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Performance Study of Positioning Structures for Underwater Sensor Networks

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Abstract - An impact study of the most relevant factors which influence the performance of general positioning structures in underwater sensor networks is conducted within this work. A major contribution of this work is the performance evaluation of four different positioning procedures and the influences of the water physical properties in the positioning performance achievements. Among others we investigate the performance dependence on temperature, salinity, and depth. The four approaches selected to perform this study are the ad-hoc positioning structure (AHPOS), the robust positioning scheme (RPS), the n-hop multilateration (N-HOP) algorithm and a new proposed approach known as the accurate underwater positioning (APOS).

1 Introduction

Nowadays the need for communication between two terminals withouth any supporting insfrastructure is growing up. Ad hoc networks are able to support such communication requirement due to the inexistence of central controlling units. Additionally ad-hoc networks are continuously gaining importance due to their cheapness and efficiency of deployment.

The underwater environment offers many possibilities for applications based on ad hoc networks both civilian as well as in military systems [1]. Autonomous acting sensor networks inspect underwater pipelines and cables in submarine gas and oil networks and positioning assistance is needed for supporting underwater surveying operations. However there are some important factors to be considered e.g. costs of deployment, node's failure due to battery depletion, or the reliability of the network itself which strongly impact the positioning structure performance and which should be carefully analized before deployment.

This work offers a detailed impact study of the most important physical conditions which affect the performance of positioning structures in underwater acoustic sensor networks. The performance comparison and discussion is based on our simulation results. Finally we conclude this work with our major findings regarding the deployment of positioning systems for underwater sensor networks.

2 Underwater Positioning

Many ocean observing and surveillance applications require accurate position knowledge of the sensor nodes which form the network. The nodes communicate to each other by message exchange. Based on these message broadcasts, the neighbour nodes may use this information exchange in order to perform a position estimation.

However one major problem is the inhomogeneous propagation characteristics of acoustic signals in the underwater channel e.g. the underwater propagation velocity is not constant and heavily depends on temperature, depth, salinity and pressure. Therefore the channel differs from node to node.

These variations may critically affect to the position estimation because range measurements are based on a good characterisation of the underwater acoustic velocity. If these velocity propagation is not accurately estimated errors in the position estimation may appear. For example a higher range deviation leads to a less exactly position estimation.
Position estimation can be performed according to different algorithms and procedures. We identify a three main phases structure common to each method. The first phase is responsible for range determination, the second estimates the position. Finally the third phase includes a refinement procedure which intends to increase the final system accuracy. The combination of these three phases leads to a number of localisation algorithms [2],[3],[4] which are in fact the four ones that are included in our performance study. Each algorithm has the ability of estimate the position of the sensor nodes in ad-hoc networks but according to different algorithms. For a more detailed algorithm description refer to [2],[3],[4].

3 Simulation Environment

We have developed the Underwater Positioning (UWPOS) simulation tool [5] which is integrated in the OMNeT++ simulation platform [6]. The code is written using the C++ programming language. Moreover the UWPOS tool integrates most well known ad hoc distributed positioning algorithms. Based on the basic package we have modified and enhanced the Positif software to allow underwater acoustic propagation and acoustic signal transmission for distance estimation by implementing three different acoustic propagation models [7] well-established and recognised within the ocean research community. In this section the different blocks which compose the architecture of the Underwater Positioning simulation software are presented.

3.1 The OMNeT++ Platform

The OMNeT++ simulation environment [6] is a discrete event simulation environment. Its primary application area is the simulation of communication networks and the simulation of complex systems. One major advantage of OMNeT++ is its free license for academic use.
Basically a OMNeT++ complete model consists of hierarchically connected modules which allows the user to define and reflect the logical structure of the system under consideration while designing or analyzing different approaches or models. The modules communicate through message passing which can contain different data types and which are sent and received through gates and connections.
Each module can have their own parameters which are used to define and specify the module behaviour. In fact modules at the lowest hierarchy level encapsulate the concrete behaviour. These modules are called simple modules and are programmed using C++ code.
The Figure 1 shows the OMNeT++ platform architecture and the interaction of the different basic components. We identify the executing model under consideration, the model component library which contains the behaviour of the different elements. Also the SIM block which is responsible for managing the overall SIMulation system, the ENVIR is the environment controller, and the CMDENV/TKENV block which defines the simulation run either by command or graphically.

