ICIC Express Letters
Volume **10**, Number **8**, August **2016**
ICIC International ©2016 ISSN 1881-803X
pp. 1857–1864

IMPROVED LOW ENERGY SELF-HEALING ALGORITHM BASED ON THE ANCHOR NODE SELECTION STRATEGY OF TETRAHEDRON SIMILARITY

Liansuo Wei[1,2], Shaobin Cai[1] and Xuefeng Dai[2]

[1]Department of Computer Science and Technology
Harbin Engineering University
No. 145, Nantong Ave., Nangang Dist., Harbin 150001, P. R. China
wlsaaaaaa@163.com

[2]College of Computer Control Engineering
Qiqihar University
No. 42, Wenhua Ave., Qiqihar 161006, P. R. China

Received December 2015; accepted March 2016

Abstract. *In the network environment of underwater passive locating node, when the anchor nodes are always in a state of activation and keep corresponding with buoy nodes, the limited energy of the nodes will be exhausted rapidly and lead to some problems such as network fault and nodes death. Therefore a special improved low energy self-healing algorithm of selecting the best anchor node based on tetrahedron similarity was proposed in this paper. When a failure occurs, a new substitution anchor node will be selected in backup candidate nodes in real time. This substitution node will be aroused as a new node to choose the recovery path adaptively and ensure the smooth real-time transmission of the data. The simulation results show that this algorithm reduced the death number of the nodes and the rate of network faults. It shows good performance in terms of survival number of nodes, network traffic, and the prolongation of network lifetime.*
Keywords: Underwater sensor networks, Anchor node, Similarity, Low energy self-healing algorithm

1. **Introduction.** Over the past few years, more and more resources have been invested to the research of Underwater Wireless Sensor Networks (UWSNs). The commercial exploitation of ocean, the scientific exploration and the protection of the national coastline are becoming symbiotic with UWSNs. UWSN is composed of a certain amount of sensor nodes and underwater robots which are located on different sea level. They work together to serve various purposes. The sensor nodes are able to collect the seabed data, avoid disasters, supervise pollution, navigate and monitor [1,2] after the establishment of UWSNs. The fundamental mission of UWSNs is to locate nodes. Nowadays, many researchers have done some researches in terms of the UWSNs positioning algorithm based on the estimated positioning mechanism and the predicted positioning mechanism, respectively. A scheme of localisation was proposed in [3,4] that approaches the problem in a range-based hierarchical manner. The process is divided into two subprocesses: anchor node localisation and ordinary node localisation. They tackle this by integrating a three-dimensional Euclidean distance estimation method and a recursive location estimation method. Even though Euclidean estimation reveals to perform best in anisotropic topologies, it is hindered by its large computation and communication overheads. Anchor node localisation is achieved through relying on surface buoys equipped with GPS sensors [5]. Another scheme of localisation was proposed for sparse 3D environments transforming the three-dimensional problem into a two-dimensional one using projection techniques [7]. However, in the network environment located passively it is easy to lead to the death of nodes, network fault and some other problems, because of the anchor nodes' staying in the state of

activation They consume their power more rapidly than other nodes. In order to make UWSNs work in a regular way, the authors brought up a positioning algorithm based on the low-energy self-healing strategy in [6]. At first this algorithm used the primitive K-node covering algorithm to select anchor nodes. After that the anchor node was partly consumed using the maximum intersection to reselect the anchor nodes. If the adjacent nodes' power, the distance between the adjacent nodes and low energy nodes and other practical factors that influence the quality of the next generation of anchor nodes are not taken into account, it will lead to the high consumption of network's energy. Aiming to improve, the low-energy self-healing algorithm is proposed by introducing a strategy of selecting the optimal anchor node in light of the regular tetrahedron similarity in this paper. When a failure occurs, a new substitution anchor node will be selected in backup candidate nodes. This substitution node will be aroused as a new node to choose the recovery path adaptively and ensure the smooth real-time transmission of the data.

The paper is organized as follows. In Section 2, the strategy of selecting anchor nodes based on the tetrahedron model similarity is reviewed. The improved algorithm of low energy self-healing is defined and the analysis of the improved algorithm is discussed in Section 3. Section 4 is devoted to analyzing the system performance through simulation example and studying the proposed algorithm, which reduced the number of nodes' deaths and the rate of network fault. The proposed algorithm is also proved to have done a good performance in terms of the survival number of nodes, network traffic and the prolongation of network lifetime. Conclusions are summarized in Section 5.

