A Sweeper Scheme for Localization and Mobility Prediction in Underwater Acoustic Sensor Networks

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Abstract- **In underwater sensor networks (UWSNs), determining the location of every sensor is important. The process of estimating the location of each node in a sensor network is known as localization. While various localization algorithms have been proposed for terrestrial sensor networks, there are relatively few localization schemes for UWSNs. Since the sensor nodes are in underwater, they are prone to a high dynamic environment due to sea waves. The position of the underwater sensor nodes keep changing due to external factors and harsh physical environment.**

In this paper we propose a sweeper scheme for localization of sensor nodes and also a mobility prediction scheme which helps in calculating the position of the sensor nodes at regular intervals. A key advantage of our scheme is that it can handle network Dynamics efficiently with the assistance of a localization service. Moreover, the scheme does not need a multiple-sink under water sensor network architecture for data gathering.

Keywords: Underwater Acoustic sensor networks, localization, mobility

I. INTRODUCTION

The earth is a water planet: over 71% of the surface is covered by the ocean, most of which has not been explored. As a promising solution to aquatic environmental monitoring and exploration, Underwater Sensor Networks (UWSNs) has attracted significant attention recently from both academia and industry. On one hand, it can enable a wide range of aquatic applications, such as oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. On the other hand, adverse environmental conditions pose a range of challenges to underwater communication and networking. Firstly, acoustic communication is usually employed in underwater sensor networks, and acoustic channels feature high error rate, long propagation delay and limited bandwidth. Secondly, underwater sensor nodes are usually mobile with water currents. Furthermore, compared to terrestrial sensor nodes, underwater sensor nodes are usually much bigger, more energy-consuming, harder to recharge and more expensive. Thus it is very costly to deploy dense underwater sensors in a large area. Last several years have overseen a rapidly growing interest in underwater sensor networks [1], [2]. They can offer significant advantages and benefits in a wide spectrum of aquatic applications, underwater environmental observation for scientific exploration, commercial exploitation, coastline protection and target detection in military or terrorist events. On the other hand, underwater sensor networks probably represent one of the hardest networking environments we have ever encountered. They drastically differ from terrestrial sensor networks in the following ways: **i)** electromagnetic waves cannot propagate over a long distance in water, **ii)** sensor nodes move with water currents and dispersion, which results in dynamic network configurations that need to be monitored. All these unique features are grand challenges to the networking issues at almost every layer of the protocol stack [1], [2].

In fact, providing scalable and efficient Localization service in UWSNs is very challenging due to the unique characteristics of underwater sensor networks. First of all, radio does not work well in water because of its rapid attenuation. Thus acoustic communications are usually adopted in underwater environments. Acoustic channels often feature low bandwidths and long propagation delays, most nodes in a UWSNs can move passively with water currents (except that some gateway nodes are fixed at the water surface or anchored at the bottom), resulting in highly dynamic network topology. To handle dynamic networks, existing Localization schemes for land-based (static) sensor networks need to update position information periodically, which introduces significant communication overhead. Similar to land-based sensor nodes, underwater sensor nodes are usually powered by batteries, which are even harder to recharge or replace in harsh underwater environment.

In short, a localization scheme designed for UWSNs should consider all these factors: long propagation delays, low communication bandwidths, dynamic topology, and energy efficient Localization of mobile sensor nodes is indispensable. So far, only a limited number of schemes have been proposed for the localization service in underwater acoustic networks, these solutions are mainly designed for small-scale static networks (usually with tens of nodes or even less). However, many aquatic applications, such as marine surveillance, require a localization solution that can scale to a large number (hundreds to thousands) of nodes.

