Thesis for the Degree of Master of Engineering

# A Study on Sensing Efficient Sensor Movement Algorithm for the Underwater Wireless Sensor Networks



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# 수중센서네트워크를 위한 인식 효율적인 센서 이동 알고리즘 연구

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# 이종근의 공학석사 학위논문을 인준함

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A thesis

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# A Study on Sensing Efficient Sensor Movement Algorithm for the Underwater Wireless Sensor Networks

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**Abstract**

Recently, there has been a growing interest in monitoring the marine environment for scientific exploration, commercial exploitation and coastline protection. One of ideal methods for this type of extensive monitoring is a networked underwater wireless sensor distributed system, referred to as an Underwater Wireless Sensor Networks (UWSNs). The UWSNs consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area.

Underwater sensor nodes (Sensors or Vehicles) will find applications in oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Moreover, unmanned or autonomous underwater vehicles, equipped with sensors, will enable the exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Underwater acoustic networking is the enabling technology for these applications.

Many researchers are currently engaged in developing networking solutions for terrestrial wireless and sensor networks and ad hoc networks. Since UWSNs have more challenge than terrestrial WSNs, adopting sensing coverage and communication capacity schemes is very important. However, due to the different nature of the underwater environment and applications, there are several drawbacks with respect to the suitability of the existing solutions for terrestrial WSNs. Moreover because UWSNs are respectively sparse than terrestrial WSNs and have a short sensing range, sensor movement scheme is also important as much sensing coverage and communication capacity schemes.

In this thesis, we investigate how the sensor's communication capacity is influenced by the sensing coverage and review the state of precious routing and data aggregation researches in terrestrial WSNs in order to apply those to UWSNs. Then, we adopt a Queen and Knapsack problem approach to deploy the underwater sensor nodes, calculate sensor dispersion and sensing efficiency factor for UWSNs and suggest an enhanced sensor movement algorithm that considers the dispersion balancing once the sensing is occurred. We simulate the proposed enhanced sensor movement algorithm in the environment of UWSNs. The simulation results show that the proposed algorithm has better efficiency than the existing sensor deployment algorithm.

# Ⅰ. Introduction

The largely unexplored vastness of the ocean, covering about two-thirds of the surface of Earth, has fascinated humans for long time. Its currents, chemical composition, and ecosystems are all highly variable as a function of space and time.

Recently, there has been a growing interest in monitoring the marine environment for scientific exploration, commercial exploitation and coastline protection. Especially since our country is a peninsula, the study of ocean environment is more important.

The ideal method for this type of extensive monitoring is a networked underwater wireless sensor distributed system, referred to as an Underwater Wireless Sensor Networks (UWSNs) [1].

A distributed and scalable UWSNs provides a promising solution for efficiently exploring and observing the ocean which operates under the following constraints:

- Unmanned underwater exploration: Underwater condition is not suitable for human exploration. High water pressure, unpredictable underwater activities, and vast size of water area are major reasons for un-manned exploration.
- Localized and precise knowledge acquisition: Localized exploration is more precise and useful than remote exploration because underwater

environmental conditions are typically localized at each venue and variable in time. Using sonar or other remote sensing technology may not acquire adequate knowledge about physical events happening in the volatile underwater environment.

- Tetherless underwater networking: While the current tethered technology allows constrained communication between an underwater venue and the ground infrastructure, it incurs significant cost of deployment, maintenance, and device recovery to cope with volatile undersea conditions.
- Large scale underwater monitoring: Traditional underwater exploration relies on either a single high-cost underwater device or a small-scale underwater network. Neither existing technology is suitable to applications covering a large area. Enabling a scalable underwater sensor network technology is essential for exploring a huge underwater space.

By deploying distributed and scalable wireless sensor networks in 3-dimensional underwater space, each underwater sensor can monitor and detect environmental events locally. Such mission can be also accomplished with fixed position sensors.

An UWSNs (consist of sensor nodes equipped with the small battery powered device with limited energy resources) consists of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. Hence, the energy efficiency is a key design issue that needs to be enhanced in order to improve the lifetime of the network.

To realize underwater sensor network applications, UWSNs have to adopt many of the tools that have been developed for terrestrial sensor networks: wireless communication, low-power hardware, energy conserving network protocols, time synchronization and localization, and programming abstractions and so on. However, some of the techniques are fundamentally different.

Especially because UWSNs are respectively sparse than terrestrial WSNs and have a short sensing range, sensor movement scheme is also important as much sensing coverage and communication capacity schemes.

In this thesis, we investigate how the sensor's communication capacity is influenced by the sensing coverage and review the state of precious routing and data aggregation researches in terrestrial WSNs in order to apply those to UWSNs. Then, we adopt a Queen and Knapsack problem approach to deploy the underwater sensor nodes, calculate sensor dispersion and sensing efficiency factor for UWSNs and suggest an enhanced sensor movement algorithm that considers the dispersion balancing once the sensing is occurred. The suggested enhanced sensor movement algorithm improves the sensing coverage by applying the threshold region that is decided as a distance between a sensor and sensing target. We simulate the proposed enhanced sensor movement algorithm in the environment of UWSNs. The simulation results show that the proposed algorithm has better efficiency than the existing sensor deployment algorithm.

The outline of the thesis is organized as follows. In Section II, we discuss the related work and analyze differences between terrestrial WSNs and UWSNs. In Section III, we propose a network model for an UWSNs and an enhanced sensor movement algorithm that considers a threshold region. In Section IV, we describe the simulation results. Finally we conclude this thesis in Section V.

# Ⅱ. Background

## 1. Underwater Wireless Sensor Networks

### 1.1 Underwater Wireless Sensor Network Architecture

For the past several centuries, the ocean has played an increasingly important role in transportation and military campaign. In emergent event investigations, e.g., for marine incidents (especially involved with chemical pollution and oil spill) and military demands (for example submarine attacks and submarine hunting), the state-of-the-art in communication technology has significantly surpassed the state-of-the-art of physical investigation in regard to effectiveness and efficiency.

Since underwater monitoring missions can be extremely expensive due to the high cost involved in underwater devices, it is important that the deployed network be highly reliable, so as to avoid failure of monitoring missions due to failure of single or multiple devices. For example, it is crucial to avoid designing the network topology with single points of failure that could compromise the overall functioning of the network. And the network capacity is also influenced by the network topology. Since the capacity of the underwater channel is severely limited, it is very important to organize the network topology such a way that no communication bottlenecks are introduced.

There are several different architectures for Underwater Acoustic Sensor

Networks, depending on the application [2]:

Two-dimensional UWSNs for ocean bottom monitoring. These are constituted by sensor nodes that are anchored to the bottom of the ocean. Typical applications may be environmental monitoring, or monitoring of underwater plates in tectonics.

Three-dimensional UWSNs for ocean column monitoring. These include networks of sensors whose depth can be controlled, and may be used for surveillance applications or monitoring of ocean phenomena (ocean bio-geo-chemical processes, water streams, pollution, etc).

Three-dimensional networks of Autonomous Underwater Vehicles (AUVs). These networks include fixed portions composed of anchored sensors and mobile portions constituted by autonomous vehicles.

