CHAPTER 3

LITERATURE SURVEY OF ROUTING PROTOCOLS

The routing protocols in this literature have been classified into four types. They are protocols focusing on medium access control, void avoidance without recovery, void avoidance with recovery using eulerian and lagrangian approach and protocols based on funneling effect.

3.1 UNDERWATER MAC PROTOCOL FOR UNDERWATER SENSOR NETWORKS

Multiple Access Collision Avoidance Mobile Nodes (MACA-MN) has been based on a sender-initiated mechanism with the binary exponential back off timer. It uses (Request to Send) RTS / (Clear to Send) CTS-based handshake messages by transmitting a train of packets. The RTS message requires the exact receiver node identity and the inter-node propagation delay. So it can establish communication with multiple neighbours at one instance with packet trains (Chirdchoo et al. 2008). However, the problem with MACA-MN protocol it has been implemented in static underwater sensor networks. Additionally, asymmetric propagation due to node mobility makes it futile in underwater sensor nodes with mobility.

Multi Receiver MAC (MR-MAC) protocol uses two receivers. It had been based on a schedule based approach and a half duplex methodology for transmissions. In this protocol a successful handshake with the packet train concept is used but this concept has been applicable to static underwater
sensor. The nodal mobility underwater sensor may associate with other receiver than the intended schedule based receiver (Liao et al. 2015). This makes a void in communication.

Underwater Power Control MAC (UPC MAC) protocol with reservation and slotted based MAC protocol where power control, rate adaptation and spatial reuse mechanism are being implemented using a game theory based approach (Nash equilibrium). It incurs lot of overhead and relies on channel state matrix information which makes it not stable (Su et al. 2015). Hence, the protocol cannot be used.

Channel Aware Pressure Routing (CARP) uses the structure of a network (topology) to determine the number of hops to overcome void. The link quality has been provided with cross layer approach along with topological information. It uses PING PONG messages. The PING message was analogous to control packet and contains fields of source identity and number of packets. The PONG message contains fields like source destination identity, number of hops, buffer capacity, remaining energy and link quality. The protocol prefers shorter hops for highest throughput and longer hops for better link quality in transmissions (Basagni et al. 2012).

Decoupled and Suppressed Handshaking MAC (DSH-MAC) forwards with the criteria of a node with NOTE and GRANT packets which were similar to RTS and CTS packets in contention-based methods. However, the packets can work independently. A receiver when receiving a NOTE packet has a quality index that denotes the highest waiting time compared with the other nodes. Data packet has been piggybacked with the NOTE packet. The GRANT packet provides information of willingness of the channel (Hu & Fei 2013). The problem with this protocol it makes decision with predicted traffic. The protocol fails due to traffic rate being not uniform in underwater sensor networks.
Noise-Aware MAC (NAMAC) protocol uses multi frequency band modems and overcome disruptions with band switching, where they can find a band with higher signal strength and a minimal noise ratio. To cope with overhead cost a group of nodes switches their bands instead of a single node. It has been primarily based on four threshold values namely tracking threshold, switching threshold, neighbour threshold and return threshold (Pescosolido et al. 2013). Anisotropic underwater environment makes this threshold value difficult to analyse.

The joint frequency and power allocation protocol had been proposed in (Jornet et al. 2010) wherein focus had been made towards the attenuation of the signal frequency; different discrete power levels had been available in the physical layer. The MAC layer, according to the back off and its current distance, then selects a suitable power level at the physical layer (Jornet et al.2010). This had been implemented with two protocols namely Focused Beam Routing (FBR) (Jornet et al. 2008) which was entirely location based and Distance Aware Collision Avoidance Protocol (DACAP) (Peleato & Stojanovic 2007). The problem with this power control protocol strategy has been obtained with preconfigured power levels, which increased the complexity in implementing the underwater network design.

Distributed-On-demand Scheduling (DOS) has been proposed with collision-free scheduling MAC layer with a static network topology, perfect synchronization and guard band. The neighbour cluster head information and schedule update conflict of interest provide information for inter and intra-cluster communications without collisions during the first and last transmission slot (Zhu et al. 2014). This work cannot be extended in underwater sensor nodes with mobility.