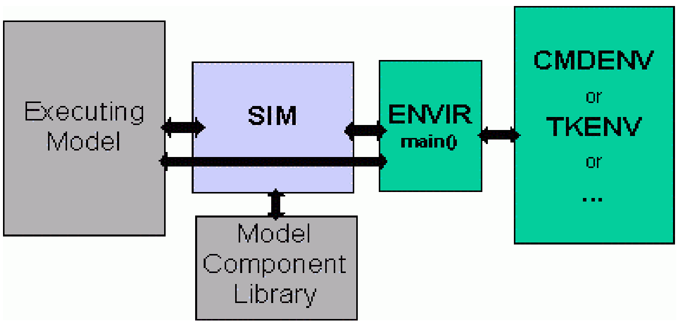

Fig. 1 OMNeT++ Platform Architecture.

3.2 The Positif Package

The Positif testing framework [8] has been developed at TUDelft by K.Langendoen and N. Reijers as part of the Consensus project [9],[10]. The Positif package implements the Robust positioning (RPS) [2], the Ad-hoc positioning (AHPOS) [3], and the N-hop multilateration (N-HOP) [4] positioning structures as part of its basic package.
We also include the accurate underwater positioning (APOS) algorithm, a new positioning structure which has been adapted to the underwater environment. The communication within the network layer supports only localized broadcast [10]; messages are delivered directly to a neighbour if this fails into communication range which is modelled as a fixed circle from the sending node. At the start of each simulation a random or grid topology is generated and a percentage of the nodes are configured with known position which are known as anchor nodes. After the simulation running a number of statistics are produced which allow for a performance evaluation of the different approaches. We use these statistics for our performance study in order to asses and evaluate the achievements of the different approaches adapted in the underwater environment. These statistics are the overall average position error and the number of correctly achieved positioned nodes.

3.3 The UWPOS Software

The UWPOS software tool [5] is based on the Positif package [8] and has been enhanced with underwater acoustic propagation facilities by implementing three different propagation methods from the Ocean Acoustics Library [7], which is a library maintained by the U.S. Office of Naval Research containing modelling software of general purpose for use within the ocean research community.
The incorporation of underwater acoustic propagation facilities allows for a detailed simulation study of the performance of the different positioning strucutures under realistic conditions.
We are then able to study the dependencies and performance achievements according to the main physical enviromental variables in the underwater medium, such as temperature, salinity and depth.
Among others, the UWPOS software allows to define a very precise underwater sound speed profile (SSP) which is the dependency of the sound velocity according with the above referred physical variables. The underwater acoustic sound velocity can be calculated according to the accurate formula proposed by Chen and Millero, known as the UNESCO formula [11], as follows:

$$c = c_0 + c_1 P + c_2 P + c_3 P + AS + BS^{3/2} + CS^2 \text{ m/s}$$

where: S = salinity(ppm); t = temp(°C)

pressure $P = [1{,}0052405(1+5{,}28\cdot 10^{-3}\sin^2\Phi)z + 2{,}36\cdot 10^{-6}z^2 + 10{,}196]\cdot 10^4$

$c_0 = 1402{,}388 + 5{,}03711\,t - 5{,}80852\cdot 10^{-2}t^2 + 3{,}3420\cdot 10^{-4}t^3 - 1{,}47800\cdot 10^{-6}t^4 + 3{,}1464\cdot 10^{-9}t^5$

$c_1 = 0{,}153563 + 6{,}8982\cdot 10^{-4}t - 8{,}1788\cdot 10^{-6}t^2 + 1{,}3621\cdot 10^{-7}t^3 - 6{,}1185\cdot 10^{-10}t^4$

$c_2 = 3{,}1260\cdot 10^{-5} - 1{,}7107\cdot 10^{-6}t + 2{,}5974\cdot 10^{-8}t^2 - 2{,}5335\cdot 10^{-10}t^3 + 1{,}0405\cdot 10^{-12}t^4$

$c_3 = -9{,}7729\cdot 10^{-9} + 3{,}8504\cdot 10^{-10}t - 2{,}3643\cdot 10^{-12}t^2$

$A = A_0 + A_1 P + A_2 P^2 + A_3 P^3$

$A_0 = 1{,}389 - 1{,}262\cdot 10^{-2t} + 7{,}164\cdot 10^{-5}t^2 + 2{,}006\cdot 10^{-6}t^3 - 3{,}21\cdot 10^{-8}t^4$