Underwater Sensor Networks (UWSNs) that we propose is composed of a large number of sensor nodes and at least one central node. Each sensor node is a tiny entity that is capable of detecting events, locally processing the sensed data, and communicating with neighbor nodes. The central node broadcasts queries or disseminates tasks to the sensors in the Downlink, and the sensed data are forwarded to the central node based on DOA (direction of arrival) in the Uplink. In this paper, we propose a novel data querying and location estimation technique referred as *sweeper* (SS) scheme that uses an adaptive antenna array (AAA) at the central node. We also propose a position estimation method for calculating the current positions of sensor nodes at regular intervals.

The idea of employing the AAA at a central node, because it is more powerful than sensor nodes (in terms of energy, computation, range and administration aspects) to provide necessary means to manage a UWSNs. In the SS scheme, task dissemination messages in the Downlink are disseminated only to the nodes in the specified region rather than to all nodes in the sensor field by using azimuth (*beam direction* and *beam width*) and range (received signal strength indicator-*RSSI*) information estimated for that region. Since the task dissemination is established directly by the SS, no hopping over the intermediate nodes to route the tasks toward the destination nodes is needed.

The sensor node receives the wake up messages; it calculates its position based on the mobility prediction algorithm. Now once the position has been calculated the sensor node replies back in the same direction of arrival of downlink (based on DOA algorithms like MUSIC, ESPIRIT). This is called uplink. The nodes positions are maintained in a location table at the central sensor node. This table can be regularly updated to keep a tab on the position of sensors.

To summarize, the main advantages of the above scheme are as follows.

1) It can handle dynamic networks with good energy efficiency.
2) It takes advantage of central architecture and adaptive antennas.
3) Helps us to keep track of the sensor nodes in regular intervals.

II. RELATED WORK

A. Localization

Localization has been widely explored for terrestrial sensor networks, and a significant number of schemes have been proposed [3], Generally speaking, these schemes can be classified into two categories: range-based schemes and range-free schemes. The former covers the protocols that use absolute point-to-point distance estimates (i.e., range) or angle estimates to calculate locations while the latter makes no assumptions about the availability or validity of such range information. Although range-based Protocols can provide more accurate position estimates; they need additional hardware for distance measures, which will increase the network cost.

On the other hand, range-free schemes do not need additional hardware support, but can only provide coarse position estimates. In this paper, we are more interested in accurate localization. Moreover, in UWSNs, acoustic channels are naturally employed and range measurement using acoustic signals is much more accurate and cheaper compared with that in terrestrial sensor networks using radio [4]. Thus, range-based schemes are potentially good choices for underwater sensor networks. However, due to the unique characteristics (such as low communication bandwidth, node mobility, and three dimensional node deployment) of underwater sensor networks, the applicability of these existing range-based schemes is unknown. Localization for terrestrial mobile sensor networks has also been explored recently [5], [6]. In [5], the authors propose a range-free localization scheme based on a sequential Monte Carlo localization method and show that their scheme can exploit mobility to improve the localization accuracy.

In [6], the authors propose predictive protocols which can control the frequency of localization based on sensor mobility behavior to reduce the energy requirements while bounding the localization error. Both of these two studies assume that sensor nodes are moving randomly and the inherent properties of object mobility patterns. As mentioned previously, there are a couple of studies on localization for underwater acoustic networks [7]. Most of the works related to underwater sensor networks have focused on routing protocols, energy minimization and MAC issues.

Localization is less explored for USNs. The sensors that are currently used in oceanographic research are localized either with Long or Short Base-Line (LBL/SBL) systems. In one case, the authors consider localization for large-scale USNs. They use surface buoys and two types of underwater nodes: anchor nodes and ordinary sensor nodes. At first, anchor nodes are localized by the help of surface buoys and then the ordinary sensors are localized using these anchor nodes. Though this architecture has benefits, locating anchor nodes is also a challenge by itself. In [8] mobile beacons are used to increase the localization coverage in 3D space. Beacons dive and rise to act as underwater GPS, [8] does not consider multi-stage localization.