Gossiping in Under Water Acoustic Mobile Ad-Hoc Network (GUWMANET) multi-hop-based protocol with a cross layer approach, with
medium access and routing functionality based on the Generic Under Water Application Language (GUWAL). The MAC layer focuses on the time-based random access method with direct transmission capabilities to eliminate the delay incurred in the round trip time. An automatic repeat request ensures an acknowledgement of the correctly received packets. GUWMANET has been based on an implicit acknowledgement. It has been based on a 128-bit multicast address with 10 bits added to provide the source node and the previous hop acknowledgement (Goetz & Nissen 2012). Because it relies entirely on topology, it cannot manage dynamic topology changes in underwater networks.

Hybrid Sender and Receiver initiated protocol (HSR) has been proposed, based on the polling, request and grant packets wherein communication is established between the receiver and its neighbours with Request To Participate (RTP) and Clear To Participate (CTP). It also contains transmission schedule of the sender to avoid collisions. There by producing a list of desired participants in the ongoing handshake (Lee & Cho 2015). The problem with this protocol has been maintaining a list of neighbours with routing table which has been not possible in the case of underwater sensor networks with oceanic currents.

A Prediction Assisted Single copy Routing (PASR) has been proposed. It collects the information history such as contact time, the contact duration, contact frequency and geographic location. An Aggressive Chronological Projected Graph (ACPG) then validates a route under a given slot with the associated mobility pattern (Guo et al. 2010). The problem with the PASR type of protocol slots for data transmission has been confined to half duplex mode wherein sensor cannot transmit and receive at the same instant.
3.2 PROTOCOLS FOR VOID AVOIDANCE WITHOUT RECOVERY

In Depth-Based Routing (DBR) the sender forwards the packet to a set of nodes at a lower depth than itself. Before it forwards the packet, it checks its packet history buffer to avoid frequent retransmission. If the packet has been already in its packet history buffer, it checks it’s hop count. If the hop count has been less than the previous hop count, then it forwards the packet by adding it to the priority queue. Otherwise, it discards the packet. It also has a timer that expires if it cannot find any neighbours within its transmission range (Yan et al. 2008). The problem with DBR has been its increased number of packet transmission (flooding) and also leads to void due to node mobility, where sensor nodes are out of communication range.

The Depth-Based Multi-Hop Routing Protocol (DBMR), an underwater sensor network protocol forwards packets using the depth and sleep schedule algorithm. The sender forwards the packet to the place where only one node has been selected as the next hop neighbour. This methodology never causes flooding of packets. It routes data with minimal energy (Guangzhong & Zhibin 2010). However, this protocol has also been susceptible to communication void.

Energy-Efficient Depth Based Routing (EEDBR) the protocol forwards packets with depth and remaining energy. It has been similar to DBR, but it with a sender based method because the nodes on the record were sorted based on their remaining energy, which showed their precedence of forwarding. To prevent redundant data packet forwarding, each contender node judges a holding time according to its remaining energy and precedence in which a smaller holding time has been assigned to a node with more remaining energy which receives the packet (Wahid & Kim 2012). This protocol attains energy efficiency but suffers from communication void.
The Energy-Efficient Fitness (EEF) protocol uses depth which has been calculated by vertical coordinates of the forwarding node, remaining energy of node and fitness value. The value of fitness obtained considers the distance between the sending node, forwarding node and sink (Ashrafuddin et al. 2013). Protocol uses location coordinates, so it’s fitness values could be calculated. The value of fitness varies with node mobility and hence this protocol cannot be implemented.

The adaptive approach to opportunistic data forwarding has been based upon holding time of data with the usage of accumulate and forward strategy (Nowsheen et al. 2014). In this protocol each node calculates the delay in its local buffer for its waiting time and forwards the packet once the adaptive timer expired. With this methodology it calculates the service time of all stored packets in the buffer, the packet ingress and the successful data transfer of outgoing links. In its waiting state, if a dependable forwarder has been absent, it revises its new holding time (Nowsheen et al. 2014). It focuses on delay sensitive application; the aid of ferry nodes makes it not suitable for underwater networking with sensor technology.

The Cubic Minimum Average Signal-To-Noise Ratio (CMAS) has been based on the structure of underwater sensor nodes and minimal hop count. The protocol calculates the received signal per link with the maximum signal strength of the overall links available with attenuation using Thorp’s model and ambient noise calculations. Then it selects the path with highest throughput (Azad et al. 2015). However, this protocol has been implemented in static networks.