$A_1 = 9{,}4742\cdot 10^{-5} - 1{,}2580\cdot 10^{-5}t - 6{,}4885\cdot 10^{-8}t^2 + 1{,}0507\cdot 10^{-8}t^3 - 2{,}0122\cdot 10^{-10}t^4$

$A_2 = -3{,}9064\cdot 10^{-7} + 9{,}1041\cdot 10^{-9}t - 1{,}6002\cdot 10^{-10}t^2 + 7{,}988\cdot 10^{-12}t^3$

$A_3 = 1{,}100\cdot 10^{-10} + 6{,}649\cdot 10^{-12}t - 3{,}389\cdot 10^{-13}t^2$

$B = -1{,}922\cdot 10^{-2} - 4{,}42\cdot 10^{-5}t + (7{,}3637\cdot 10^{-5} + 1{,}7945\cdot 10^{-7}t)\cdot P$

$C = -7{,}9836\cdot 10^{-6}P + 1{,}727\cdot 10^{-3}$

4 Performance Study

In this section we show an overview on the performance regarding the four studied algorithms. The standard scenario consists of a the network of 100 nodes which are placed in an area of 100 square kilometres. Among the sensor nodes, there are five nodes with previous position information known as anchors. The transmission range is 3000 meters in average. Next we present the simulation results.

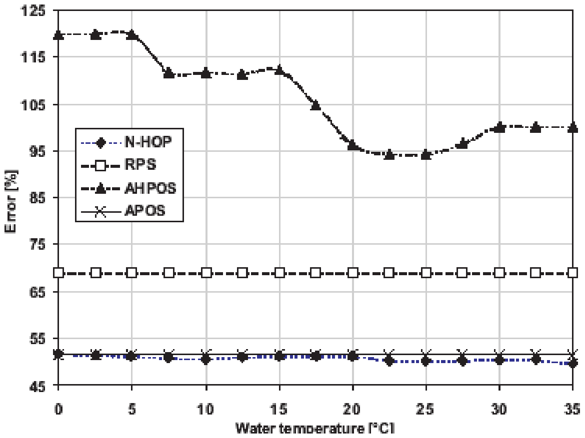

Fig. 2. Average final error vs. Temperature

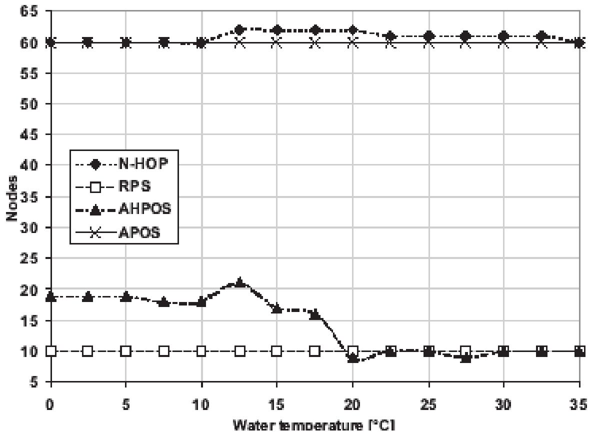

Fig. 3. Positioned nodes vs. Temperature

In Figure 2 and Figure 3 the performance results according to the dependency on the water temperature are represented. Figure 2. shows the average final error achieved by each algorithm at different water temperatures from 0°C (found in artic regions) to 35°C (found in tropical and near the equator areas). And Figure 3 shows the number of correctly positioned nodes at the end of simulation. In this case the salinity and depth were set to standard underwater conditions i.e. at a depth of 10m and a salinity of 34,8ppt (parts per thousand). We obserwe that the RPS algorithm [2]and our proposed APOS approach achieve a constant performance while the water temperature varies but the performance achieved by RPOS is very limited. However the N-HOP [3] algorithm is able to position a high percentage of the at a final error similar to APOS. A remark from these results is that the N-HOP [4] is not as stable as our APOS. A general characteristic is that the number of positioned nodes decreases when the the temperature increases.

