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A Survey of Routing Protocols for Underwater Wireless Sensor Networks

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***Abstract*—Advancement in network sensor technology has contributed a lot towards a better society and has opened new avenues of research. Underwater Wireless Sensor Networks (UWSN) attracts a lot of attention of the researchers, due to its military applications, environmental monitoring and prediction of natural disaster. Vibrant underwater weather conditions and node movement make designing of an efficient routing protocol for underwater wireless sensor network a challenging task. This paper represents a comprehensive survey and analysis of existing routing protocols for underwater wireless sensor networks. The main contribution of this paper includes classification of the existing routing techniques based on the routing mechanisms. It presents comparison and analysis of the existing routing techniques based on various important features and highlights the major issues that are the obstacles for designing of an efficient routing protocol for UWSN.**

***Keywords*—Underwater Wireless Sensor Networks; Wireless Sensor Networks**

I. Introduction

The idea of underwater communication is not a new one. In World War II, an underwater telephone network was used by US military to communicate with submarines. Components of underwater wireless sensor networks include sensors, vehicle and sink nodes that are set up to collaborate and communicate for performing various tasks. In UWSN the communication is carried out using acoustic waves or combination of acoustic and radio waves. The acoustic communication has some limitations such as low bandwidth and high error rates. Whereas the advantages include longer communication range and it is less affected by noise.

It is considered as a reliable technology for deploying underwater wireless sensor networks. UWSN systems are imagined as self-configured applications. For example, cabled ocean observatories are built on submarine cables to deploy an extensive fiber-optic network of sensors such as cameras, wave sensors and seismometers covering miles of ocean floor. Recently sensors technology has progressed enough to enable the deployment of UWSN successfully. Generally, but not always the UWSN is divided into clusters where each cluster has its own sink which is connected to sensor nodes. The connection is through the direct path or using multiple hops. Signals from sink node are sent to the earth stations through a vertical link. The surface station handles multiple communications with the help of transceivers [1], [2].

There are numerous applications of UWSN, such as surveillance, prediction of natural disasters, oil and mineral exploration, military applications, seismic observations, monitoring of underwater pipelines and support for swarm underwater robots [3].

Other applications of UWSN includes surveillance, preventing natural climate changes, oil and mineral exploration etc., and challenges of UWSN include delay, Infeasibility of deployment in different conditions and costly network equipment [4].

Sample network environment in UWSN is illustrated in the following Fig. 1. It shows the general structure of the UWSN, various deployment methods of UWSNs are represented such as cabled sea floors and acoustic communication links.

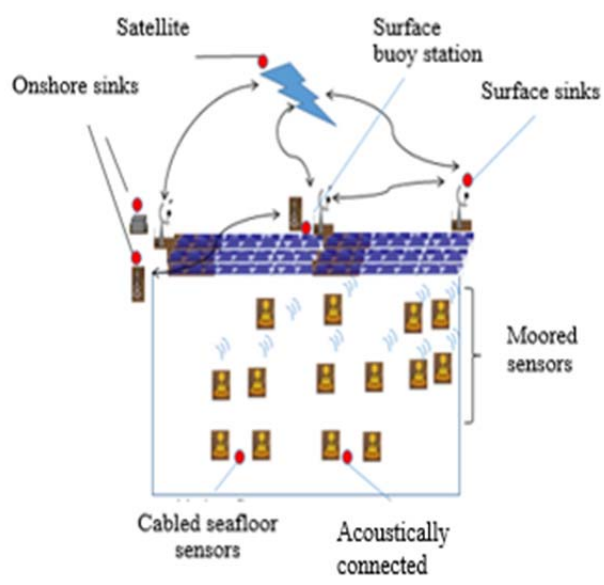

Fig. 1. UWSNs architecture.

The novel aspect of this paper is the state-of-the-art analysis and overview of the existing routing protocols for UWSN. Each routing technique is explained with necessary details for the ease of understanding for the reader. Rest of this paper is organized as follows. Section II presents the Related work. In Section III Classification of the UWSNs Routing protocols is presented. Section IV comprises of the details of existing routing protocols for UWSN. Section V contains the comparative analysis of the routing protocols discussed in the previous section. Finally, the conclusion is presented along with suggestions for the future work.

