Chapter 12: A survey on routing techniques in underwater wireless sensor networks

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Outline

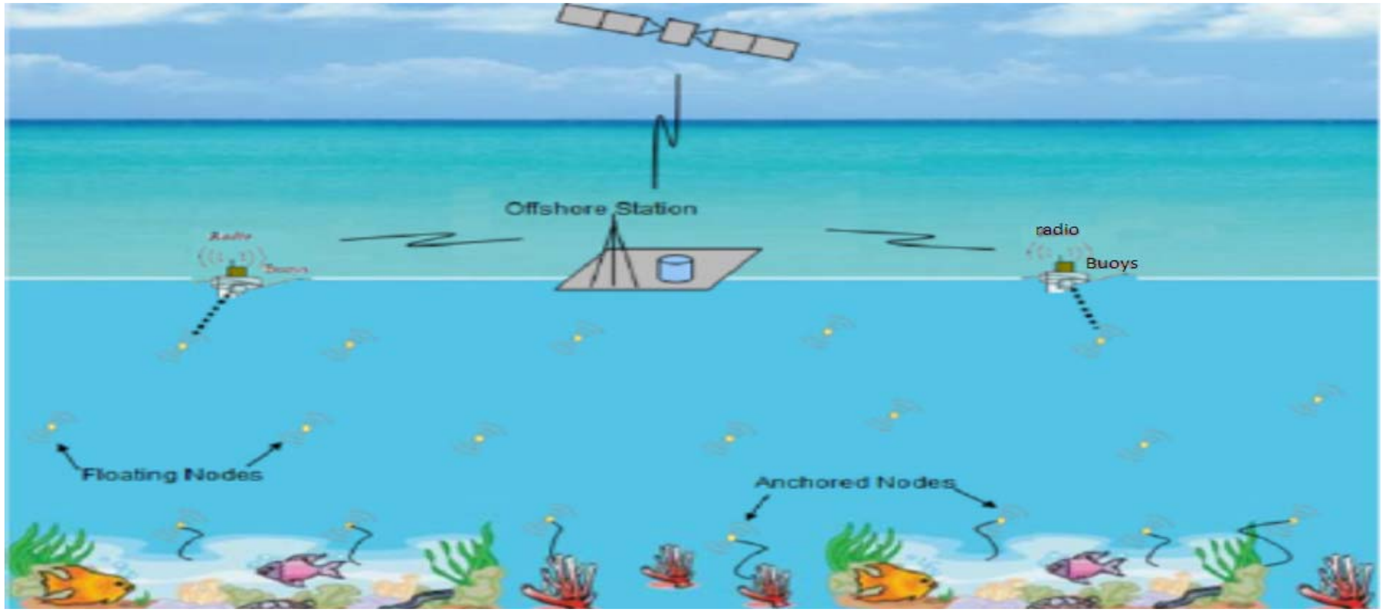
- Abstract
- Introduction
- Background
- Comparison between terrestrial and underwater wireless sensor networks
- Routing protocols for UWSNs
- Conclusion

Abstract

- Underwater Wireless Sensor Networks(UWSNs) are finding different applications for offshore exploration and ocean monitoring.
- The sensor nodes located at the sea bed cannot communicate directly with the nodes near the surface level; they require multi-hop communication assisted by appropriate routing scheme.
- Significant attention has been given to construct a reliable scheme, and many routing protocols have been proposed in order to provide an efficient route discovery between the sources and the sink.
- The main purpose of this study is to address the issues like data forwarding, deployment and localization in UWSNs under different conditions.

Introduction

- With the increasing role of ocean in human life, discovering these largely unexplored areas has gained more importance during the last decades.
- The current research in UWSNs aims to meet the criterion by introducing new design concepts, developing or improving existing protocols and building new applications.



Introduction(cont.)

- In such circumstances, the routing protocols should be able to determine the node locations without any prior knowledge of the network.
- Not only this, the network also should be capable of reconfiguring itself with dynamic conditions in order to provide an efficient communication environment.
- Moreover, a significant issue in selecting a system is establishing a relation between the communication range and data rate with the specific conditions.

Background

1. Basics of acoustic communications
2. Deployment and network architecture
3. Localization
4. Reliability

Basics of acoustic communications

- Although we have a couple of more options in the form of electromagnetic and optical waves, but underwater characteristics and sensor communication requirements have ruled them out.

- electromagnetic wave
  - It has a very limited communication range at high frequencies due to high attenuation and absorption effect
- optical link
  - Due to its short range (less than 5m) is not good enough for distributed network structure
  - A precise positioning is required for narrow beam optical transmitters.
  - when the water is not so clean (like shallow water)is not considered as a good choice for long distance underwater communications.

Basics of acoustic communications(cont.)

- acoustic signal
  - It provides the facility of omnidirectional transmission and distributed channel access with acceptable signal attenuation.
  - Although the speed of sound is assumed to be constant in most of the situations, but actually it depends on water properties like temperature, salinity, and pressure.
  - However, the speed of sound increases with the increase in any of these factors including temperature, depth, and practical salinity unit (PSU).

Deployment and network architecture

- two-dimensional
  - Sensor nodes are anchored at the bottom where these can be organized in different clusters and are interconnected with one or multiple underwater gateways by means of acoustic links.
  - The underwater gateways are responsible for relaying data from ocean bottom to surface sink.

- three-dimensional architecture
  - sensor nodes float at different depth levels covering the entire volume region being monitored.
  - These nodes are attached with the surface buoys by means of wires and their lengths can be regulated in order to adjust the depth of the sensor nodes.
  - They have used a purely geometric based approach to determine the required number of sensor nodes in order to cover the whole monitoring area.

Localization

- In some applications, sensed data become meaningless without time and location information.
- Localization is essential for data labeling while some time critical applications require timely information.
- It assumes that all the sensor nodes are equipped with pressure sensor in order to provide depth position or z-coordinate information.

Reliability

- For underwater environments, reliable delivery of sensed data to the surface sink is a challenging task as compared to forwarding the collected data to the control center.
- In terrestrial sensor networks, multiple paths and packet redundancy are exploited in order to increase the reliability.
- For underwater sensor networks, many authors are also proposing schemes based on packet redundancy , but for resource constraint underwater environments, techniques like this are not easily affordable.
- acknowledgments and retransmissions provide reliability by recovering lost data packets; however these efforts result in additional traffic and large end-to-end delays.

