A POWER CONSERVATIVE UNDERWATER LOCALIZATION PROTOCOL

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ABSTRACT

This paper introduces an algorithm to determine the position of wireless sensors operating in the underwater environment. It has been designed to improve the existing ones by limiting the use of power which is the most critical resource that shortens the active life of acoustic underwater sensor networks. The presented algorithm is analyzed by showing that its limit case is the well-known localization algorithm described in [1].

Index Terms — localization algorithms, underwater localization, power preservation, sensor networks

1. INTRODUCTION

Underwater acoustic sensor networks (UW-ASN) introduce new and innovative applicability scenarios [2,3]: they can be used to support monitoring, exploration, disaster prevention, mine recognition and so on. In this respect, the underwater environment introduces new problems and issues: in the first place, establishing and maintaining communications and then, assuring a good level of service.

We address a fundamental topic in the underwater sensor network research field, that is, *localization*. In fact, knowing the exact position of sensor nodes is the first condition to assure the correct delivery of services, starting from the structural ones, like routing, up to the applications.

Although there is a variety of algorithms to localize wireless sensor nodes in a terrestrial system, see e.g. [4,5], they are not suitable for the underwater environment [6]. In fact, the adoption of acoustic waves, due to the limits of RF waves in the medium, introduces problems like high variation delays, multipaths, limited bandwidth, high error rates. Hence, the need arises for an ad-hoc localization algorithm specific to the underwater environment.

In the light of the limits in the underwater environment, we define a localization algorithm for large scale networks that reduces the power consumption by limiting the number of unnecessary messages exchanged among nodes. Moreover, the proposed protocol requires no time synchronization, saving power also in this way. Furthermore, the algorithm is flexible, allowing to balance the precision in localization with the residual power, consequently prolonging the active life of the sensor network.

2. RELATED WORK

While research on wireless sensor network is a well-established field [7], the problems and issues that arise when dealing with the localization of underwater sensors have been under thorough investigation only in the recent years [8,9,10]. A relevant result in large scale networks has been achieved in [11] that proposes a scalable hierarchical approach: the whole localization process is divided into anchor node localization and ordinary node localization. The drawback in [11] is that the approach requires time synchronization to successfully locate the sensors: time synchronization increases power consumption, since it adds a relevant communication overhead because of the high delays that transmitting through water imposes.

An important step forward to define a localization algorithm in large-scale UW-ASNs is represented by [1] and [12]. Specifically, the former proposes a robust, 3D distributed and iterative algorithm, named Three-Dimensional Underwater Localization (3DUL); the latter describes how to localize nodes by means of iterative estimations with the aid of Autonomous Underwater Vehicles (AUV).

Our proposal generalizes 3DUL by considering the residual power of sensor batteries: specifically, when the sensors have full energy, our algorithm behaves as 3DUL, while, when batteries are low, our algorithm, borrowing a few ideas from [12], adopts a power conservative strategy to determine the position of sensors with a lower precision.

3. REFERENCE SCENARIO

A possible deployment of an UW-ASN is shown in Fig. 1. Three or more buoys float at the surface of the water as in [1]. These nodes are referred to as *permanent anchors*.

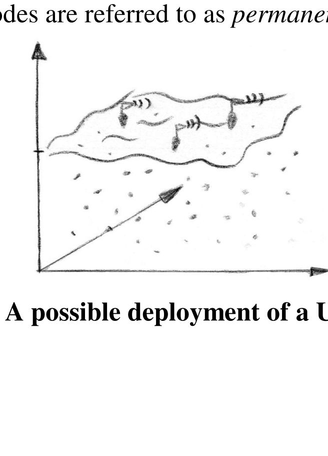

Fig. 1. A possible deployment of a UW-ASN.

A large number of underwater sensor nodes are deployed at different depths. We require that each of these nodes is equipped with CTP (Conductivity, Temperature, Pressure) sensors both to estimate the sound speed in the medium and its depth. The described scenario is coherent with [1] and the interested reader may refer to [1] for further details.

4. THE LOCALIZATION ALGORITHM

The localization algorithm is based on four node states:

- A *permanent anchor node* knows its position by means of an independent methods, like GPS;
- A *transient anchor node* knows its position by means of the localization protocol;
- An *active node* does not know its position but it has enough energy to take an active role in the localization protocol, exchanging messages;
- A *passive node* does not know its position and it has not enough energy both to exchange localization messages and to participate to the network activity.

When we speak of an *anchor node*, we mean either a permanent anchor or a transient anchor. Analogously, an *unknown node* is an active or passive node.

Changes in the state of a node are regulated by the number of exchanged messages and its residual energy as depicted in the automaton of Fig. 2. Transitions take place at every *turn*, whose duration is prefixed and controlled by a timeout.

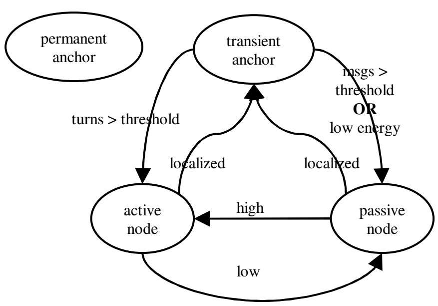

Fig. 2. The automaton regulating the state of a node.

A permanent anchor never changes its state; a transient anchor maintains its state for a short amount of time. A transient anchor may become passive if its level of energy is low or if it exchanged too many messages; in the second case, the node consumed energy in the localization process, so has to conserve the remaining power for the application.

An active node becomes a transient anchor when it acquires its position; if its battery goes low in the meanwhile, the node becomes passive to spare as much energy as possible in the localization process. A passive node may become a transient anchor if it is able to determine its position and it has enough energy. It is possible for a passive node to have a full-charged battery, e.g. when it receives and processes few messages. The thresholds are set to appropriate values depending on the capacity of batteries, the energy required to transmit a message and the average movements of sensors.

