Volume 3, Issue 6, June 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

# Novel Localization Scheme for 3D UW-ASNs

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***Abstract*— In this paper, we are trying to elaborate the idea of mining applications in the aquatic scenario and also highlight the basic differences between terrestrial sensor webs with the aquatic paradigm while exploring the different positioning approaches. We propose a new algorithm which uses the (mining counter-measure) MCM applications through of an UUV-guided positioning system in an UW-ASN. Also, we have compared with the other related work previous done on this very same field and we have proved that our work yields better results than the previous work done and the performance analysis through various MATLAB simulations have been shown.**

***Keywords*— Aquatic Wireless Acoustic Sensor Webs (UW-ASNs), Acoustic communication, Terrestrial Wireless Sensor Webs (TWSNs), Radio Frequency (RF), Localization, Anchor Node, UA (Aquatic Acoustic) Node, Surface Buoy, MCM.**

## I. INTRODUCTION

Wireless aquatic acoustic webbing is the enabling technology for the applications such as oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance technologies and in collaborative monitoring missions [1] [2] [3].

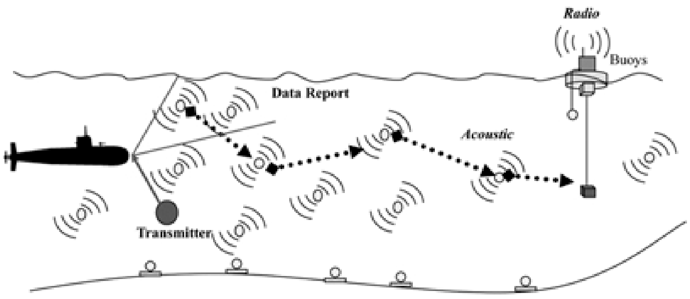



Fig. 1: Aquatic Sensor Web

Wireless webbing technologies have experienced a considerably development in the last fifteen years, not only in the standardization areas but also in the market establishment of a bunch of devices, services and applications. Recently, wireless sensor webs have been proposed for their establishment in aquatic environs where a lot of applications like agriculture, pollution monitoring, offshore exploration, etc. would benefit from this technology [4][5]. Despite having similarities with TWSNs, UWSNs exhibit several architectural differences with respect to the terrestrial ones, which are mainly due to the transmission medium characteristics (sea water) and the signal employed to transmit the data (acoustic ultrasound signals) [6]. Then, the design of appropriate web architecture for UWSNs is seriously hardened by the conditions of the communication system and, as a consequence, what is valid for TWSNs is perhaps not valid for UWSNs. Fig. 1 shows the aquatic sensor web in which the aquatic sensor nodes communicate and send the sensed data report from an AUV or any other moving vehicle to the buoys at sink. The AUVs receive the information from the transmitters. Maintaining all established connections becomes complicated in unstable aquatic channel. Aquatic sensor webs or aquatic acoustic wireless sensor webs mainly differ in the communication media employed for information transmission. The work described in [7] reviews the physical fundamentals and engineering implementations for efficient information exchange via wireless communication using physical waves as the carrier among nodes in an aquatic sensor web. The physical waves include sound, radio, and light. Based on the comparative study, one can select carriers for aquatic sensor webs that enhance the communication efficiency in specified aquatic environ.

## II. POTENTIAL APPLICATIONS

Sensor Webs in the aquatic domain have a huge potential for monitoring the health of river and marine environs [8]. A sensor web established aquatic can be used to monitor physical variables such as water temperature and pressure as well as variables such as conductivity, turbidity and certain pollutants [9] [10].

*Navy Applications:* The UUV provides strategic and operational advantages to the Navy and security forces by reducing the cost and human risk significantly in the MCM operations, as well as by extending the reach of information, surveillance and reconnaissance. MCM operations are conducted by the Navy to estimate the location and destruction of the naval mines [11]. These UUV systems can be launched off the naval platform, offer significant protection against major threats such as naval mines.

## III. RELATED WORK

In this paper, we have emphasized on the problem of Positioning. In aquatic environ, sensor nodes need to justify their own locations because they may be drifted by water currents [12]. Moreover, some kinds of measured information are meaningless without location information. We need to introduce a new localization method which operates undersea with the least use of GPS. In aquatic situation, sensor nodes can easily measure their depth with hydraulic gauge. Localization is the prominent problem and its solution is the need of the hour as it directly relates with other problems like Channel Assignment and Cluster-head Selection in homogeneous UW-ASNs in the circumstances in which the Figure 2 scenario is considered.