II. Related Work

Thumpi et al., [4] present a survey of existing routing protocols for under water wireless sensor networks. The authors elaborate the ten widely known types of routing protocols for UWSN i.e., Vector-Based, Robustness Improved Location, Depth-Based Routing, Hop-by-Hop Dynamic Addressing, Focused Beam Routing, PS-free, a low Propagation delay Multi-Path and Pressure Routing Protocol. They also express comparison of these protocols with advantages and disadvantages of each.

Another quite comprehensive survey presents various aspects of UWSN routing protocols in [5]. In this paper WSN routing protocols in various areas are described in detail including UWSN. It presents a comparison of selected UWSN routing protocols in terms of forwarding mechanism, location services and design goals such as density and mobility etc.

A review of UWSNs protocols is presented by [6]. It presents UWSNs applications, advantages and disadvantages. UWSNs protocols are compared in terms of their basic characteristics such as mobility, energy efficiency and location information. A comparative analysis of for evaluation of different UWSN protocols is presented in [7].

Routing protocols such as DBR QLEAR and VBR are explained for an understanding of the reader and limitations of these protocols are elaborated. It also presents UWSNs applications, advantages and disadvantages. UWSNs protocols are compared in terms of their basic characteristics such as mobility, energy efficiency and location information

The novelty of our work lies in the classification of the routing protocols based on the routing mechanism and the comparison of the routing techniques is described from diverse perspectives and on broader scales.

III. Classification of Uwsns Routing Protocols

Routing is a challenging task in UWSN, movement of the nodes, high noise ratio, and dynamic underwater weather conditions makes it more complex. Different routing techniques introduced for routing in UWSN are classified in this section. We categorise the routing techniques into following categories i.e. Flooding based, Location based, Power aware, Depth based and Hybrid routing techniques. In the upcoming sections. Fig. 2 presents the classification of the routing protocols for UWSNs.

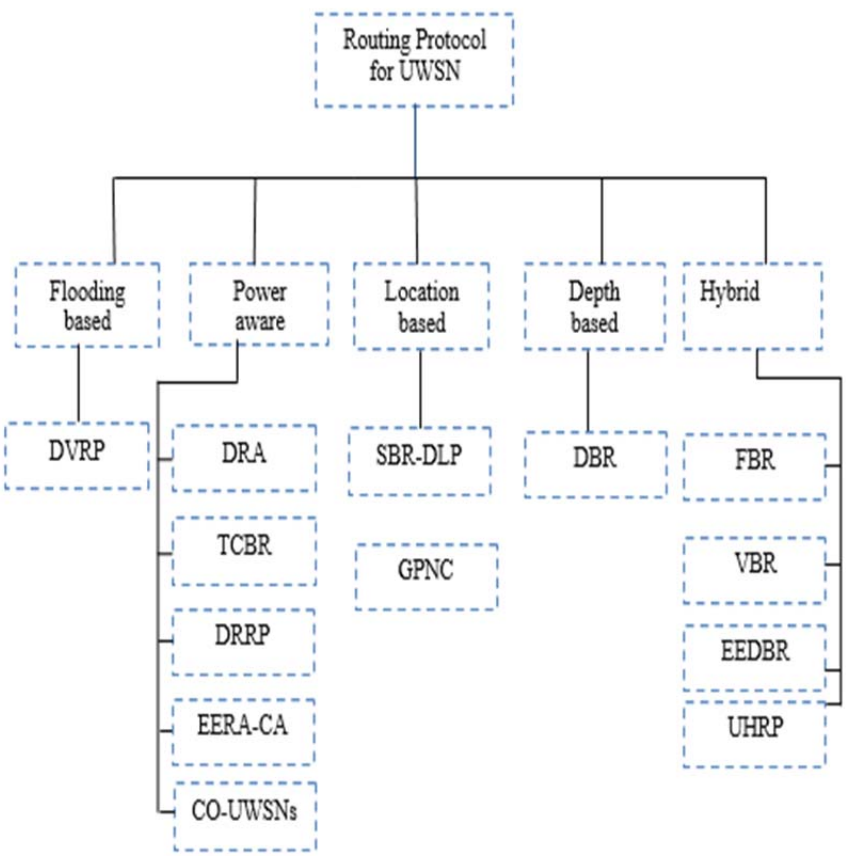

Fig. 2. Classification of the routing protocol.