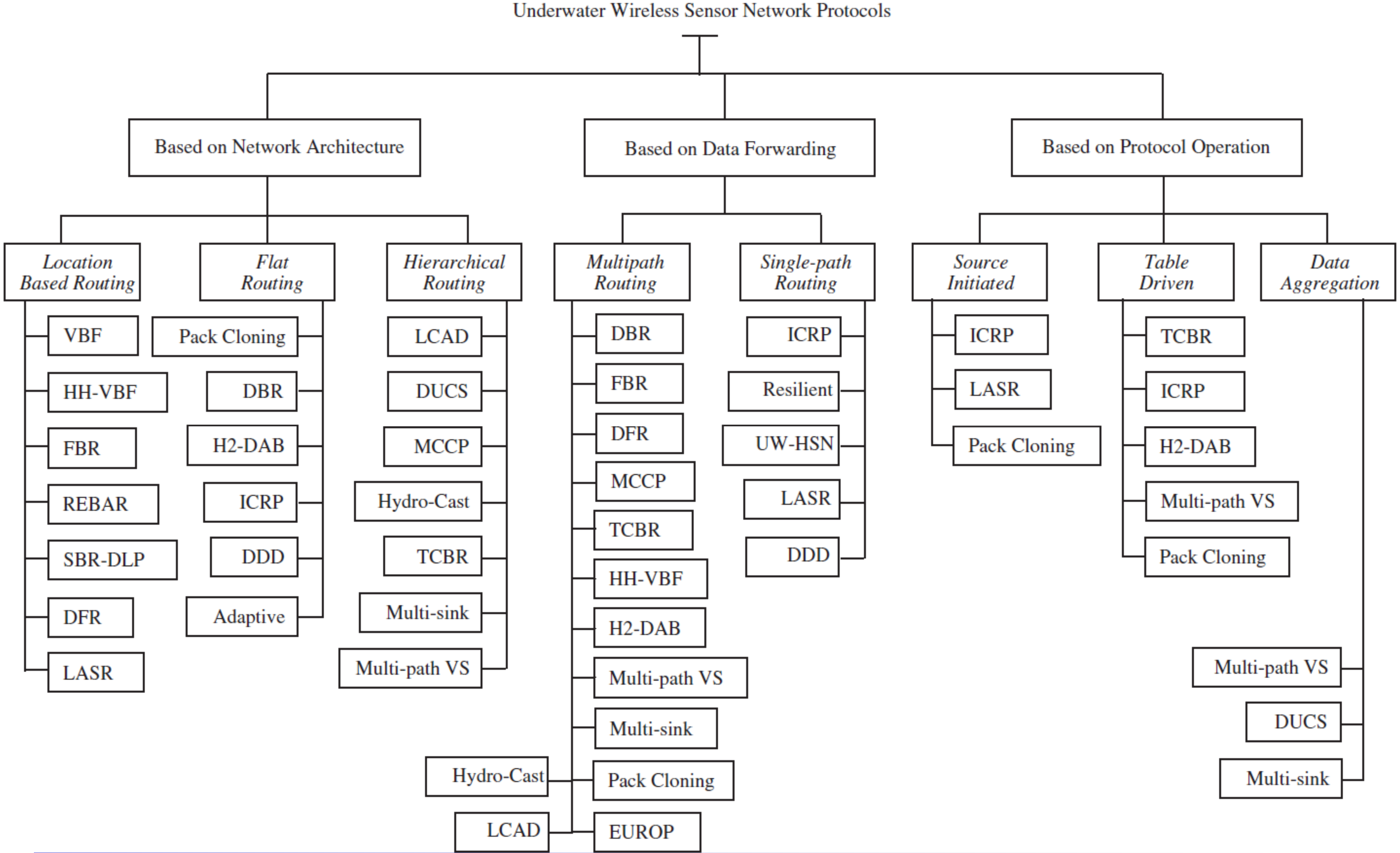
Comparison between terrestrial and underwater wireless sensor networks

Terrestrial WSNs	Underwater WSNs
Most applications require dense deployment	Sparse deployment is preferred not only due to expensive equipment but also in order to cover large monitored areas
Most of the network architectures assume that sensor nodes are stationary so different topologies can be applied	Nodes continue to move 1–3 m/s with water currents, so network cannot be viewed as a fixed topology (Peng et al., 2010)
A network with static nodes considered more stable especially in terms of communication links	Routing messages from or to moving nodes is more challenging not only in terms of route optimization but also link stability becomes an important issue
Generally considered more reliable due to a more matured understanding of the wireless link conditions evolved over years of R&D	Reliability is a major concern due to inhospitable conditions. Communication links face high bit error rate and temporary losses. Fault tolerant approaches are preferred
Nodes are considered moving in 2D space even when they are deployed as ad hoc and as mobile sensor networks	Nodes can move in a 3D volume without following any mobility pattern
Usually the destination is fixed and seldom changes its location. In the event when destination is changes its location, still these movements are predefined	Sinks or destinations are placed on water surface and can move with water current. Due to random water movement, predefined paths are difficult to or cannot be followed.
Deployment affects the performance of the network. Generally, deployment is deterministic as nodes are placed manually so data is routed through pre-determined paths	Non-uniform and random deployment is common. More self-configuring and self-organizing routing protocols are required to handle non-uniform deployment
In most cases, nodes are assumed to be homogenous throughout the network. Networks of this type provide better efficiency in most of the circumstances (Yarvis et al., 2005)	Heterogeneous network is common. Inclusion of heterogeneous set of sensor nodes raises multiple technical issues related to data routing (Shin et al., 2007)
Radio waves are available; nodes can communicate with low propagation delays at speed of light (3×10^8 m/s) (Zhou et al., 2011b)	Acoustic waves replace radio waves (at speed of 1.5×10^3 m/s). Communication speed is decreased from speed of light to speed of sound, results in high propagation delays (five orders of magnitude) (Heidemann et al., 2006). It can be problematic for real-time applications
High data rate, normally in the order of MHz	Low data rate, normally in the order of KHz. Hardly can exceed 40 kb/s at 1 km distance (Stojanovic, 1999). Moreover the attenuation of acoustic signal increases with frequency and range (Lysanov, 1982; Coates, 1989)

Comparison between terrestrial and underwater wireless sensor networks (Cont.)