In [9], a prediction-based localization scheme is proposed for mobile underwater sensor networks. Here, anchor nodes are able to predict their mobility model and they confirm the accuracy of their prediction via measurements with surface buoys. If their model is accurate enough, they do not broadcast updates. This means if the nodes follow a certain mobility pattern they do not receive unnecessary messages, saving communication cost. In [9] the authors assume that the anchor nodes are localized by surface buoys but the cost or the contention that will be caused by this operation is not discussed. Their simulation results are not based on an underwater physical layer or a MAC layer. The mobility models proposed for underwater sensor networks are very few. They are borrowed from oceanography.

B. Mobility Characteristics of Underwater Objects

Underwater objects are moving continuously with water currents and dispersion .Research in hydrodynamics shows that the movement of underwater objects is closely related to many environment factors such as the water current, water temperature [10], [11]. In different environments, the mobility characteristics of underwater objects are different. For example, the mobility patterns of objects near the seashore demonstrate a certain semi-periodic property because of tides; but for objects in rivers, their moving behaviors have no such property. While it is almost impossible to devise a generic mobility model for underwater objects in all environment conditions, some mobility models for underwater objects in specific environments based on hydrodynamics have been devised. This indicates that the movement of underwater objects is not a totally random process. Temporal and spatial correlation is inherent in such movement, as it makes their mobility patterns predictable in nature.

The moving speed of the object changes continuously and shows certain semi-periodic property. This is mainly due to the tides and bathymetry. The exhibited strong time-domain correlations tell us that it is possible to estimate the future value based on the measured past values with high accuracy. Further, [26] and [27] show that spatial correlations exist in underwater environments, which means that the movement of one object is closely related to its nearby objects. In other words, underwater objects possess certain group movement properties.

III. THE ARCHITECTURE

Sensor nodes have two major tasks: Sensing and transmitting data. In most of the current UWSN applications, sensor nodes carry on both tasks continuously. In the SS scheme, the nodes sense and/or transmit data only when they are specifically assigned to do so. We turn on the sensing units and/or wake up the transceivers of the nodes those are in a specific region only when needed. We expect to have major gains by this scheme, since much energy is used for sensing and redundant sensors produce superfluous data overloading the network. For this purpose, we assume that the central node has high processing capability and is equipped with an AAA. The central node selectively disseminates tasks to the sensor nodes in the interested region by specifying beam direction (α) and beam width (Δ) of that region. We assume that a UWSN with an SS has the following characteristics:

1) The nodes are scattered arbitrarily to the sensor field.
2) The central node sweeps the sensor field in a sweeping manner, i.e., changing the beam direction and/or beam width. SS may be implemented using different antenna array techniques such as switched beam that have beams at predefined directions with constant beam width or adaptive beam whose beam direction and beam width changes adaptively based on the channel propagation dynamics . Hence, the type of the AAA implementation can be determined according to the requirements.
3) Since the monitored field is not expected to be geographically flat, the reach ability of the nodes may differ according to their locations. The multipath propagation effect in the wireless channel may be stated as the drawback for the SS scheme. Because of multipath fading and path loss, the transmitted power from the central node may not be delivered equally to all nodes located at the same distance. This problem may be eliminated to some extend by deploying the central node in a location where it can mostly have line-of-sight propagation to the nodes.

In a similar sense, beacon placement in WSNs is important to improve the quality of context-aware applications in an uneven terrain with propagation uncertainties. In conventional UWSN, the data traffic produced by the readings from a set of sensors in the down link and also traffic carrying task commands or queries from the sink in the uplink overload the data communication links .With the SS scheme, since only a subset of sensor nodes are involved in sensing and routing process, data traffic and task query messages in the UWSN can be reduced considerably, leading to prolonged sensor lifetime. For example, sensors in a region can be activated just before a target is expected to enter into that region. In addition, the total delay between the polling time and the response arrival time becomes shorter compared to multi-hop task dissemination schemes. Since the direction of the beam and the *RSSI* values specify polar coordinates of the sensors in the *particular region*, the SS provides rough but easier and more practical location estimation of these sensors compared to the other beacon based or beaconless location estimation schemes. Moreover, SS can be used to simplify the aggregation of sensed data based on location.

