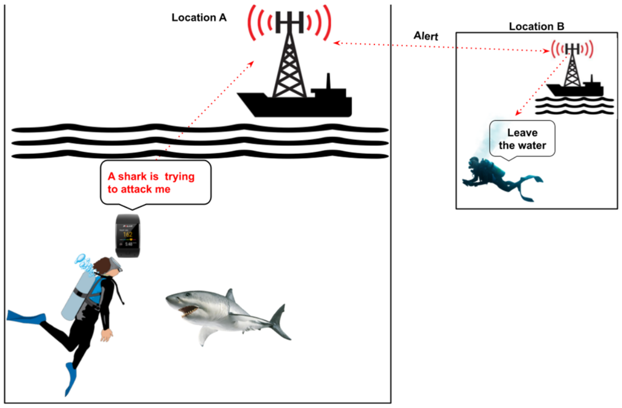

Fig. 5. Danger alerting sub-module

3.3 Main phases

URSD can be broken into four main phases:

1. Network generation: The first step is to build a random network and distribute number of visiting and sensor nodes within the area, generating the random nodes can be done as in equations 1 and 2:

$$NodesCoord(i,x) = (rand(\ \ ) * width) \tag{1}$$
$$NodesCoord(i,y) = (rand(\ \ ) * width) \tag{2}$$

where i represents the i^{th} node, x and y represents the coordinates and *width* is the width of the network.

2. Data collection: During this phase, the information about the diver's statusis aggregated from his WBSN, also information about the time, the diver'slocation and the destination location. This information is encapsulated and sent using the sink node over a cellular network to the diver's serving node.

3. Data processing: In this phase, the serving unit relieves the diver's packet, and searches if there is a suiTable route established previously, if so, it responds to the diver's with the route. Otherwise, multiple paths between the source and destination are established and the best path is chosen. For the shortest path approach, the best route is the one with minimized distance, calculating the distance of the path can be done as in Eq. (3):

$$ShortestPath = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{3}$$

where x_1 and y_1 are used to represent the coordinates of the source node, x_2 and y_2 are used to represent the coordinates of distance node.

For our proposed model URSD, the best path is the one with highest number of nodes and reasonable path distance, calculating the distance in URSD follows the following steps:

1. First, the distance between the source and destination node is calculated using the shortest path as in Eq. (3).

2. Then, the distance between the nodes that exist in the path and the other sensor nodes in network is calculated, but first, the slope of the path must be calculated as in Eq. (4).

$$Slope = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{4}$$

where x represents the source node and y is the distance node, then after computing the slope value, we compute the distance between all the nodes and their corresponding point on the slope, to find the pointsof the slope we use the Eq. (5).

$$y^i = slope * \left(x_1^i - x_2^i\right) + y_1 \tag{5}$$

Where y^i represents the y_2 coordinates of the i^{th} point on the slope, and x^i represents the coordinates of the i^{th} point on the slope, and the final step is to check if the distance between the sensor nodes and its corresponding point on the slope is less than the accepted radius then it is taken, otherwise it is ignored. Thus, the distance of the URSD model can be computed as in Eq. (6):

$$Distance_{URSD} = shortestPath + distance(accepted_{nodes} + points_{slope}) \tag{6}$$

As can be seen in Fig. 6, while the diver moves from visiting node 1 to visiting node 3, it faces sensor node A and C, which according to our approach it lies within the accepted radius, while node B, doesn't lie within the accepted radius and thus rejected, which in total implies 2 sensor nodes within the path. Following the psedu code of the URSD implementation.