Greedy Geographic Forwarding based on Geospatial Division (GGFGD) has been based on geospatial divisions. The protocol path to the next forwarding node depends upon path delay, path loss and residual energy as the metrics. Geospatial division has been performed based on four
positions: vertex adjacent, surface adjacent, edge adjacent and totally disjoint. It has been developed in three-dimensional topology-based environments where the network has been divided into small cubes with multipath capabilities. Similarly, Geographic Forwarding Based on Geospatial Division (GFGD) has also been proposed which has a superior performance versus GGFGD due to directional forwarding (Jiang et al. 2015). However, these protocols were simulated using a predefined static topology.

The work of redundancy allocation in underwater sensor networks has been discussed with code word for three schemes namely adaptive allocation, constant redundancy allocation and rate less scheme. It primarily focuses on time varying channel conditions with binary symmetric channel used in static networks. It uses an adaptive equalizer at the output to balance the varying attenuation with time and inter symbol interference. The probing sequence may provide the necessary channel state information for the desired information bit along with its bit errors. The protocol has been assessed with data for a link of 3 kilometres long and has been efficient in terms of shorter transmission (Tomasi et al. 2015). The problem associated with this approach assumes constant bit error rate which has not been constant in underwater network scenario.

Depth Energy Aware Dominating Set (DEADS) protocol a co-operative communication based graph theory approach which uses sink mobility (Umar et al. 2015). Depth Energy Aware Dominating Set (DEADS) uses two mobility patterns linear mobility which has been horizontally varying and elliptical mobility which has been vertically varying about its major axis. A Dominating Set (DS) has been constructed in DEADS based on the depth and residual energy. This helps in co-operative routing in the initial stage after neighbour selection. In the routing stage, data has been sent based upon the threshold value to its co-operative partner nodes (Umar et al. 2015).
The problem with this protocol has been reactive based and unsuitable for continuous monitoring and this incurs high overhead of control packets with increased energy consumption.

Efficient and Balanced Energy consumption Technique (EBET) used the key intuition to achieve balanced energy consumption with its respective distance. Initial establishment of communication links by sensor nodes has been done with the help of optimal distance based threshold value with transmission radius. Several routes are being obtained in the route establishment phase. Then the initial energy of sensor nodes has been equally portioned. However, in the data transmission stage it chooses the criteria for transmission based on the Energy Level Number (ELN). If a node has consumed excessive energy than its previous node, then it sends a control packet to the previous node to deny sending data packets. The previous node which receives the control packet finds a high energy level number node for forwarding in its locality thus prolonging network lifetime (Shah et al. 2015). The problem with this approach has been nodes location varies and the transmission radius changes and the optimal distance for forwarding cannot be found.

Energy efficient interference-aware routing (Shashaj et al. 2014) has been based on graph theory approach focusing on scheduling and routing policies with different set of suitable power levels available. The scheduling policies are based on four means First In First Out (FIFO) packet transmission priority has been based on packet transmission, (LOAD) priority has been based on number of packets in buffer, (LWS) priority has been based on the nodes that are furthest distance to the sink, (FAIR) priority has been given to nodes such that lesser amount of transmissions which attain a fair amount of data transmitted. The routing policies are also based on four means (FAN) time epoch between packet being ready for transmission and effective
transmission in underwater channel, (LIGHT) decrease the maximum buffer size at forwarding nodes, (SP) reduces the number of hops towards the sink, (LIN) minimizes the entire traffic load in the network. The thorough investigation of best transmission time, along with awareness of forwarding link transmission power level makes this protocol effective in terms of energy efficiency and interference aware capabilities (Shashaj et al. 2014). The problem with this protocol has been contention free method using Binary Phase Shift Keying (BPSK) modulation and transmission of a packet begins only on boundaries of time slot.

Adaptive Hop by Hop Vector Based Forwarding (AHHVBF) a location based protocol wherein radius of the pipeline has been found with control packet such as neighbour request and neighbour acknowledgement, neighbour discovery and its direction has been changed according to the available neighbour distribution. In addition, the power level of neighbour node has also been made adaptive with cross layer fashion for forwarding with its hop by hop fashion depending on its node density. Holding time of packet has been based upon the destination node or the node closest to the destination from the present forwarding node. This type of protocol has been suitable for static network or network with horizontal mobility which has been clearly evident from the random walk and 2D mobility models used (Yu et al. 2015). Thus it cannot be extended to location free dynamic networks.