1) Two-dimensional Underwater Sensor Networks

A reference architecture for two-dimensional underwater networks is shown in Figure 1. A group of sensor nodes are anchored to the bottom of the ocean with deep ocean anchors. Underwater sensor nodes are interconnected to one or more underwater sinks (uw-sinks) by means of wireless acoustic links. Uw-sinks, as shown in Figure 1, are network devices in charge of relaying data from the ocean bottom network to a surface station. To achieve this objective, uw-sinks are equipped with two acoustic transceivers, namely a vertical and a horizontal transceiver. The horizontal transceiver is used by the uw-sink to communicate with the sensor nodes in order to: (i) send commands and configuration data to the sensors (uw-sink to sensors); (ii) collect monitored data (sensors to uw-sink). The vertical link is used by the uw-sinks to relay data to a surface station. In deep water applications, vertical transceivers must be long range transceivers as the ocean can be as deep as 10 *km*. The surface station is equipped with an acoustic transceiver that is able to handle multiple parallel communications with the deployed uw-sinks. It is also endowed with a long range RF and/or satellite transmitter to communicate with the onshore sink (os-sink) and/or to a surface sink (s-sink).

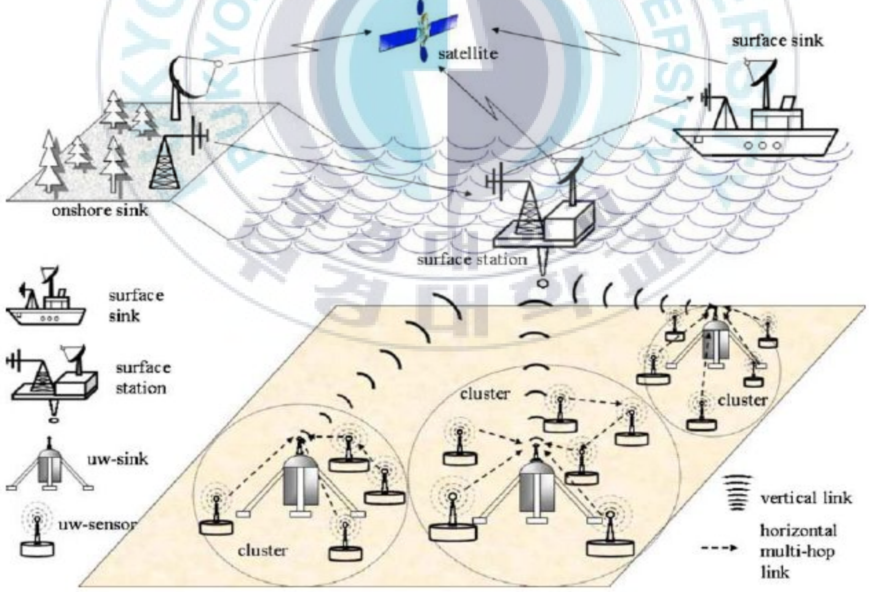



Figure 1. Two-dimensional UWSNs architecture

Sensors can be connected to uw-sinks via direct links or through multi-hop paths.

2) Three-Dimensional Underwater Sensor Networks

Three dimensional underwater networks are used to detect and observe phenomena that cannot be adequately observed by means of ocean bottom sensor nodes, i.e., to perform cooperative sampling of the 3D ocean environment. In three-dimensional underwater networks, sensor nodes float at different depths in order to observe a given phenomenon.

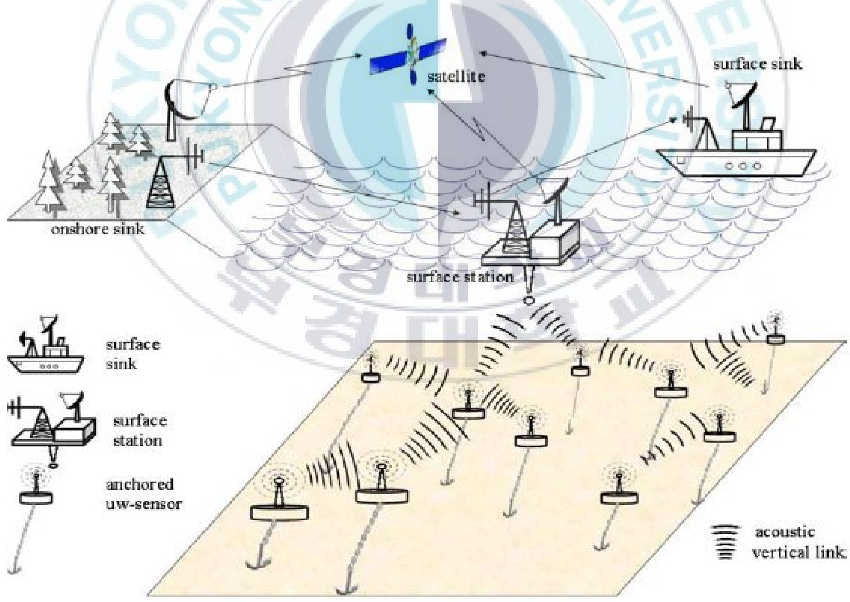



Figure 2. Three-dimensional UWSNs architecture

One possible solution would be to attach each uw-sensor node to a surface buoy, by means of wires whose length can be regulated so as to adjust the depth of each sensor node [3]. However, although this solution allows easy and quick deployment of the sensor network, multiple floating buoys may obstruct ships navigating on the surface, or they can be easily detected and deactivated by enemies in military settings. Furthermore, floating buoys are vulnerable to weather and tampering or pilfering. For these reasons, a different approach can be to anchor sensor devices to the bottom of the ocean. In this architecture, depicted in Figure 2, each sensor is anchored to the ocean bottom and equipped with a floating buoy that can be inflated by a pump. The buoy pushes the sensor towards the ocean surface. The depth of the sensor can then be regulated by adjusting the length of the wire that connects the sensor to the anchor, by means of an electronically controlled engine that resides on the sensor. A challenge to be addressed in such architecture is the effect of ocean currents on the described mechanism to regulate the depth of the sensors.

Many challenges arise with such an architecture that needs to be solved in order to enable 3D monitoring, including:

- Sensing coverage: Sensors should collaboratively regulate their depth in order to achieve 3D coverage of the ocean column, according to their sensing ranges. Hence, it must be possible to obtain sampling of the desired phenomenon at all depths.
- Communication coverage: Since in 3D underwater networks there may be no notion of uw-sink, sensors should be able to relay information to the surface station via multi-hop paths. Thus, network devices should coordinate their depths in such a way that the network

topology is always connected, i.e., at least one path from every sensor to the surface station always exists.

Sensing and communication coverage in a 3D environment are rigorously investigated in [4]. The diameter, minimum and maximum degree of the reachability graph that describes the network are derived as a function of the communication range, while different degrees of coverage for the 3D environment are characterized as a function of the sensing range. These techniques could be exploited to investigate the coverage issues in UWSNs.

3) Sensor Networks with Autonomous Underwater Vehicles

AUVs can function without tethers, cables, or remote control, and therefore they have a multitude of applications in oceanography, environmental monitoring, and underwater resource study. Previous experimental work has shown the feasibility of relatively inexpensive AUV submarines equipped with multiple underwater sensors that can reach any depth in the ocean [5]. Hence, they can be used to enhance the capabilities of underwater sensor networks in many ways. The integration and enhancement of fixed sensor networks with AUVs is an almost unexplored research area which requires new network coordination algorithms such as:

- Adaptive sampling: This includes control strategies to command the mobile vehicles to places where their data will be most useful. This approach is also known as adaptive sampling and has been proposed in pioneering monitoring missions such as [6]. For example, the density of sensor nodes can be adaptively increased in a given area when a higher sampling rate is needed for a given monitored phenomenon.

- Self-configuration: This includes control procedures to automatically detect connectivity holes due to node failures or channel impairment and request the intervention of an AUV. Furthermore, AUVs can either be used for installation and maintenance of the sensor network infrastructure or to deploy new sensors. They can also be used as temporary relay nodes to restore connectivity.