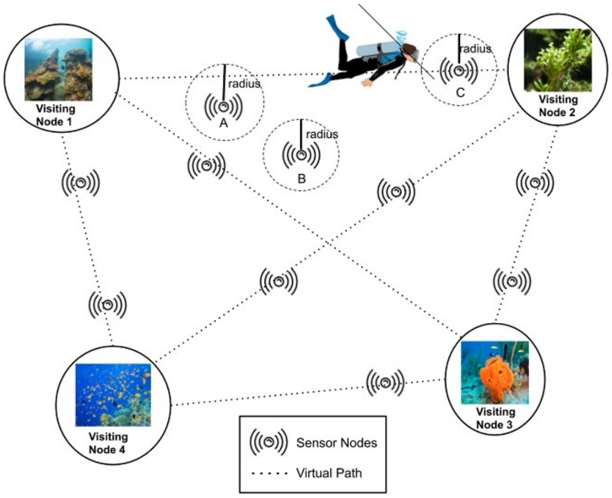

Fig. 6. URSD model

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1. Initializing main parameters
2. Initialize network topology with defined height and width
3. for  i = 1 to numberOfSensorNodes
   initialize i random sensor nodes
4. for j = 1 to numberOfVisitingNodes
   initialize j random visiting nodes
5. for k = 1 to numberOfTrips
   initialize k random source - distance trips
6. for x = 1 to numbeOfTrips
    find shortest path for each of the generated x trips using following     equation:
        $ShortestPath = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$
   find slope of the line of the trip using the following equation:
        $Slope = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$
    for k = 1 to numberOfSensorNodes
    find distance between all k nodes and slope line
    check which nodes rely within the accepted radius (cross the slope)
    add distance to the accepted new nodes to the trip distance
    find new distance of the trip by adding distance of new accepted nodes