A multi-hop relay network protocol has been proposed where the traffic intensity of forwarding nodes nearby the sonobuoy leading to funneling effect. In this case non forwarding nodes of a geographic region for a specific route will be the forwarding nodes of other routes. Two types of uncertainty are being discussed: forwarding node solo itself known as internal uncertainty, and the other type external uncertainty due to its improper synchronization with other nodes. The protocol has been simulated using a
cylindrical tuple based upon the centre coordinates, a vector whose geo-cast direction and distance was in the three-dimensional plane and (r) a radius perpendicular to the direction (Chen & Pompili 2011). The implementation of network wide synchronization has been reliable with the sonobuoy. When compared with this approach which has been based on a constant radius.

The aforementioned protocols in sections 3.1 and 3.2 suffer from communication void due to node mobility, energy drain since batteries is difficult to recharge. The protocol except those used in realistic routing has been simulated using thorp’s model.

3.3 PROTOCOLS FOR VOID AVOIDANCE WITH RECOVERY

The protocols with void avoidance and recovery can be classified as eulerian based schemes with message based approach or lagrangian based schemes with mechanical devices (Caruso et al. 2008). Eulerian approach describes the data are taken from every point at that instance of time. Lagrangian approach describes the equation of motion of a sensor node to get out of void (Caruso et al. 2008). Some of the lagrangian based approaches are partially lagrangian where they initially transmit message with internetworking capabilities and when the sensor is struck in void it uses lagrangian nodes or floating buoys to overcome void. These protocols are discussed below.

Improved Adaptive Mobility of Courier nodes with Threshold optimized Depth (IAMCTD) based routing has been described with the four metrics. The first function was based on depth calculated by considering the number of dead nodes. Secondly residual energy which has been calculated for the node and energy required for the data transmission. The third value of Signal-to-Noise Ratio (SNR) has been calculated by using transmission power along with attenuation and noise. The fourth metrics has been the sojourn tour
of courier nodes with respect to the mobility information shared with its network density. The selection of optimal forwarders was decided by three priorities of the signal quality index which was same as SNR, an energy cost function based on enduring energy and a depth-dependent function based on both local signal-to-noise ratio and enduring energy (Javaid et al. 2014). The protocol does not focus on internetworking between sensors for obtaining data.

A novel void recovery paradigm has been proposed that uses geographical routing with the concept of packet advance. The topology based approach in which the topology information has been available with autonomous underwater vehicle. When a node struck with communication void topological changes are made by the winch-based apparatus or a floating buoy to overcome it. Then anycast routing where it can find a neighbour node nearest to the void node has been used. The adjusted information then are available to all of the nodes with replay messages in a distributed topology structure (Coutinho et al. 2015). A similar analysis has been performed in the geographic and opportunistic based routing protocol (Coutinho et al. 2014), depth control routing (Coutinho et al. 2013) and QUO-VADIS (Chen & Pompili 2014). However, these topology control mechanism incurs extra energy cost.

An Autonomous Underwater Vehicle AUV-aided Underwater Routing Protocol (AURP) with autonomous underwater vehicles as relay nodes with short range and huge value of data rate for transmissions in underwater channel has been proposed. Communicating between the underwater sensor nodes to the sink, relies upon relay nodes which are analogous to AUV with controlled mobility (Yoon et al. 2012). However, the extra energy cost involved by AUV makes this protocol unsuitable for underwater sensor networks.
Energy efficient routing protocol has been proposed for underwater networks based on the forwarding criteria of depth, residual energy and optimal distance from the source. The source node provides flexibility in transmission power according to the destination so that the signal reaches with the same transmitted power. The optimal hop position based energy efficient routing is divided into two phases. In the first initialization phase it checks the node identity, position of forwarders then priority has been assigned with residual energy value. In the second data forwarding phase, it checks the availability of packets for forwarding and forwards checking its packet history buffer to avoid redundant packet forwarding and provides the correct priority based on the residual energy and distance (Geethu & Babu 2015). The protocol uses courier nodes which are similar to Autonomous Underwater Vehicle (AUV) and in turn increases the excess energy cost rather than focusing on internetworking with sensors.