For example, we can learn average temperature at a specific region from the nodes. When we use the SS scheme with *RSSI,* we can aggregate data not only for a direction but also for a specific region. Although the boundaries of targeted regions cannot be determined very accurately due to multipath propagation effects, the resulting location based aggregates can be accurate enough for many sensor network applications. All of these can be achieved without any additional hardware or software components in sensor nodes that have stringent cost and size constraints. The SS scheme complies with any MAC, network and transport layer protocol, and does not impose any modifications in the protocols of these layers.

IV. OPERATION

The operation of the SS scheme can be explained with respect to *DOWN link* (the link for the flow of task dissemination and querying messages from the central node to sensor nodes) and *UP link* (the link for the flow of sensed data from sensor nodes to the central node). In order to involve the sensor nodes in monitoring a certain task region, the central node first determines the required parameters. Note that AAA either estimates α and Δ_R by using some advanced signal processing algorithms in the fully adaptive scheme or sets these parameters to some predetermined values in the switched beam scheme. The method of estimation of these parameters is beyond the scope of this paper, and therefore we assume that they are perfectly obtained by the AAA. In order to guarantee conveyance of sensed data to the central node, the routing beam should be set to have enough size to cover the entire region. Moreover, the routing beam should at least cover the region between the central node and the farthest edge of the entire region in radial direction. After determining the parameters, the central node broadcasts *Wakeup* message to all nodes covered by the routing beam specified by the parameters α and Δ_R .

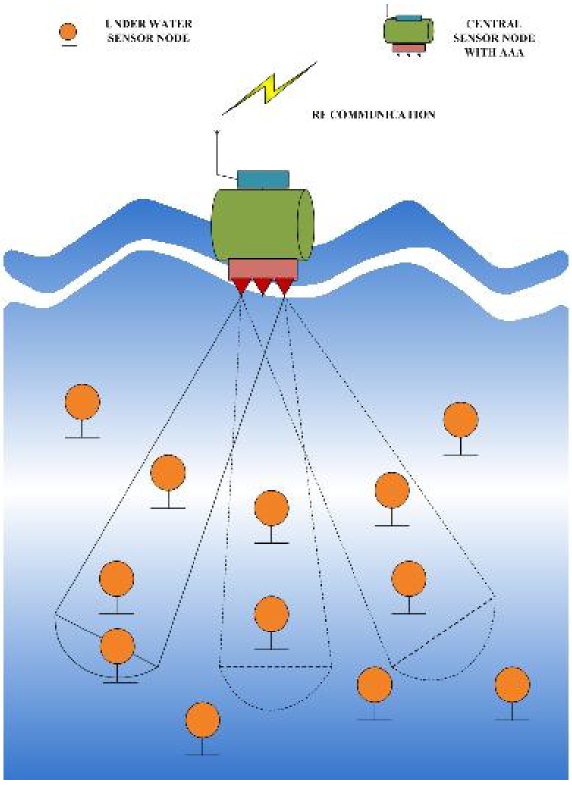

Figure 1. sweeper scheme for localization

Now once the wake up messages are send to all the nodes within the range of the beam, these nodes check for the current position in the sensor network, namely the (x,y,z) coordinates, which have already been recorded by the gps device before dropping them into the ocean. Now the new position is calculated based on position estimation algorithm in the following manner. Considering a sensor node to be designed in a circular casing, once the sensor node has been thrown into the sea, let us assume the phenomenon called as uniform circular motion is exhibited on the sensor node.

In physics, **uniform circular motion** describes the motion of a body traversing a circular path at constant speed. The distance of the body from the axis of rotation remains constant at all times. Though the body's speed is constant, its velocity is not, velocity, a vector quantity, depends on both the body's speed and its direction of travel. This changing velocity indicates the presence of acceleration; this centripetal acceleration is of constant magnitude and directed at all times towards the axis of rotation.

