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Review

Routing protocols based on node mobility for Underwater Wireless Sensor Network (UWSN): A survey

Mukhtiar Ahmed[a,b,*], Mazleena Salleh[a], M.Ibrahim Channa[b]

[a] Department of Computer Science, Faculty of Computing, UTM, Malaysia
[b] Department of Information Technology, Faculty of Science, QUEST, Nawabshah, Sindh, Pakistan

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ABSTRACT

Recently, the Underwater Wireless Sensor Network (UWSN) is the major research area for researchers due to its versatile applications like: tactical surveillance, seismic monitoring, assisted navigations, pollution monitoring, and many more scientific based applications. Majority numbers of researchers have introduced the routing protocols based on node mobility but still research needs improvement to design the efficient routing protocols which control the node movement. This article focuses the routing protocols based on node mobility with its classification like: vector based, depth based, clustered based, AUV based, and path based. In classification the major focus is on deployment, node mobility, data forwarding, route discovery, and route maintenance. The article also focuses the existing problems in the mobility based routing protocols. We have introduced two analysis methods one is analytical method and other is numerical simulation method. In analytical method we have compared the proposed routing protocols through architectural parameters and performance characteristics parameters. In numerical simulation analysis we presents the simulation of proposed routing protocols through packets delivery ratio and observed that addressing depth based H2-DAB routing protocol remains well performer among all other proposed routing protocols. The core ideas of this research paper will guide the researchers to further research in the field of UWSN routing protocols based on node mobility.

1. Introduction

Nowadays, resource discovery in the underwater environment has become one of the important goals to reduce dependency on land resources (Ghoreyshi et al., 2016). Due to the underwater harsh environment the discovery of application based information is complicated and costly. The examples of application based information are: tactical surveillance, seismic monitoring, assisted navigations, pollution monitoring, and many scientific based information. The researchers are engaged to retrieve the application based information through the designing of the routing protocols, the researchers have introduced majority numbers of routing protocols; some routing protocols are vector based, some are clustered based, some are geographical routing protocols, and some are path based routing protocols; but still research needs improvement due to underwater behavior and environmental conditions (Li et al., 2016). In underwater environment the RF signaling are not suitable due to long propagation and extra low frequencies; hence, acoustic signals are employed as an enabling communication medium in UWSN (Wahid and Dongkyun, 2010). The acoustic signaling also faces many challenges in underwater environment because the propagation delay of acoustic signaling is five orders of magnitude higher than radio signaling. The bandwidth of acoustic signals may also be affected due to distance, noise, and high power absorption (Akyildiz et al., 2005). The connectivity between sensor nodes may also be affected due to void regions (Chen et al., 2008). Underwater sensor nodes have limited battery power and it is complicated to recharge the battery in underwater harsh environment. The design of routing protocols also affected due to localization problem (Chen et al., 2009). The majority of the researches have used the terrestrial network methodologies which are not suitable for underwater harsh environment. The efficient research is needed for the designing of routing protocols for underwater wireless sensor network. This research article focuses the design of node mobility based routing protocols; because underwater environment supports the node mobility models due to water pressure and water current. The two famous mobility models are described in Section 2. In this research article we have classified the routing protocols based on node mobility like: vector based, depth based, clustered based, AUV based, and path based. The major contribution of this paper is as follows:

- This article focuses routing protocols based on node mobility with its designing detailed approach and issues. We have classified the

* Corresponding author at: UTM, Malaysia, Computer Science, 81310 Johar Behru, Johar Behru, Malaysia.

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routing protocols based on node mobility which is the first approach. The node mobility models show the behavior of node in underwater environment.

- This research article also focuses the analytical performance analysis for node mobility routing protocols.
- In this research article we also focus the numerical simulation performance analysis for data delivery ratio which shows that which node mobility routing protocols are better in performance.
- This article also focuses the open research issues which will guide the researcher to further research in the designing of routing protocols.

The classification of routing protocols based on node mobility is shown in Fig. 3. This article further consists on: Section 2 focuses the random walk mobility model and random way point mobility model for node movement. Section 3 is consists on proposed node mobility routing protocols with its' detailed design, data forwarding mechanisms; route discovery, route maintenance and issues faced by routing protocols. Section 4 is consists on analytical and numerical simulation based analysis of proposed routing protocols. Section 5 focuses the future challenges.

2. Node mobility models

In underwater environment the node mobility may change the topology structure with respect to water pressure and water current (Vlajic and Stevanovic, 2009; Headrick and Freitag, 2009; Cheng et al., 2009; Wang et al., 2006; Pompili et al., 2006). Majority of the researchers have proposed the dynamic node movement. In generalized there are two famous mobility models are used in underwater environment as described in following sub sections.

2.1. Random Walk (RW) node mobility model

Through Random Walk (RW) model the mobile node can move in underwater environment from its current location to the new location as shown in Fig. 1. Mathematical approach of RW elaborates the direction, speed (S_{min} and S_{max}) and range factors from 0 to 2π with time interval T. If we assume that the speed is uniformly selected from pre-defined range than the *CDF* of the travelled distance during each time can be calculated as in Wang and Akyildiz (2010) and in Eq. (1).

$$\mathrm{FRW}(S) \quad = \frac{S-(S_{min}\times T)}{(S_{max}\times T)-(S_{min}\times T)} \tag{1}$$

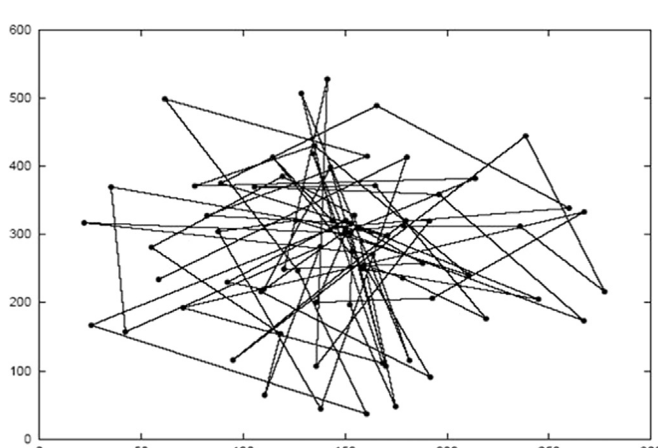

Fig. 1. Travelling pattern of mobile node through RW (Wang and Akyildiz, 2010).

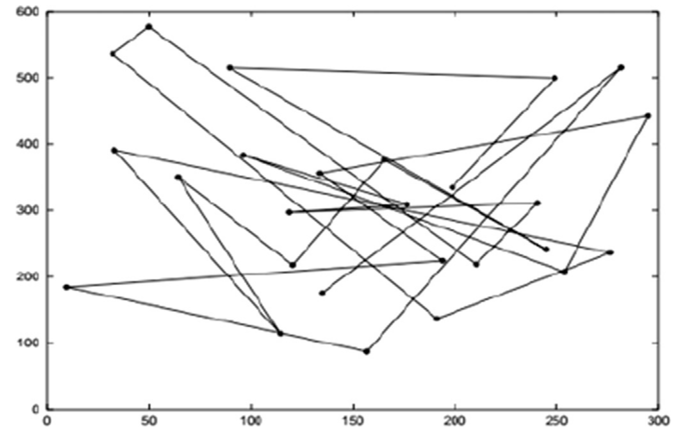

Fig. 2. Travelling pattern of mobile node through RWP (Wang and Akyildiz, 2010).