Increased number of hops during the routing process	*Number of hops depends on depth of the monitoring area* (normally 4–7 hops)
Low energy consumption (Lanbo Liu and Cui, 2008)	High energy consumption due to longer distances (consequence of sparse nodes deployment) and complex signal processing. The power required to transmit may decay with powers greater than two of the distance (Sozer et al., 2000)
Larger batteries can be used and can be replaced or recharged with ease	Battery power is limited and usually cannot be easily replaced or recharged. The routing protocols should adopt a mechanism of power down during the communication and use *minimum retransmission*
Nodes are less error prone and can continue to work for longer time	Nodes are more error prone and can die (due to fouling or corrosion) or leave the working area. More reliable and self recovering routing algorithms are required
Cooperative localization schemes like Time of Arrival (ToA) and Time-Difference-of Arrival (TDoA) are used for GPS-free localization	Techniques like TDoA are not feasible due to unavailability of accurate synchronization in under water (Jun-Hong et al., 2006)
Schemes like receiver-signal strength- index (RSSI) can be used for cooperative localization	RSSI is highly vulnerable to acoustic interferences such as multipath, Doppler frequency spread and near-shore tide noise, and cannot provide accuracy for more than few meters
Automatic Repeat Request (ARQ) techniques are used for the error recovery and packet loss detections	ARQ techniques are inefficient due to large propagation delays, as retransmissions incur excessive latency as well as signaling overheads (Ayaz and Abdullah, 2009)
Forward Error Correction (FEC) techniques are used to increase the robustness against errors	FEC is not easily affordable due to redundant bits at extremely small bandwidth of acoustic communication
GPS waves use 1.5 GHz band. For terrestrial sensor networks these frequencies are supported and GPS facility can be used for localization purpose	Geographical routing is not supported as such high frequencies bands are impractical for UWSNs (Domingo and Prior, 2008). Ultimately, have to rely on distributed GPS-free localization or time synchronization schemes known as cooperative localization

Routing protocols for UWSNs



Vector based forwarding (VBF)

- Problem:
  - Continuous node movements require frequent maintenance and recovery of routing paths, which can be even more expensive in 3d volume.
- Assumption:
  - It is assumed that every node already knows its location, and each packet carries the location of all the nodes involved including the source, forwarding nodes, and final destination.
  - Data packets are forwarded along redundant and interleaved paths from the source to sink, which helps handle the problem of packet losses and node failures.
- Solution:
  - the idea of a vector like a virtual routing pipe is proposed and all the packets are forwarded through this pipe from the source to the destination.
  - Using this idea, not only the network traffic can be reduced significantly but also the dynamic topology can be managed easily.

Vector based forwarding (VBF) (cont.)

Drawback:

●if nodes are much sparsely deployed or become sparser due to some movements

●VBF is very sensitive about the routing pipe radius threshold, and this threshold can affect the routing performance significantly.

●some nodes along the routing pipe are used again and again in order to forward the data packets from sources to the destination, which can exhaust their battery power.

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

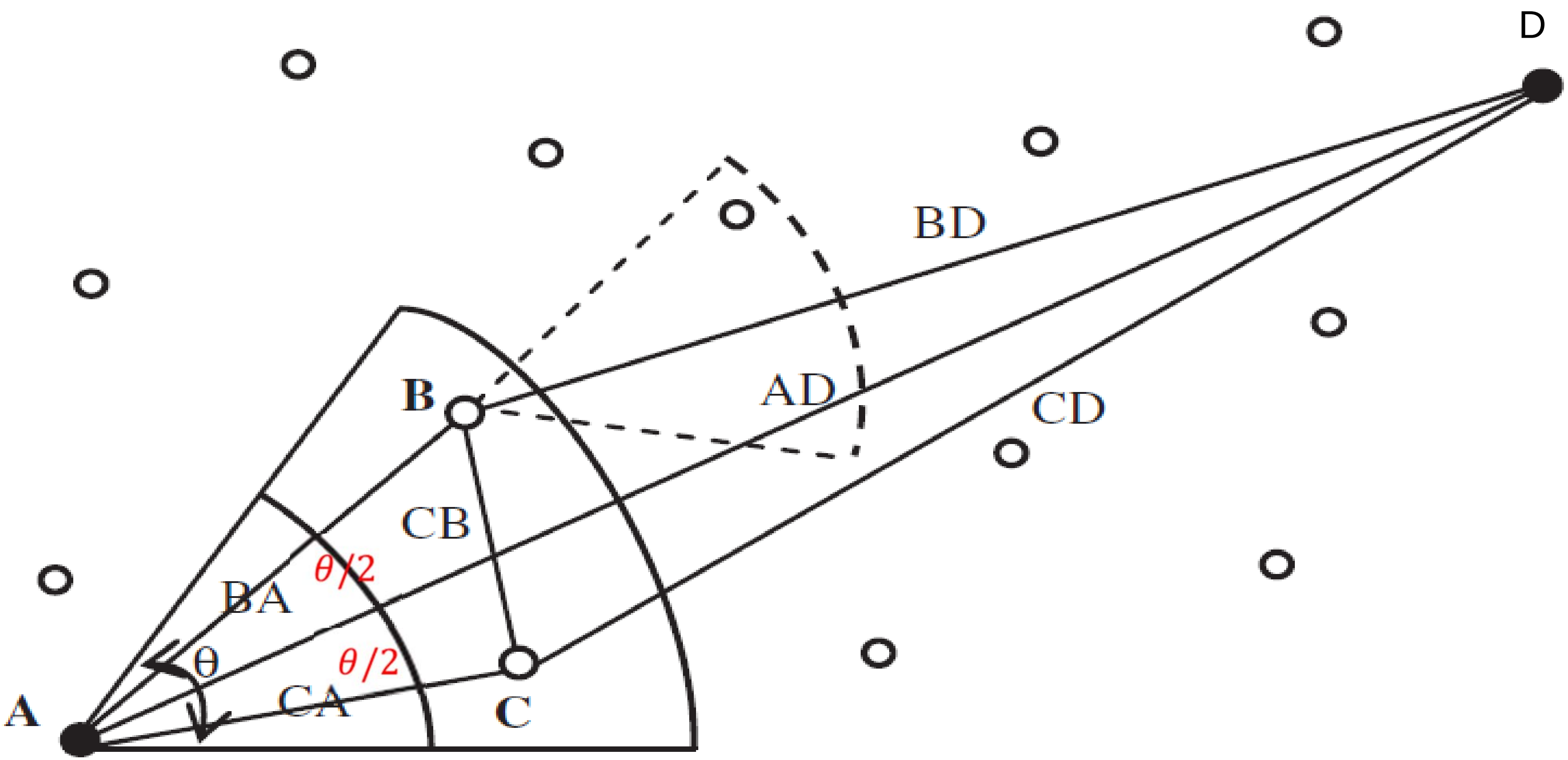
- In order to increase the robustness and overcome these problems
- It defines per hop virtual pipe for each forwarder.
- Every intermediate node makes decision about the pipe direction based on its current location.
- HH-VBF significantly produces better results for packet delivery ratio, especially in sparse areas compared to VBF.
- It has inherent problem of routing pipe radius threshold, which can affect its performance.
- Due to its hop-by-hop nature, HH-VBF produces much more signaling overhead compared to VBF

