Tree of Wheels: A New Hierarichal and Scalabale Topology for Underwater Sensor Networks

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ABSTRACT
Underwater Wireless Sensor Network (UWSN) is a new network paradigm that is being proposed to explore, monitor and protect the oceans. Some of the Underwater Sensor Nodes applications include oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. The topology and model of communication play crucial roles in UWSNs. Very different topologies for UWSNs have been proposed which some of them are two- dimensional and three dimensional. In this paper we have presented a new topology called tree of wheels (ToWs) that is very suitable for three dimensional (3D) domains like aquatic environments. This topology is hierarchical and scalable which is capable of adapting itself to large numbers of nodes and overcoming distributed localization. With accurate connectivity degree and hierarchal level we can exactly estimate number of nodes which we are going to deploy for this environment. Furthermore, this topology can solve some other problems such as coverage and self-localization. ToWs has some specific properties that we will investigate them and explore its advantage and disadvantage.

Keywords*;*Topology Network, Tree of Wheels (ToWs), Underwater Wireless Sensor Network (UWSN), Wireless Sensor Network (WSN*)*.

1. INTRODUCTION
A wireless sensor network of the type introduced here refers to a group of sensors, or nodes that are linked by a wireless media to perform distributed sensing tasks. Connections between nodes may be formed using such media as infrared devices or radios. Wireless sensor networks will be used for some tasks such as surveillance, widespread environmental sampling, security and health monitoring. They can be used in any environment virtually, even those where wired connections are not possible, where the terrain is inhospitable, or where physical placement is difficult [15].

Here, we have investigated another separated field of WSNs which is known as Underwater Sensor Network or Under Water Sensor Network. Both underwater whatever capitalized Water or not, are as same and used in many related literatures. Underwater Sensor Network (UWSN) is a new branch of Wireless Sensor Network (WSN) that is considerably different from ground base or terrestrial sensor networks in many aspects.

Underwater sensor networks are envisioned to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Multiple unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a need to enable underwater communications among underwater devices. Underwater sensor nodes and vehicles must possess self-configuration capabilities, i.e., they must be able to coordinate their operation by exchanging configuration, location and movement information, and to relay monitored data to an onshore station [16].

The different characteristics of UWSN and trade off between UWSN and WSN have been discussed in many researches. In this paper, we aim to propose a new architecture for very large scale underwater sensor network. In deployment part of sensors topology plays a crucial role in issues such as communication performance, power consumption, network reliability and fault tolerance capabilities. Hence, it is so critical and deployment of sensors in targets environment should be analyzed. For instance it is very important to avoid deploying underwater sensors with single point of failure and bottleneck to improve reliability of our networks in harsh conditions. For this purpose we present enhanced clustering algorithm to build a topological architecture and we try to set some topological features for our proposed model. Given scalability is regarded as the main advantage of clustering algorithms. In this paper we comprise the different clustering algorithm and propose our topology for building scalable UWSN with capability of fault tolerance and end to end delay estimation. Proposed architecture improves inter-cluster connectivity therefore, provides a fault tolerance capability with its virtual links.

Many researchers have been engaged in developing networking solutions for terrestrial wireless ad hoc and sensor networks. Although many recently developed network protocols for wireless sensor networks exist, the unique characteristics of the underwater acoustic communication channel require new efficient and reliable data communication protocols, whose design is affected by many challenges as we listed most important ones here with comparison with ground base wireless sensor networks [27].

UWSNs Challenges in Comparison with WSNs: The propagation delay is five orders of magnitude higher than in electro-magnetic terrestrial channels due to the low speed of sound. The propagation speed of acoustic signals in water is about 1.5 × 103 m/sec, which is five orders of magnitude lower than the radio propagation speed (3×108 m/sec). Furthermor, the available bandwidth of underwater acoustic channels is limited and dramatically depends on both transmission range and frequency. The available acoustic bandwidth depends on the transmission distance due to high environmental noise at low frequencies (lower than 1 kHz) and high-power medium absorption at high frequencies (greater than 50 kHz); only a few kHz may be available at tens of kilometers, and tens of kHz at a few kilometers [4, 29 and 30].