2.2. Random Way Point (RWP) mobility model

Through Random Way Pont (RWP) mobility model the mobile node can move in underwater environment from its current location to the new location with random selection of an area as shown in Fig. 2. The CDF can be calculated as in Eq. (2) (Wang and Akyildiz, 2010).

$$F^{RWP}(S) = \frac{s^2}{R_{max}^2} \tag{2}$$

In Eq. (2) the mobile node travels towards the new destination with speed of pre-defined range, the destination location uniformly distributed in the circle at the current location with radius $r \le R_{max}$.

3. Routing protocols based on node mobility

The design of an efficient and reliable routing protocols based on node mobility for underwater environment is really a challenging issue. The research communities have tried to resolve the issues of node mobility through efficient proposed routing algorithms but still research is required to design the more efficient mobility based routing algorithms. Some mobility based routing protocols' with their deployment, architecture, route discovery, route maintenance, and packets forwarding mechanism is defined in this section. The classification of routing protocols based on node mobility is mentioned in Fig. 3.

3.1. Vector based routing protocols

Vector based routing protocols based on node mobility develops the routing pipe or pipes in between source and sink nodes. The famous vector based routing protocols based on node mobility are discussed below.

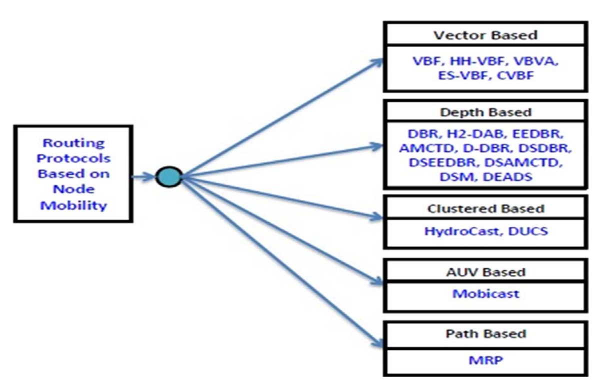

Fig. 3. Classification of routing protocols based on node mobility for UWSN.

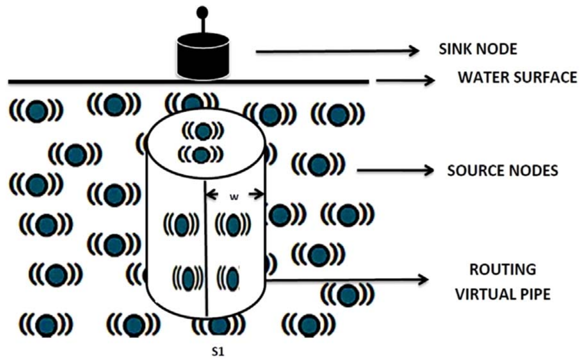

Fig. 4. An illustration of VBF (Xie et al., 2006).

3.1.1. Vector Based Forwarding (VBF)

In Xie et al. (2006) the Vector Based Forwarding (VBF) is proposed for underwater wireless sensor network. The VBF is an opportunistic geographic routing protocol based on mobility does not require the state information of the sensor nodes. VBF forwards the packets along the redundant paths to overcome the problem of packets loss. The position of source, destination, and forwarder nodes are included in the header of the data packets which is transmitted using VBF (Darehshoorzadeh and Boukerche, 2015). The virtual pipe (vector) can be created between the two nodes by using the position of source and destination; through the virtual pipe the packets can be forwarded. Consider the example shown in Fig. 4 where *S1* and *D1* are source and sink nodes, respectively. A vector of $\overrightarrow{S1D1}$ is established between source and destination through virtual pipe. In VBF only the few nodes within the virtual pipe are involved to forward the packets to the destination. Therefore VBF is stateless and receiver-based routing protocol that needs only the position of destination node. In VBF, if nodes receive the packets and are closer to the routing vector line between *S1* and *D1* than these nodes includes their position into the packet header as the forwarder and transmits the packets. In Fig. 4 the *t*, *p* and *k* nodes received the packets and are neighbors of source node, these nodes are considered as the potential forwarder nodes. Node *k;* which is not placed in the virtual pipe, discards the received packets. To define the pipe, a predefined distance threshold *w* for the closeness of nodes to the line between source and destination is considered (Darehshoorzadeh and Boukerche, 2015). In VBF the self-adaption algorithm is used to reduce the number of forwarding nodes and conserve energy. In VBF the node may be the potential forwarder or may be the potential candidate, potential candidate node waits for the period of time determined by its *desirable factor*. Desirable factor shows the nearness of the node to the previous forwarder, and the vector between *S1* and *D1*. The more desirable the node, the less time it must wait. During the wait time the node has ability to listens to the medium to see how many nodes are forwarding the same packets as the current node. When a candidate's wait time expires, it forwards its packet if the minimum desirability factor of the other forwarders is less than a predefined value. Through the node forwarding mechanism only the few nodes are involved in the packets forwarding which focuses the scalability and robustness of the VBF.

3.1.2. Issues with VBF

In a network with low density or node movement, it is possible that the number of nodes located in the virtual pipe from source to destination is few or none, which will degrade the overall performance of the network. Furthermore if in virtual pipe the forwarder nodes continuously forward the packets than they may lose their energy level and dies earlier. The VBF has not ability to recover the void region nodes, if any node goes to void region than it discards the packets.

3.1.3. Hop-by-Hop Vector Based Forwarding (HH-VBF)

In Nicolaou et al. (2007) Hop-by-Hop Vector Based Forwarding (HH-VBF) is proposed and HH-VBF is the extension of VBF (Wahid et al., 2011). HH-VBF eliminates the drawbacks of VBF. HH-VBF uses the multiple virtual pipes from source to destination nodes. In HH-VBF the vector is computed on per-hop basis i.e each forwarding node computes a vector from itself towards the sink (Khan et al., 2015).

3.1.4. Issues with HH-VBF

HH-VBF utilizes the better approach than VBF to enhance the data delivery ratio but it still face some drawbacks like: the re-computation on each hop affects the performance of HH-VBF in sparse area. Continuous use of the hop-by-hop approach increases the signaling overheads and will affect the overall network throughput. In HH-VBF the proper localization algorithm is not adapted.

3.1.5. Vector-Based Void Avoidance (VBVA)

In Xie et al. (2009) Vector-Based Void Avoidance (VBVA) routing protocol for underwater wireless sensor network is proposed. The VBVA is designed for the removal of voids in efficient way. If there are no voids in the forwarding path than the VBVA works like VBF. If voids exist on the forwarding path the VBVA adopts two methods for removal of voids one is vector-shift and other is back-pressure. In vector-shift mechanism the VBVA route the packet along the boundary of the convex void by shifting the forwarding vector of data packets. In back-pressure mechanism VBVA uses the concave void approach for reverse path to the forwarder node and then considers the vector shift mechanism to forward the packets (Xie et al., 2009).