The localization protocol from the point of view of an anchor is the same as 3DUL: at the beginning of a turn, it broadcasts a packet containing its position. Then, it answers to each active node that acknowledged the broadcast message with a packet containing the time when the acknowledge has been received and the time when this packet is delivered. As described in [1], this piece of information is enough to have a good estimation of the propagation time between the two nodes and, by means of a model of sound speed in water, it is possible to have an accurate estimation of the distance between *the active node* and the anchor, even if the clocks are not synchronized.

An active node operates as an unknown node in the 3DUL algorithm: when it receives a broadcast message from an anchor, it records its position. Then it acknowledges the broadcast message. When the anchor sends an ack message to confirm that the ack message sent from the active node is received the active node can calculate the distance from the anchor node. If it knows the position of at least three anchor nodes it calculates its position using trilateration. As in 3DUL, this calculation is performed only if the numerical problem is stable, thus ensuring an accurate estimation of the position; the details to check robustness are explained in [1]. A passive node receives the broadcast message sent by an anchor and remembers it. Then it calculates its position as the point which lies equidistant from every known anchor, with an error depending on the size of the intersection of the transmitting balls of the anchors. The transmitting ball is the sphere whose center is the anchor and whose radius is maximal distance a packet sent from the anchor may travel and still be received. It depends on the energy used to modulate the acoustic wave and the physical state of the water: the sound speed model can be used to have a strict upper bound to the real coverage range. The algorithm is depicted in Fig. 3 as an event-driven C-like pseudo-code where the emphasized parts correspond to the parameters. The `localize` procedure is widely documented and discussed in [1], where also the pseudo-code is available.

5. AN ALGORITHMIC ANALYSIS

The proposed algorithm is an extension of 3DUL: if `lowenergy()` is always false and `msg_threshold` is infinite, then our algorithm reduces to 3DUL. On the contrary, if `highenergy()` is always false and `anchor_threshold` is infinite, then sent messages per turn equals the number of anchors; an unknown node becomes an anchor only if the distance between the centers of the transmitting balls is approximately the sum of the radii. We will refer to this peculiar instance of our algorithm as the *intersecting balls* (IB) algorithm. In this case the amount of used energy used by is minimal, but the localization ability of the algorithm is limited if the `error_threshold` is small, while the algorithm becomes very imprecise if `error_threshold` is high.

```
-- tmeout:
 if (state == anchor)
  if(msg_N > msg_threshold) {
   state = passive; msg_N=ack_N=anchor_N = 0; }
  else if (anchor_N > anchor_threshold) {
   state = active;  msg_N=ack_N=anchor_N = 0; }
 else anchor_N = anchor_N + 1;
 if (state ∈ {anchor,active} && lowenergy())
  state = passive;
 if (state == passive && highenergy())
  state = active;
 if (state ∈ {anchor,perm_anchor}) {
  send broadcast(Pos); msg_N += 1; }
n = 0; set timeout;
-- receive_broadcast (A) from N:
 if (state ∈ {passive,active}) {
  Pos = (n · Pos + A)/(n + 1);
  n++; A[n] = A; r = soundspeed_range();
  if (n == 1) err = r^2;
  else err=min{err,r^2-max{‖A-A[i]‖^2/4:1≤i<n}};
  if (err < error_threshold) state = anchor; }
 if (state == active)
  send ack(n, t1[n] = time()) to N;
-- receive_ack(k,t1) from N;
 t2 = time();
 if (state ∈ {anchor,perm_anchor}) {
  send ackack(t2, t3 = time(), k) to N;
  msg_N++; }
-- receive_ackack(t2,t3,k) from N:
 t4 = time();
 if (state == active) {
  d[k] = soundspeed() ((t2-t1[k]) + (t4-t3))/2;
  ack_N++;
  if (ack_N > 2) localize(k);}
```

Fig. 3 Localization algorithm.

In general, if `anchor_threshold` is high, a transient anchor tends to maintain its state for a long time enhancing performances in the case of almost static networks. On the contrary, a very low value of `anchor_threshold` makes the network very reactive to changes, especially when the timeout corresponds to a very small interval.

On the average, the overall performance of the algorithm is in between 3DUL and IB; the balance is controlled by the definition of the `lowenergy()` and `highenergy()` functions. The error on positions in the average case is roughly `error_threshold`. Similarly, the coverage, that is, the number of nodes that are able to determine their positions is lower bounded by the estimation made for 3DUL. Finally, the used power is a function of the number of exchanged messages: a passive node only receives messages from any anchor node in range; an active node sends one message to every anchor node in range, and receives two messages from it; every anchor node sends one broadcast message per turn and it sends one individual message to any active node in range. Thus, our algorithm has the IB algorithm as the best case with respect to the power usage and 3DUL as its worst case. The depends on the values of parameters and on the spatial distribution of nodes, mainly on their density.

6. CONCLUSION

The proposed solution is clearly power conservative with respect to 3DUL, which is a high-performance algorithm for the problem under analysis. Moreover, our algorithm has a chance to localize also when the unknown node has received less than three messages. Therefore, our algorithm has a good performance both in the number of sent messages, which is a measure of the consumed energy, and in coverage, i.e., the number of nodes that are able to calculate their positions. The price we pay for these benefits is a less accurate estimate in the position of some sensors, specifically the ones marked as passive nodes.

We made a first analysis basing our deductions on the structure of the algorithm in comparison with 3DUL. As for 3DUL, we do not expect that the analytical model to be conclusive because of tis complexity. For this reason, we started to develop a simulator of our algorithm to test it in a variety of controlled situations.

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