Focused beam routing (FBR)

- Problem:
  - Without any prior location information of nodes, a large number of broadcast queries can burden the network, which may result in reducing the overall expected throughput.
  - In order to reduce such unnecessary flooding

- Assumption :
  - Their routing technique assumes that every node in the network has its own location information, and every source node knows about the location of the final destination.

Focused beam routing (FBR) (cont.)



Focused beam routing (FBR) (cont.)

- Drawback:
  - if nodes become sparse due to water movements, then it is possible that no node will lie within that forwarding cone of angle.
  - it might be possible that some nodes, which are available as candidates for the next hop, exist outside this forwarding area.
  - when it is unable to find the next relay node within this transmitting cone, it needs to rebroadcast the RTS every time, which ultimately increases the communication overhead, consequently affecting data deliveries in those sparse areas.
  - it assumes that the sink is fixed and its location is already known, which also reduces the flexibility of the network.

Energy-Efficient Routing Protocol (EUROP)

- Problem:
  - Underwater sensor nodes are battery powered and these batteries cannot be replaced easily
  - They tried to reduce large amount of energy consumption by reducing broadcast hello messages.
- The depth of the sensor node can be regulated by adjusting the length of wire that connects the sensor to the anchor.
- The sink on the surface can communicate only with the sensors that belong to shallow water.
- The sensor nodes use RREQ and RREP packets to communicate with each other, and the next hop can be determined by the rule of from deep to shallow and so on.

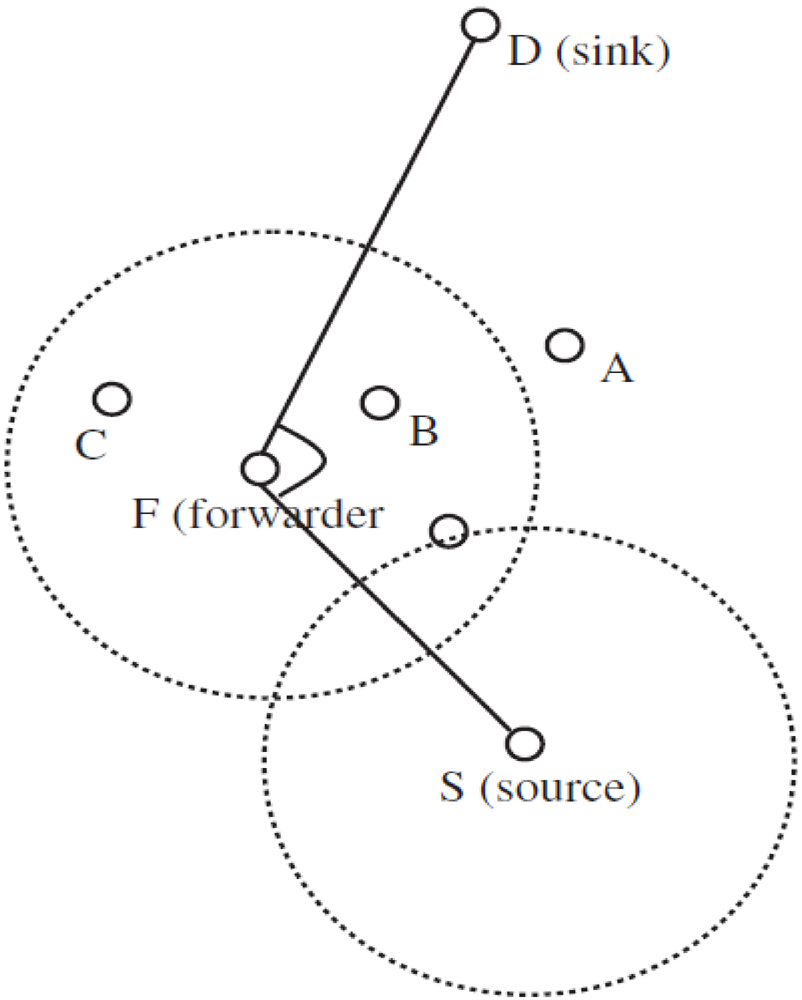
Energy-Efficient Routing Protocol (EUROP)(cont.)

- In terms of communication as many control packets are eliminated by introducing depth sensor inside the sensor node.
- Installing the depth sensor and electronic module is not a simple decision because cost per node will increase and the additional devices will burden the critical node energy, hence decreasing the life of the sensor node.

Directional Flooding-Based Routing(DFR)

- Problem:
  - Dynamic conditions and high packet loss degrade reliability, which results in more retransmissions.
  - There is no guarantee about the data delivery, especially when a link is error prone.
  - In order to increase the reliability
- Assumption:
  - It is assumed that every node knows about its location, the location of one-hop neighbors, and the final destination.
- Solution:
  - Limited number of sensor nodes takes part in this process for a specific packet in order to prevent flooding over the whole network, and forwarding nodes are decided according to the link quality.
  - DFR addresses the void problem by allowing at least one node to participate in the data forwarding process.

Directional Flooding-Based Routing(DFR)(cont.)



Directional Flooding-Based Routing(DFR)(cont.)