3.1.6. Issues with VBVA

Even the VBVA used the better approach than VBF and HH-VBF but still it faces some drawbacks like: due to continuous node movement the node may away from the virtual pipe and may forward the data packets continuously and in resultant the loss of packets will occur and the energy level of that node may also be affected. The back-pressure mechanism is time consuming and in the duration of back-pressure there are so many chances that the nodes may lose their packets. No any proper algorithm for vector-shift and back-pressure mechanisms is defined.

3.1.7. Energy-Saving Vector Based Forwarding (ES-VBF)

In Wei et al. (2012) Energy-Saving Vector Based Forwarding (ES-VBF) routing protocol for underwater wireless sensor network is proposed. The ES-VBF focuses the nodes energy information to save the energy level of those nodes which are continuously forwarding the data packets within the routing pipe as in Xie et al. (2006). ES-VBF produces the better results than VBF.

3.1.8. Issues with ES-VBF

ES-VBF is not beneficial for removal of voids and if node goes to voids than obviously will drop the packets and in resultant the data delivery ratio will be degraded. The algorithm of ES-VBF is only applicable for those nodes which are in the range of the routing pipe; if node may remain away from the routing pipe and may drop the packets continuously and will exhaust soon and will reduce their energy level.

3.1.9. Cluster Vector Based Forwarding (CVBF)

In Ibrahim et al. (2014) Cluster Vector Based Forwarding (CVBF) routing protocol for underwater wireless sensor network is proposed. CVBF approach considers the sparse and dense area of the underwater to enhance the data delivery ratio and to reduce the end-to-end delay. Authors of CVBF claimed that the approach and methodology defined in CVBF is better than VBF, HH-VBF, VBVA, and ES-VBF. CVBF approach divides the whole network into the number of predefined clusters. In every cluster the member nodes are selected with their geographic location. One node at the top of each cluster is selected as a virtual sink. The rest of nodes in each cluster transmit the data packets to their respective cluster virtual sink. The routing inside each cluster follows the methodology of VBF routing protocol. CVBF defines one virtual routing pipe for each cluster. The routing pipe radius is equal to the transmission range of a node. When cluster virtual sink node will receive the data packets from the sensor nodes, it will perform an aggregation function on the received data, and transmit them towards the main sink node deployed on water surface through single-hop mechanism.

3.1.10. Issues with CVBF

Development of multiple clusters and multiple routing pipes are not so easy in underwater environment due to continuous water pressure. Due to the node movement the nodes may away from routing pipes and will drop the packets; in resultant the data delivery ratio may be affected.

3.2. Depth Based Routing

Depth based routing protocols based on node mobility refers the water depth mechanism for data transfer from source to destinations. Some researchers have assigned depth addressing mechanism from top to bottom, some researchers have divided the depth in different layers, and some researchers have divided the depth in different rectangular regions. The famous depth based routing protocols based on node mobility are described below.

3.2.1. Depth-Based Routing (DBR)

In Yan et al. (2008) the Depth Based Protocol (DBR) is proposed for underwater wireless sensor network. In data forwarding mechanism the each sensor node makes its own decision on its depth and the depth of the previous sender node. Fig. 5 focuses the data forwarding mechanism with the sender node *S* and the neighbor nodes *n1, n2* and *n3*; but the candidate forwarder nodes are *n1* and *n2* are nearer to the sink node deployed on the water surface. In count the *n1* is nearer to sink node and is preferred to forward the packets and *n2* will remain on wait state. DBR handles the resources in efficient way without requiring the full dimensional location information of sensor nodes.

3.2.2. Issues with DBR

In DBR the multiple copies of the same data packets are shared by sensor nodes which results in a high transmission delay, high volume of packets collision and energy consumption.

3.2.3. Hop-by-Hop Dynamic Addressing Based (H2-DAB)

Hop-by-Hop Dynamic Addressing Based (H2-DAB) routing protocol is multi-sink, scalable, robust and energy efficient (Ayaz and Abdullah, 2009). In H2-DAB, the dynamic addressing mechanism is used to control the node movement in underwater due to water current. H2-DAB protocol divides the water depth into different levels from surface to bottom. Some sensor nodes are deployed at the bottom level of water and some are distributed in different depth levels from bottom to surface. The addressing mechanism of H2-DAB is based from smaller depth level to the large depth level of water. The nodes which are nearer to sink have smaller addresses and when node goes to bottom level the addresses becomes larger as shown in Fig. 6. The dynamic addresses are generated by the surface sinks through *Hello packet*. Any node which receives or generates the data packets will transfer these data packets to the upper level with greedy method algorithm. When data packets are received by surface sinks the delivery is considered as successful delivery. The surface sinks are linked with the RF signaling.

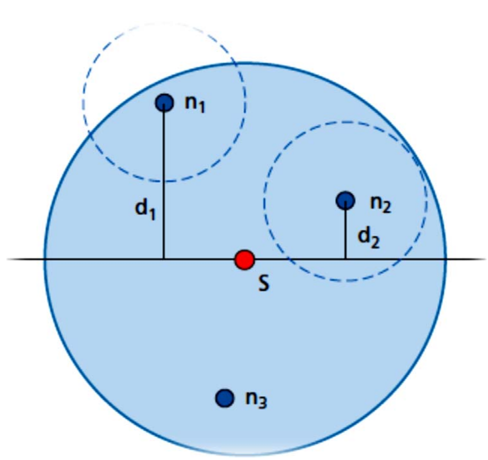

Fig. 5. Forwarding node selection in DBR (Yan et al., 2008).

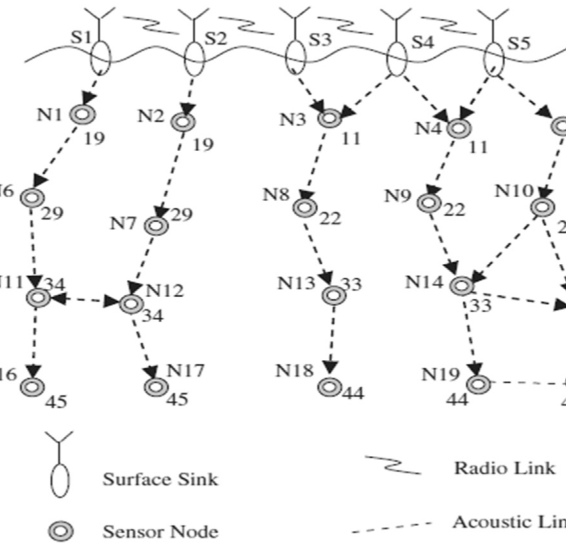

Fig. 6. An illustration of H2-DAB (Ayaz and Abdullah, 2009).

3.2.4. Issues with H2-DAB

Hop count mechanism and greedy algorithm of H2-DAB is not properly defined. The nodes nearer to the surface sink lose the energy more than the nodes deployed at bottom because they are used frequently.