2. The Strategy of Selecting Anchor Nodes Based on the Tetrahedron Model Similarity.

For the sake of clear expression, this paper takes advantage of the structure of passively located network, with the structure including sensor node, anchor node and surface buoys. Sensor nodes are distributed in the detection filed of underwater 3D environment randomly and dived into different depths according to their own density. Anchor nodes can provide the positional information to the other sensor nodes. Surface buoys are equipped with GPS, and provide the anchor nodes with positional information. The water base station collects the data and does computing. The anchor nodes are able to correspond with surface buoys to identify their position, which is similar to the realization of underwater GPS [8]. The surface buoys equipped with GPS can obtain the information of their position and provide service for the anchor nodes, which is equal to "satellite nodes" of the underwater positioning mechanism.

Sensor nodes have the same structure as anchor nodes, and their major job is to perceive incidence and exchange information with their adjacent nodes, positioning themselves while perceiving incidence. The specific relevant symbols and their meanings are shown in Table 1.

2.1. Selection of the backup anchor nodes.

In the localization process of the sensor nodes, first of all, no node is selected as backup anchor from anchor nodes and sensor

Table 1. Symbols and meanings

Symbol	*Meaning*
SN	*Sensor node*
AN	*Anchor node*
$C(s_i)$	*The communication range of node* s_i
R_{s_i}	*The sensing range of node* s_i
$D(x,y)$	*The distance between* x *and* y
$CN(A_i)$	*The adjacent aggregation that node* A_i *and its neighbors have in common*
$R(A_i)$	*The aggregation of nodes that are about to replace node* A_i

nodes, so the original anchor node localization of sensor nodes is sure to consider. All the anchor nodes' trust value is set to 1, and all the sensor nodes are the nodes that are not located. With the development of the positioning process, more and more sensor nodes are successfully located and set as the backup anchor nodes. After the distribution of nodes in the network environment, each sensor node is positioned within the communication range of 4 anchor nodes. The 4 anchor nodes should make sure to be non-coplanar. The mathematical anchor model is as follows:

$$\forall SN\, s_i \in SN\, \exists \text{ at least } 4ANS\, b_j \text{ s.t } D(s_i, b_j) \leq \min(C(s_i), C(b_j)) \tag{1}$$

where SN is a sensor node, AN is anchor node, s_i and b_j are sensor nodes, $C(s_i)$ is the communication range of node, and $D(s_i, b_j)$ is the distance between s_i and b_j. In order to localize sensor node s_i in a $k-1$ dimension environment, there should be at least k anchor nodes covering the sensor nodes s_i according to (1). That is to say, there should be at least 4 anchor nodes covering sensor nodes in a 3D environment.

When the number of one hop nodes is $m \geq 4$, all of the one hop anchor nodes take part in the sensor's positioning. If the number of one hop anchor nodes is $m < 4$, after m adds the number m_1 of the backup anchor nodes within one hop range, then $m + m_1 \geq 4$ and it meets the positioning requirements. At this time choose the maximum value among the $4 - m$ values of δ as the backup anchor node. The calculation of δ is:

$$\delta = \lambda_1 \frac{E_r}{E_o} + \beta_1 \eta + \gamma_1 \frac{1}{d'} \tag{2}$$

where E_o and E_r are the initial power and the rest power of backup anchor node, respectively, η is the trust value of backup anchor node. d' is the estimated distance between sensor nodes and backup anchor nodes, λ_1, β_1 and γ_1 are the weighted scalars, respectively, and $\lambda_1 + \beta_1 + \gamma_1 = 1$.

$$\eta = \begin{cases} 1 \\ 1 - \frac{\delta}{\sum_{i=1}^{n} \sqrt{[(u-x_i)^2 + (v-y_i)^2 + (w-z_i)^2]}} \end{cases} \tag{3}$$

where (u, v, w) is the estimated coordinate of sensor node, and (x_i, y_i, z_i) is the coordinate of anchor node or backup anchor node. Here i, δ is the trust operator.