One of the design objectives of AUVs is to make them rely on local intelligence and less dependent on communications from online shores. In general, control strategies are needed for autonomous coordination, obstacle avoidance and steering strategies. Solar energy systems allow increasing the lifetime of AUVs, i.e., it is not necessary to recover and recharge the vehicle on a daily basis. Hence, solar powered AUVs can acquire continuous information for periods of time of the order of months [7].Several types of AUVs exist as experimental platforms for underwater experiments. Some of them resemble small-scale submarines.

Others are simpler devices that do not encompass such sophisticated capabilities. For example, drifters and gliders are oceanographic instruments often used in underwater explorations. Drifter underwater vehicles drift with local current and have the ability to move vertically through the water column. They are used for taking measurements at preset depths [8].

Underwater gliders [9] are battery powered autonomous underwater vehicles that use hydraulic pumps to vary their volume by a few hundred cubic centimeters in order to generate the buoyancy changes that power their forward gliding. When they emerge on the surface, global positioning system (GPS) is used to locate the vehicle. This information can be relayed to the onshore station while operators can interact by sending control information to the gliders. Depth capabilities range from 200 m to 1500 m while operating lifetimes range from a few weeks to several months. These long durations are possible because gliders move very slowly, typically 25 cm/s (0.5 knots). In [10], a control strategy for groups of gliders to cooperatively move and reconfigure in response to a sensed distributed environment is presented. The proposed framework allows preserving the symmetry of the group of gliders. The group is constrained to maintain a uniform distribution as needed, but is free to spin and possibly wiggle with the current [11].

## 1.2 Applications for UWSNs

We have just described the UWSNs architectures. And there are the numerous applications for UWSNs. Table 1 summarizes Applications for UWSNs.

Table 1. Applications for underwater wireless sensor networks

| Applications | Characteristic |
|---|---|
| Ocean sampling networks | Networks of sensors and AUVs can perform synoptic, cooperative adaptive sampling of the 3D coastal ocean environment [12].<br>Experiments demonstrated the advantages of bringing together sophisticated new robotic vehicles with advanced ocean models to improve the ability to observe and predict the characteristics of the oceanic environment [6]. |
| Environmental monitoring | UWSNs can perform pollution monitoring (chemical, biological) [13].<br>Monitoring of ocean currents and winds, improved weather forecast, detecting climate change, under-standing and predicting the effect of human activities on marine ecosystems, biological monitoring [14]. |
| Undersea explorations | UWSNs can help detecting underwater oilfields or reservoirs, determine routes for laying undersea cables, and assist in exploration for valuable minerals. |
| Disaster prevention | UWSNs that measure seismic activity from remote locations can provide tsunami warnings to coastal areas [15], or study the effects of submarine earthquakes (seaquakes). |
| Assisted navigation | Sensors can be used to identify hazards on the seabed, locate dangerous rocks or shoals in shallow waters, mooring positions, submerged wrecks, and to perform bathymetry profiling. |
| Distributed tactical surveillance | AUVs and fixed underwater sensors can collaboratively monitor areas for surveillance, reconnaissance, targeting and intrusion detection systems [3]. |
| Mine reconnaissance | The simultaneous operation of multiple AUVs with acoustic and optical sensors can be used to perform rapid environmental assessment and detect mine-like objects. |

## 1.3 Analysis of Underwater Communication Environment

Acoustic communications are the typical physical layer technology in underwater networks. In fact, radio waves propagate at long distances through conductive sea water only at extra low frequencies (30-300 Hz), which require large antennae and high transmission power. Moreover, transmission of optical signals requires high precision in pointing the narrow laser beams. Thus, links in underwater networks are based on acoustic wireless communications [16].

Underwater acoustic communications are mainly influenced by path loss, noise, multi-path, doppler spread, and high and variable propagation delay. All these factors determine the temporal and spatial variability of the acoustic channel, and make the available bandwidth of the underwater acoustic channel limited and dramatically dependent on both range and frequency.

Hereafter we analyze the factors that influence acoustic communications in order to state the challenges posed by the underwater channel for UWSNs. The factors that influence acoustic communications in UWSNs are shown as table 2.

Table 2. The factors that influence acoustic communications in UWSNs

<table>
<tr><th colspan="2">Factors</th><th>Characteristics</th></tr>
<tr><td rowspan="2">Path loss</td><td>Attenuation</td><td>This mainly provoked by absorption due to conversion of acoustic energy into heat. The attenuation increases with distance and frequency.</td></tr>
<tr><td>Geometric spreading</td><td>This refers to the spreading of sound energy as a result of the expansion of the wavefronts. It increases with the propagation distance and is independent of frequency.</td></tr>
<tr><td rowspan="2">Noise</td><td>Man made noise.</td><td>This mainly caused by machinery noise (pumps, reduction gears, power plants), and shipping activity (hull fouling, animal life on hull, cavitation), especially in areas encumbered with heavy vessel traffic.</td></tr>
<tr><td>Ambient noise</td><td>This related to hydrodynamics (movement of water including tides, current, storms, wind, and rain), and to seismic and biological phenomena [17].</td></tr>
<tr><td colspan="2">Multi-path propagation</td><td>Multi-path propagation may be responsible for severe degradation of the acoustic communication signal, since it generates intersymbol interference (ISI).<br>The extent of the spreading is a strong function of depth and the distance between transmitter and receiver.</td></tr>
<tr><td colspan="2">High delay and delay variance</td><td>The propagation speed in the UWSN's channel is five orders of magnitude lower than in the radio channel. This large propagation delay (0.67 s/km) can reduce the throughput of the system considerably.</td></tr>
<tr><td colspan="2">Doppler spread</td><td>The Doppler frequency spread can be significant in UWSN's channels [16], thus causing a degradation in the performance of digital communications: high data rate transmissions cause adjacent symbols to interfere at the receiver. This requires sophisticated signal processing to deal with the generated ISI.<br>The Doppler spreading generates<br>1) a simple frequency translation, which is relatively easy for a receiver to compensate for.<br>2) a continuous spreading of frequencies that constitutes a non-shifted signal, which is more difficult to compensate for.</td></tr>
</table>

## 2. Analysis of Routing and Data Aggregation Techniques in Wireless Sensor Networks

To realize applications of UWSNs, we can borrow the routing and data aggregation schemes that that have been developed for terrestrial sensor networks. But because of different environment, there exist challenges for adoption of scheme for UWSNs.

Due to recent technological advances, the manufacturing of small and low-cost sensors has become technically and economically feasible. These sensors measure ambient conditions on the environment surrounding them and then transform these measurements into signals that can be processed to reveal some characteristics about phenomena located in the area around these sensors. A large number of these sensors can be networked in many applications that require unattended operations, hence producing a WSN.

Typically, WSNs contain hundreds or thousands of these sensor nodes, and these sensors have the ability to communicate either among each other or directly to an external base station. One of the main design goals of WSNs is to carry out data communication while trying to prolong the lifetime of the network and prevent connectivity degradation by employing aggressive energy management techniques. Especially, the underlying network structure can play a significant role in the operation of the routing protocol in WSNs.

The routing techniques are classified into three categories based on the underlying network structure [18]: flat, location-based, and hierarchical routing.

In addition to the routing protocol, data aggregation also plays one of critical factors because the data on the field can be the same information. So data aggregation can reduce the redundant data transfer to save the limited node energies. Figure 3 presents the routing and data aggregation techniques in WSNs.


Figure 3. Routing techniques in WSNs

## 2.1 Routing Schemes

### 1) Flat Routing

Flat routing is that all nodes in the fields exchange the information with each other in the equal position. Due to the large number of such nodes, it is not feasible to assign a global identifier to each node. This consideration has led to data-centric routing, where the BS sends queries to certain regions and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data. Early works on data centric routing (e.g., SPIN and directed diffusion [19]) were shown to save energy through data negotiation and elimination of redundant data. These two protocols motivated the design of many other protocols that follow a similar concept. As shown in Figure 3, there are several flat routing methods in WSNs.