3.2.5. Energy Efficient Depth Based Routing (EEDBR)

In Wahid et al. (2011) the Energy Efficient Depth Based Routing (EEDBR) protocol is proposed. EEDBR is consists of two phases; one is knowledge acquisition phase and second is data forwarding phase. EEDBR has used the simple network architecture based on ordinary sensor nodes and sink nodes; ordinary sensor nodes are deployed from top to bottom regions with acoustic signaling; whereas sink nodes are deployed on the water surface with acoustic signaling to the ordinary sensor nodes and RF signals with onshore data center. The knowledge acquisition phase will share the information to the neighbor sensor nodes with its *Hello* packet format, the fields of *Hello* packet format are: (i) Sender ID, (ii) Residual Energy, and (iii) Depth. The neighbor nodes only store smaller depth information for sensor node. The nodes which have smaller depth are only involved in data forwarding mechanism. The data forwarding phase is based on residual energy and depth. The data forwarder nodes are those nodes which are nearer to sink nodes. The selection of neighbor nodes for data forwarding mechanism is based on high residual energy. This selection criterion will balance the energy consumption between sensor nodes. The packets holding time is based on residual energy. EEDBR sets the priority list to calculate the holding time, residual energy, and sender ID, and depth parameters. The authors have focused the packets forwarding mechanism on basis of priority list.

3.2.6. Issues with EEDBR

EEDBR faces some serious issues like: in sparse area the EEDBR cannot achieve high delivery ratio due to depth calculation mechanism. The mechanism for balancing energy consumption for nodes is not properly defined by EEDBR.

3.2.7. Adaptive Mobility of Courier nodes in Threshold optimized Depth (AMCTD)

In (Jafri et al., 2013) the Adaptive of Courier nodes in Threshold optimized Depth (AMCT) is proposed. AMCTD routing protocol is divided in four sections. First section is initialization; in this section each node computes its weight with density of entire network and the movement of courier nodes has been designed. Second section is data forwarding in which the optimal forwarders are decided with prioritization of weight for neighbor nodes which are nearer to source node. Third section refers the consists on the updating weight and depth threshold adaption, the entire network assigns the weight with depth prioritization of depth and residual energy is changed according to sparse network. In the fourth section the movement of the courier nodes and variations in depth threshold of nodes have been planned to manage with network sparse.

3.2.8. Issues with AMCTD

The weight calculation mechanism of AMCTD is not so easy in sparse network because if we take care of depth the sparse calculation mechanism will be uncontrollable.

3.2.9. Directional Depth Based Routing (D-DBR)

In Diao et al. (2015) the Directional Depth Based Routing (D-DBR) is proposed. D-DBR forwards the data packets through optimal path to the sink node. D-DBR is single sink network protocol which reduces the number of hops and propagation delay. Sink node with high battery power is deployed on the surface of water and sensor nodes are deployed at depth of water. D-DBR uses the holding time function and angle holding time function for route directives. D-DBR also uses the Time of Arrival (ToA) ranging technique in data forwarding mechanism.

3.2.10. Issues with D-DBR

Like EEDBR the D-DBR also cannot achieve the high delivery data ratio in sparse area. No proper methodology is defined by D-DBR for the energy saving of ordinary sensor nodes. Void regions are the main problem in underwater environment; so the D-DBR is not efficient for removal of voids and if forwarder node die earlier due to void region the overall network throughput will be degraded.

3.2.11. Delay-Sensitive Depth Based Routing (DSDBR)

In Javaid et al. (2015) the DSDBR is proposed which is the improved version of DBR. DSDBR is based on depth information, holding time and depth threshold. In DSDBR the sensor node sensed the transmitted data within the transmission range. Source node will forward the packets to those neighbor nodes which keeps lower depth. When neighbor node will receive the data packets it will calculate the holding time and depth threshold. Depth threshold limits the depth of current and previous node during transfer of packets. Depth threshold is depends upon weight function and weight function can be calculated through network size and eligible neighbor forwarding values.

3.2.12. Issues with DSDBR

DSDBR methodology is not suitable for removal of void regions. If any node comes in the range of void regions that node will drop the packets and in resultant the packets delivery ratio will be affected.

3.2.13. Delay-Sensitive Energy Efficient Depth Based Routing (DSEEDBR)

In Javaid et al. (2015) the Delay-Sensitive Energy Efficient Depth Based Routing (DSEEDBR) is proposed. The DSEEDBR resembles with DSDBR and also is the part of the same research article; the authors have proposed the enhanced network lifetime along with delay sensitivity in EEDBR with depth calculation mechanism. In DSEEDBR the forwarder nodes calculates the transmission loss, noise loss of channel and depth difference with respect to predict time lag of the packet to be forwarded for sake of energy saving.

3.2.14. Issues with DSEEDBR

Due to the depth calculation mechanism the forwarder nodes will face the heavy burden and will die earlier; so the claim of energy efficiency for DSEEDBR is not reliable.

3.2.15. Delay-Sensitive AMCTD (DSAMCTD)

In Javaid et al. (2015) the Delay-Sensitive AMCTD (DSAMCT) is proposed. DSAMCTD depth based routing protocol refers the quick movement of the courier nodes with prioritize the distant transmissions with decreasing of network density. DSAMCTD varies the depth threshold of sensor nodes whereas sensor nodes forward the packets to the courier nodes with largely minimizing the delay factor. Nodes apply different Priority Factor (PF) formulae for data forwarding through computation of holding time with different network densities.

3.2.16. Issues with DSAMCTD

In DSAMCTD the calculation of priority factor and computation of holding time with different network densities is not an easy task due to the uncontrollable water pressure.

3.2.17. Dynamic Sink Mobility (DSM) Depth Based Routing

In Khan et al. (2015) the Dynamic Sink Mobility (DSM) Depth Based Routing is proposed. Authors claimed that the DSM maximizes the stability, throughput, and lifetime of network. In DSM the nodes are deployed randomly, the 3D underwater environment is divided into four rectangular regions with four groups of nodes. In DSM the node density can be calculated for separate region and sink moves towards the regions which keep the maximum node density. Sink node receives data from the center of region through nodes and AUVs. AUV is also responsible to move towards rest of the regions and collects the maximum data and broadcast to the movable sink node.

3.2.18. Issues with DSM

In DSM the limited area of the 3D environment of water is divided into four regions; however the water movement and pressure cannot support such kind of division with movable sink and AUVs; so the claim of authors for stability may be affected due to the underwater pressure.

3.2.19. Depth and Energy Aware Dominating Set (DEADS) Routing

In Umar et al. (2015) the Depth and Energy Aware Dominating Set (DEADS) Routing algorithm with mobility sink is proposed. DEADS proposed the Dominating Set (DS) based cooperative routing algorithm with sink mobility. The DEADS is consists of three phases: phase one is neighbor selection phase, second is DS and Cooperator Connector (CC) set formation phase, and third is threshold based data sensing phase and routing phase. In phase one the node selects the neighbor node with depth threshold and achieves their depth and residual energy. In second phase the source nodes utilizes information of first phase and select their respective DS and CC nodes for cooperative routing. In third phase the source nodes sense the data on basis of pre-defined threshold value and forward to their cooperative node nodes.