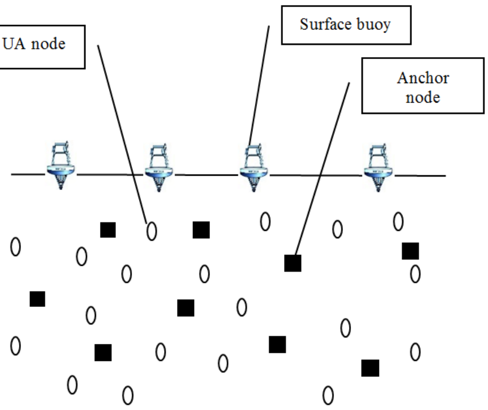



Fig. 2: Aquatic Sensor Web Architecture

In general localization method in water, sensor nodes identify their positions based on distances from some anchor nodes (in common language, landmarks). There are many Localization or Positioning schemes deduced.

*A. Strewn positioning approach*

1. Approximation-based schemes:
   a. Dive 'N' Rise Localization (DNRL) [13] is a Strewn Approximation-based localization scheme. Its main usage is in the field of mobile UW-ASNs. The procedure it applies enables the Dive 'N' Rise (DNR) Beacons (or localized) to descend and ascend in the water column. DNRL uses one-way ranging ToA (Time of Arrival) technique and uses lateration.
   b. Multi-Stage Localization (MSL) [14] is an extension of DNRL which includes an iterative phase. DNR beacons are not propelled and use successfully localized nodes as a beacon which is unable to ascend or descend but allowed to send self-coordinates.
   c. AAL (AUV-Aided Localization) [15], LDB (Localization with Directional Beacons) [16] and LSL [17] and LSLS (Large-Scale Localization Scheme) [18] are other Approximation-based schemes.

2. Likelihood-Based Schemes: They are the schemes which estimate the localization by using the nodes' previous coordinates and mobility patterns. In [19], the authors make use of the hierarchical architecture of [17] and idealize a new concept of Scalable Localization with Mobility Prediction (SLMP) for mobile UW-ASNs.

*B. Centralized positioning approach*

1. Approximation-Based Schemes:
   a. MASL (Motion-Aware Self Localization) [20] aims to provide accurate localization by addressing inaccurate distance estimates in mobile UW-ASNs. MASL involves a scenario in which each node collects its location and its neighbour's locations also and then it forwards to an AUV or UUV.
   b. Area-based Localization Scheme (ALS) [21] gives the estimate of the area where the sensor node resides rather than its set of coordinates. The anchor nodes partition the region into non-overlapping areas by sending messages at varying transmission power levels. ALS is less energy efficient than other silent localization protocols such as Aquatic Positioning System (UPS) [22] approach.
2. Likelihood based Schemes: These involve approaches such as Collaborative Localization (CL) is explained in [23]. The author uses this approach for the fleet of aquatic drifters. It assumes a scenario in which aquatic sensors are responsible for collecting data from the depths of the marines and carrying them to the surface.

## IV. PROPOSED WORK

The problem of positioning is taken very seriously these days as new algorithms and schemes are now being researched and found out to overcome the situation when several nodes are there in the aquatic scenario looking to be localized with minimum error and maximum localization success.

*A. Aquatic Acoustic Web Scenario and Assumptions*

We contemplate a 3D aquatic acoustic web scenario in which the sensor nodes are floating at different levels. As shown in Fig. 3, the UUV is moving in a straight line set beacon points at different time intervals and as per the situation demands, some sensor nodes encountered in the path of the UUV can also be given the responsibility of being a temporary beacon point so that keeping the sparse 3D sensor web in mind, the nodes beneath the level at which the UUV is moving and also above that level can be localized with more efficiency. So to enhance the localization success, we need to ponder the scenario illustrated in Fig. 3 and also cogitates the algorithm named UUV – Enabled Positioning Scheme (UEPS) shown in Table 1. In the figure below, the nodes $S_2$ and $S_3$ have been localized at different situations. The node $S_1$ is the node which is not accurately localized and perceives the directional beacon beam from only one beacon point, whereas the other nodes $S_2$ and $S_3$ hear the directional beacon beam from two beacon points at different height *H* respectively. The scenario shown in Fig. 3 is majorly devised to play the fulcrum role in the Navy MCM (mine counter-measure) operations. First of all, the MCM operation is conducted by the naval forces which search for any aquatic naval mines which may be floating in the middle of the ocean 3D volume or may be at the bottom of the ocean or the ocean floor.