2) Hierarchical Routing

Flat Routing Method is efficient in the small-scale networks because of its simple routing construction procedure. But the large the scale of network is, the much the quantity of routing information is. And there are long delays in sending the routing information from the remote sensor node and in transferring data from the remote source nodes. Therefore it needs a routing method in which all nodes can waste the equivalent battery in order to guarantee the long lifetime.

Hierarchical routing method was proposed to resolve such a problem, in which all nodes are partitioned into logical groups and each logical group has the head node that control the data traffic in the corresponding group. The creation of clusters and assigning special tasks to CHs can greatly contribute to overall system scalability, lifetime, and energy efficiency.

Hierarchical routing is an efficient way to lower energy consumption within a cluster, performing data aggregation and fusion in order to decrease the number of transmitted messages to the BS. Hierarchical routing is mainly two-layer routing where one layer is used to select cluster heads and the other for routing. However, most techniques in this category are not about routing, but rather "who and when to send or process/ aggregate" the information, channel allocation, and so on, which can be orthogonal to the multi-hop routing function. As shown in Figure 3, there are several hierarchical routing methods in WSNs.

Table 3 summarizes the comparisons of flat and hierarchical routing methods according to the specific parameters.

Table 3. Comparisons of flat and hierarchical routing methods

| | Hierarchical Routing method | Flat Routing method |
|---|---|---|
| Scheduling | Reservation-based scheduling | Contention-based scheduling |
| Collision | Collisions avoided | Collision overhead present |
| Duty cycle | Reduced duty cycle due to periodic sleeping | Variable duty cycle by controlling sleep time of nodes |
| Aggregation point | Data aggregation by cluster head | Node on multi-hop path aggregates incoming data from neighbors |
| Complexity | Simple but non-optimal routing | Routing can be made optimal but with and added complexity |
| Synchronization | Requires global and local synchronization | Links formed on the fly without synchronization |
| Overhead | Overhead of cluster formation throughout the network | Routes formed only in regions that have data for transmission |
| Latency | Lower latency as multiple hops network formed by cluster heads always available | Latency in waking up intermediate nodes and setting up the multipath |
| Energy dissipation | Energy dissipation is uniform | Energy dissipation depends on traffic patterns |
| Fairness | Guarantee | Not guarantee |

3) Location-Based Routing

In this kind of routing, sensor nodes are addressed by means of their locations. The distance between neighboring nodes can be estimated on the basis of incoming signal strengths. Relative coordinates of neighboring nodes can be obtained by exchanging such information between neighbors [20-22].

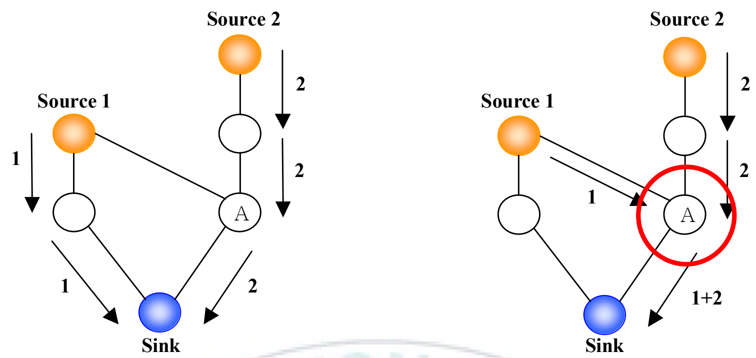
Alternatively, the location of nodes may be available directly by communicating with a satellite using GPS if nodes are equipped with a small low-power GPS receiver [23]. To save energy, some location-based schemes demand that nodes should go to sleep if there is no activity. More energy savings can be obtained by having as many sleeping nodes in the network as possible. The problem of designing sleep period schedules for each node in a localized manner was addressed in [23, 24]. As shown in Figure 3, there are several location-based routing methods in WSNs.

## 2.2 Data Aggregation Schemes

### 1) Data Aggregation in Sensor Networks

Data aggregation is one of the power saving strategies in the ubiquitous sensor network, combining the data that comes from many sensor nodes into a set of meaningful information.

Before starting the data aggregation techniques, we should investigate the routing models [25] that are assumed to consist of a single data sink attempting to gather information from a number of data sources. Figure 4 is a simple illustration of the difference between simple models of routing schemes that use data aggregation (which we term Data-Centric (DC)), and schemes that do not (which we term Address-Centric (AC)). They differ in the manner that the data is sent from a source to a sink. In the AC routing, each source independently sends data along the shortest path to the sink based on the route that the queries took ("end-to-end routing"), whereas in the DC routing the sources send data to the sink, but routing nodes on the way look at the content of the data and perform some form of aggregation and consolidation functions on the data originating at multiple sources.




(a) AC Routing (b) DC Routing

Figure 4. Illustration of AC routing Vs. DC routing

In ad hoc networks, a routing model follows the AC routing, so each source sends its information separately to the sink like the Figure 4(a). In sensor networks, a routing model follows the DC routing, so the data from the two sources are aggregated at node A, and the combined data is sent from node A to the sink like the Figure 4(b). Therefore in sensor networks, the data aggregation technique is a critical factor different from ad hoc networks to save the power consumptions of the nodes in order to extend the sensor network lifetime.

In sensor networks, the data aggregation tree can be thought of as the reverse of a multicast tree. So, optimal data aggregation is a minimum Steiner tree on the network graph. Instead of an optimal data aggregation, sub-optimal data aggregations are proposed to generate data aggregation trees that are aimed to diminish the transmission power. The table 3 summarizes the properties and disadvantages of sub-optimal data aggregation methods.

The prevenient data aggregation methods [25] are efficient to the model where a single point in the unit square is defined as the location of an "event", and all nodes within a distance S (called the sensing range) of this event that are not sinks are considered to be data sources (which we term Event-Radius Model). In the model where some nodes that are not sinks are randomly selected to be sources, e.g. a temperature measurement and environment pollution detection (which we term Random-Source Model), it needs appropriate strategies for an efficient data aggregation.

Table 4. Comparisons of the data aggregation methods

| Data aggregation method | | Properties | Disadvantages |
|---|---|---|---|
| Optimal | Minimum Steiner Tree | The optimal number of transmissions required per datum for the DC protocol is equal to the number of edges in the minimum Steiner tree in the network. | The NP-completeness of the minimum Steiner problem on graphs. |
| Sub-optimal | CNS (Center at Nearest Source | The source that is nearest the sink acts as the aggregation point. All other sources send their data directly to this source that then sends the aggregated information on to the sink. | The more great the gaps between the aggregation point and sources, the more the batteries consumptions. |
| | SPT (Shortest Paths Tree) | Each source sends its information to the sink along the shortest path between the two. Where these paths overlap for different sources, they are combined to form the aggregation tree. | The shorter the overlapped paths when the shortest route is established from each source to the sink, the more the batteries consumptions. |
| | GIT (Greedy Incremen t-al Tree) | At the first step the tree consists of only the shortest path between the sink and the nearest source. At each step after that the next source closest to the current tree is connected to the tree. | It takes some time for the identical data to arrive to the aggregation point and to aggregate the identical data from other source nodes. |

2) Data Aggregation in Ad-Hoc Networks

Most of the ad hoc networks are based on point-to-point communications, so the data aggregation in ad hoc networks is not considered a critical issue except the multi-path routing. In some routing protocols such as DSR [26], AODV [27], LMR [28], TORA [29], and so on, multi-paths can be established from the sources to the destination. In that case the data aggregation can be performed through the overlapped paths en route. But it depends on each routing technique, which is implemented in ad hoc networks. Amongst the multi-path routing techniques, TORA builds a directed acyclic graph rooted at the destination in ad hoc networks. So using DAG all data in the field can be assembled at the destination node.