Broadcast routing mechanism is used in flooding based techniques. The information is broadcast from the sender node to intermediate nodes until it is delivered to the intended destination node. In power aware routing mechanism, energy information is the basic unit for the selection of the forwarding node to transfer data and control messages. Network lifetime is enhanced by better utilization of energy of the sensor nodes.

Depth based protocols consider the depth information of the participating nodes to select the forwarding node along with other factors. Location based geographic protocols use location information of the nodes through GPS service.

Hybrid protocols use a combination of the above-stated routing techniques for achieving better results in different application scenarios.

IV. ROUTING PROTOCOLS FOR UWSNS

A. *Flooding Based*

Diagonal and Vertical Routing (DVRP):

DVRP uses broadcast routing mechanism. Zone angle towards the surface sink is used to reduce the broadcast overhead. Low energy consumption is attained to increase the life time of the network [8]. Flooding is confined by selecting the route with the vertical direction and lowest angle towards the sink.

Fig. 3 depicts that node O and D lie on the pie at angle zero. Vertical and lower angle route is selected for forwarding the packet. DVRP presents good results in terms of energy efficiency and an end to end data delivery. In special cases where no vertical angle is found, it becomes difficult to find the best possible and costs efficient route.

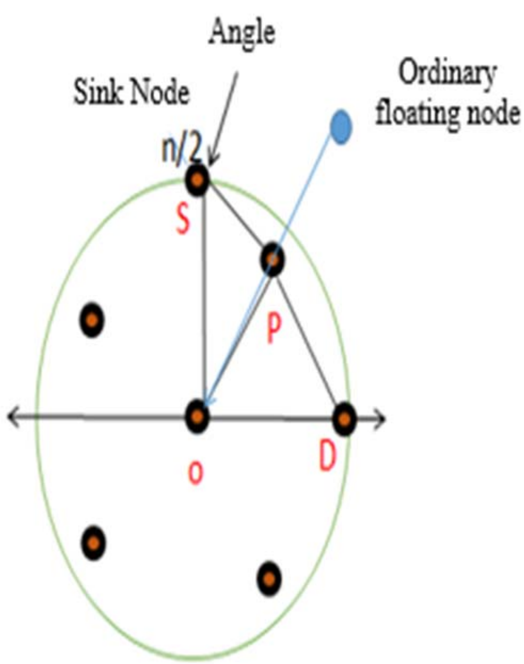

Fig. 3. Forwarding mechanism of DVRP.

B. *Power Aware*

Distributed Routing Algorithm (DRA):

DRA introduces two routing algorithms for delay-insensitive and delay-sensitive applications. In delay insensitive routing algorithm each node can select the best next hope for forwarding the packet and focuses on low energy consumption. It applies packet train concept and the whole train is acknowledged with a single reply.

In this routing scheme lost or missing packets are retransmitted. Delay sensitive applications require low error rate and efficient communication. Delay sensitive algorithm considers these issues and shows good results under the assumed conditions. One drawback is small network is used for simulation. Experiments should be performed on larger scale network for better evaluation of the performance of DRA [9].

Temporary Cluster Based Routing (TCBR)

TCBR routing technique [10] is designed to focus on balancing the energy consumption among all the nodes. There are two types of nodes in TCBR network, ordinary nodes and special nodes. Ordinary nodes are simple sensor nodes which are responsible for sensing and forwarding the data to the special nodes. Special nodes collect data from ordinary nodes and forward it towards the sink. Special nodes broadcast hello packet to neighbor nodes of 4 hops after specific time interval.