2.2. **Selection of anchor node candidate.** In the 3D environment, the node which is located in the middle of regular tetrahedron has higher positioning accuracy. Therefore, in this paper the proximity degree between the tetrahedron which consists of the four anchor nodes randomly selected or candidate anchor node and regular tetrahedron has been regarded as a reference for the strategy of selecting the backup anchor nodes. Regular tetrahedron is a closed geometry, which is composed of four congruent regular triangles connected side by side. In other words, it is a regular triangular pyramid. Let us assume that there are n points in a space, and $n \geq 4$. There is at least one of the n points, which is non-coplanar with the other $n - 1$ points. Now connect any four points which are non-coplanar to form a tetrahedron, and make a comparison among all of the tetrahedrons to know which one is much more similar to the regular tetrahedron, which in other words is the regular triangular pyramid. We can get the anchor node candidates, and the method is described as follows.

Mark the four vertices of every tetrahedron as A, B, C and D, respectively, and label the corresponding sides connected by two of the four vertexes as *AB, AC, AD, BC, CD* and *BD*, calculate the length of the six sides and then make a comparison among them. The smaller the D-value of the six sides is the more similar to regular tetrahedron the tetrahedron is. Comparing all the tetrahedrons, the tetrahedron which has the minimum D-value of the six sides is the most similar to regular tetrahedron. Mark the length of the six sides as L_{AB}, L_{AC}, L_{AD}, L_{BC}, L_{BD}, and L_{CD}, respectively, and their D-value are labeled as δ_1, δ_2, $\ldots$, δ_{30}. Therefore, we get $\delta_1 = L_{AB} - L_{AD}$, $\delta_2 = L_{AB} - L_{BC}$,

$\ldots$, $\delta_{30} = L_{BD} - L_{CD}$. There are 30 D-values in total, which can be represented as $\delta = \delta_1 + \delta_2 +, \ldots, +\delta_{30}$. Here δ is called the tetrahedron similarity, acting as the trust value of the backup anchor node η calculated by (3). The smaller the value of δ is, the bigger the trust value of anchor η is, and the more similar to regular tetrahedron this tetrahedron is. That is to say, δ can be the judgment of the shape of regular tetrahedron.

In the UWSNs, there are two circumstances of determining whether the random distribution of an unknown node is inside the tetrahedron.

The first circumstance is shown in Figure 1. If the unknown node is located inside the tetrahedron, the gross volume of the four internal tetrahedrons divided by sensor nodes is equal to the total volume of the regular triangular pyramid which can be expressed as:

$$V_{ABCN} + V_{ABND} + V_{ACND} + V_{NBCD} = V_{ABCD} \tag{4}$$

The second circumstance is shown in Figure 2. If the unknown node is located outside the tetrahedron, the gross volume of the four internal tetrahedrons divided by sensor nodes is greater than the total volume of the regular triangular pyramid which can be expressed as:

$$V_{ABCN} + V_{ABND} + V_{ACND} + V_{NBCD} > V_{ABCD} \tag{5}$$

During the sequencing phase of the anchor node candidates, the proposed approach will sort the anchor node tetrad in view of whether the nodes are inside the tetrahedron. The δ of the sensor nodes, which is inside the tetrahedron and has the smallest value, acts as the selection scheme of the anchor node candidates, and so forth. The sequencing scheme was stored in surface buoys.