## 3. Issued Problems

### 3.1 Major Challenges in Underwater Environment

As remarked above many researchers are currently engaged in developing networking solutions for terrestrial wireless ad hoc and sensor networks. Since UWSNs have more challenge than terrestrial WSNs, adopting efficient routing and data aggregation schemes is very important. However, due to the different nature of the underwater environment and applications, there are several drawbacks with respect to the suitability of the existing solutions for WSNs. Main differences between terrestrial and underwater sensor networks are shown in table 5 [2].

Table 5. Differences between terrestrial and underwater WSNs

| | Differences |
|---|---|
| Cost | While terrestrial sensor nodes are expected to become increasingly inexpensive, underwater sensors are expensive devices. This is especially due to the more complex underwater transceivers and to the hardware protection needed in the extreme underwater environment. |
| Deployment | While terrestrial sensor networks are densely deployed, in underwater, the deployment is deemed to be more sparse, due to the cost involved and to the challenges associated to the deployment itself. |
| Power | The power needed for acoustic underwater communications is higher than in terrestrial radio communications due to higher distances and to more complex signal processing at the receivers to compensate for the impairments of the channel. |
| Memory | While terrestrial sensor nodes have very limited storage capacity, uw-sensors may need to be able to do some data caching as the underwater channel may be intermittent. |
| Spatial correlation | While the readings from terrestrial sensors are often correlated, this is more unlikely to happen in underwater networks due to the higher distance among sensors. |

Among differences between terrestrial and underwater WSNs, because UWSNs are respectively sparse than terrestrial WSNs and have a long transmission range, data transmission scheme is also important as much routing and data aggregation schemes.

The harsh characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity and variable delays, require very efficient and reliable new data communication algorithm.

## 3.2 Sensor Placement

In [30,31] an optimization problem on sensor placement is formulated to provide sufficient grid coverage of sensor field where two polynomial-time algorithms are presented to find out the optimum number of sensors and to place them such that the maximum coverage of the sensor field is achieved. The proposed scheme is for the fixed sensor nodes and runs better for the sensor fields that have obstacles. For the case that there are some obstacles that can hinder the communications between nodes in the field, the knowledge of the terrain is required before deployment.

Sensor placement is formulated as an optimization problem and then solved with integer linear programming (ILP) in [32]. This approach deals with sensor fields that have various sensor types different in costs and ranges. It finds out the types and the locations of sensor nodes for maximum coverage of the sensor field in terms of cost minimization.

The art gallery problem (AGP) [33] determines the minimum number of observers needed to cover the interior of an art gallery room such that every point is covered by at least one observer. A polynomial-time algorithm is presented to solve the 3D version of the AGP, which is an NP hard problem in [33].

Coverage was focused as the main criterion on power aware operation strategies in sensor networks in [34]. A set of sensor nodes is selected to be active by using an ILP based scheme. Since the sensors not active are placed in a special powersaving sleep mode, the overall energy consumption is reduced while maintaining the guaranteed sensor coverage.

Computational geometry and graph theoretic techniques, specifically the Voronoi diagrams and graph search algorithms are combined and a polynomial-time algorithm is presented for coverage calculation in [35]. The proposed algorithm finds the lowest coverage path, which maximizes the distance of the path to all sensor nodes, and the highest coverage path, which minimizes the distance of the path to the closest sensor nodes. Additional sensor deployment heuristics are also given to improve the stochastic coverage in [35].

All of these strategies are based on a central node and an algorithm that finds out the locations of the sensor nodes such that the maximum coverage is provided and then places the nodes into the selected locations. However in many applications, sensor nodes are randomly deployed and they randomly move around. A tactical underwater surveillance system that can be used to detect enemy submarines, SDVs, mines and divers is one example for such applications. Our scheme is a distributed one that fits the requirements of this application area.

## 3.3 Detection and Classification

In [36] an effective intrusion detection system is introduced. An anomaly detection algorithm which uses statistics on packet header values is developed. System combines the information from multiple sensors to improve detection accuracy.

A wavelet packets based scheme for classification of underwater targets from the acoustic backscattered signals was developed in [37]. System uses a feature selection scheme and a backpropagation neural-network classifier.

A new adaptive underwater target classification system which uses backscattered acoustic data from targets is presented in [38]. System consists of upper and lower branches. The upper branch works as a memory system to identify the closest matches of an unknown pattern in the feature space and provides decision by using K-NN (KNearest Neighbor) algorithm. The lower branch performs feature mapping and classification.

A small underwater robot designed for experiments with sensor networks is described in [39]. Robot consists of a motor driver and various types of sensors. A large tank which contains fresh water was used as test bed. Depth measurement was accomplished by using the pressure sensor. Temperature of the water is tested in different depths.

In [40] a tree-based modeling method for classification of a fault-prone tactical military software module is presented. The system performed real time detection, classification and tracking of mobile and fixed objects in the field.

### 3.4 Network Topology in Underwater WSNs

The network topology is in general a crucial factor in determining the energy consumption, the capacity and the reliability of a network. Hence, the network topology should be carefully engineered and post-deployment topology optimization should be performed, when possible.

Underwater monitoring missions can be extremely expensive due to the high cost of underwater devices. Hence, it is important that the deployed network be highly reliable, so as to avoid failure of monitoring missions due to failure of single or multiple devices. For example, it is crucial to avoid designing the network topology with single points of failure that could compromise the overall functioning of the network.

The network capacity is also influenced by the network topology. Since the capacity of the underwater channel is severely limited, it is very important to organize the network topology such a way that no communication bottleneck is introduced[41].

# Ⅲ. Proposed Sensor Movement Algorithm for Improved Sensing Coverage and Efficiency

## 1. Foundamental Algorithms for Suggested Model

The two algorithms are foundation for the suggested model. One is Queen problems and another is Knapsack problems. The Queen Problems is located the Queen in the $n \times n$ size chessboard without caught by other Queen. The Knapsack Problems is decided the solution how fulfill the knapsack so as to the optimization value. The main motivation for adopted these algorithms is to deploy the underwater sensor nodes, calculate sensor dispersion and sensing efficiency factor for UWSNs and suggest an enhanced sensor movement algorithm that considers the dispersion balancing once the sensing is occurred.

### 1.1 Queen Problems

In chess, a queen can move as far as she pleases, horizontally, vertically, or diagonally. A chess board has 8 rows and 8 columns. The standard $8 \times 8$ Queen's problem asks how to place 8 queens on an ordinary chess board so that none of them can hit any other in one move.

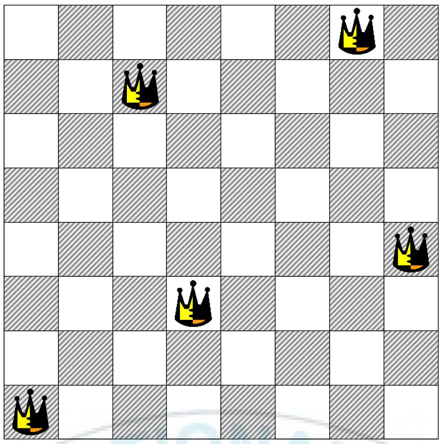


Figure 5. An example of Queen problems

The minimum number of queens needed to occupy or attack all squares of an $8 \times 8$ board is 5. The following results for the number of distinct arrangements $N_p(k,n)$ of $k$ queens attacking or occupying every square of an $n \times n$ board for which every queen is attacked by at least one other, with the $n = 8$ value. The table 6 summarizes the number of solutions for Queen problems. The 4,860 solutions in the $n = 5$ case may be obtained from 638 fundamental arrangements by rotation and reflection.