- Drawback:
  - More and more nodes will join the flooding of the same data packet, which ultimately increases the consumption of critical network resources.
  - when the sending node cannot find a next hop closer to the sink, the void problem would still be encountered as no mechanism is available

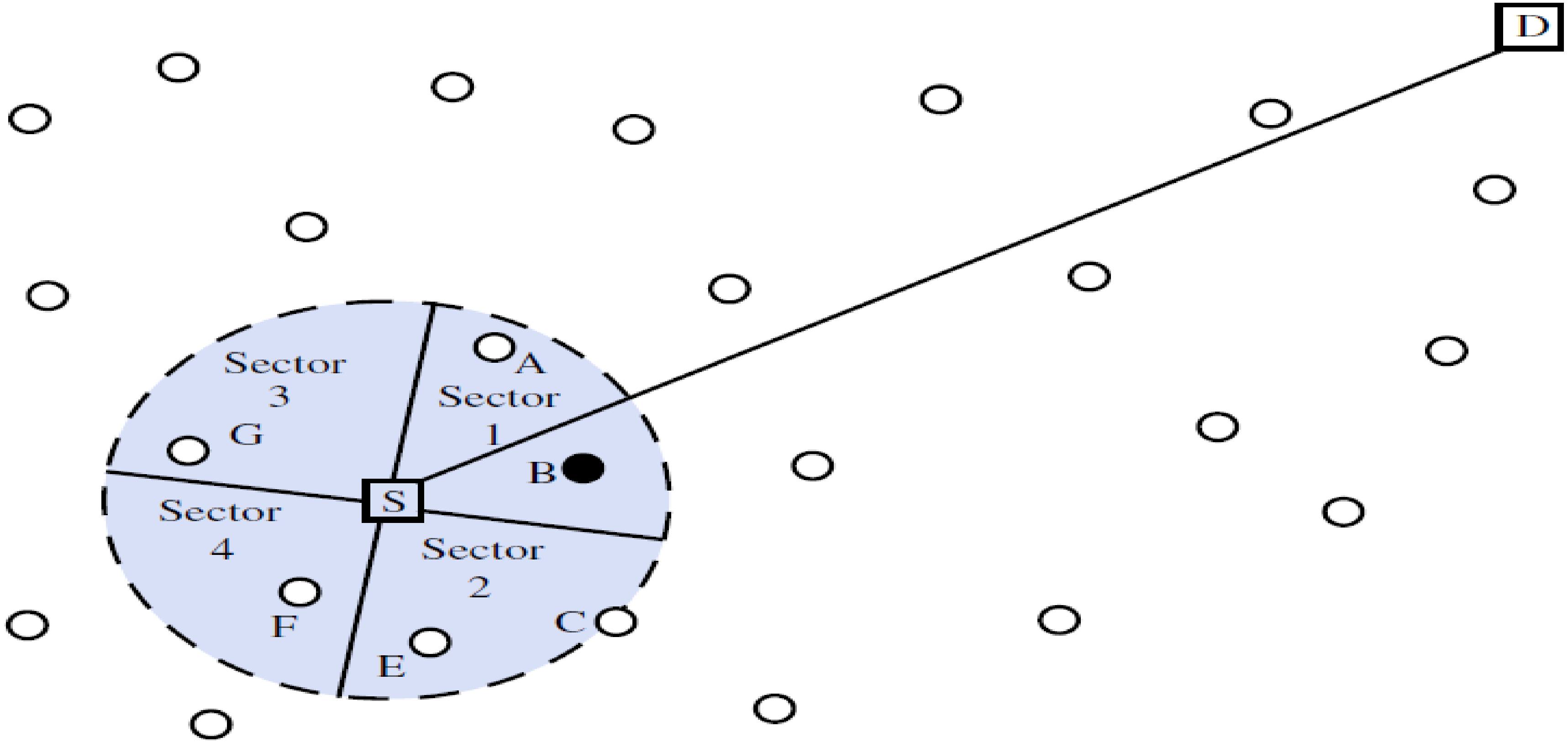
Sector-based Routing with Destination Location Prediction (SBR-DLP)

- Problem:
  - Most of them assume that the destination is fixed and its location is already known (Improvements)
  - It helps route a data packet in a fully mobile underwater acoustic network.
- Assumption:
  - it is assumed that every node knows its own location information and pre-planned movement of destination nodes.

- It will try to find its next hop by broadcasting a Chk_Ngb packet:
  1. current position
  2. packet ID

- The nodes that meet this condition will reply to Source by sending a Chk_Ngb_Reply packet

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



Sector	Candidates	Distance to D	After filtering
1	A, B	500, 480	A, B
2	C	550	
3	–	–	
4	–	–	
		Next relay node	B

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

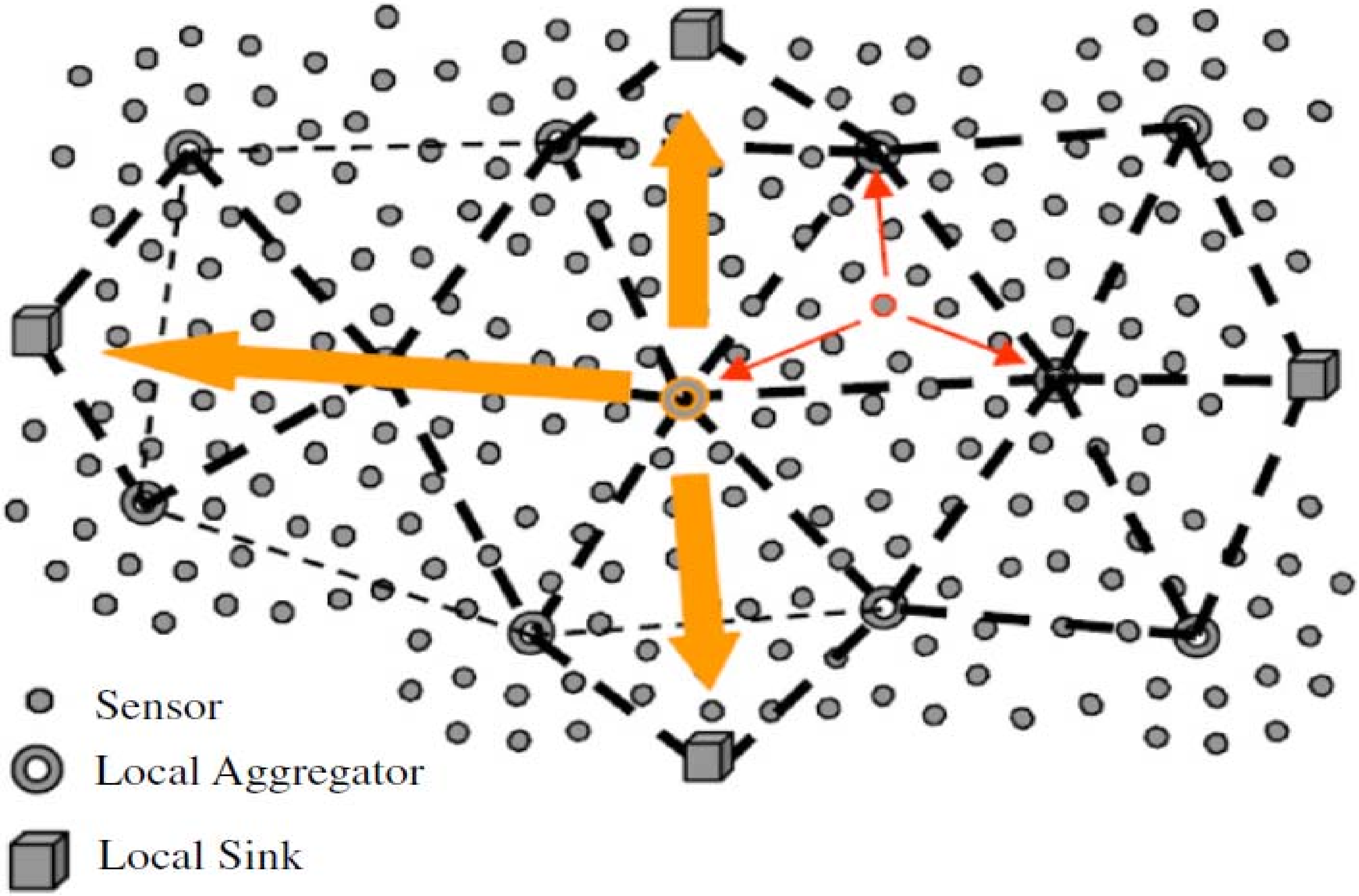
- Benefits:
  - This solves the problem of having multiple nodes acting as relay nodes.
- Drawback:
  - this assumption has two issues:

1. it reduces the flexibility of the network.
2. it is important to note that water currents can deviate the destination node from its scheduled movements.

Multipath virtual sink architecture

- Problem:
  - Sufficient robustness and redundancy must be available in the network in order to ensure that it will continue to work even when a significant portion of the network is not working properly.
- In the proposed architecture, the whole network is divided into clusters of sensor nodes where each cluster has either one or multiple local aggregation points.
- These aggregation points will form a small mesh network that connects to local sinks
- Assumption:
  - Here it is assumed that local sinks are connected via high speed links, possibly RF communications to a network where resources are more than sufficient in order to fulfill the communication needs of different applications.

Multipath virtual sink architecture (cont.)



Multipath virtual sink architecture (cont.)

- Goal:
  - It is to ensure that data packets are received at any one or more of these local sinks, which collectively form a virtual sink.

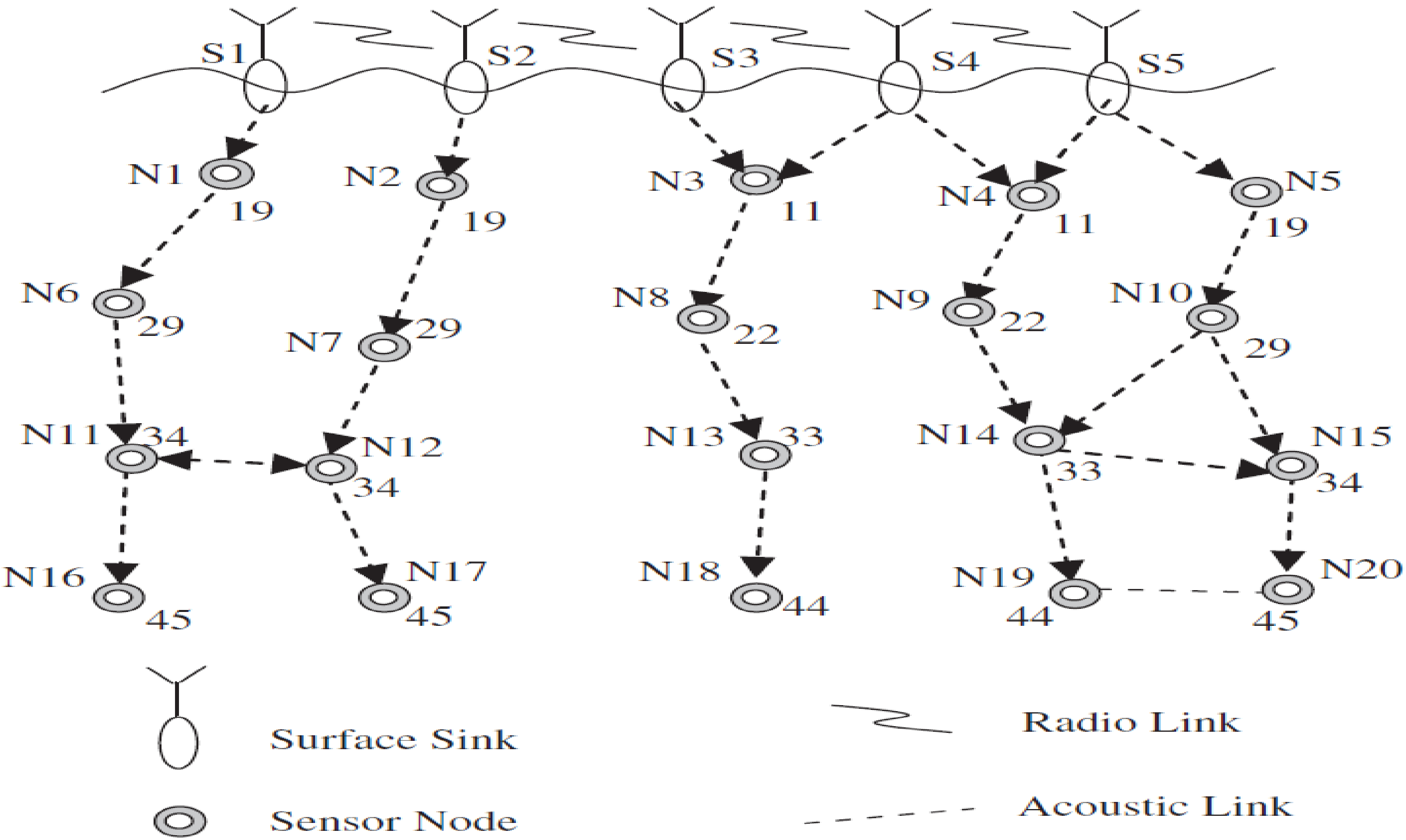
- Benefits:
  - reliability is improved as duplicate packets are delivered towards multiple sinks through multiple paths.