3.2.20. Issues with DEADS

In DEADS the calculation mechanism of three phases is based only on source nodes and source nodes may lost their energy level earlier and may die; so the overall network throughput may be affected.

3.3. Clustered Based Routing Protocols

Clustered based routing protocols based on node mobility refer the formation of clusters. Clustered based routing protocols develops the cluster head nodes and clustered member nodes; cluster head nodes collects the data from cluster member nodes and forwards the data to the destination nodes or sink nodes. This review article describes the two relevant clustered based routing protocols based on node mobility; these are HydroCast and DUCS which are described below.

3.3.1. Hydraulic Pressure Based Any cast Routing (HydroCast)

Hydraulic Pressure Based Any cast Routing (HydroCast) is the geographic distributed localization mobile routing protocol (Lee et al., 2010). HydroCast transfers the data packets to the surface buoys by using the measured pressure levels. HydroCast is stateless and hydraulic pressure protocol which prefers the inexpensive distributed localization. HydroCast resolves the issues of DBR routing protocol. HydroCast utilizes the depth information along with relevant cluster through pressure levels. HydroCast forms the clusters without hidden information of terminal nodes.

In HydroCast architecture the clusters are formed with the maximum progressive of those nodes which are closer to the destination nodes. The maximum progressive can be calculated through packets delivery and probability parameters. A sensor node which is the part of the cluster, the information of that node will be embedded in the packet format. In data forwarding mechanism the maximum progressive node has highest priority. The maximum progress node has shortest time-out for transmission. In HydroCast protocol the local maximum recovery method is used, which performs the limited flooding mechanism approach. In the flooding mechanism the local maximum node is called the performer node. The tetra horizontal method has also been used in the designing of this protocol; this method will identify the neighbor nodes for local maximum node. The local maximum nodes transfer the information to other local maximum nodes through limited number of hops to the destination. HydroCast has used the greedy based mechanism for removing of void regions which enhances the data delivery ratio.

3.3.2. Issues with HydroCast

In HydroCast the multiple numbers of same packets are received by sink node which enhances the extra load on network. Energy efficiency parameter is not clearly defined.

3.3.3. Distributed Underwater Clustering Scheme (DUCS)

In Domingo and Prior (2007) Distributed Underwater Clustering Scheme (DUCS) is proposed for underwater wireless sensor network. The authors claimed that DUCS is the energy-efficient and scalable routing protocol. DUCS is for long term applications (Ayaz et al., 2011). DUCS is self-organizing routing protocol which uses the distributed algorithm to divide the network into multiple clusters. The nodes are divided into *cluster-heads* and *non-cluster-heads*. One *cluster-head* makes the cluster of the *non-cluster-heads*. The *non-cluster-heads* or *cluster-member* nodes forwards the data packets to the own *cluster heads*. From *non-cluster-heads* to *cluster-head* node the transmission is single hop. When the data packets have been received by the *cluster-heads*, they use the aggregation function to forward the data packets to the other *cluster-heads* through multi-hop; finally the *cluster-heads* forwards the same data packets to the sink node which is deployed on water surface. DUCS is based on two phases one is setup phase and other is operation phase. In setup phase DUCS makes the clusters and in operation phase DUCS forwards the data packets to the sink node. *Cluster-member* nodes will coordinate the *cluster-heads* called the intra-cluster coordinates and *cluster-heads* communicates with other *cluster-heads* is called the inter-cluster coordination. In operation phase the several frames are transmitted to the *cluster-heads* from *cluster-member* nodes. The frame is composed with the series of data messages.

3.3.4. Issues with DUCS

In DUCS protocol the continuous node movement reduces the life of the clusters. In the operation phase the data delivery ratio may be reduced if the *cluster-head* moves away from the routing due to water current.

3.4. AUV Based Routing Protocols

Routing protocols based on mobility Autonomous Underwater Vehicles (AUVs) are called the AUV based routing protocols. This article refers the Mobicast routing protocol which refers the mobility nodes is described below.

3.4.1. Mobicast (2013)

In Chen and Lin (2013) the energy efficient Mobicast routing protocol is proposed for underwater wireless sensor network. The Mobicast is power-saving *3D* routing protocol which overcomes the problem of unpredictable *3D* holes. In Mobicast the "***apple peel***" scheme is proposed to resolve the problem of unpredictable *3D* holes. The architecture of Mobicast is based on underwater sensor nodes which are deployed randomly in *3D* area of water around the Autonomous Underwater Vehicles (AUV) in form of *3D zone of reference* or ***3D ZOR*** as shown in Figs. 7(a) and (b). The AUV travels along the user defined path and collects the information from the

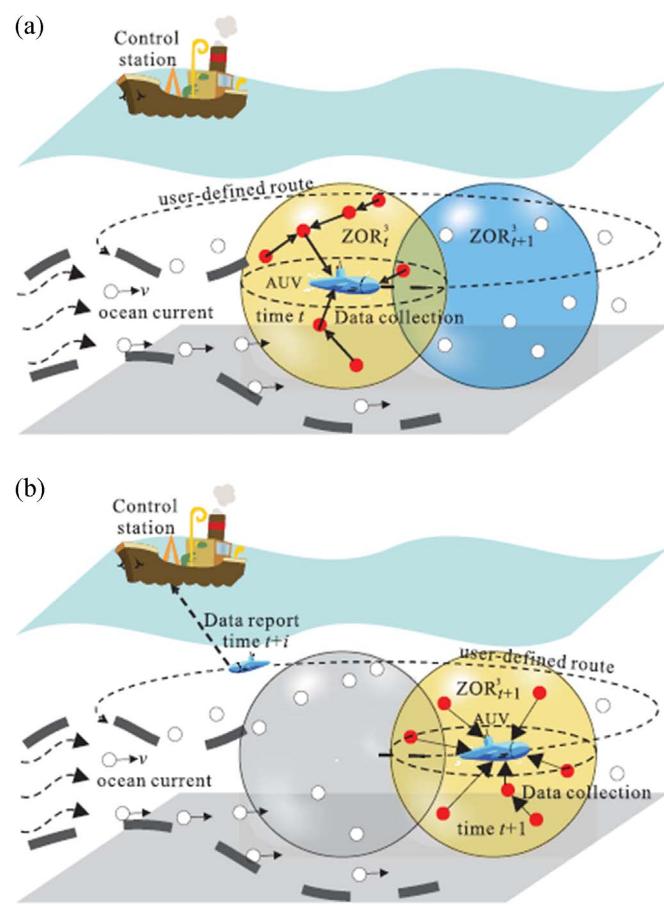

Fig. 7. (a). AUV collects data from sensor nodes with ZOR_t^3 with time t (Chen and Lin, 2013). (b). AUV collects data from sensor nodes with ZOR_t^3 with time t+1 (Chen and Lin, 2013).

sensor nodes within different time intervals of ***3D ZORs***. The sleep and active nodes are used to resolve the problem of unpredictable holes. Active nodes are responsible to forward the sensed data to the AUV. The Mobicast uses the geographic *3D* Zone of Relevance (***3D ZOR^3***) and *3D* Zone of Forwarding (***3D ZOF***) which are created by AUV at time *t* to indicate which sensor node should forward the sensed data to the AUV as shown in Figs. 7(a) and (b).