Table 6. The number of solutions for Queen problems

| $k$ queens | $n \times n$ | $N_p(k,n)$ |
|---|---|---|
| 2 | 4 | 3 |
| 3 | 5 | 37 |
| 3 | 6 | 1 |
| 4 | 7 | 5 |
| 5 | 8 | 4,860 |

The following polynomial gives the solution to the question, "How many different arrangements of $k$ queens are possible on an order $n$ chessboard?" as 1/8th of the coefficient of $a^k b^{n^2-k}$ [42].

$$p(a,b,n)=\begin{cases} (a+b)^{n^2}+2(a+b)^n\left(a^2+b^2\right)^{(n^2-n)/2} \\ +3\left(a^2+b^2\right)^{n^2/2}+2\left(a^4+b^4\right)^{n^2/4} & n \text{ even} \\ \\ (a+b)^{n^2}+2(a+b)\left(a^4+b^4\right)^{(n^2-1)/4} \\ +(a+b)\left(a^2+b^2\right)^{(n^2-1)/2} \\ +4(a+b)^n\left(a^2+b^2\right)^{(n^2-n)/2} & n \text{ odd} \end{cases} \tag{1}$$

1.2 Knapsack Problems

Suppose a hitch-hiker has to fill up his knapsack by selecting from among various possible objects those which will give him maximum comfort. This Knapsack problem can be mathematically formulated by numbering the objects from 1 to $n$ and introducing a vector of binary variables $x_j \ (j = 1, \dots, n)$ having the following meaning:

$$x_j = \begin{cases} 1 & \text{if object } j \text{ is selected;} \\ 0 & \text{Otherwise.} \end{cases} \tag{2}$$

Then, if $p_j$ is a measure of the comfort given by object $j$, $w_j$ its size and $c$ the size of the knapsack, our problem will be to select, from among all binary vectors $x$ satisfying the constraint

$$\sum_{j=1}^{n} w_j x_j \le c \tag{3}$$

the one which maximizes the objective function

$$\sum_{j=1}^{n} p_j x_j \tag{4}$$

A naive approach would be to program a computer to examine all possible binary vectors $x$, selecting the best of those which satisfy the constraint. Unfortunately, the number of such vectors is $2^n$, so even a hypothetical computer, capable of examining one billion vectors per second, would require more than 30 years for $n = 60$, more than 60 years for $n = 61$, ten centuries for $n = 65$, and so on. However, specialized algorithms can, in most cases, solve a problem with $n = 100000$ in a few seconds on a mini-computer.

The problem considered so far is representative of a variety of knapsack-type problems in which a set of entities are given, each having an associated value and size, and it is desired to select one or more disjoint subsets so that sum of the sized in each subset does not exceed (or equals) a given bound and the sum of the selected values is maximized.

Knapsack problems have been intensively studied, especially in the last decade, attracting both theorists and practicians. The theoretical interest arised mainly from their simple structure which, on the one hand allows exploitation of a number of combinatorial properties and, on the other, more complex optimization problems to be solved through a series of knapsack-type subproblems. From the practical point of view, these problems can model many industrial situations: capital budgeting, cargo loading, cutting stock, to mention the most classical applications. In the following we shall examine the most important knapsack problems, analyzing relaxations and upper bounds, describing exact and approximate algorithms and evaluating their efficiency both theoretically and through computational experiments[43].

1) Terminology

The objects considered in the previous section will generally be called *items* and their number be indicated by *n*. The value and size associated with *j*th item will be called *profit* and *weight*, respectively, and denoted by $p_j$ and $w_j$ $(j = 1, \ldots, n)$.

It is always assumed, as is usual in the literature, that profits, weights and capacities are positive integers. The results obtained, however, can easily be extended to the case of real values and, in the majority of cases, to that of nonpositive values.

The prototype problem of the previous section,

$$\begin{aligned} \text{maximize} \quad & \sum_{j=1}^{n} p_j x_j \\ \text{subject to} \quad & \sum_{j=1}^{n} w_j x_j \le c \\ & x_j = 0 \ \text{ or } 1, \quad j = 1,\ldots,n, \end{aligned} \tag{5}$$

is known as the 0-1 Knapsack Problem. We consider the generalization arising when the item set is partitioned into subsets and additional constraint is imposed that at most one item per subset is selected.

The problem can be generalized by assuming that for each $j\ (j = 1,\ldots,n)$, $b_j$ items of profit $p_j$ and weight $w_j$ are available $(b_j \le c / w_j)$: thus we obtain the Bounded Knapsack Problem, defined by

$$\begin{aligned} \text{maximize} \quad & \sum_{j=1}^{n} p_j x_j \\ \text{subject to} \quad & \sum_{j=1}^{n} w_j x_j \le c \end{aligned} \tag{6}$$

$$0 \le x_j \le b_j \qquad j = 1, \dots, n$$

$$x_j \text{ integer} \qquad j = 1, \dots, n$$

## 2. Suggested Sensor Movement Algorithm for UWSNs

### 2.1 Setup Phase

Figure 2 shows a network topology with several sensors. Every sensor is suspended by anchor in this thesis. Here, we assume that every sensor deploys random position in the underwater and the size of cluster is decided previously. Sensors which deployed at random position, calculate the current depth by adopting equation (7).

$$D = \frac{(v \times t)}{2} \tag{7}$$

From equation (7), $v[m/s]$ is a coefficient which expresses the speed of acoustic in the underwater.

After each sensor calculates the current depth, sensors exchange the information of depth among themselves. Then, they choose the highest sensors in the cluster. The sensor which chosen in the cluster calculates the number of plane by adopting equation (8).

$$P_n = \frac{D_{\max}}{R} \tag{8}$$

$D_{\max}[m]$ is the depth of sensor which locates the highest in the cluster, $R[m]$ is transmission range of normal sensor. Number of plane grant between 0 and $(n-1)$ in numerical order. The depth of $i$ th sensor calculates by adopting equation (9).

$$D_i = D_{\max} - \{(R \times 0.5) + (R \times i)\} \tag{9}$$

From equation (9), the highest sensor in the cluster decides the number of planes and then broadcast to the cluster.

## 2.2 Movement Phase

At previously phase, every sensor collects basis information in order to move the efficient sensing position. Based on this information, in this phase sensors are deployed or moved by following algorithm Figure 6.

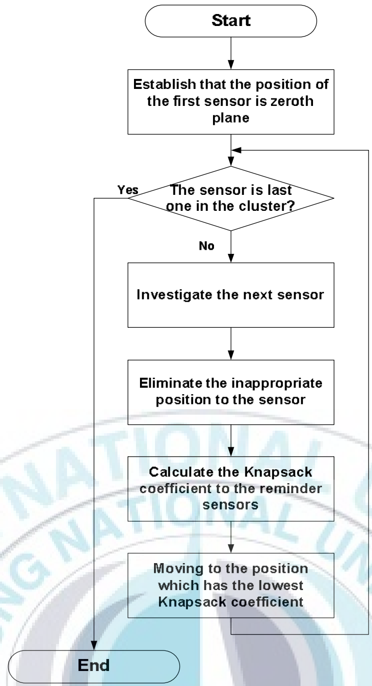



Figure 6. Sensor movement and deployment algorithm

As shown in Figure 6, we establish that the position of the first sensor is zeroth plane. Then, we investigate the next sensor. And we consider the Queen Problem to the position of sensors.

The Queen Problem is located the Queen in the $n \times n$ size chessboard without caught by other Queen. Here, we apply a Queen Problem scheme to eliminate the inappropriate position to the sensor and to prevent the gather around same sensing coverage.