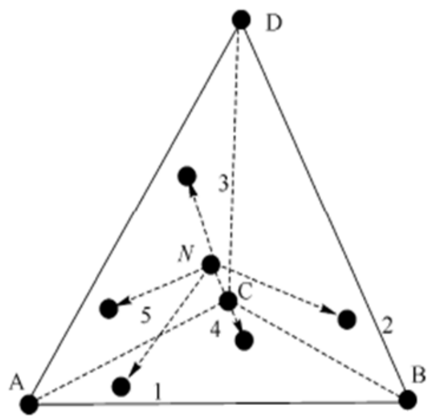


FIGURE 1. The sensor nodes inside the tetrahedron

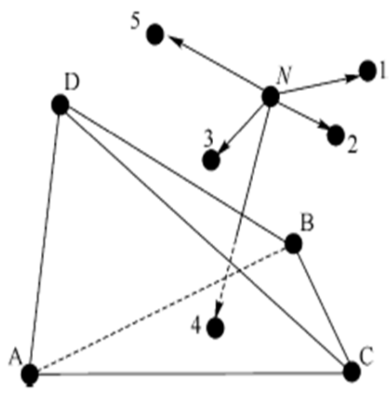


FIGURE 2. The sensor nodes outside the tetrahedron

3. **Improved Low Energy Self-Healing Algorithm.** In [6], the authors brought up a positioning algorithm based on the low-energy self-healing strategy. Each anchor node is provided with a critical value of energy. When the anchor node's energy reaches the critical value, the anchor node will follow the low-energy self-healing operation. The critical value of energy can make sure that anchor node has enough power to finish the selecting process before its death. However, because the above algorithm used the primitive K-node covering algorithm to select anchor node, the maximum intersection should be used to reselect anchor nodes after reduction of anchor nodes' power, which includes the nodes' own calculation and the correspondence among nodes. In this way the network's energy will be highly exhausted. Therefore, this paper introduces the strategy of selecting the optimal anchor node, which aims to improve the low energy self-healing algorithm. It is based on the tetrahedron similarity and the nodes inside the tetrahedron. The difference between the former algorithm and the latter one lies in selecting anchor node does not only taking preference for four anchor nodes. Instead it is based on the sets of the anchor node candidates established by the intersection of neighboring sets. Therefore, the number of the anchor node candidates are greater than 4. According to the direct combination of anchor nodes, the tetrad sequence of non-coplanar anchor nodes, which is sorted by the tetrahedron similarity in descending order can be selected. In this way anchor nodes will reach the state of low energy and they can wake up the backup anchor nodes more rapidly.

The improved low-energy self-healing algorithm is described as follows.

Step 1: When the node A_i in the network was initialized, it exchanges information with its neighboring nodes, and obtains nodes and the intersection set_i of the neighboring sets.

Step 2: After the node A_i follows the first step of the selection strategy of anchor nodes, select one of the optimal anchor nodes from set_i according to the information of energy and distance.

Step 3: After the node A_i identifies the optimal set of anchor node candidates from every neighboring intersection, select four anchor nodes from the set of anchor node candidates in sequence to determine whether they are coplanar, then sort the non-coplanar nodes in ascending order according to δ and take priority for selecting the anchor nodes inside the tetrahedron which is composed of A_i.

Step 4: When anchor node was partly consumed, the node A_i checks the list of its own anchor node tetrad directly, and then selects the first tetrad group including the rest three anchor nodes and excludes the low-energy nodes from front to back. The notification message to the nodes which are in the monitoring state in order to make them switch into anchor nodes.

Step 5: The nodes finish switching after they receive the notification message that was sent, and at the same time the low-energy nodes are switched into sensor nodes.

The complexity of the improved algorithm mainly focuses on the selection of anchor node candidates, the coplanar judgment for every tetrads and the sequencing. At first, during the initial selecting process, every candidate node was selected in the intersection through the traversal of every node. The time complexity is $O(N)$. Then make a coplanar judgment on the tetrads and the time complexity is $\alpha \cdot C_n^4 \cdot N$. At last the time complexity of sorting the tetrad nodes is $\beta \cdot O(N^2)$. Therefore, the time complexity is:

$$O(N) + \alpha \cdot C_n^4 \cdot N + \beta \cdot O(N^2) \tag{6}$$

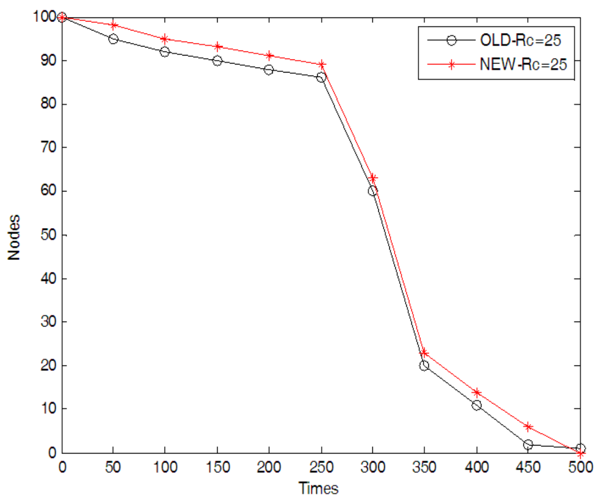
where α, β are constants respectively. The time complexity of the improved algorithm does not increase actually, comparing with the time complexity of the original algorithm [6].