This acceleration, in turn, produced by a centripetal force which is also constant in magnitude and directed towards the axis of rotation. Assuming the sensor node to be rigid body, any point in the sensor node is the same on the entire surface, For example lets us consider the position of the gps receiver as a point in the sensor node called as **A**, after Some interval of time the point a moves to different position called **B,** thus buy using the above prediction algorithm stated below we can calculate the new position of sensor node. To perform accurate prediction, knowledge of the movement pattern of a node is imperative.

Without this knowledge, the prediction accuracy would be greatly reduced. The mobility pattern information is to be exchanged among communication node pairs so that the prediction module can use the algorithm to compute the position estimate. The movement is circular; the node also needs to provide the center coordination information at each exchange.

In a discrete time system model is used to describe the nodes mobility attributes .These are mainly used in the prediction algorithm. The discrete time system of the sensor nodes are represented in the form of vectors at any instance of time K. Now let’s consider the vector (the initial position in the form of gps coordinates)

$$s_k = [x_k, y_k, z_k, vx_k, vy_k, vz_k,]^T$$

Where in x_k, y_k and z_k specify the current 3-D position of the node, while vx_k, vy_k and vz_k specify the velocity components on each axis respectively. The state information is exchanged between a pair of nodes that form a point-to-point wireless link. The prediction algorithm is to estimate position of the node at the next time s_k and instance k+1, Using state information and mobility pattern information which is represented by the equation

$$p_k = \{[x_k, y_k, z_k, vx_k, vy_k, vz_k], p_k\} \rightarrow [\hat{x}_{k+1}, \hat{y}_{k+1}, \hat{z}_{k+1}]$$

Mobility prediction uses the current location information, the projected velocity, and the mobility pattern parameters to predict the location at a future time instance.