To be more precise the protocol design should be purely based on networking with message based transmissions without the superior nodes with passive or active mobility.

Sensors placement and sensors dispatch has been proposed (Wang et al. 2008). It stated that a group or an individual sensor with mobility had been moved to provide optimal connectivity and coverage. Several works have been done with this context by using autonomous underwater vehicle or Unmanned Underwater Vehicle (UUV). But the context of this work does not focus on connectivity with internetworking between sensors. Hence next section will focus on the message based transmission strategies.
3.4 PROTOCOLS FOR VOID AVOIDANCE WITH RECOVERY AND MESSAGE-BASED TRANSMISSION

The void avoidance-based protocols with a packet-based approach are discussed and mainly focus on the geographical routing protocols with the concept of advance. Hence, it considers the node that has been closer to the sink and the furthest within its transmission range (Melodia et al. 2004).

Vector-Based Void Avoidance (VBVA) protocol was developed to avoid collision void. The routing mechanism uses concave and convex routing to overcome voids with unequal load distribution of packets among sensor nodes. For convex voids it uses vector shift mechanism for data packets routing to deliver it to the end node. If the vector shifting fails then concave voids are detected. Then backpressure methods are used for avoiding voids where packets are forwarded in a direction opposite to the end node until proper forwarding vector was found (Xie et al. 2009 b).

Local maximum routing recovery uses a network energy consumption model based on the communication range (nodes within the transmission range) and carrier sensing range (nodes that exclude the other nodes within the communication range), where the carrier sensing range was greater than the communication range. When a node has been struck with voids, it increases its communication range by adjusting its transmission power to overcome voids. Initially, each node tries to route towards a node with minimal hops and energy consumption (Coutinho et al. 2014b). The problem with this type of approach was increasing the communication range also increases the interference from other nodes.

Routing and Multicast Tree-Based Geo-Casting (RMTG) a handshake-based protocol, where nodes forward data packets to a specified group based on its geographical coordinates based on its prior hop
acknowledgement. The geographical coordinates are provided by a Global Positioning System (GPS). In cases where void nodes are in the geo-cast region, it uses the nearest leaf nodes of the tree to determine its position and creates a tree and tries to reroute along its face with its clockwise and anticlockwise direction based upon the nearest leaf node’s threshold value (Dhurandher et al. 2010). The coordinates cannot be provided below the surface in an underwater environment with GPS which makes this protocol incapable.

Weighting Depth and Forwarding Area Division DBR (WDFAD DBR) protocol with multi-sink architecture and anchor nodes, relay nodes and sink nodes has been discussed. The relative coordinates of nodes are being available based on the RSSI (received signal strength indicator). It uses the criteria of depth of the present forwarder and then anticipates depth of the adjoining hop of forwarding node with lower depth. Packet holding time has been calculated by weighting of the aggregate which is between 0 to 1 weight value and the depth difference of the two hop neighbour. Efficient use of energy consumption has been optimized by dividing the forwarding area which has been classified as primary forwarding area and auxiliary forwarding area using nodal density and channel state it avoids duplicate packet transmission (Yu et al. 2016). The problem with this protocol imposed the design on RSSI which determines the relative distance between the node and any deviation will lead to communication void.

Methodology of Void Aware Pressure Routing (VAPR) (Noh et al. 2013).

1) Every sonobuoy on surface sends a beacon message.
2) Sensors which receive the beacon message update its depth only if the beacon sequence is greater than the previous beacon sequence.

3) If the beacon sequence is equal to the previous beacon sequence then it checks for its hop count.

4) If steps 2 and 3 are true then it updates its Next hop Data forwarding direction (N_DF_dir) and Data forwarding direction (DF_dir).

5) The direction is set ‘up’ when the beacon is received from shallower depth node for data flow.

6) Route Initialization

It is used to initialize each node’s internal states

i. Initially each node in the network begins as an isolated local maximum with hop count equal to infinity except sonobuoy.

ii. Then it will have a connected component to one of the sonobuoy whose state will be changed to non local maxima.

iii. If current sensor node is a source node then

Set DF_Dir = 0
Hop count = 0
Sequence number = 0

Else

Π = depth
Set DF_Dir = 0
N_DF_Dir = 0
Sequence number = 0
Hop count = \infty

The Else statement indicates it as a forwarding node

7) Data Forwarding

Nodes forward data solely based on the data forwarding direction (DF_Dir) and Next hop data forwarding direction (N_DF_Dir).