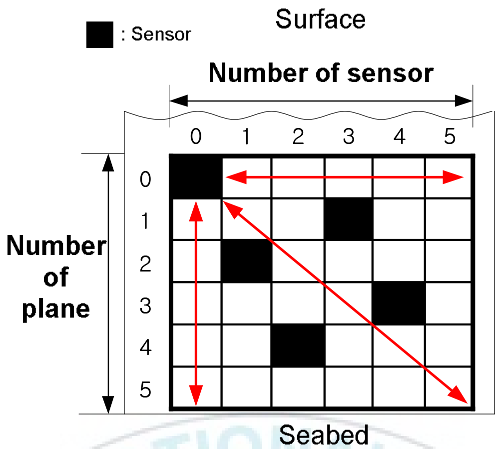



Figure 7. Sensors deployed by based on the Queen Algorithm

As shown in Figure 7, we check the appropriate position for the sensors row by row until the end of sensor in the cluster. Each row eliminates the inappropriate position to the sensor. Then, sensors choose the plane which has the widest sensing coverage as contrasted with the sensor moving distance. In order to choose the appropriate plane for the sensor, we apply a Knapsack Problem scheme to select the short moving distance as contrasted with the widest sensing coverage.

The Knapsack Problem is decided the solution how fulfill the knapsack so as to the optimization value. In order to apply the Knapsack Problem for the appropriate position, we calculate the each sensor moving distance from first to last position and sensing coverage at each plane.

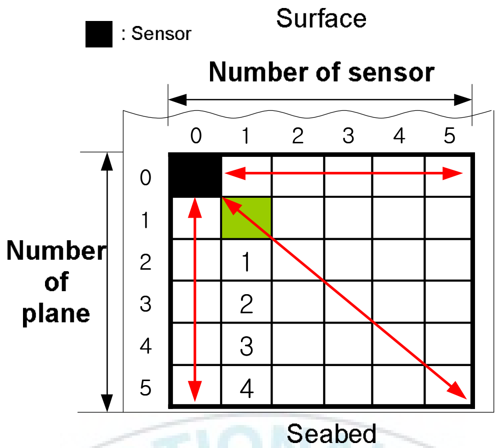



Figure 8. Sensor moving distance among the available position

In order to calculate the sensing coverage, we estimate how many duplicated cells in the sensing coverage. If one sensor has two duplicated cells in the sensing coverage like Figure 9, the sensing coverage decreases to a half at the two cells.

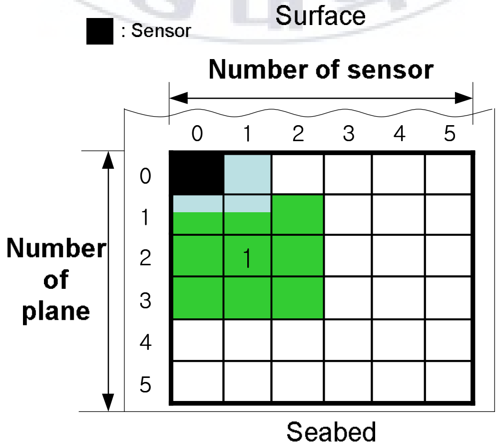



Figure 9. Sensing coverage

After the sensors calculate moving distance and sensing coverage, decided the Knapsack coefficient as Table 7. Then, the sensors move to the position which has the lowest Knapsack coefficient. The performance is repeatedly until meet with the end of last one.

Table 7. Comparison of Knapsack coefficient

| Number of sensor | Moving distance | Sensing coverage | Knapsack coefficient |
|---|---|---|---|
| 1 | 1 | 8 | 1/8=0.125 |
| 2 | 2 | 9 | 2/9=0.222 |
| 3 | 3 | 9 | 3/9=0.333 |
| 4 | 4 | 9 | 4/9=0.444 |

## 2.3 Coefficient which Reflects the Conditions of UWSNs

To appraise the conditions of sensors in the network, we suggest two types of coefficient. The one is to calculate the conditions of sensor dispersion in the same cluster, the other is to calculate the average of sensing coverage in the cluster.

In case of the measuring to the dispersion, the coefficient $N_d$ between $n$ and $n+1$ sensors adopted by equation (10).

$$N_s = \frac{\sum_{i=0}^{n-1} |N_i - N_{i+1}|}{n-1} \tag{10}$$

Where $N_i$ represents the position of $i$ th sensor. If all sensors are uniformly dispersed in the same cluster, the dispersion coefficient measure high conditions. On the other hands, all sensors are lump together in the same cluster, the dispersion coefficient measures low conditions.

In case of the measuring to the average sensing coverage in the same cluster, the coefficient adopted by equation (11).

$$S_c = \frac{N_c - N_{wc}}{n} \tag{11}$$

Where $N_c$ represents the number of all cells in the cluster, $N_{wc}$ represents the number of cells which didn't allocate in the cluster, and $n$ represents the number of all sensors in the cluster.

In case of the measuring to the sensing efficiency, the coefficient adopted by equation (12).

$$S_e = \frac{\sum_{i=0}^{n} \left( N_{dc} \times \frac{1}{n_i + 1} - N_{uc} \right)}{n} \tag{12}$$

Where $N_{dc}$ represents the number of cells which coincide with above two sensing coverage, $N_{uc}$ represents the number of cells which uncovered in the cluster, $n_i$ represents the maximize number that coincide with above two sensing coverage, and $n$ represents the number of all sensors in the cluster.

For example, as shown in Figure 10, the cluster has $6\times6$ size cells, four sensors, and eight uncovered cells. Also, the cluster has twenty-six cells which don't coincide with other sensing coverage and two cells which coincide with other sensing coverage.

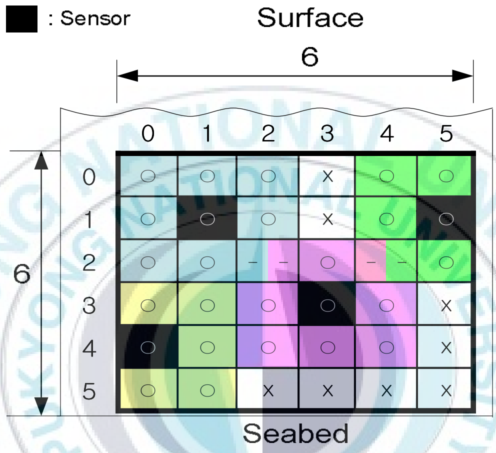



Figure 10. An example of calculating the sensing efficiency

From equation (12), we estimate the sensing efficiency in the Figure 9. as equation (13).

$$S_e = \frac{\sum_{i=0}^{n}\left(N_{dc}\times\frac{1}{n_i+1}-N_{uc}\right)}{n} = \left(\frac{26\times\frac{1}{1}+2\times\frac{1}{2}-8}{4}\right) = 4.75 \quad (13)$$

# Ⅳ. Simulation and Performance Evaluation

We evaluate the performance of the proposed algorithm via simulations. The sensing efficient sensor movement algorithm Section Ⅲ are used as the simulation model for our simulation. We assume every sensor deploys random position in the underwater and the size of cluster is decided previously.

We compare the proposed enhanced sensor movement algorithm to the origin setup algorithm which has the sensor increase from twenty to fifty and the plane increase from four to ten. When we conduct simulations for the sensor movement algorithms, we assume that all sensors in the cluster complete the setup phase and ready to the movement phase.