7. end
```

4. Path generation and evaluation: Finally, the best path is sent back to the diver that is the best covered with sensor nodes and that would preserve hishealth status in the best case.

3.4 Simulation environment and setup

URSD is simulated and compared to the shortest path algorithm using a simulator built using Matlab R2017a, the simulator contains module that generate thenetwork topology, which consists of visiting nodes that are generated randomly and distributed among the diving space area, these nodes are linked to each otherusing virtual paths, the module is described in section 3.1. The proposed simulator, the sensor nodes are randomly distributed along these paths.

For creating the architecture, another module sends the packet of the user's information, receives the packet and generates the best path as described previously in section 3.2. Finally, the last step is to compute theshortest path and compare the results to it.

On a computer running the Windows 7 Professional 64-bit operating system, an Intel(R) Core(TM) i7-8550U CPU, and 8 GB of RAM memory, all simulation experiments are carried out. The parameters needed to configure the URSD simulator are listed in Table 2.

Table 2
Parameters setup

Parameter	Value
Number of underwater visiting nodes	35
Number of underwater sensor nodes	50
Range of sensor nodes (Vasilescu et al., 2005)	25 meters
Speed of diver	100 m
Close vicinity	50

4. Simulation results

For evaluating URSD simulator and comparing it to the shortest path approach, three different topologies have been generated, each with different area (width and height) (200*m* x 200*m*, 300*m* x 300*m* and 500*m* x 500*m*) and will becalled topology A, topology B and topology C respectively, and in each topologyfifty random source-destination trips have been generated, and an average of the fifty trips for each run has been taken as a final result to be evaluated. Since the main objective of URSD is to route the diver within the path that has the greatest number of sensor nodes, it is expected that it will has more nodes when compared to the shortest path, while taking the diving time and distance also in consideration. And ensuring that the diver remains connected as much as possible.Thus, the experiments will ran 50 time for each topology and the results will be divided into three main categories:

- Number of sensor nodes
- Distance of diving
- Duration of diving

4.1. Number of sensor nodes

1. Topology A

The goal of this experiment is to increase the number of sensor nodes in thediving trip as much as possible. The first experiment for the first topology with 200m width and 200m height, had an average number of sensor nodes8 and 16 for shortest path and URSD respectively. Fig. 7 ensures that the URSD had the greatest number of sensor nodes compared to the shortest path in most of the trips, since it aims at finding the best path that ensures the highest existence of sensor nodes, to be able to keep tracking the diver's location and health status during the diving period. It's also noticeable that with our proposed model, the number of sensor nodes are doubled up in most trips.

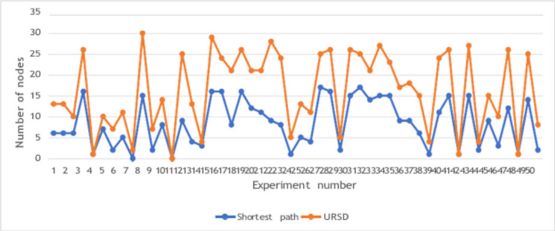

Fig. 7. Topology A: Number of Sensor Nodes distributed among the selected path

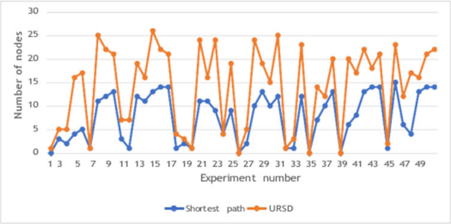

Fig. 8. Topology B: Number of Sensor Nodes distributed among the selected path

2. Topology B

For the second topology that has 300m width and 300m height, fifty random trips were also generated, and Fig. 8 represents the results with an average of 6 and 11 sensor nodes for shortest path and URSD respectively.Which means that this experiment also showed a higher number of sensor nodes for our proposed model. We might notice that with increasing the area of the topology; the average number of sensor nodes decreased, this can be justified since the splay between nodes increases proportionally to the area.

3. Topology C