Fully distributed algorithm is used by Mobicast which reduces the power consumption of the sensor nodes and the message overheads. Mobicast enhances the data delivery ratio.

3.4.2. Issue with Mobicast

To create a user defined route in underwater 3D environment is very hard because of water pressure. Due to the continuous water movement if the active nodes may remain away from the AUV than the active nodes can drop the packets and ultimately the packets delivery ratio may be affected.

3.5. Path Based Routing Protocol

Path based routing protocols develops the single or multiple paths from source to sink nodes. Multiple path development mechanism enhances the data delivery ratio as compare to single path. This article refers the Multi-layer Routing protocol (MRP) which is purely based on the movement of the sensor nodes from source to sink nodes.

3.5.1. Multi-layer Routing Protocol (MRP)

In Wahid et al. (2014) Multi-layer Routing Protocol (MRP) is proposed for underwater wireless sensor network. MRP routing protocol is used to resolve the problem of localization and enhances the battery life of ordinary sensor node. The network architecture of MRP is based on sink nodes, super nodes and sensor nodes. The sink nodes are placed on the water surface and super nodes are fixed and spread in different water levels. Sensor nodes are deployed at the bottom of the water. MRP develops the *2D* layers around the super node. MRP is used to develop the layer *ID* and sensor node *ID* for packets forwarding with different power levels as shown in Fig. 8. The authors claimed that the super node is used to enhance the battery life of ordinary sensor nodes.

3.5.2. Issues with MPR

MRP uses the 2D node deployment mechanism but underwater supports 3D deployment. In MRP the packets holding time algorithm is not properly defined. If sensor node may remain away from super node than the sensor node may drop the packets and ultimately the packets delivery ratio might be affected.

4. Performance analysis

The performance analysis of routing protocols based on node mobility can be measured through analytical and numerical simulation methods. Performance analysis through analytical method focuses the designing parameters and performance metric parameters. The numerical simulation method focuses the simulation response of data delivery ratio. Through the measuring of the data delivery ratio we observed that which routing protocol performed well in underwater environment through node movement with respect to water pressure and environmental conditions of water.

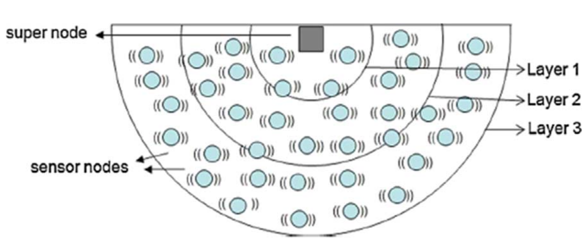

Fig. 8. Formation of different layers around super node (Wahid et al., 2014).

4.1. Performance through analytical method

Results and analysis is based on the different performance metrics and characteristics of the routing protocols based on mobility. The performance metrics of mobility routing protocols are based on the rating *low*, fair and *high* through the simulation response by using the NS2.30 with AquaSim. We have considered the metrics like: performance, cost efficiency, data delivery, delay efficiency, energy efficiency, bandwidth efficiency, and reliability of the routing protocols based on mobility. Table 1 shows the different parameters' characteristics for routing protocols with its classification like. In Table 1 VBF forwards the multiple copies of data packets and H2-DAB forwards the single copy of data packet. If we compare the DUCS and Mobicast with hop-by-hop or end-to-end data forwarding mechanism; the DUCS refers the hop-by-hop and Mobicast refers the end-to-end data. In same way we can compare all protocols with other parameters in Table 1 like: distributed clustering, clustering source based, protocols have single sink node or multiple sinks, protocols' forwards the *Hello* message or not and protocols' needs localization or not. Table 2 shows the comparison of routing protocols based on mobility through performance metrics. For example in Table 2 if we consider the H2-DAB routing protocol; its performance metric is fair than DUCS and in same way if we consider the reliability of DBR which is higher than VBF. Table 2 shows the comparison in different protocols through performance metrics.

4.2. Performance through Numerical Simulation Method

Numerical simulation method focuses the comparison of proposed routing protocols through packets delivery ratio. Majority numbers of the survey papers presented the simulation based survey through terrestrial networks as mentioned in Vaishampayan and Garcia-Luna-Aceves, (2004), Sung-Ju et al. (2002), Lee et al. (2000), Zungeru et al. (2012), Suruliandi and Sampradeepraj (2015), He et al. (2003). Like terrestrial networks the performance comparison for underwater wireless sensor networks for routing protocols is already done by the researchers; as Han et al. (2015a) compared the data delivery ratio of multi-path and single path routing protocols and presented the comprehensive survey in UWSN. Another survey paper described by Han et al. 2015b); in this survey paper the authors have compared the simulation results of H2-DAB, GEDAR, E-PULRP, and PER routing protocols with data delivery ratio, energy consumption, and end-to-end delay. Our survey article is the unique as compare to Han et al. (2015a) and Han et al. (2015b); because we have classified the proposed routing protocols with different classes and observed the behavior of each and every routing protocol through data delivery ratio. We have compared every routing protocol within the class. The simulation based comparison in this survey article validates the theoretical analysis. Routing protocols finally among higher in data delivery ratio within classes has been compared with each other and we observed that the depth based H2-DAB remains well performer as compare to other proposed routing protocols because H2-DAB is based on real time parameters. We have used NS2.30 with AquaSim simulator with general parameters for simulations as shown in Table 3.

4.2.1. Vector Based Routing Protocols

Routing Protocols based on node mobility numerical simulation performance for data delivery ratio (%) is measured in Fig. 9. The data delivery ratio of CVBF is higher than VBF, HH-VBF, VBVA, and ES-VBF because in CVBF the whole network is divided into number of multiple temporary clusters; due to maximum number of cluster the data delivery ratio becomes high but the cost of the entire network will

Table 1
Comparison of Routing Protocols Based on Mobility through Characteristics.