- Drawback:
  - the problem of redundant transmission exists, which can consume critical underwater resources.

Hop-by-Hop Dynamic Addressing Based Routing (H2-DAB)

- The purpose of H2-DAB is to solve the problem of continuous node movements.
- Dynamic addresses are used for sensor nodes in order to solve the problem of water currents, so that sensor nodes will get new addresses according to their new positions at different depth intervals.
- multiple surface buoys are used to collect the data at the surface and some nodes are anchored at the bottom.
- H2-DAB has many advantages:
  - it does not require any specialized hardware
  - no dimensional location information required
  - node movements can be handled easily without maintaining complex routing tables.

Hop-by-Hop Dynamic Addressing Based Routing (H2-DAB) (cont.)



Hop-by-Hop Dynamic Addressing Based Routing (H2-DAB) (cont.)

Drawback:

The problem of multi-hop routing still exists as it is based on multi-hop architecture, where nodes near the sinks drain more energy because they are used more frequently.

Distributed Underwater Clustering Scheme (DUCS)

- Energy efficiency is a major concern for UWSNs because sensor nodes have batteries of limited power
- The whole network is divided into clusters using a distributed algorithm.
- Sensor nodes are organized into local clusters where one node is selected as a cluster head for each.
- All the remaining nodes (non- cluster heads) transmit the data packets to the respective cluster heads
- After receiving the data packets from all the cluster members, cluster head performs signal processing function like aggregation on the received data, and transmits them towards the sink using multi-hop routing through other cluster heads

Distributed Underwater Clustering Scheme (DUCS) (cont.)

- The selection of cluster head is completed through a randomized rotation among different nodes within a cluster in order to avoid fast draining of the battery.

- DUCS completes its operation in two rounds
  - The first round is called setup, where network is divided into clusters
  - The second round, which is called network operation, transfer of data packets is completed.

- DUCS not only achieves high packet delivery ratio, but also considerably reduces the network overhead and continues to increase throughput consequently.

Distributed Underwater Clustering Scheme (DUCS)(cont.)

- First, node movements due to water currents can affect the structure of clusters, which consequently decreases the cluster life.

- Frequent division of sectors can be a burden on the network as the setup phase is repeated many times.

- Second, during the network operation phase, a cluster head can transmit its collected data towards another cluster head only.

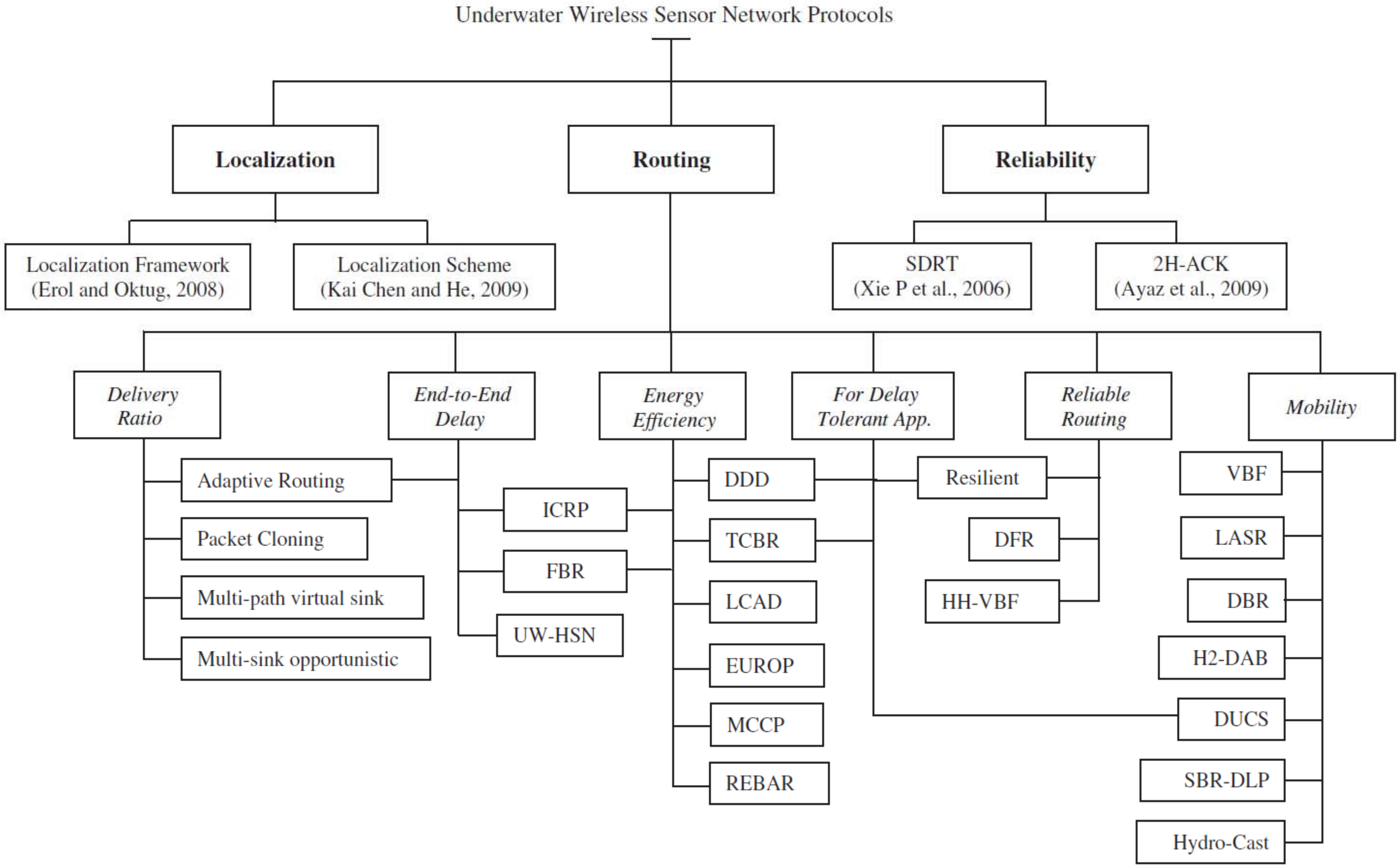
- Water currents can move two cluster head nodes away, where they cannot communicate directly even a few non-cluster head nodes are available between them.

Conclusion

- In summary, it is not possible to conclude that any particular routing technique is the best for all scenarios as each of them has some definite strengths and weaknesses, and suitability for specific situations.