High bit error rates and temporary losses of connectivity (shadow zones) can be experienced and UWSNs are highly dynamic. In a UWSN, the majority of sensor nodes, except some fixed nodes equipped on surface-level buoys, have low or medium mobility due to water current and other underwater activities. From empirical observations, underwater objects may move at the speed of 2-3 knots (or 3-6 kilometers per hour) in a typical underwater condition. This kind of node mobility results in an unstable neighborhood for a node in the network, which is a big challenge for routing protocol design.

UWSNs are highly error-prone. Underwater acoustic communication channels are affected by any factors such as path loss, noise, multi-path, and Doppler spread. All these factors cause high bit-error and delay variance. Thus, communication links in UWSNs are highly error-prone. Moreover, sensor nodes are more vulnerable in harsh underwater environments. Compared with their counterparts on land, underwater sensor networks have a higher node-failure rate and batteries are energy constrained and cannot be recharged easily (solar energy cannot be exploited underwater) [27, 30].

Most impairments of the underwater acoustic channel can be addressed at the physical layer by designing receivers that are capable of dealing with high bit error rates, fading, and the inter-symbol Interference (ISI) caused by multipath. Conversely, characteristics such as the extremely long and variable propagation delays, limited and distance-dependent bandwidth, and temporary loss of connectivity, must be addressed at higher layers [27].

The remainder of this paper is organized as follows: In Section 2, we review related works. In Section 3, we consider those challenges which led us to our model, in section 4 we present our contribution as description of ToWs and in section 5 we introduce some of the topological parameters of this architecture that are used in the underwater environment and finally in last section we draw the main conclusions and our point of view for future works.

2. RELATEDWORK

This section reviews some scalability matter researches and categorizes clustering algorithms proposed in some literatures for WSNs. Different architectures and design goals/constraints have been considered for various presented algorithms of WSNs. At last we summarize a collection of clustering algorithms and topological architectures for WSNs and present classification of the various approaches and our proposed plan with comparison in a summary table.

Topology issues and clustering algorithms have been extensively studied in WSNs and recently in UWSNs. In [10] they proposed In-Network data processing, since sensor nodes might generate significant redundant data, similar packets from transmissions would be reduced. Data aggregation combines data from different source by using different factors such as min, max and average. Some of these functions can be performed either partially or fully in each sensor node with In-network data processing model. It is worth noting that sometimes it may be necessary to assign backup CHs for cluster or rotate the role of being CH among sensors in cluster.

As in [11] researchers discussed, the deployment is either deterministic or self-organizing. In deterministic situations, sensors are manually placed and data is routed through pre-determined paths. In some cases CHs are excluded from sensing duties, in order to avoid depleting their energy rather quickly. As in [7] they review Baker and Ephremides proposed algorithm, Linked cluster algorithm (LCA) is among the early ones on clustering of wireless networks. In LCA focus is mainly on forming an efficient network topology that can handle mobility of nodes. By clustering, CHs are supposed to form a backbone network to which cluster members can connect while they are moving. The objective of the proposed distributed algorithm is to form clusters such that a CH is directly connected to all nodes in its cluster. In [12], Nagpal and Coore proposed CLUBS, an algorithm that forms clusters through local broadcast and converge in a time proportional to the local density of nodes. Basically, cluster formation in CLUBS is based on the following three characteristics:

• Every node in the network must be connected to a cluster.
• Maximum diameter of all clusters in the network should be the same.
• Clusters should support the intra-cluster communication, which means nodes in a cluster must be able to communicate with each others.

The algorithm forms clusters with a maximum of two hops. The algorithm does not terminate unless all nodes in the network join some cluster as a CH or as a follower. Unlike most of the published schemes, the goal of Banerjee and Khuller is to form a multi-tier hierarchical clustering [13]. Fig. 1 illustrates the concept of hierarchy of clusters. A number of cluster's properties such as cluster size and the degree of overlap, which are useful for the management and scalability of the hierarchy, are also considered while grouping the nodes [7, 13].

Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the most popular clustering algorithms for WSNs [14]. It forms clusters based on the received signal strength and uses the CH nodes as routers to the base-station. All the data processing such as data fusion and aggregation are local to the cluster. LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. Initially a node decides to be a CH with a probability of p and broadcasts its decision. Each non-CH node determines its cluster by choosing the CH that can be reached using the least communication energy. DWEHC and HEED are other models which are similar in many ways; every node in the network participates in the clustering process, they do not make any assumption about the network size and consider energy reserve in CH selection [7].

3. DEPLOYMENT CHALLENGES

Management and Scalability are two issues which considered together. The sensors are expected to be deployed randomly in the area of interest by a relatively uncontrolled means, e.g. dropped by a helicopter in order to collectively form a network in an ad-hoc manner. Given the vast area to be covered, the short lifespan of the battery-operated sensors and the possibility of having damaged nodes during deployment, large population of sensors are expected in most WSNs applications. It is envisioned that hundreds or even thousands of sensor nodes will be involved. Designing and operating of such large size network would require scalable architectural and management strategies. Therefore it is so important to avoid designing the network topology with single points of failure that makes whole of the network goes down. Since the capacities of the underwater channels are limited, it is very important that set up the network topology such a way there is not any communication bottleneck is introduced. These networks should operate unattended for long period of times. Their task is sensing the environment and reports their detection to a single or few special nodes referred to as sinks.

A crucial aspect of UWSN is energy saving to prolong the network lifetime. On the other hand, equally fundamental issue is to avoid loops in packet routing. For supporting scalability problems, nodes are often grouped into disjoint and mostly non-overlapping clusters. Sometimes these clusters are connected directly to surface buoys or in hierarchal models via other clusters as their parents.

In ground base WSN several topologies concerning with pre-configured sensors, such as Mesh, Hexagonal, Pyranet or de Bruijn, were proposed by some researchers [21]. The common flaws among them are that, the number of neighbors a node could have is so scarce as to significantly affect their fault-tolerance capabilities, and a longer network diameter often introduces a considerable transmission delay, but because of limitations we do not have any pre-configured topology for UWSNs so far. There is a gap between topological architecture and sensor deployment for UWSNs. As we know usually most of the ground base sensor network deployments are two dimensional, therefore we do not need to hierarchal topology but because we should work on depth of the water, employing the hierarchal topologies are inevitable.

During the design phase of a large-scale sensor network, the designer should decide on the number of clusters, and considerably on the optimum locations and numbers of the sink nodes. Then the number of sensors which obey one leader as cluster head should be estimated. In [9], they called this problem as "multiple sink sensor network design problem" when they want to calculate relation between sink and other sensors at last they tried to provide some solutions.

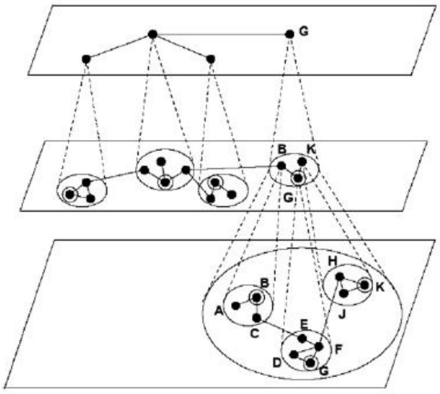

Figure 1. An Example of a multi-tier hierarchical clustering from [13]

PROPOSED ARCHITECTURE

Here, we propose efficient and scalable network architecture, named as ToWs, for pre-configured WSNs which can adapt itself to randomly deployment of sensors. In ToWs, sensor nodes are first deployed as a Tree model and then the children connect to each other like a wheel with virtual links but multi hop channel. In each wheel they select their CH by using ranking algorithm. This algorithm can be one of previous discussed algorithms or one simple algorithm.

ToWs Definition: A ToWs With amplitude T and level L denoted by a ToWs (K, L), can be hierarchal constructed. A (K, 1) ToWs is a tree that its children are connected to each other like a Ring. Furthermore, there is a center node (CN) that children are connected to it. Each CN with its brothers are one cluster. K is the number of children. Thus number of nodes within each cluster is equal to K. For instance, (4, 2)

ToWs has 21 nodes like a normal tree with 4 children and its network degree (ND) is 8 because each CN has K-1 extra edges to its brothers and with 1 channel is connected to its father. Similarly it is connected to its children (in contrast with normal Tree that each node just is connected to its father and children). Each node in (K, 1) ToWs is labeled from d1 to d (k). Similarly, each (K, C) ToWs has k sub networks of (K, C) ToWs, which labeled with index dc where 2 < c < L. figure 2 shows the ToWs of level 1.