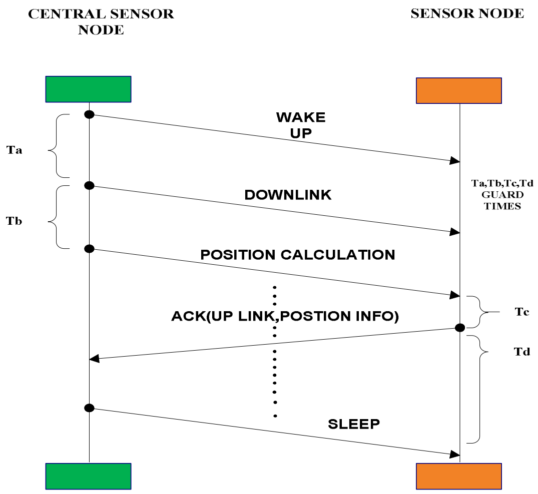

Figure 2. Activity Diagram

A. SWEEPER SCHEME: A DESCRIPTION

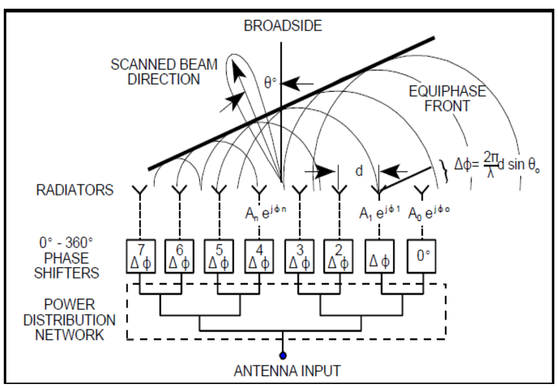

Figure 3. Sweeper scheme

The linear phased array with equal spaced elements is easiest to analyze and forms the basis for most array designs. Figure above schematically illustrates a corporate feed linear array with element spacing d. It is the simplest and is still widely used .By controlling the phase and amplitude of excitation to each element, as depicted, we can control the direction and shape of the beam radiated by the array. The phase excitation, $\Phi(n)$, controls the beam pointing angle θ_o, in a phased array. To produce a broadside beam, θ_o =0, requires phase excitation, $\Phi(n)$ =0. Other scan angles require an excitation, $\Phi(n)$ = nkd sin (θ_o), for the nth element where k is the wave number ($2\pi / \lambda$). In this manner a linear phased array can radiate a beam in any scan direction θ_o , provided the element pattern has sufficient beam width. In traveling one wavelength (λ) a wave incurs a phase lag of 2π radians. So, in traveling the distance ΔR, it incurs a phase lag of $2\pi \; \Delta R / \lambda$ radians. As seen from the above diagram $\Delta R = d \sin\theta$. Hence, the element-to-element phase difference needed to steer the beam θ radians off broadside is

$$\Delta\phi = 2\pi \frac{d \sin\theta}{\lambda}$$

B. PREDICTION CALCULATION

For a node with circular movement, assuming the center of the circle is known (from the mobility information exchange), the radius of the circle is calculated as the distance between the center of the circle and the current node position. The calculation of next position is as following

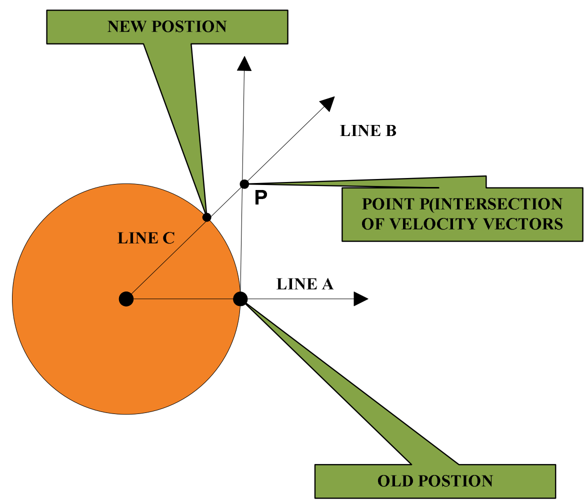

Figure 4. Mobility prediction

To calculate the position of the node we must do coordinate transformation to the origin (center of the circle).Now let's consider the current position of the node to be as follows:

$$[x_k, y_k, z_k]^T = [x_k - x_o, y_k - y_o, z_k - z_o,]^T$$

Where x_o , y_o and z_o are the 3-d coordinates of the origin of the circle (center). Assuming that the sensor nodes moves in a uniform circular motion and with a constant velocity, in order to calculate the angle between the position vectors that represent the initial and new position, we use the following formula

$$\delta = \frac{t_{k+1} - t_k}{\frac{2\pi r}{v}} * 2\pi = \frac{v(t_{k+1} - t_k)}{r}$$

Where r is the radius of the circle and v is the scalar velocity of the node. Draw line A between the origin and the node position$[x_k, y_k, z_k]^T$, line B between the origin and$[X_{K+1}, Y_{K+1}, Z_{K+1}]^T$, and line C through$[x_k, y_k, z_k]^T$ with $[V_K, V_K, V_K]^T$ as its direction vector. The coordination of the intersection of Line B and Line C (i.e., point P) is: $[X_K + \alpha VX_K, Y_K + \alpha VY, Z_K + \alpha VZ]^T$ where α is calculated as

$$\alpha = \frac{r * \delta}{v}$$

Calculating the distance d between the point P and origin O

$$d = \sqrt{(x_k + \alpha vx_k)^2 + (y_k + \alpha vy_k)^2 + (z_k + \alpha vz_k)^2}$$

Now the position at a time t_{k+1} is:

$$x_{k+1} = (x_k + \alpha vx_k)$$

$$y_{k+1} = (y_k + \alpha vy_k)$$

$$z_{k+1} = (z_k + \alpha vz_k)$$

The coordinate of the predicted node position is transformed back to the original coordinate system:

$$x_{k+1} = x_{k+1} + x_o$$

$$y_{k+1} = y_{k+1} + y_o$$

$$z_{k+1} = z_{k+1} + z_o$$

Thus the above calculated are the predicted coordinates for the sensor node. After the current coordinates of the sensor node are calculated, the coordinates are sent to central node via direction antennas.