- The field of underwater sensor networks is rapidly growing, and still there are many challenges that need to be explored.

Classification of UWSN protocols according to their proficiency



Comparison of routing protocols based on their characteristics

Protocol/ architecture	Single/ Multiple copies	Hop-by-hop/ end-to-end	Clustered/ single entity	Single/multi-sink	Hello or control packets	Requirements and assumptions	Knowledge required/ maintained	Remarks	Year of pub.
VBF (Xie et al., 2006b)	Multiple	End-to-end	Single-entity	Single-sink	No	Geo. location is available	Whole network	Considered as first geographic routing approach for UWSN	2006
HH-VBF (Nicolaou et al., 2007)	Multiple	Hop-by-hop	Single-entity	Single-sink	No	Geo. location is available	Whole network	Enhanced version of (Xie et al., 2006a), robustness improved by introducing hop-by-hop approach instead of end-to-end	2007
FBR (Jornet et al., 2008)	Single-copy	Hop-by-hop	Single-entity	Multi-sink	Yes	Geo. location is available	Own and sink location	A cross layer location-based approach, coupling the routing, MAC and phy. layers.	2008
DFR (Daeyoup and Dongkyun. 2008)	Multiple	Hop-by-hop	Single-entity	Single-sink	No	Geo. Location is available	Own, 1-hop neighbors and sink info.	A controlled packet flooding technique, which depends on the link quality, while it assumed that, all nodes can measure it.	2008
REBAR (Jinming et al., 2008)	Single-copy	Hop-by-hop	Single-entity	Single-sink	No	Geo. location is available	Own and sink location info.	Similar with (Jornet et al., 2008) but use adaptive scheme by defining propagation range. Water movements are viewed positively	2008
ICRP (Wei et al., 2007)	Multiple	End-to-End	Single-entity	Single-sink	No	n/a	Source to sink information	Control packets of route establishment are carried out by the data packets	2007
DUCS (Domingo and Prior. 2007)	Single-copy	Hop-by-hop	Clustered	Single-sink	Yes	n/a	Own cluster info. (1-hop)	A self-organizing algorithm for delay-tolerant applications, which assumes that sensor nodes always have data to send	2007
Packet Cloning (Peng et al., 2007)	Multiple	Hop-by-hop	Single-entity	Multi-sink	No	n/a	amount and sequence of clones	Unlike controlled broadcast, discernible clones of a data packet are forwarded according to network conditions	2007
SBR-DLP (Chirdchoo et al., 2009)	Single-copy	Hop-by-hop	Single-entity	Single-sink	Yes	Geo. location is available	Own location and sink movement	Similar with (Jinming et al., 2008), but does not assumes that destination is fixed plus it consider entire communication circle instead of single transmitting cone	2009
Multipath Virtual Sink (Seah and Tan 2006)	Multiple	Hop-by-hop	Clustered	Multi-sink	Yes	Network with special setup	Own cluster information	Advantage of multipath routing without creating any contention near the sink	2006
DDD (Magistretti et al., 2007)	Single-copy	Single hop	n/a	n/a	Yes	Network with special setup	About dolphin node presence	A sleep and wake-up scheme, which requires only one-hop transmission	2007

Comparison of routing protocols based on their characteristics(cont.)

DBR (Yan et al., 2008)	Multiple	Hop-by-hop	Single-entity	Multi-sink	No	Nodes with Special H/W	No network information maintained	Considered 1st depth based routing. After receiving data packet, nodes with lower depth will accept and remaining discards	2008
H2-DAB (Ayaz and Abdullah. 2009)	Single-copy	Hop-by-hop	Single-entity	Multi-sink	Yes	n/a	1-hop neighbor's	Short dynamic addresses called Hop-IDs are used for routing, assigned to every node according to their depth positions	2009
HydroCast (Uichin et al., 2010)	Multiple	Hop-by-hop	Clustered	Multi-sink	No	Nodes with special H/W	2-hop neighbor's	Similar with (Yan et al., 2008). Any cast pressure based routing, a subset of forwarder nodes are selected to maximize greedy progress	2010
EUROP (Chun-Hao and Kuo-Feng, 2008)	Single-copy	Hop-by-hop	Single-entity	Single-sink	Yes	Network with special setup	1 hop neighbor's	Nodes are deployed in layers. Water pressure is used for deep to shallow depth based routing	2008
UW-HSN (Ali and	Single-copy	Hop-by-hop	Single-entity	Single-sink	Yes	Network with special setup	1 hop neighbor's	A hybrid approach, RF is used for large and acoustic for small data volumes	2008
TCBR (Ayaz et al., 2010)						Network with special setup	3-hop neighbors	Temporary clusters are formed to balance energy consumption in whole network	
MCCP (Pu et al., 2007)	Single-copy	Hop-by-hop	Clustered	Multi-sink	Yes	n/a	2-hop neighbors	2-hop cluster formation algorithm, but does not support multi-hop communication	2007
Resilient Routing (Dario Pompili and Ian 2006)	Single-copy	End-to-end	Single-entity	Single-sink	No	Nodes with special H/W	Discovered paths to destination	A 2-phase resilient routing. First, primary and backup paths are configured, and then these are repaired if node failure occurs	2006
Multi-Sink Opportunistic (Tonghong, 2008)	Multiple	Hop-by-hop	n/a	Multi-sink	No	Network with special setup	Location of nearer mesh node	A best effort protocol. Data packets are forwarded along redundant and interleaved paths, towards multi-sinks	2008
LCAD (Anupama et al., 2008)	Single-copy	Hop-by-hop	Clustered	Single-sink	Yes	Nodes with special H/W	Own cluster information	Clusters are formed, in order to avoid multi-hop communication	2008
LASR (Carlson et al., 2006)	Single-copy	End-to-end	Single-entity	Single-sink	Yes	Network with special setup	Source to sink information	A DSR modification. Location and link quality awareness is included. Preferred only for small networks	2006
Adaptive Routing (Zheng et al., 2008)	Multiple	Hop-by-hop	Single-entity	Single-sink	Yes	n/a	Own and 1 hop neighbors info	Both, the packet and network characteristics are considered before deciding about the packet forwarding	2008

Homework #12:

1. What's Sector-based Routing with Destination Location Prediction and describe it benefit ?

2. What's protocol Hop-by-Hop Dynamic Addressing Based Routing (H2-DAB) and describe drawback ?