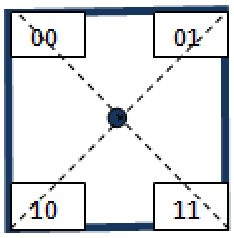

Figure 2. The Tree of Wheels in level 1 with 5 nodes

Therefore each node has unique address. They can be constructed by grouping basic building blocks. In figure 4 we have a (5, 1) ToWs as one cluster with its cluster head which places in center of cluster.

For larger networks and in order to have more distributed networks you can increase the number of K, for instance you can have a ToWs with 10 nodes in each cluster, therefore it is an adaptive topology with consideration to our constraints in sensor networks. In figure 3, we see a cluster with 8 nodes and probable multi hop connection between follower nodes. In this figure white node with black circumference is cluster head. The blue sensor cannot communicate with CH directly, therefore connected to CH with multi-hop channel which we named this links of communication as Virtual Link (VL). These kinds of VLs are made up of some multi-hop channels, with number of hops limitation. In each cluster, each node is connected to its neighbors with direct links or multi-hop links but all of connection between brother nodes is virtually. The black node in figure 3 is peak of one cluster. In each level peak node is a simple follower or cluster head in previous level. This way of hierarchy makes it easy to deploy large number of sensors in a topological figure with high degree of connectivity. At end of this paper in figure 5, we draw ToWs (5.3) as clear example of distribution of this topology. In this figure we can observe the distribution and deployment of large number of sensors are depends on number of K that we preferred at setup time.

Selection of CH in our proposed architecture is randomly or pre-assign. It has high cluster overlapping which is not interesting in this point of view, but because of its hierarchal characteristic and balanced clustering, this characteristic is negligible. Specific diameter and balanced clustering make it noticeable in other presented approaches. Table1 compares related works discussed in previous section with ToWs in different approaches.

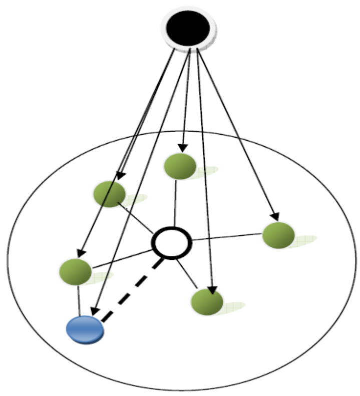

Figure 3. Cluster with seven direct nodes and one outlying follower

TOPOLOGICAL PERFORMANCE

In this section we calculate some normal parameters for our proposed network. As you see, ToWs is made up of clusters that the number of clusters in each level is equal to K+1. We illustrate one cluster of ToWs (5) in figure 5. So each cluster acts independent as an Autonomous System (AS). So, it can driven most of the routing protocol for each AS without any congestion and interference.

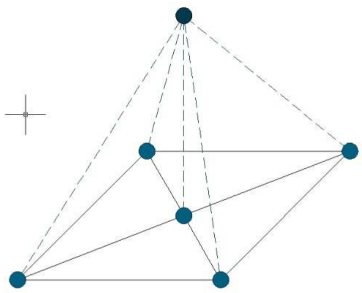

Figure 4. ToWs (5, 1) cluster

One way for counting the number of nodes (Number of Nodes) for regular ToWs is counting of clusters. Another way is using its tree base characteristic. We define K as number of nodes in each base graph, and L as its level, so we have:

$$NN = \sum_{L=0}^{n} k^L$$

Another parameter which is important is network degree (ND):

$$ND = 2K$$

And the next one is Diameter (D) that can be defined in this way: Maximum distance between two nodes within a network. In normal case:

$$D = 2L$$

If k = 4:

$$D = 2L - 1$$

As you see, difference between ToWs and normal tree which its children are connected to each others. But if you have large scale network you will see that these connections edge can be more significant. Orderly designing can make us to have specific diameter, which is very better than an unknown diameter. You will need to some broadcasting or flooding of packets. It can help you to estimate the number of hops for worst cases. Most of the time, there is no specific topology for UWSNs. In the best case if we consider Tree-base topology for UWSNs, it is less scalable than ToWs network. If we need a centralize network we can decrease number of K otherwise we can increase K to reach to distributed network with more efficient connections.