Ordinary nodes have less processing capabilities. A small percentage of the overall nodes in the network is selected as special nodes which reduce the overall cost. TCBR protocol has some draw backs, such as delay caused by indirect communication. In the case of traffic overhead the processing capabilities of special nodes will be tested.

Dynamically Reconfigurable Routing Protocol of UWSN (DRRP):

DRRP [11] is energy efficient routing protocol. It transmits data packets only in directed areas. Localization information is not required in this routing technique and nodes keep track of the neighbor nodes delicately.

An undelivered packet is retransmitted to the backward path until it is received by a node which can forward it to its intended destination. Sink node handles replacement of the missing nodes according to the information gained through the path followed by the packet. DRRP protocol requires intelligent sensor nodes to keep the record of the movement and location of neighbor nodes. It adds extra overhead and increases the cost.

Energy Efficient Routing Algorithm (EERA):

Energy efficient routing algorithm focuses on to enhance network life time. In EERA-CA special nodes concept is introduced that act as cluster heads. Cluster head nodes are responsible for forwarding data received by ordinary sensor nodes.

Ordinary nodes can communicate with special nodes directly or using intermediate links. EERA-CA network is in cost efficient. If no best route is found initially it can cause latency in route discovery. Fig. 4 presents the architecture of EERA-CA.

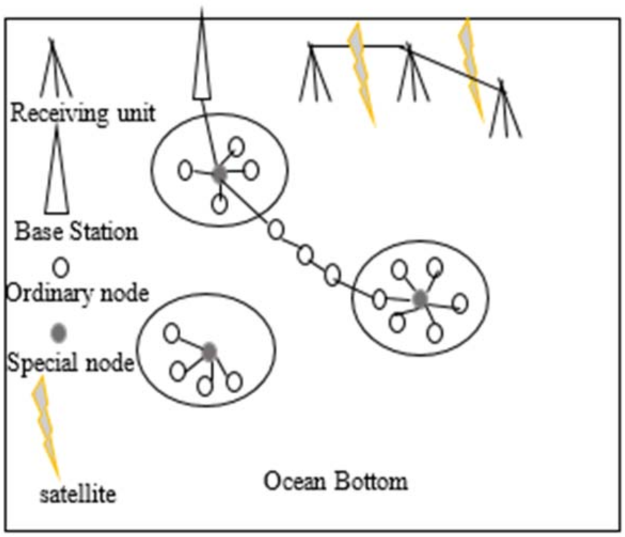

Fig. 4. Architecture of EERA-CA.

Cooperative Energy-Efficient Protocol for Underwater WSNs (Co-UWSNs):

In Co-UWSNs the idea of cooperation among nodes is used. In this scheme sender node shares its data packet with neighbor nodes who are potential to transfer it to its destination. At every joining point of two nodes one relay node is set up. Relay point node receives the packet, amplifies it and forwards it to the sink. Co-UWSNs provide high data delivery rate and lower end to end delay.

C. Location Based

Sector-based Routing with Destination Location Prediction (SBR-DLP):

SBR-DLP is a location based routing protocol. Each node knows its location and also the pre-planned movement of the destination node. Sender node can predict the location of the destination node based on the pre-planned movement. SBR-DLP is particularly designed for mobile nodes [12].

Sender node first broadcasts message chk_ngb. It includes location information of the sender and sector number where the node is currently located. Nodes which is closest to the destination within the same sector sends a reply of the chk_ngb message. It is selected as a forwarding node.

Fig. 5 presents the routing mechanism of SBR-DLP. Overall network is divided into various sectors. In ideal case traffic overhead is minimized by predicting the destination node movement. In actual network environment movement of nodes may differ to the predicted pre-planned estimates.

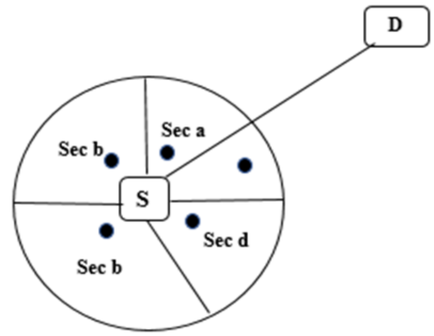

Fig. 5. Network architecture of SBR-DLP.