Topology C is the largest one, with 500m width and 500m height, it was picked to evaluate the performance in large areas. As seen by Fig. 9 we expanded the area of the diving space, the efficiency of the routing as decreased with an average of 3 and 6 sensor n6odes for shortest path and URSD respectively. Such results can lead to a certain conclusion that with increasing the diving area the number of sensor nodes should alsobe increased. Table 3 describes a summary of the performance in regards to the average number of sensor nodes of both models in the three topologies.

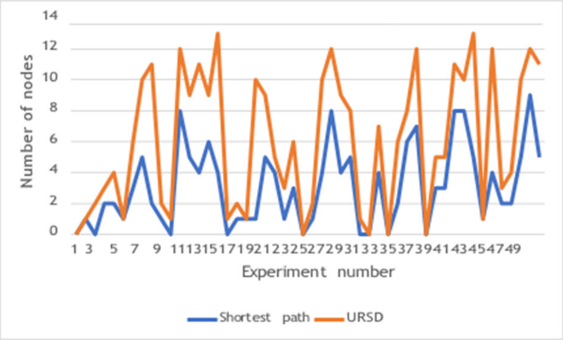

Fig. 9. Topology C: Number of Sensor Nodes distributed among the selected path

Table 3
Average number of sensor nodes

	Shortest path	URSD
Topology A	8	**16**
Topology B	6	**11**
Topology C	3	**6**

4.1. Distance of diving

1. Topology A

Although the distance has been taken into consideration in the URSD approach, it is still expected that the shortest path performs better in terms of distance. Since the main goal of the shortest path is to route the diver with the shortest route regardless of connectivity. Fig. 10 shows that the average path distance of URSD is longer than the shortest path in most of the trips,but it is also considerable that in most of the trips the distance of both approaches is very close. The average diving distance of both approaches are 8.93m and 200.65 for shortest path and URSD respectively. Such results might be justified by the fact that for a diver it is more important tobe monitored during the diving time rather than diving for shorter paths. In contrast, diving for the longest path might let him see and explore more under-water resources.

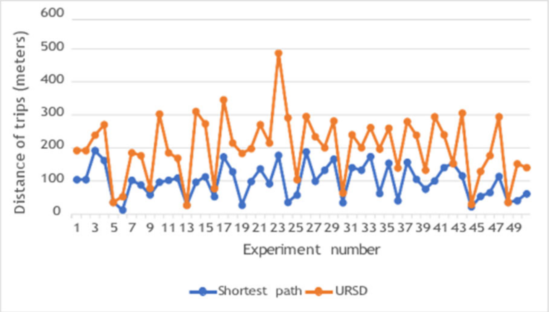

Fig. 10. Topology A: Distance of trips (meters)

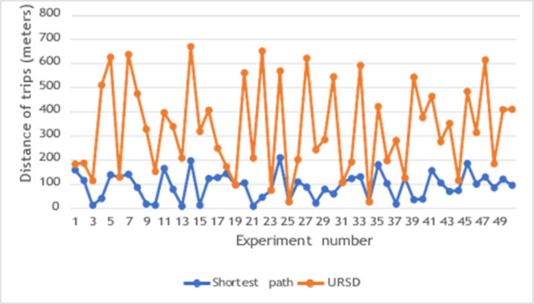

Fig. 11. Topology B: Distance of trips (meters)

2. Topology B

In topology B, the shortest path also performed better in terms of distance of trips, but also URSD had competing performance. The results showed an average distance of 93.47m and 333.54m for shortest path and URSD respectively. In Fig. 11 the total trips' distance for the 50 experiments for both approaches is shown.

3. Topology C

For the largest topology C, we can see slight difference between the two approaches, shortest path outcomes URSD but with a very slight difference. Which can be acceptable when compared to the improved results of URSDin finding optimal path with best connectivity. (See Fig. 12).

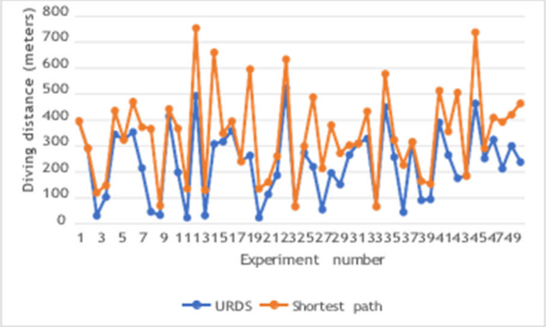

Fig. 12. Topology C: Distance of trips (meters)

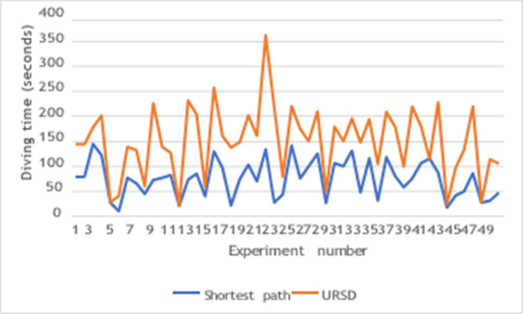

Fig. 13. Topology A: Duration of trips (seconds)

4.1. Duration of diving

1. Topology A

For topology A, both approaches had reasonable diving time not exceeding 400 seconds (6.66 minutes) for the longest trip. Which can be justified by the small diving area in this topology. Also, if we compare both approaches performance; we'll find that shortest path outperformed URSD but with a reasonable difference in most of the trips. The average diving time for shortest path and URSD was 73.83 and 149.75 secondsrespectively, which is less than 3 minutes for both approaches. Figure 13 represents the duration time of the fifty randomly-generated trips.

2. Topology B

For topology B, the area of diving is enlarged and the difference of diving period between both approaches has also been maximized, the average diving time for shortest path and URSD was 69.76 and 248.85 seconds respectively, which is less than 5 minutes for both approaches. Although the shortest path performed well in terms of duration, we should also mention than the difference between both approaches is on the account of the efficiency of finding the optimal path with increased number of sensor nodes. (See Fig. 14).

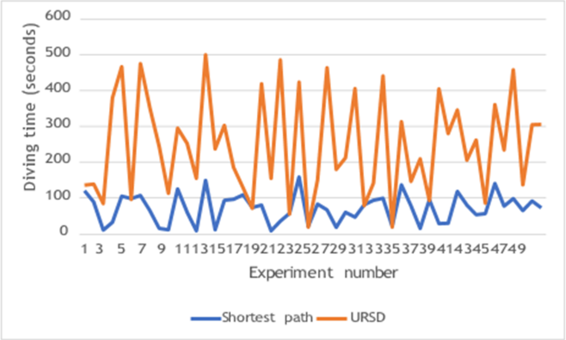

Fig. 14. Topology B: Duration of trips (seconds)

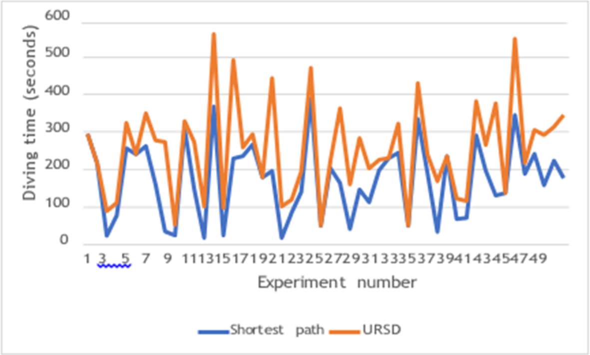

Fig. 15. Topology C: Duration of trips (seconds)

3. Topology C