Topology represents the network sensing ability, the connectivity of topology should as well maintained as a necessity for the successful information deliver, including queries, sensing data and control messages [23]. Our model is distributed and adaptive. ToWs can help protocol designers to imagine a regular network with recursive structure. It adapts itself to mobile and changeable network. According to the situation it can increase the number of its node in first level to last level. Making improvement on ToWs in any field could be another interesting research topic for researchers. At present, we are working on self-configuration algorithm for this network. One of our future approaches is to solve the centralizing and overhead problems in the nodes which are the nearest to surface. For routing protocol on ToWs three main challenges are as follow: Energy efficient (minimum energy consumption for certain routing request), Lifetime-aware (avoid unevenly energy distribution among sensor nodes), and Choosing the cluster head (with ranking or depends on location of sensors).

VI. CONCLUSION

In this paper, we briefly examined the architectural and system clustering design issues for UWSNs. We believe that combination of scalable architecture with clustering algorithm improve the performance of large scale underwater sensor networks. Estimation of number of nodes and hops would be a main advantage of proposed scalable architecture in order to find new approaches for fault tolerance, power-saving mechanisms, scalability and efficient resource management which are the major challenges for UWSN designs. The unique features of our scalable architecture raise new challenges, but they also create opportunities to explore. In order to extend the lifetime of UWSNs, power efficiency should be pursued at both the node and network levels. Moreover, an accurate lifetime estimation model is necessary for UWSN designs and can help determine important design parameters to prolong lifetime. We aim to remove the gap between topological architecture and randomly deployment with proposing an adaptive topology for UWSNs which is estimable and computable. The ToWs can be help for designer of protocol to imagine a regular network with hierarchal structure. For each number of deployment it is very flexible with changing number of K. It adapts itself to mobile and changeable network and with balanced clustering and hierarchal architecture with high degree of inter-cluster connectivity makes it reliable architecture for underwater sensor networks.

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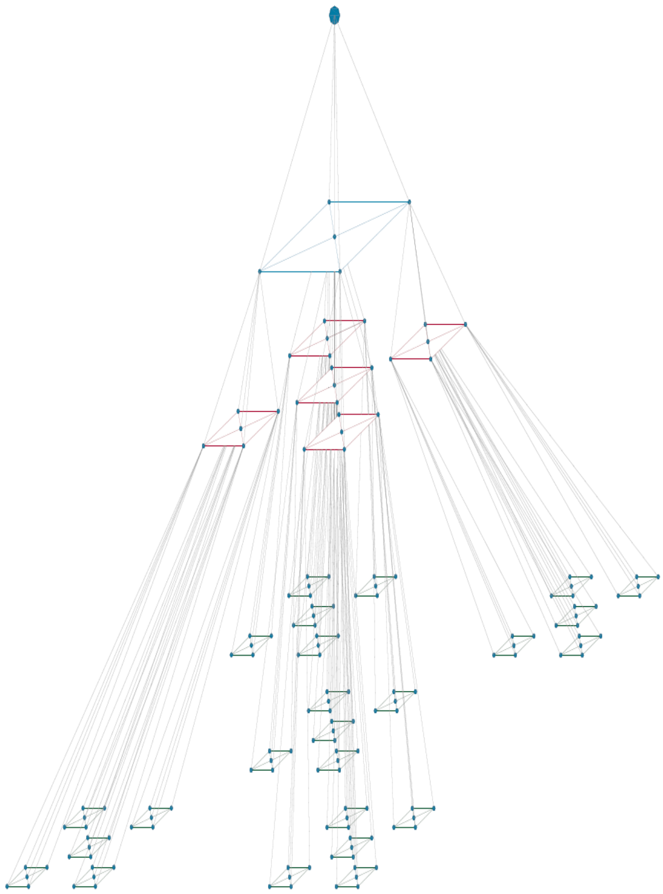

Figure 5. ToWs (5.3) with all possible connections