Geographic Routing Protocol Based on Partial Network Coding for UWSNs (GPNC):

GPNC is an efficient and reliable geographic routing protocol based on partial network coding for UWSN [13]. GPNC protocol encodes data packets and uses the location information of nodes to forward data packets towards the sink.

When a node wants to forward a packet to the sink it first encodes the packet using partial network encoding, then the closest node to the destination is selected as a next hope. GPNC protocol is to designed to decrease the network delays and reduce the cost in terms of energy consumption by bringing down the rate of retransmission.

D. Depth Based

Depth based routing protocol (DBR)

DBR routing protocol does not keep a record of complete dimension and location information of nodes. The source node sends its depth information along with data packet to the intermediate node. Intermediate node compares its depth with the depth of source node, in either case node with less depth and near to the sink is selected as forwarding node [14]. DBR is cost efficient compared to other location based routing protocols. The collision must be avoided in cases when more than one node becomes equally eligible for forwarding the packet.

Fig. 6 presents the forwarding node selection scenario of DBR. Nodes n1, n2 and n3 are neighbors of one hop of the sender node S. Node n3 is deeper in depth, so it will not be considered, node n1 and n2 both are eligible for forwarding the data, n1 being more close to the sink is selected as the forwarding node.

E. Hybrid Routing Protocol

Focused Beam (FBR):

FBR [15] uses flooding based routing mechanism. Flooding is controlled using different transmission power intensity starting from the lowest transmission power. Each node in the network keeps a record of its location and location of the destination node.

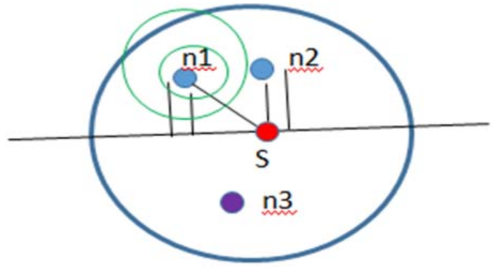

Fig. 6. Routing mechanism of DBR.

Fig. 7 presents a communication scenario in FBR, Node A wants to transmit a packet to the destination node D, it first broadcasts RTS (Request to Send) message to its neighbor nodes using the lowest transmission power. If no next hop is found, then the transmission power is amplified. The candidate nodes lie on the cone 0/2 relative to the line AD. Eligible nodes will reply to RTS. FBR is cost efficient in such scenarios where a forwarding node is found with every first RTS broadcast. If nodes move away from the angle and no node is found on the cone angle. RTS is repeated with enhanced transmission power, which is an addition to the flooding overhead.

Vector Based Forwarding (VBF):

VBF [16] is a location based routing protocol. Broadcast overhead is reduced by setting a limit on transmission range. Sender node knows the location of the destination. Routing packet in VBR contains the address of the sender, forwarding node and destination node which is usually the sink node. For successful implementation of VBR exact location information of the nodes is required.

In Fig. 8 communication scenario of VBR is shown, nodes within the forwarding vector participate in the communication.

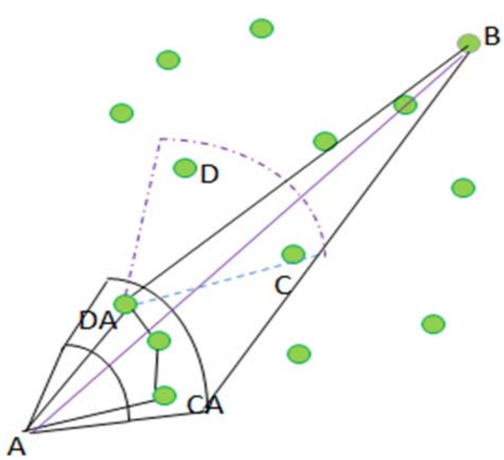

Fig. 7. Representation of FBR routing scenario.