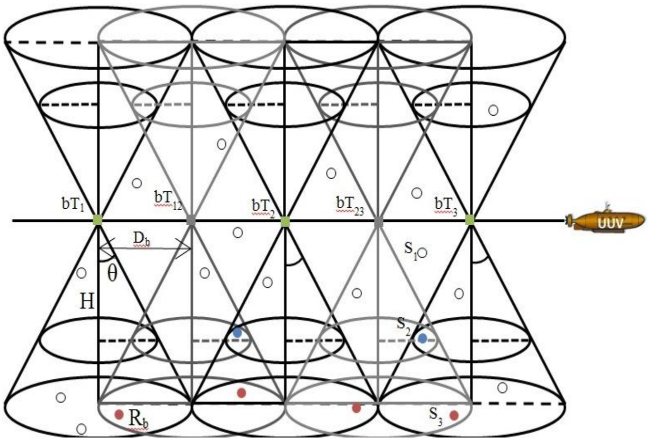



Fig. 3: 3D UW-ASN scenario involving the UUV, beacons and sensor nodes

*B. Proposed UEPS Algorithm*

In the Fig. 3 shown above, the UUV is moving on a straight-line path setting the beacon points at different time intervals such as $bT_1$, $bT_2$ and $bT_3$. The geometric cone formed by the directional antennae of the beacons. We also see in this figure, the two different beacons – the beacons set by the UUV and the other ones are the temporary beacons, i.e. the responsibility given to a sensor node being encountered in its straight-line path. The height of the cone is H, its radius is $R_b$, and its beacon angle is θ. The depth of a node can be directly measured by a cheap pressure sensor, which is denoted as *H*. The key challenge to position a node's location is thus to determine its 2D position at the fixed depth (the node is denoted as *S*). This scenario can be used in MCM operations conducted by the Navy. If the density of the 3D aquatic volume is increased, the one-third of the maximum transmission range of the UUV model used and the trade – off between the transmission range and the attenuation of the denser medium of the ocean deep is taken. Now further, we will be elaborating our 3D UW-ASN architectural scenario. The fact that when the UUV sends a directional beacon towards the sensor field, those nodes who have heard the beacon actually fall in the conical beacon beam and the beam forms different circles with different *H*. With a fixed depth *H*, the centre of the circle is $(x, y, H)$, and the radius of the circle is

$$R_b = \tan\left(\frac{\theta}{2}\right) \times \Delta H \tag{1}$$

Here θ is the angle of the conical beacon whose height is $\Delta H = |\, H_U - H \,|$. Thus, when UUV wanders at fixed depth of water sending beacons, we could map the nodes from 3D to 2D with those determined circles. For example, when node *S* falls in the circle of depth *H* (or the circle covers *S*), *S* can receive beacons from *H* from the UUV, and thus can roughly estimate its position from the coordinate $(x, y, H)$. This basic scheme, however, would introduce a relatively large error, because *S* can be actually at the border of the circle. We first define the *Initially-heard beacon point* and the *Finally-heard beacon point* in those series of beacons. As shown in Fig. 4, the UUV's movement trajectory is the broken line. Sensor node *S* perceives the beacons when UUV sends them at points from $I(x_1, y_1)$ to $F(x_2, y_1)$ and we define these points as beacon points. UUV sends a beacon at point $I(x_1, y_1)$, and this beacon is the first beacon is the first beacon which the sensor *S* perceives we define this point as the Initially-heard beacon point. UUV moves in a straight broken line paralleled with *x*-axis. We assume that the node *S* is positioned on the top side of the UUV's current moving trajectory. *I* is node *S*'s the *Initially-heard beacon point* and *F* is node *S*'s the *Finally-heard beacon point* with corresponding coordinates $(x_1, y_1)$, $(x_2, y_1)$ respectively. The distance between *S* and *I* or *F* is $R_b$ calculated using Equation (1). The position of *S* is thus calculated as,

$$\begin{cases} x = \frac{x_1 + x_2}{2} \\ y = y_1 + \sqrt{{R_b}^2 - \left(\frac{x_1 - x_2}{2}\right)^2} \end{cases} \tag{2}$$