Classification	Protocol	Single/ multiple copies	Hop-by-hop / end-to-end	Depth Address Based	Path Based	Distributed Clustered Based	Clustering Source Based	Single/ Multi-Sink	Hello Message	Localization Needed
Vector Based	**VBF**	Multiple	End-to-End	NO	NO	NO	NO	Single-sink	NO	YES
	HH-VBF	Multiple	End-to-End	NO	NO	NO	NO	Single-sink	NO	YES
	VBVA	Multiple	End-to-End	NO	NO	NO	NO	Single-sink	NO	YES
	ES-VBF	Multiple	End-to-End	NO	NO	NO	NO	Single-sink	NO	YES
	CVBF	Multiple	End-to-End	NO	NO	NO	NO	Single-sink	NO	YES
Depth Based	**DBR**	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	YES
	H2-DAB	Single	Hop-by-Hop	YES	NO	NO	NO	Multi-sink	YES	NO
	EEDBR	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
	AMCTD	Multiple	End-to-End	NO	NO	NO	NO	Multi-sink	NO	NO
	D-DBR	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
	DSDBR	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
	DSEEDBR	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
	DSAMCTD	Multiple	End-to-End	NO	NO	NO	NO	Multi-sink	NO	NO
	DSM	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
	DEADS	Multiple	Hop-by-Hop	NO	NO	NO	NO	Multi-sink	NO	NO
Clustered Based	**HydroCast**	Multiple	Hop-by-Hop	NO	NO	NO	YES	Multi-sink	NO	NO
	DUCS	Single	Hop-by-Hop	NO	NO	YES	NO	Single-sink	YES	NO
AUV Based	**Mobicast**	Multiple	End-to-End	NO	NO	YES	NO	Single-sink	NO	NO
Path Based	**MRP**	Multiple	End-to-End	NO	YES	NO	NO	Multi-sink	YES	NO

Table 2
Comparison of Routing Protocols Based on Mobility through Performance Metrics.

Classification	Protocol	Performance	Cost Efficiency	Data Delivery	Delay Efficiency	Energy Efficiency	Bandwidth Efficiency	Reliability
Vector Based	**VBF**	Low	N/A	Low	Low	Fair	Fair	Low
	HH-VBF	Fair	N/A	Fair	Fair	Low	Fair	High
	VBVA	Fair	N/A	Fair	Fair	Low	Low	Fair
	ES-VBF	Fair	N/A	Fair	Fair	Fair	Fair	Low
	CVBF	Fair	Fair	Fair	Fair	Low	Fair	Fair
Depth Based	**DBR**	High	High	High	High	Low	Fair	High
	H2-DAB	Fair	High	High	Fair	Fair	Fair	Fair
	EEDBR	Fair	High	Fair	Fair	High	Fair	Fair
	AMCTD	Fair	High	Fair	Fair	Fair	Fair	Fair
	D-DBR	High	Fair	High	High	Fair	Fair	Fair
	DSDBR	Fair	High	Fair	Fair	Fair	Fair	Fair
	DSEEDBR	Fair	High	Fair	Fair	High	Fair	Fair
	DSAMCTD	Fair	High	Fair	Fair	Fair	Fair	Fair
	DSM	Fair	Fair	Fair	Fair	Fair	Fair	Fair
	DEADS	Fair	High	Fair	Fair	Fair	Fair	Fair
Clustered Based	**HydroCast**	High	Fair	High	High	Fair	Fair	Fair
	DUCS	Low	High	Fair	Low	Fair	Fair	Low
AUV Based	**Mobicast**	Low	Fair	Fair	Fair	Low	Low	Fair
Path Based	**MRP**	High	High	High	Fair	Fair	Fair	High

Table 3
Simulation parameters used by NS2.30.

Parameters	Rating
No. of Nodes	100 to 600
Deployment Size (3D)	1500×1500×1500 m
Surface to bottom layer distance	250 m
Communication range	500 m
Packet size	512 bytes
N/W traffic	1 packet/sec
Routing Pipe radius	100 m

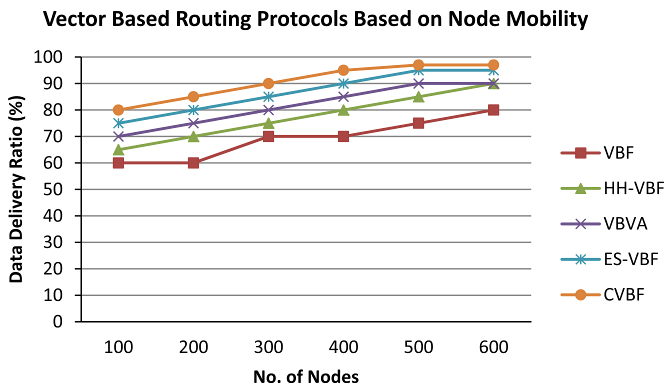

Fig. 9. No. of nodes versus Data Delivery Ratio (%) for Vector Based RPs.

be increased. The data delivery ratio of the rest of the routing protocols is less but the entire cost of network is very low. However the data delivery ratio of ES-VBF is also better but the designing of ES-VBF is based only on energy saving; the authors of the ES-VBF used the energy parameters in desirableness factor and due to its energy calculation mechanism the data delivery ratio reduced in comparison of CVBF.

4.2.2. *Depth Based Routing Protocols*

In Fig. 10 the data delivery ratio of depth based routing protocols is shown. We considered the number of nodes from 100 to 600 and we observed that; if the numbers of nodes are increases the data delivery ratio also increases and on number of 600 nodes we observed that the data of H2-DAB is higher than other proposed depth based routing protocols. Almost all the proposed depth based routing protocols have greater than 95% but the data delivery ratio of H2-DAB is 98% because H2-DAB has used the horizontal movement of nodes with lower HopID and greedy fashion algorithm. H2-DAB has also considered the dense and sparse network parameters.

4.2.3. *Clustered Based Routing Protocols*

Fig. 11 focuses the data delivery ratio of clustered based routing

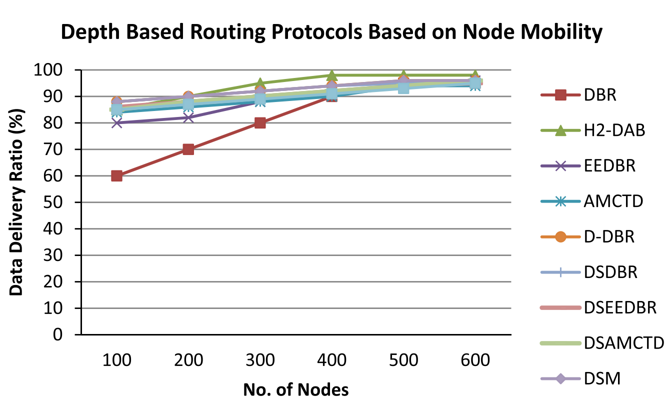

Fig. 10. No. of nodes versus Data Delivery Ratio (%) for Depth Based RPs.

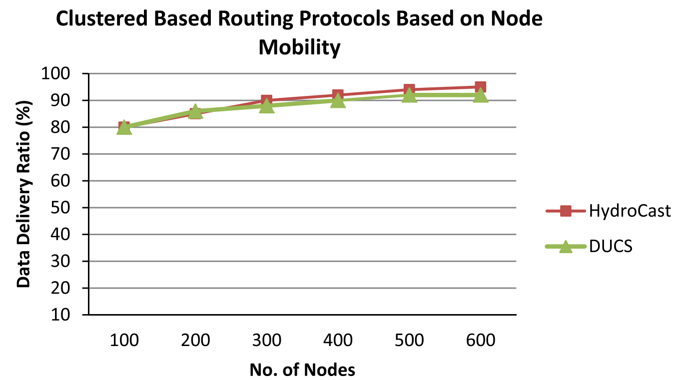

Fig. 11. No. of nodes versus Data Delivery Ratio (%) for Clustered Based RPs.

protocols. In Fig. 11 if the numbers of nodes are 600 nodes the data delivery ratio of HydroCast is higher than DUCS because in HydroCast the tetra horizontal mechanism is used which reduces the number of nodes in data forwarding mechnism. The data delivery ratio of DUCS is smaller than HydroCast because in DUCS the irrelevant continuous movement of nodes reduces the life of the sensor nodes and sensor nodes dies earlier which affects the data delivery ratio.