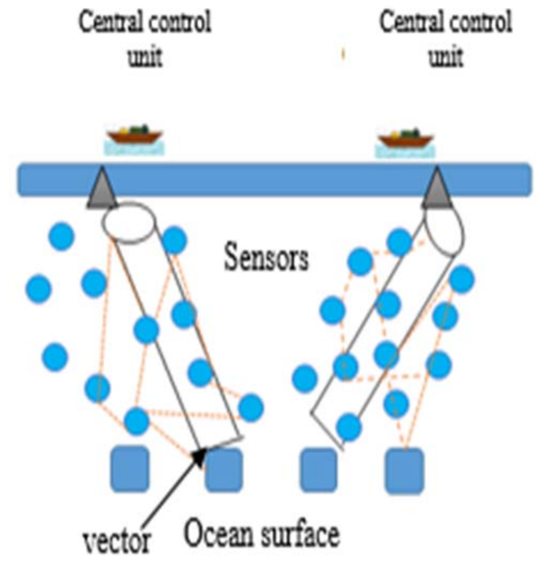

Fig. 8. Vector based routing protocol.

Energy Efficient Localization-Free Depth Based Routing Protocol (EEDBR):

EEDBR [17] is an energy efficient routing protocol. It uses energy and depth information of the nodes to select the forwarding node. Nodes update their energy status periodically if remaining energy level of a node has a huge difference with previous energy level.

It broadcasts hello packet to the neighbors of one hop to update neighbor's information. Hello packet contains the depth information of the node. In cases where nodes with same depth but different energy level are the candidates for selection as a forwarding node. In those cases, the node with high energy level is selected as a forwarding node.

Energy efficiency and long network life time is given by the EEDBR protocol. There is no significant improvement in data delivery rate of the routing protocol for which comparison is provided i.e. DBR.

Under Water Hybrid Routing Protocol (UHRP)

UHRP protocol uses flooding based and reactive routing techniques. The focus of UHRP is to reduce the flooding overhead and to enable the un-localized nodes to communicate with the sink [18].

In UHRP simple scoped flooding is used for forwarding the packet. An un-localized node is out of the range for direct communication to the sink. It first requires establishing a connection to localized node, which can forward the data packet towards the sink. UHRP uses scoped flooding to reduce the flooding overhead but in the case of unlocalized node route discovery causes extra overhead and latency.

Multi-Layered Routing Protocol (MRP)

MRP is a localization free protocol, it uses the super nodes for forwarding the data to the sink. Super nodes are equipped with high energy level and forward received packets from other nodes. MRP produces good results in terms of low energy consumption and an end to end delay. Fig. 9 presents the architecture of MRP [19].

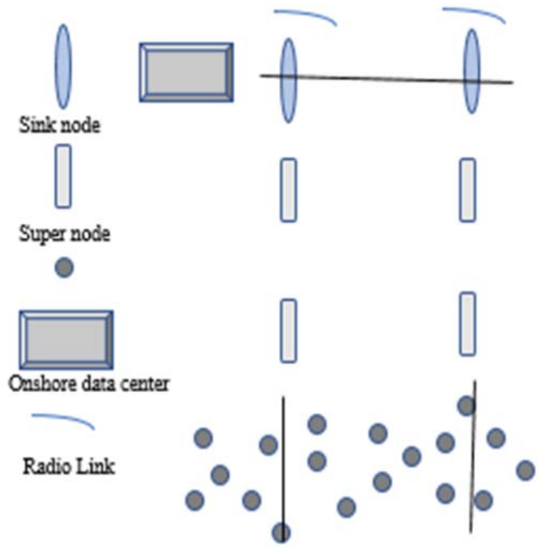

Fig. 9. Architecture of MRP.

V. Comparison and Analysis of Existing UWSNs Protocol

Overall summary and analysis of the existing routing protocols of UWSNs is presented in Table 1. The parameters considered for comparison of routing protocols include energy efficiency, overhead, state-full or state-less and advantages, disadvantages of each routing protocols. Each technique works well for a specific purpose and in a specific environment.