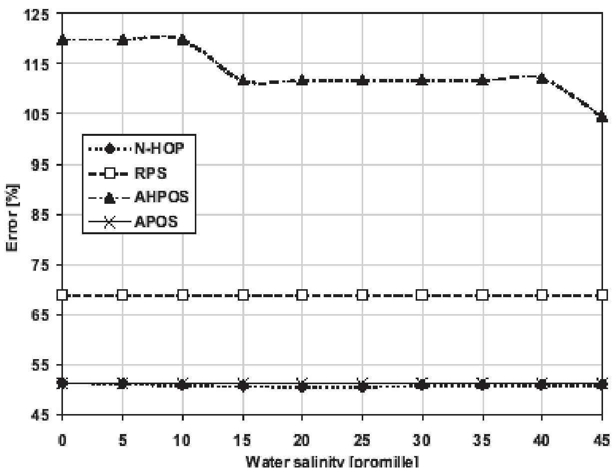

Fig. 4. Average final error vs. Salinity

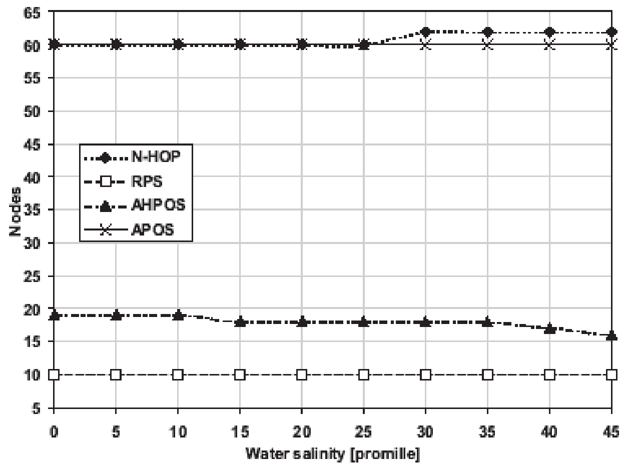

Fig. 5. Positioned nodes vs. Salinity

Following we investigate the influence of the variations in the water salinity. These influences are specially critical in stuaries and in those areas where rivers interact with the sea or ocean due to the mix of different salinity concentrations. In Figure 4 and Figure 5 we observe how the salinity effect is not as intense as with temperature variations. Moreover we observe how the performance suffer minor variations and is approximatly constant starting from a salinity of about 15ppt. Regarding salinity variations again the N-HOP and our APOS approaches achieve similar good performance results.
Next Figure 6 and Figure 7 provide simulation results of the investigation while varying water depth.