4.2.4. *AUV Based Routing Protocol*

In Fig. 12 the data delivery ratio of AUV based Mobicast routing protocol is shown. We observed the packets delivery ratio from 100 to 600 numbers of nodes; if number of nodes are 100 the data delivery ratio is 70% and if number of nodes are 600 the data delivery ratio is 85%.

4.2.5. *Path Based Routing Protocols*

In Fig. 13 the data delivery ratio of path based MRP routing protocol is given. In Fig. 13 the data delivery ratio is measured from 100 to 600 numbers of nodes; if number of nodes are 100 the data delivery of MRP is 90% and if number of nodes are 600 the data delivery of MRP is 95%.

4.2.6. *Comparison among Higher in Data Delivery Ratio*

In Fig. 14 the data delivery ratio of higher in classification is shown. In Fig. 14 we observed that the data delivery ratio of H2-DAB among higher in classification is 98% which is higher than CVBF (higher in vector based), HydroCast (higher in clustered based), Mobicast (AUV based) and MRP (path based).

5. Future challenges

There are so many research challenges for the designing of underwater routing protocols that needs to be investigated. Some future research challenges are described below.

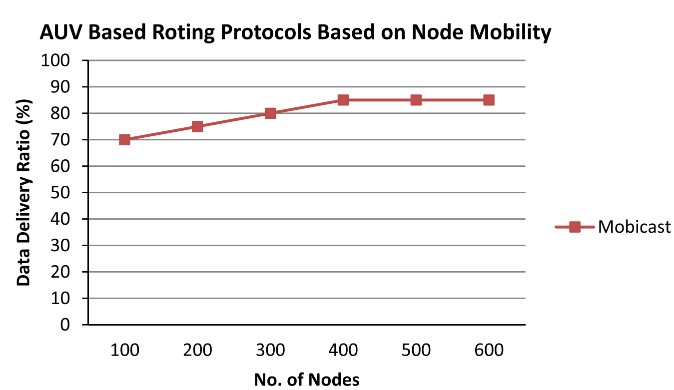

Fig. 12. No. of nodes versus Data Delivery Ratio (%) for AUV Based RP.

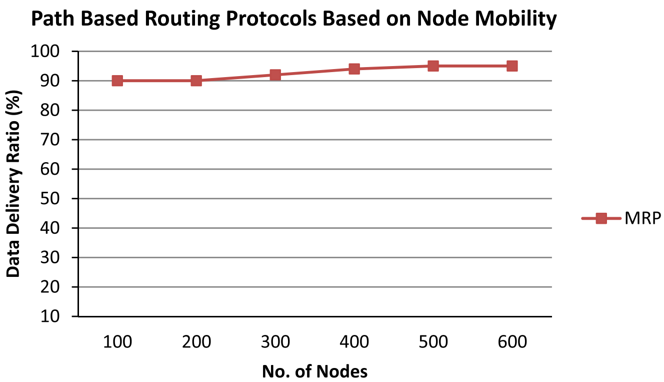

Fig. 13. No. of nodes versus Data Delivery Ratio (%) for Path Based RP.

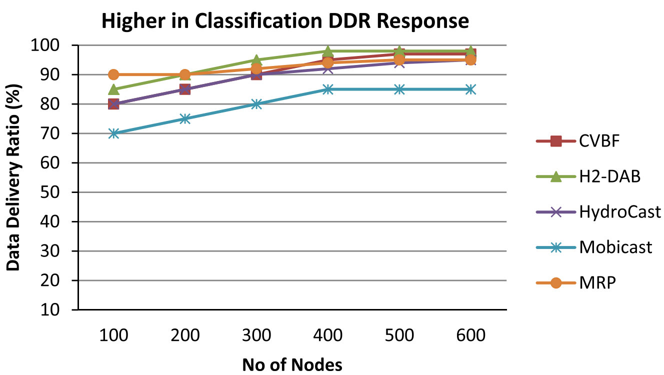

Fig. 14. No. of nodes versus DDR (%) Higher in DDR from Classification.

i. **Self-configured algorithms**: In case for failure of any sensor node the network must be self-configured to maintain the data forwarding mechanism. The future research must take care for developing of self-configured algorithms which maintain the data forwarding mechanism.

ii. **Multi-copy avoidance algorithms**: If multiple copies of the same data packets received by intermediate nodes than intermediate nodes must discard the duplicated data packets. The reliable algorithms are needed to discard the same data packets from intermediate nodes in efficient way.

iii. **Balancing of Energy level:** The existing algorithms for energy balancing are better but still efficient algorithms are needed to balance the energy level of sensor nodes.

iv. **Location discovery algorithms**: In location-based routing techniques the existing location discovery algorithms are not reliable. The reliable location discovery algorithms are needed for location-based routing protocols.

v. **Security algorithms:** The researchers have overlooked the security issue in most of the existing routing protocols. The reliable secure algorithms are needed for routing protocols to make secure the valuable information.

vi. **Delay controlling**: There is need of an efficient algorithm that adapts the delay variance of acoustic link between sender-receiver pair (horizontal and vertical links) for single or multipath.

vii. **Handling of connectivity losses**: An efficient mechanism is required to handle connectivity loss without aggravating the immediate retransmission for delay tolerant application.

viii. **Robust algorithm for deep underwater**: A robust routing algorithm is needed for deep underwater network scenario that considers ground and surface effects along with the varying characteristics of the ocean layers.

ix. **Accuracy in simulation**: Accurate and credible modeling or simulation is mandatory for data transmission on network layer.

x. **Minimum control overheads**: Efficient (routing/MAC) algorithm with minimum control overhead is required for long network lifetime.

xi. **Localization**: Localization and trajectory issues must be resolved using minimum signaling power and signaling overhead.

xii. **Removal of voids**: Identification and avoidance of void regions during the transmission of data between nodes is also a challenging issue.

6. Conclusion

Routing protocol based on node mobility is one of the challenging issues. Over the past years many of the routing protocols based on node mobility have been proposed with different characteristics. We have classified the routing protocols as vector based, depth based, clustered based, AUV based, and path based. Each routing protocol is carefully analyzed with its node mobility, data forwarding, route discovery, route maintenance, and performance issues. We have also focused the performance of proposed routing protocols through analytical method. The simulation scenarios show the data delivery ratio of all the mobility based routing protocols according to its classification. The data delivery ratio in % for all routing protocols according to their classification is shown in this article. We observed that the performance of H2-DAB is better than other proposed routing protocols because the depth addressing mechanism of H2-DAB covers the node movement in efficient way. The open research issues of this article will help the researchers to further research in the field of routing protocols for UWSN.

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