Whereas Hybrid routing approach is a good solution to support multiple situations and scenarios. It can help to resolve many issues of UWSNs. It can combine features of various routing protocols to customize and address the specific requirement of UWSNs application. Various research efforts have been introduced in this area since last few years few of them will be discussed here.

In [20] UWSNs protocols such as depth based constraint based are presented in detail and analysis upon various feature i.e network topology and use of control packets is presented. A similar survey in [21] presents classification of the routing protocols in following categories flooding based, multipath based, cluster based and miscellaneous protocols, it further provides the details of the protocols.

VI. Conclusion

In this research work we focus on different popular routing techniques in underwater wireless networks. Routing is a challenging task in UWSN. Various protocols are designed for different scenarios and situations. Comparative analysis of the different proposed techniques is presented as well. The routing protocols elaborated are most widely used and applicable. The detailed description of routing techniques with examples is helpful for basic understanding.

The research gaps are highlighted can work as the starting point for future research directions in designing of a routing protocol for underwater wireless sensor networks. The novel aspect of this research is that it contains the major innovations in routing protocols introduced each year from 2008 to 2016. This paper evaluates the selected routing protocols according to the above-defined parameters: efficiency, error rate scalability etc. This will help in understanding the development and evolution of UWSNs protocols in during the last 8 years.

VII. Future Work

In future work, we aim to include more recent developments in this research domain. A systematic study for classification will be performed considering other important parameters and features of the routing techniques. Seeing the rapid changes and advancement in the sensors networks technology. In future work, we also aim to describe the impact of how technological advancement has affected the design or selection of a routing protocol technique.

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TABLE I. COMPARISON OF DIFFERENT ROUTING PROTOCOLS FOR UWSNS

Routing Protocol	Approach	State Full	Energy Efficient	Overhead	Advantages	Drawbacks	Year
DBR	Depth information	No	No	Less	Less cost	Collision avoidance required	2008
FBR	Transmission power	Yes	yes	Medium	Less cost of route discovery.	Route discovery overhead increases.	2008
SBR-DLP	Flooding in neighbors	Yes	No	Medium	Reduced routing overhead.	Prediction of nodes-pre-planned movement, not a flexible approach	2009
DRA	Packet Train concept is used, Focus is on Low energy consumption.	No	Yes	Less	Low energy consumption.	Increase in no nodes can challenge the same performance result	2010
TCBR	Special nodes are used for forwarding the data packets.	No	No	Medium	Reduces cost	Overhead is increased using indirect communication	2010
VBF	Position of the node in vector decides selection of forwarding node.	Yes	No	Less	Broadcast overhead is reduced.	To acquire exact location of the nodes not an easy task.	2011
EEDBR	Data forwarding node is selected on the basis of depth and energy information.	No	yes	Medium	Low energy consumption and longer network lifetime	Data delivery rate of the protocol is very low than DBR.	2012
DVRP	Energy status, and zone angle	Yes	Yes	Medium	Energy efficient Better data delivery.	In cases of no best vertical angles,difficult to find the best possible route.	2013
UHRP	Flooding	Yes	No	Medium	Scoped flooding reduces the routing overhead.	Route discovery overhead delays route establishment process.	2014
DRRP	Directional Antenna Transmission	No	No	High	Less overhead than localization routing schemes.	Keep track of the neighbor nodes information, which is difficult.	2014
EERA-CA	Special nodes used as cluster head.	No	Yes	Medium	Longer network life,and energy efficient,low cost	If Cluster head is not able to forward the date then neighbour node are found which can create latency in route discovery.	2015 .
GNPC	Data packets are encoded using partial network coding.	No	Yes	Low	Re transmission rate is reduced which lowers the cost and energy consumption.	Encoding of data packets causes additional overhead in case of larger packets.	2015
Co-UWSN	Cooperation at node level for data delivery.	No	Yes	Medium	High data delivery, less end to end deay, longer network life time.	In few experiments transmission loss ratio is high compared to other nodes.	2015
MRP	Super nodes with high energy level are used	No	Yes	Low	Better results of data delivery and end to end delay delivery	If more than assumed number of layers is created, it affect the performance of MRP.	2015