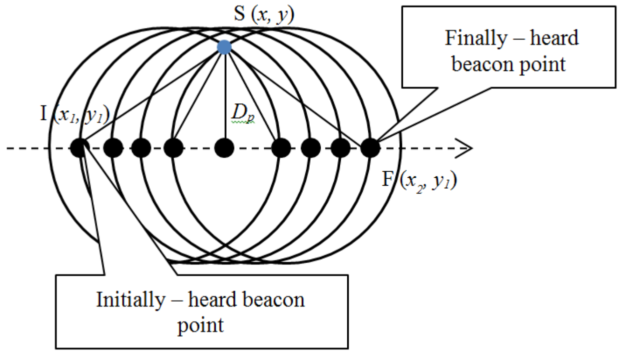
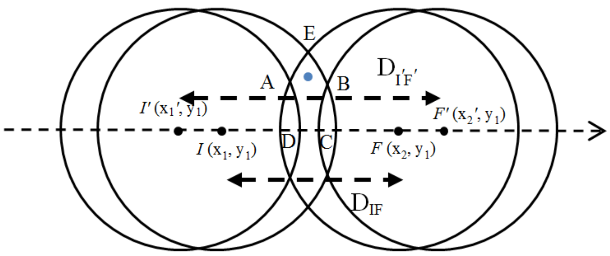



Fig. 4: Positioning using the Initially-heard and Finally-heard beacon points.

Now as shown in Figure 5, we define the *mobile anchor point I'* before the *Initially-heard beacon point I* as the *pre-heard beacon point* of *I* and the *mobile anchor point F'* post the *Finally-heard beacon point* of *F*. The distance between two adjacent mobile anchor points which we called *beacon-beacon distance* is defined as $D_b$. If we include the beacon interval t and the speed of UUV $v_U$ in the beacon sending by the UUV, then the node can calculate $D_b$ as $D_b = bT \times v_U$. We also define the distance between I and F is $D_{IF}$, this is due to the fact that the UUV moves in a straight line paralleled with x-axis, hence $D_{IF} = |IF| = |x_2 - x_1|$. We also define the distance between I′ and F′ as $D_{IF}'$, hence the relation between $D_{IF}$ and $D_{IF}'$ is $D_{IF}' = |I'F'| = |IF| + 2D_b = D_{IF} + 2D_b$. Four circles centred at I′, I, F, F′ with radius $R_b$ form the intersection area. With different $D_{IF}'$, the intersection will have different shape as shown in figure 5. Now, here is the case where $D_{I'F'}=|I'F'| \geq 2R_b$ as shown in figure 5. When computing the positions of the nodes in the intersection area, they have the same characters, and we compute *S*'s coordinate (*x*, *y*) as follows:

$$\begin{cases} x = \frac{x_1+x_2}{2} \\ y = y_1 + \frac{\sqrt{R_b{}^2-\left(\frac{x_1-x_2}{2}\right)^2}}{2} \end{cases} \quad (3)$$

We, therefore, present our UEPS algorithm in Table 1. The UUV moves parallel to the *x*-axis as per the bottom-up approach (shown in figure 3), with a constant speed $v_U$ over the 3D sensor establishment volume.




$D_{I'F'}=|I'F'| \geq 2R_b$

Fig. 5: Sensor node (blue dot) lies in a small area ADCBE.

When a sensor node receives a beacon successfully, the timer *T* is increased by *bT*, which is the time interval between the two beacons set by the UUV travelling in a straight line as illustrated in the aquatic sensor web architecture and scenario shown in figure 3. When the node receives the next beacon, it stores the UUV's new position coordinates *x*, *y* and increase the time *T*. After that, it checks whether the difference between *y* and *y1* is greater than or equal to $D_p$. If this value is true, which means that the UUV has moved to the estimated position of the sensor node, it stops receiving beacon signal in poscalc() procedure and then it calculates the sensor node's position using the Equation (3) according to the case we have considered i.e. $D_{I'F'} \geq 2R_b$. Since UEPS is divided into different procedures or sub-routines, it is a Strewn algorithm.