The central node after receiving the message updates the location table based on the node id. The AAA at the central node can sweep the entire network for current position of the sensor nodes at regular intervals, so that the user at the other end can have track of the nodes in the network. The positions are maintained in the location table.

V. SIMULATION

In this paper in order to test the performance of the proposed idea, we make use of Monte Carlo simulation. The Monte Carlo method is just one of many methods for analyzing uncertainty propagation, where the goal is to determine how *random variation*, *lack of knowledge*, or *error* affects the *sensitivity*, *performance*, or *reliability* of the system that is being modeled. Monte Carlo simulation is categorized as a sampling method because the inputs are randomly generated from *probability distributions* to simulate the process of sampling from actual inputs. It is a type of simulation that relies on repeated random sampling and statistical analysis to compute the results. This method of simulation is very closely related to random experiments, experiments for which the specific result is not known in advance. In this context, Monte Carlo simulation can be considered as a methodical way of doing so-called what-if analysis. The performance of the Mobility prediction Algorithm is simulated using Monte Carlo methods extensively. Here the performance of the algorithm is analyzed based on the Prediction Ration and the number of random samples. For this kind of sampling we make use Uniform Distribution. From the below **figure.5** we can see that as the numbers of runs increases the ratio of predicting the next location increases and also the prediction ratio falls within the Uniform Distribution. From the above simulation we can conclude that the performance of the algorithm is fair.

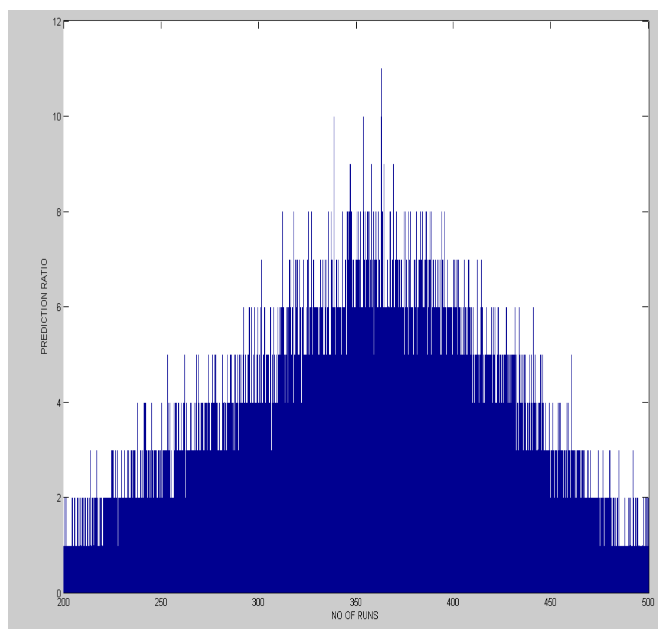

Figure 5. mobility prediction schemes performance with respect to prediction ratio

VI. CONCLUSION

Under-Water Acoustic Sensor Networks (UW-ASN) are novel networking paradigms and some applications call for 3D space deployment for special military or civilian purpose. In such a network, sensor localization and mobility prediction of sensor nodes remains a challenge problem. In this paper, we have proposed a sectored sweeping scheme with the help of the adaptive array antenna and also a mobility prediction scheme that helps us to keep track of the position of the sensor nodes at regular intervals. The central sensor node sweeps the entire network for the position of the sensor nodes. The main advantage of this scheme is there is one to one communication between the central node and the sensor nodes. By this way hop-by-hop communication is avoided and energy is saved, it can handle dynamic networks with good energy efficiency.

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