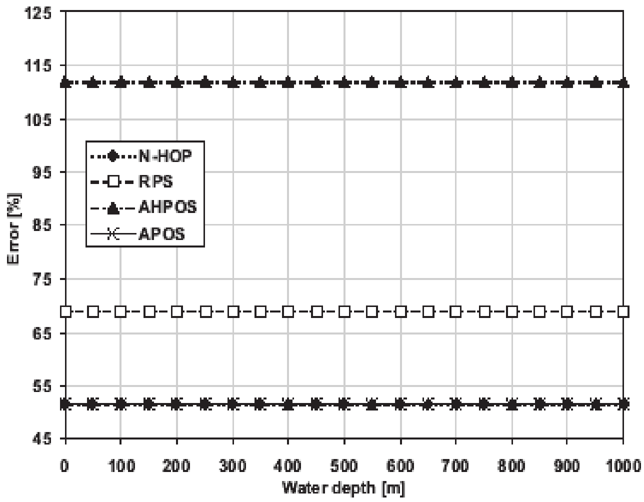

Fig. 6. Average final error vs. Range

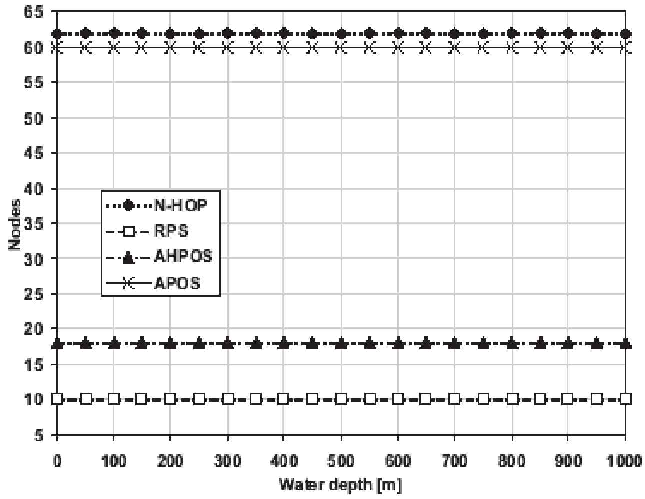

Fig. 7. Positioned nodes vs. Range

Water depth should be considered within this study due to the nature of our network depths from 10 to 1000 meters are typicall depth ranges. This range depth can be considered as shallow water regions, more commonly known as coastal regions. However according to the simulation results we observe how the effects of the pressure in the performance achievements of the differents algorithms is invariant due to the fact that the acoustic wave propagation velocity is almost insensible to pressure variation in those ranges.
Finally we include an ocean scenario to more accurately estimate the achivable performance after simulation under realistic conditions. The environment parameters and conditions refer to the equator, 1° latitude of the atlantic ocean. Under realistic conditions we observe that the N-HOP and our proposed APOS positioning structures achieve best performance results while the AHPOS approach seems to be the most inestable one as Figure 8 and Figure 9 show.

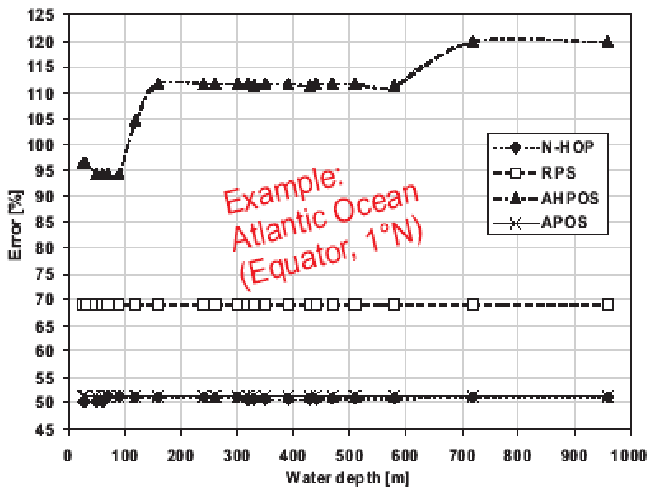

Fig. 8. Average final error vs. Range

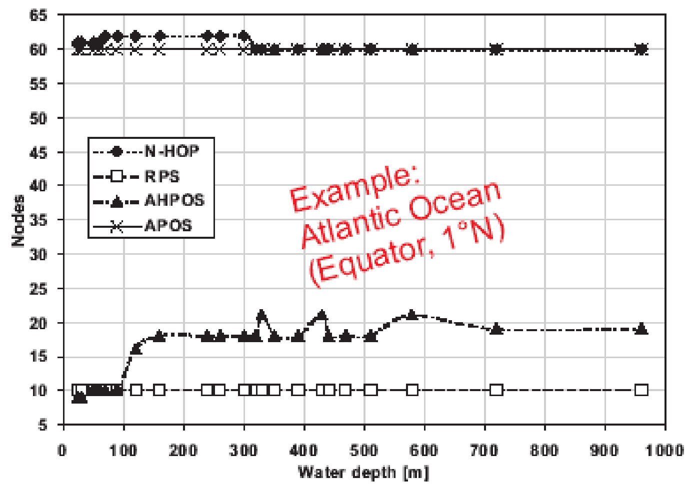

Fig. 9. Positioned nodes vs. Range

Based on these simulation results a similar system performance is achieved by the N-HOP and our proposed APOS structure. However we argue that our APOS positioning structure is more suitable for underwater acoustic scenarios because during the first phase of the algorithm i.e. the distance estimation to neighbours, the compuation is made based on the local geometry of the nodes instead on adding the succesive distance hop-distances from the nodes to the nearest anchor as in the N-HOP approach. This effect is even more critical in underwater networks where the environment conditions are continuosly changing and where the distance estimations can be strongly influenced leading to higher position error estimations. Moreover this position error estimation adds on every additional hop. On the other hand the local geometry of the nodes is supposed to remain stable in time, only affected by node battery depletion, node replacement or by changing the network topology through new nodes to the network e.g. for increasing the detection accuracy and the underwater sensor network performance.

5 Summary

A impact study of the most important physical variables which affect the acoustic wave propagation in the underwater environment i.e. salinity, depth and temperature, and their influences on the performance of four different positioning algorithms has been conducted within this work. After evaluation our proposed scheme seems to overcome the other approaches.

According to the obtained simulation results we argue that these physical variables have to be taken into consideration and should be integrated into an underwater positioning structure in order to achieve a good system performance.

6 References

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