| **Table 1: UUV – Enabled Positioning Scheme (UEPS) Algorithm** |
|---|
| **1.** **func** START |
| **2.** Initialize *H*, height of the UUV, *T*, the time factor as initial points and Rec1st as False |
| **3.** **return** True |
| **4.** **end func** |
| **5.** **func** BeaconRcvd() |
| **6.** **if** Rec1st = = False then |
| **7.** Rec1st ← True |
| **8.** 1stBeaconRcvd() |

```
9.    else
10.      NxtBeaconRcvd()
11.   end if
12.   return True
13. end func
14. func NxtBeaconRcvd()
15.   Initialize x1, y1, bT, vU, θ, HU, DP
16.   Rb ← tan (θ/2) × (HU - H)
17.   bTm ← 2Rb / vU + 1
18.   T ← T + bT
19.   return True
20. end func
21. func NxtBeaconRcvd()
22.   Initiallyize x2 and y2.
23.   T ← T + bT
24.   if | y - y1 | ≥ DP then
25.     poscalc()  // Function to calculate node's position
26.   end if
27.   chtime() //Check the time factor
28.   return True
29. end func
30. func poscalc()
31.   if T > bTm then
32.     poscalc()
33.   end if
34.   return True
35. end func
36. func poscalc()
37. Initialize UUV transmission range value Tu as 2.35, 2.1
    and 2 km.
38.   Rb ← tan (θ/2) × (H – HU)
39.   DI'F' ← (x2 – x1) + 2bT vU
40.   if DI'F' ≥ 2Rb then
41.      Equation (3) computes x & y, the node's location
42.      Equation (6) computes the localization success
43.   end if
44.   Turn off the receiver
45.   return True
46. end func
```

## V. PERFORMANCE ANALYSIS

We analyse the performance of our UEPS algorithm through MATLAB simulations. About a thousand sensor nodes are randomly established in 500m × 500m × 500m 3D volume. The UUV follows a pre-defined trajectory as shown in figure 3 at a fixed depth with a constant speed over the 3D aquatic sensor web establishment volume, and the mounted transducers on the UUV has the fixed acoustic radiating power to reach the farthest nodes that may be established on the bottom of the 3D volume or space. We set the speed of UUV 1.54 m/s (approx. 3 knots). Our metrics for performance analysis are beacon intervals (*bT* values in seconds) and beacon angle ($\theta$ in degrees). To measure the hit percentage of localization i.e. how much the nodes are localized, we use the localization success percentage, which is defined as

$$L_s = \log_{10}(T_u) \times e^{P(bT)} \tag{6}$$

Here, $L_s$ is the percentage of localization success, $T_u$ is the transmission range of the UUV and *P(bT)* is the probability of beacon intervals for the localization of sensor nodes established in the three-dimensional aquatic scenario volume. The performance metrics for this equation is shown in Table 2. The P(bT) here can be taken in the range 50 – 95 % and 50 – 80 % because of the two main scenario properties – high percentage of naval mines and low percentage of naval mines to be destroyed. So we can see that in the best case the maxima value of the localization success can be up to 96% and in the worst case, the maxima can reach up to 85 %. Therefore UEPS gives the coordinates of the to-be-positioned nodes with a relatively high localization success.

In figure 6 above, we show the localization success for different beacon intervals. We fluctuate the probability of frequent beacon intervals *P(bT)* where bT = 1s to 15s. As we see from equation (6), the localization success depends on beacon intervals *bT* and the transmission range of the UUV $T_u$. The logarithmic value of order 10 is taken because of the fact that the 3D volume space is always measured in the orders of 10. In the Fig. 6, we set the range of $T_u$ value from 2 – 2.35 km because of the fact that we are using REMUS 6000 UUV which has the maximum transmission range up to 6 km. To reduce the web overhead and power consumption of the UUV for higher web lifetime, we reduced the transmission capability so that it can be quite adequate for the current scenario of MCM operations in small 3D volume.

So, we randomly selected about one-third of the maximum transmission range i.e. 2 km as the lower bound and 2.35 as the upper bound.