Last topology with largest area, the difference between both approaches have been minimized again here. With average diving time for shortest path and URSD 174.40 and 256.29 seconds respectively, the deference is not noticeable in this topology and can be ignored if we are looking at the efficiency of the approach. (See Fig. 15).

5. Conclusion

Enhancing and improving the tourists' experience plays an essential role in the growth of the tourism sector, where tourists with good experience are more probable to return than others. Thus, in this paper we proposed a new approach that can enhance the underwater diving experience. The proposed approach aims at routing the diver in underwater environment to visit different cultural and natural resources, also the approach aims at monitoring and tracking several vital indicators of the diver and alerting him in case of undesirable condition happened. Simulation experiments were conducted to evaluate URSD approach and compare it to the shortest path, and it is observed that the URSD can route the diver in underwater environment within paths that have larger number of nodes with a slightly reasonable longer diving period (less than two minutes) for the largest diving area. Furthermore, it can be concluded that the URSD approach can enhance and improve the divers experience and can help them mitigate underwater risks.

References

Ahmad, I., Rahman, T., Zeb, A., Khan, I., Othman, M. T. B., & Hamam, H. (2022). Cooperative energy-efficient routing protocol for underwater wireless sensor networks. *Sensors*, *22*(18), 6945.

Almobaideen, W., Krayshan, R., Allan, M., & Saadeh, M. (2017). Internet of Things: Geographical Routing based on healthcare centers vicinity for mobile smart tourism destination. *Technological Forecasting and Social Change*, *123*, 342-350.

Almobaideen, W., Saadeh, M., Al-Anbaki, N., Zaghloul, R., & Aladwan, A. (2015, September). Geographical route selection based on user public transportation and service preferences. In *2015 9th International Conference on Next Generation Mobile Applications, Services and Technologies* (pp. 144-149). IEEE.

Aravind, K., & Maddikunta, P. K. R. (2022). Multiobjectives for optimal geographic routing in IoT health care system. *Complexity*, *2022*, 1-15.

Arianmehr, S., & Jabraeil Jamali, M. A. (2020). HybTGR: a hybrid routing protocol based on topological and geographical information in vehicular ad hoc networks. *Journal of Ambient Intelligence and Humanized Computing*, *11*, 1683-1695.

Buhalis, D., & Law, R. (2008). Progress in information technology and tourism management: 20 years on and 10 years after the Internet—The state of eTourism research. *Tourism management*, *29*(4), 609-623.

Chen, J., Wu, X., & Chen, G. (2008, October). REBAR: a reliable and energy balanced routing algorithm for UWSNs. In *2008 Seventh international Conference on grid and cooperative computing* (pp. 349-355). IEEE.

Claudet, J., Lenfant, P., & Schrimm, M. (2010). Snorkelers impact on fish communities and algae in a temperate marine protected area. *Biodiversity and Conservation*, *19*, 1649-1658.

Delgado, J. P. (2011). The impact on and opportunities arising from tourism to submerged sites. In *Scientific Colloquium on Factors Impacting Underwater Cultural Heritage* (p. 54).

Farooq, U., Ullah, M., Khan, R. U., Alharbi, A., Uddin, M. I., Haq, M. I. U., & Alosaimi, W. (2021). IDBR: IoT enabled depth base routing method for underwater wireless sensor network. *Journal of Sensors*, *2021*, 1-8.

Glaesser, D., Kester, J., Paulose, H., Alizadeh, A., & Valentin, B. (2017). Global travel patterns: an overview. *Journal of travel medicine*, *24*(4), tax007.

Ismail, M., Islam, M., Ahmad, I., Khan, F. A., Qazi, A. B., Khan, Z. H., ... & Al-Rakhami, M. (2020). Reliable path selection and opportunistic routing protocol for underwater wireless sensor networks. *IEEE Access*, *8*, 100346-100364.

Jabri, R., & Manaseer, S. (2018). Using a New Routing Metric in Paths Discovery Process for MAODV. *Open Access Library Journal*, *5*(4), 1-11.