4. **Simulation Results.** In the simulated underwater environment, 100 sensor nodes are distributed at the environment of 100m multiply 100m multiply 100m. Determine the node's density through changing the communication range of nodes and show the node's

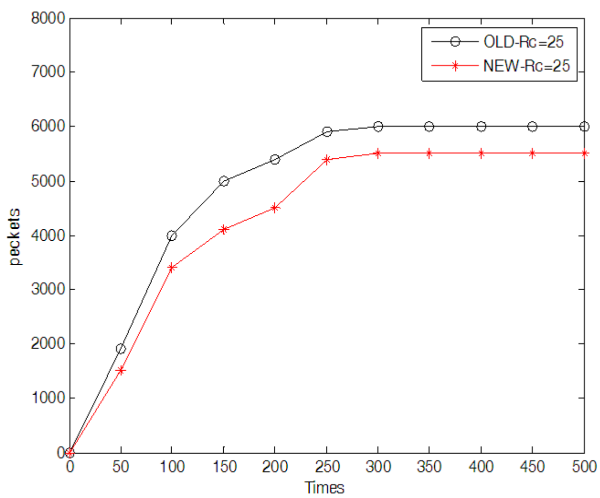
expected neighboring number in this way. The initial power of every node may not be completely the same, therefore the initial power of every node is set to 100 J. Table 2 shows the power consumption of communication actions for each sensor. In the simulation, we use the k-anchor covering algorithm to finish the initialization of anchor nodes. The communication range of nodes is among 25m to 40m. At first, when the radius of the node communication range is 25m, this paper makes a comparison of the network lifetime and the influence of communication amount between low-energy self-healing algorithm and the improved one shown in Figure 3, labeled as OLD-Rc and NEW-Rc, respectively.

TABLE 2. Simulation parameters

Parameter	*Value*
The capacity of data packets	*36 bytes*
Send a data packet	0.5 *J*
Receive a data packet	0.15 *J*
Transfer a data packet	0.105 *J*
The power consumption in sleep/s	$105u_j$



(a)

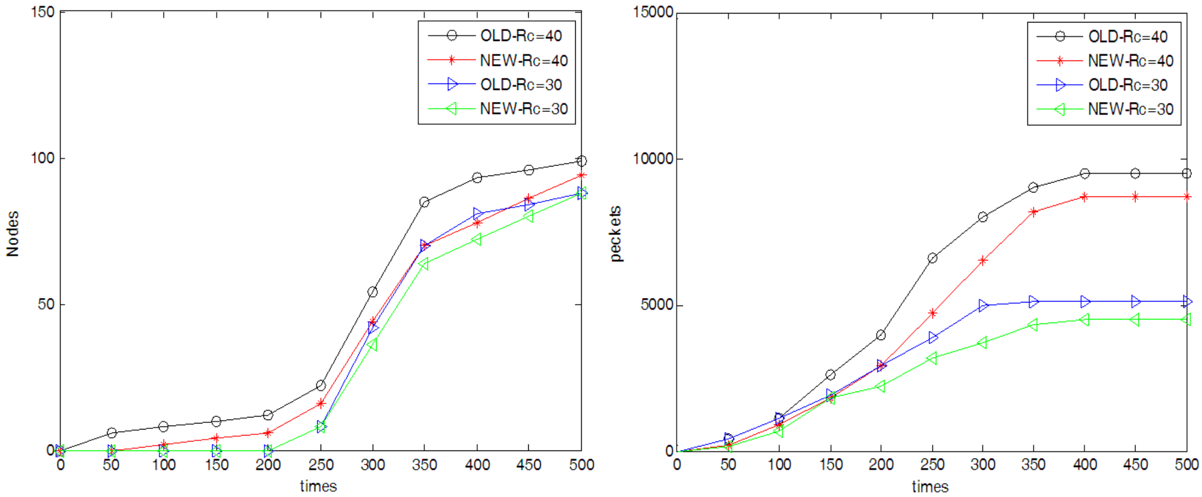


(b)

FIGURE 3. (a) Comparison of the number of surviving nodes when the communication radius is 25m, (b) comparison of the communication traffic when the communication radius is 25m

From Figure 3(a), it can be seen that since the simulation is conducted for 200 times, the amount of the dead nodes begins to increase. The improved algorithm and the original one have the same trend, but the surviving nodes in the improved algorithm network are superior to the primitive algorithm. Anchor nodes' energy consumption on average is higher than sensor nodes', therefore anchor nodes are usually the dead nodes in general. In other words, anchor node begins to run the low-energy self-healing algorithm. The improved algorithm makes the number of the dead nodes decrease slowly when the number of simulation ranges from 0 to 250. When the number of simulation reaches 350 or so, the amount of the primitive algorithm's dead nodes is higher than 80%. When the number of simulation is 400 or so, the amount of the primitive algorithm's dead nodes reaches 90%. The death curve of the improved algorithm is better than the primitive algorithm on the whole, and at the same time the network lifetime can be stretched.