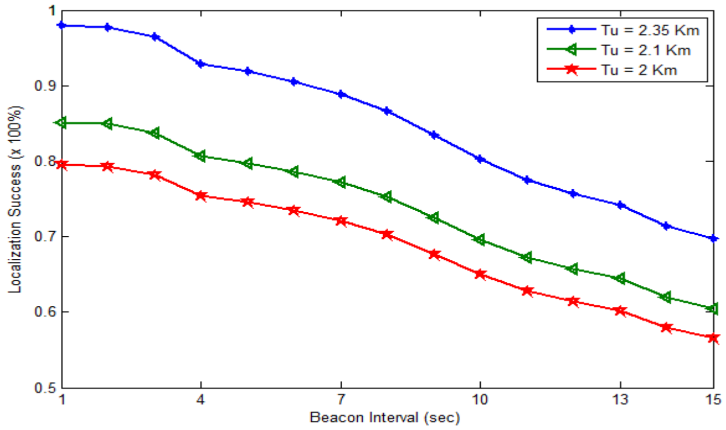



Fig. 6: Different Localization Success line graphs by varying $T_u$

We also observe that when $T_u$ is at 2.35 Km, we obtain the localization success at approximately 98% and when $T_u$ is 2.1 Km, the localization success reduces to 85% and then further reduces to 80% when $T_u$ is 2 Km. This is because within the value range from 2 – 2.35 Km, the UUV gets the opportunity to send and receive more and more localization messages in a dense aquatic sensor web. We have increase the density so as to improve the localization success used in the MCM applications. As we decrease Tu to 2 Km, we also observe a substantial decrease in the localization success and hence the less number of nodes would be localized or positioned in a given specific time frame.

Table 2: Performance Metric used in the positioning scheme

| **Metric** | **Value / Range** |
|---|---|
| UUV Transmission Range, $T_u$ | 2.00 - 2.35 Km |
| Beacon Interval, *bT* | 1 - 15 sec |
| Probability of Frequent Beacon Intervals, *P(bT)* | 50 – 95% or 50 – 80% |

From the result obtained, ranging the value of $T_u$ as 2.35 Km, 2.1 Km and 2 Km, we observe that the localization success decreases as we increase the beacon interval. This is because as the beacon interval increases i.e. the probability of frequent beacon intervals increases, the *beacon-beacon distance* $D_b$ increases and it goes more out of the UUV's transmission range $T_u$.

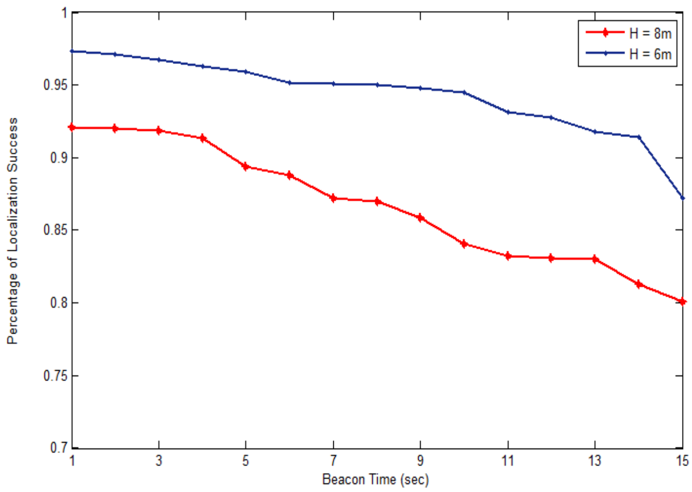



Fig. 7: Previous Work by varying the height above the to-be-positioned node, H

From the illustration of the figure 7 above, the related work in this field has been done by varying the height of the beacon conical beam on the to-be-positioned node done by the authors in [22]. When the height is 6 meters, which is the appropriate height for the REMUS class UUV for better localization success, the highest localization success achieved is at 97% when the beacon time interval is 1 second. But as this beacon time increases, the localization success plummets gradually. When H is at 8 meters, the base of the conical beam is larger due to the larger radius (see equation (1)) and hence the localization success is reduced considerably even when the beacon time is at 1 second i.e. at 93%. We also see quite a zig – zag form in red line throughout and in blue line after the beacon time is 13 seconds. Keeping in mind the equation (7), we have already discussed that the beacon interval *bT* is directly proportional to the beacon – beacon distance $D_b$. Therefore, by increasing the upper bound of the probability *P(bT)*, the localization success also increases.

## VI. Conclusion

The proposed scenario and its associated algorithm have a great significance in the field of Navy MCM operations which require a denser establishment of the UW-ASN including small number of UUVs. The previous work done was by considering the height of the conical beacon beam over the sensor nodes for better positioning percentage and we have devised a new UW-ASN scenario and used the transmission range of UUV as a useful parameter that clearly determines the localization success and thus proves better approach than the previous work done.

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