Jassim, M., & Almobaideen, W. (2013). A segment-based tree traversal algorithm for enhancing data gathering in wireless sensor networks. In *Proceedings of the 2013 International Conference on Electronics, Signal Processing and Communication Systems* (pp. 154-161). INASE.

Jornet, J. M., Stojanovic, M., & Zorzi, M. (2008, September). Focused beam routing protocol for underwater acoustic networks. In *Proceedings of the 3rd International Workshop on Underwater Networks* (pp. 75-82).

Khasawneh, A. M., Kaiwartya, O., Abualigah, L. M., & Lloret, J. (2020). Green computing in underwater wireless sensor networks pressure centric energy modeling. *IEEE Systems Journal*, *14*(4), 4735-4745.

Lee, U., Wang, P., Noh, Y., Vieira, L. F., Gerla, M., & Cui, J. H. (2010, March). Pressure routing for underwater sensor networks. In *2010 Proceedings IEEE INFOCOM* (pp. 1-9). IEEE.

Mahato, D. P., Sandhu, J. K., Gitanshu, & Dutta, K. (2020, January). Distributed routing for underwater wireless sensor networks using cuckoo search-ant colony optimization. In *Proceedings of the 21st International Conference on Distributed Computing and Networking* (pp. 1-5).

Moshref, M., Al-Sayyed, R., & Al-Sharaeh, S. (2021). An enhanced multi-objective non-dominated sorting genetic routing algorithm for improving the QoS in wireless sensor networks. *IEEE Access*, *9*, 149176-149195.

Moshref, M., Al-Sayyed, R., & Al-Sharaeh, S. (2022). Improving the quality of service in wireless sensor networks using an enhanced routing genetic protocol for four objectives. *Indonesian Journal of Electrical Engineering and Computer Science*, *26*(2), 1182-1196.

Nicolaou, N., See, A., Xie, P., Cui, J. H., & Maggiorini, D. (2007, June). Improving the robustness of location-based routing for underwater sensor networks. In *Oceans 2007-Europe* (pp. 1-6). IEEE.

Paraskevas, A., & Buhalis, D. (2002). Outsourcing IT for small hotels: The opportunities and challenges of using application service providers. *Cornell Hotel and Restaurant Administration Quarterly*, *43*(2), 27-39.

Porter, M. E. (2001). Michael; ilustraciones Gibbs. *Strategy and the Internet*, *63*, 78.

Rangel, M. O., Pita, C. B., Gonçalves, J. M. S., Oliveira, F., Costa, C., & Erzini, K. (2014). Developing self-guided scuba dive routes in the Algarve (Portugal) and analysing visitors' perceptions. *Marine Policy*, *45*, 194-203.

Shakila, R., & Paramasivan, B. (2020). Withdrawn: Performance analysis of submarine detection in underwater wireless sensor networks for naval application.103293.

Stiller, C., Roß, F., & Witte, H. (2006). A handheld/server based assistance system for tourists with special needs. *Database*, *111*(111), 111.

Su, H., Wang, Z., & An, S. (2013). MAEB: Routing protocol for iot healthcare.

Vasilescu, I., Kotay, K., Rus, D., Dunbabin, M., & Corke, P. (2005, November). Data collection, storage, and retrieval with an underwater sensor network. In *Proceedings of the 3rd international conference on Embedded networked sensor systems* (pp. 154-165).

Xia, F., Yang, L. T., Wang, L., & Vinel, A. (2012). Internet of things. *International journal of communication systems*, *25*(9), 1101.

Xie, P., Cui, J. H., & Lao, L. (2006). VBF: Vector-based forwarding protocol for underwater sensor networks. In *NETWORKING 2006. Networking Technologies, Services, and Protocols; Performance of Computer and Communication Networks; Mobile and Wireless Communications Systems: 5th International IFIP-TC6 Networking Conference, Coimbra, Portugal, May 15-19, 2006. Proceedings 5* (pp. 1216-1221). Springer Berlin Heidelberg.Yan, H., Shi, Z.J., Cui, J.H., 2008. Dbr: depth-based routing for underwater sensor networks, in: International conference on research in networking, Springer. pp.72–86.

Yang, G., Dai, L., Si, G., Wang, S., & Wang, S. (2019). Challenges and security issues in underwater wireless sensor networks. *Procedia Computer Science*, *147*, 210-216.

Yoo, H. J., Cho, N., & Yoo, J. (2009, September). Low energy wearable body-sensor-network. In *2009 Annual International Conference of the IEEE Engineering in Medicine and Biology Society* (pp. 3209-3212). IEEE.