8) Initialize all nodes in the connected set

IF node DF_Dir is DOWN
THEN NBR (\pi) \leq NODE (\pi)
And NBR (DF_Dir) = NBR (N_DF_Dir)
Combine the node in forwarding set.
IF node DF_Dir is UP
THEN NBR (\pi) \geq NODE (\pi)

and NBR (DF_Dir) = NBR (NDF_Dir) by which the neighbour are added in the forwarding set and select the best node for upward forwarding.

9) Clustering

i. Form all nodes in the forwarding set (F) and select the best one.

ii. Get one hop neighbour from the best node and form cluster.

iii. Remove the best node from its one hop neighbour and from forwarding set.

iv. If F (Forwarding set) is not empty
Repeat i-iii
Else Stop

The purpose of the VAPR protocol discussed in detail because it has been compared with several proposed protocol. VAPR operation fully relied on control messages (beacon). However, the collisions due control packets are said to be 80%, where 65% was between control and data, and 15% due to control and control packets (Basagni et al. 2010).

Hydrocast has been based on permissible delay and normalized advance (Lee et al. 2010). The normalized advance has been calculated by advance divide by cost (Lee et al. 2005). The cost has been calculated by packet delivery probability and did not provide energy efficiency and incurred long detour paths due to controlled flooding at the void node for recovery.

3.5 PROTOCOLS WITH FUNNELING EFFECT

The problem with the underwater sensor network has been that the nodes closer to the sink may drop many packets and may consume more energy than the other nodes which are further apart. This is termed as the funneling effect (Wan et al. 2005). These nodes may also run out of energy termed as energy holes problems.

The region where funneling effect takes place has been denoted as intensity region which can be defined as the number of hops is smaller and the traffic intensity is larger (Ahn et al. 2006).

The recovery aspect of funneling effect has been classified by two means; primarily sink oriented approach and recovery by sensors itself. The sensor oriented approach was resource constrained with energy consumption had problems with aggregated paths. Aggregated path was a merger of two or more paths from various nodes in the intensity region (Ahn et al. 2006).
The Funneling-based Multiple Access Control for Underwater (FMAC U) with handshaking-based protocol characteristics. When an RTS packet was received at the sink, it sets its fairness bit to zero and checks the availability of the transmission slot to decide whether to send a CTS packet. The CTS packet contains slots in assigned order for data transmission and the transmission order with a timer flag. To avoid RTS packet flooding at the sink, it uses a pseudorandom binary spreading sequence for its immediate neighbour with code division multiple access (Fan et al. 2011). This protocol uses recovery from sink and does use contention free method which has several limitations.

U-Fetch protocol uses topology-based approach for a combination of multi-hop signalling and polling with the help of the Autonomous Underwater Vehicle (AUV) for data retrieval strategies. U fetch consists of mobile sinks (AUV), sensor nodes and head nodes. The head nodes send a beacon message to sensor nodes that replies with a probe request and the head node polls for specific data rather than using a random back-off time. To avoid collisions between beacons, it uses cBeacon messages to nodes that did not receive the beacon in the first instance. Then, communication between head nodes and AUV occurs with a contention free handshaking-based procedure (Favaro et al. 2013). This protocol uses the aid of mechanical devices and focus has not been made on internetworking sensor technology.

A Fair Data Transmission Strategy (FDTS) has been proposed to avoid collisions in the MAC layer and to attain equality in throughput. It uses queue management, transmission control and competition waiting. Queue management has been based upon the duo of transferring priority and discarding priority of a message. The transmission control policy has been based upon time distance ratio with every node allocating a channel. The competition waiting, mechanism where the receivers decides and choose only
one of the contenders. The remaining other contenders reaches sleep state until the end of the current transmission. The protocol provides fair amount of throughput to all of the sensor nodes irrelevant to its distance by assigning a weight value (Yuan et al. 2014). However, fairness was achieved without nodal mobility and does not focus on nodes in intensity region.