The images, which can be seen in Figure 3(b), stem from the anchor nodes selection of the both algorithms in the first place. The main job of the improved algorithm is to finish



(a) (b)

FIGURE 4. (a) The number of dead nodes with the change of time between different communication radius, (b) the comparison among communication traffic between different communication radius

the backup of nodes in this process. After the backup of nodes is done, the communication traffic of the improved algorithm is lower than the primitive algorithm, due to the few number of the data packets produced by the working of the query algorithm when using the backup algorithm to select anchor nodes. However, then the number of data packets stop increasing; the main reason is that the backup node gradually exhausted. Due to the death of network node, the traffic was not increased when the number of simulation reaches 350.

We can find from Figure 4(a), the death number of nodes increases with the increasing of communication radius. In the simulation, the density of nodes applied in practice can be changed through adjusting the communication radius of the network nodes. In our simulation, setting the communication radius to 30m is better than 40m.

It can be concluded from Figure 4(b) that the network traffic increases with the increasing of the communication radius, due to the incremental number of the nodes' neighbors. The network traffic of the improved algorithm tends to increase, as the communication traffic increases. When the number of simulation is about 400, the communication among nodes is zero and the network traffic will not increase more because most of the nodes have already died.

5. **Conclusions.** This paper has studied the previous low-energy self-healing algorithm, which only takes the maximum intersection into account; however, the communication among nodes, the nodes' consumption has not been calculated. In this way the network's energy is highly consumed. This paper uses the strategy of selecting the best anchor nodes in light of the tetrahedron similarity to improve the low-energy self-healing algorithm. When a breakdown occurs, select the backup nodes for substitution as the new anchor nodes at once, and then choose the recovery path adaptively to ensure the smooth transmission in real time. The simulation results show that the proposed algorithm reduced the number of nodes' deaths and the rate of network fault. As for future work, we plan to find an alternative to localizing the anchor nodes. We are also working on optimizing the number of hops for the self-healing algorithm so that we can minimize the communication overheads.

Acknowledgement. The paper is supported by National Science Foundation of China (61571150, 41176082), Program for New Century Excellent Talents in University (NCET-13-0753), National Science Foundation of Heilongjiang Province, China (F201331, 424006 21), Specialized Research Fund for the Innovation Talents of Science and Technology (2014RFQXJ012).

REFERENCES

[1] F. Akyildiz, D. Pompili and T. Melodia, Challenges for efficient communication in underwater acoustic sensor networks, *ACM Sigbed Review*, vol.1, no.2, pp.3-8, 2004.
[2] F. Akyildiz, D. Pompili and T. Melodia, Underwater acoustic sensor networks: Research challenges, *Ad Hoc Networks*, vol.3, no.3, pp.257-279, 2012.
[3] W. Cheng, A. Y. Teymorian, L. Ma et al., Underwater localization in sparse 3D acoustic sensor networks, *Proc. of Infocom*, vol.13, no.3, pp.236-240, 2008.
[4] Y. Diao, Z. Lin, M. Fu et al., Localizability and distributed localization of sensor networks using relative position measurements, *Large Scale Complex Systems Theory & Applications*, vol.13, no.1, pp.1-6, 2013.
[5] L. Girod and D. Estin, Robust range estimation using acoustic and multimodal sensing, *Intelligent Robots and Systems*, vol.33, no.3, pp.1312-1320, 2012.
[6] M. Watfa, T. Nsouli and M. Ayach, Reactive localisation in underwater wireless sensor networks with self-healing, *International Journal of Intelligent Systems Technologies and Applications*, vol.12, no.1, pp.68-85, 2013.
[7] Y. Ma and Y. H. Hu, ML, source localization theory in an underwater wireless sensor array network, *WiCOM*, vol.31, no.9, pp.1-4, 2014.
[8] J. J. Caffery Jr. and G. L. Stuber, Subscriber location in CDMA cellular networks, *IEEE Trans. Vehicular Technology*, vol.47, no.2, pp.406-416, 2011.