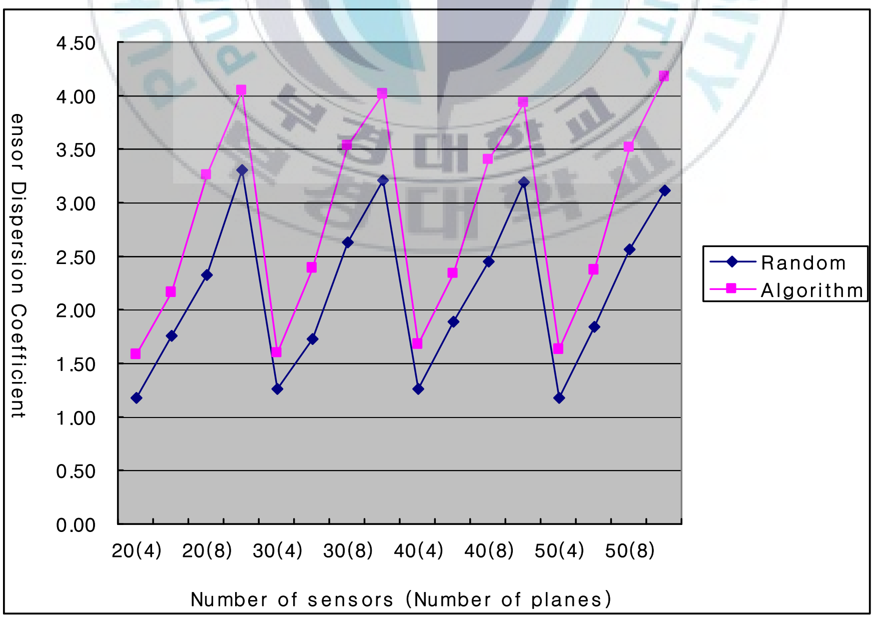



Figure 11. Analysis the sensor dispersion coefficient in order to compare random and sensor movement algorithm

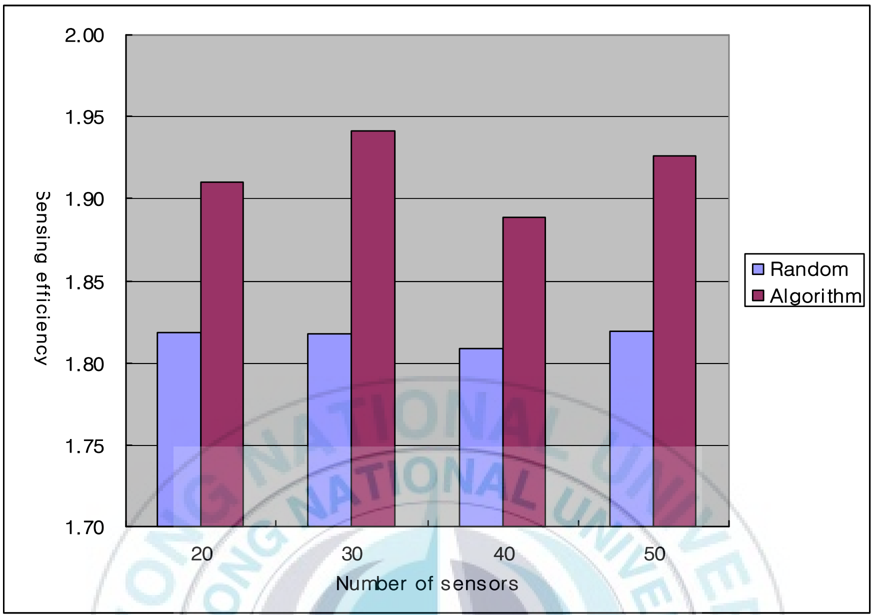



Figure 12. Analysis the sensing efficiency in order to compare random and sensor movement algorithm

Figure 11 and 12 shows that the enhanced sensor movement algorithm has higher sensor dispersion and sensing efficiency than random deployed method. The enhanced sensor movement algorithm improves approximately 30.75 % comparing to the sensor dispersion and sensing efficiency for sensor movement algorithm. And in case of using the Three-dimensional UWSNs, the sensor movement algorithm performs more efficiently.

# Ⅴ. Conclusion

In this thesis, we investigated how the network's energy consumption is influenced by the transceiver parameters and reviewed the state of precious routing and data aggregation researches in WSNs to apply those to UWSNs. Then, we adopt a Queen and Knapsack problem approach to deploy the underwater sensor nodes, calculate sensor coverage and sensing efficiency for UWSNs, and suggest a sensor movement algorithm that considers the sensing balancing once the sensor is deployed. The suggested sensor movement algorithm improves sensor dispersion performance and sensing efficiency.

We simulate the proposed sensor movement algorithm in the environment of UWSNs. According to the simulation results, the sensor movement algorithm reduces the sensor's lump and improves the sensor's sensing efficiency. These results mean that the sensor movement algorithm has better sensing efficiency than the random deployed method. Consequently, we conclude that the proposed sensor movement algorithm outperforms others from a sensing-efficient and our algorithm is more suitable for UWSNs applications.

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## 수중센서네트워크를 위한 인식 효율적인 센서 이동 알고리즘 연구


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요 약

최근 과학적, 상업적 탐구와 해안선 보호를 위한 수중 환경의 관찰에 대한 관심이 증대되고 있다. 특히 우리나라의 경우는 삼면이 바다로 이루어져 있기 때문에 해양에 대한 연구는 더욱 중요하다.

광범위한 해양 관찰을 위한 이상적인 기법으로 수중 무선 센서 네트워크라고 불리는 수중 무선 센서들로 이루어진 분산 시스템이 있다. 주어진 영역에 대한 협동적인 관찰 임무를 수행하는 다양한 수의 센서들과 센서들을 장착한 무인 또는 자동 수중 장치들은 수중 자원 탐사와 과학적 자료 수집을 가능하게 한다. 수중 센서 노드들은 해양 데이터 수집, 오염 관찰, 근해 탐사, 재해 예방, 항해, 전략적 감시 등의 어플리케이션들에 사용될 수 있다. 수중 음파 네트워크는 이러한 어플리케이션들을 가능하게 하는 기술이다.

현재 많은 연구자들이 지상 센서 네트워크에 대한 네트워크 기법들에 대하여 연구하고 있다. 수중센서네트워크는 지상 센서네트워크에 비해 더 많은 제약 조건들을 가지고 있기 때문에, 효율적인 라우팅과 데이터 통합 기법이 더욱 중요하다. 그럼에도 불구하고 수중환경과 어플리케이션들의 차이점들로 인해 지상 센서네트워크를 위해 개발된 기법들을 수중 센서네트워크에 직접 적용하는 것은 적합하지 않은 점이 존재한다.

기존의 3 차원 수중 센서 네트워크에서는 센서 배치를 무작위로 하여, 센서들의 뭉침 현상에 의한 인식 효율성 하락을 초래했다

본 논문에서는 3 차원 수중 센서 네트워크의 센서 배치를 무작위로 했을 경우, 인식 효율성이 떨어지는 점을 보완하기 위해 센서의 배치를 여왕말 문제와 배낭문제에 따라 변경하는 센서 이동 알고리즘을 제안한다. 제안된 알고리즘은 센서의 뭉침 현상을 방지함으로써 결과적으로 인식 효율성의 향상을 통해 무작위로 배치하는 경우에 비해 뛰어난 성능을 보장한다. 시뮬레이션 결과에 따르면 무작위 배치에 비해 알고리즘을 적용한 경우가 센서 분산 지수에서 평균 30% 향상되었고, 센서의 수에 따른 인식 효율성이 전체적으로 개선된 것을 확인하였다. 그러므로 본 논문에서 제안한 센서 이동 알고리즘은 기존의 방법에 비해 더 인식 범위 효

율적인 성능을 보임으로써, 해양의 데이터 수집, 환경 감시, 군사적인 목적 등의 광범위한 장소에서 데이터 수집이 필요한 응용분야에서 유용하게 사용될 것으로 판단된다.

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