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# ALWadHA Localization Algorithm: Yet More Energy Efficient

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**ABSTRACT** Many wireless sensor networks (WSNs) applications, techniques, and algorithms require the position of the sensor nodes. Sensor nodes mainly rely on localization algorithms to determine their own physical location. Usually, these sensor nodes are equipped with a limited power source. Therefore, a localization algorithm used by a WSN should be an energy-aware algorithm. One of the energy efficient localization algorithms that has been proposed recently is an efficient localization algorithm for wireless ad hoc sensor networks with high accuracy (ALWadHA). In this paper, we investigate the impact of using three techniques by ALWadHA in improving the energy efficiency of ALWadHA: first, a single-estimation approach whereby a node estimates its position only once; second, dynamic power control whereby reference nodes reduce their transmission power based on their distance to the node that broadcasts the location request; and third an incremental and exponential requesting rate approach, which controls the frequency rate of sending the location request. Simulation results show that the final approach reduces the energy consumption of ALWadHA by 51.5%, without compromising the accuracy of the position estimation.

**INDEX TERMS** Localization algorithm, energy efficiency, WSN, ALWadHA, position estimation, dynamic power control, successive-refinement localization algorithm.

## I. INTRODUCTION

The proliferation of wireless communication technologies has enabled the development of wireless sensor networks (WSNs), which consist of a large number of small and cheap sensors with limited resources, such as computing, communication, storage and energy [1]. These sensor nodes are able to sense, measure and collect raw data from the environment, perform simple computations and then transmit only the required and partially processed data to the node responsible for fusion [2], [3].

WSNs have been deployed extensively in various areas and used by different applications, such as Smart Grid, Smart Cities and Smart Water System [4]–[7]. Most of these applications require that the position of the nodes be determined. Moreover, several WSN techniques require highly accurate knowledge of the nodes' location, for example, the network management and geolocation routing protocol. The main advantages of node location information are enhancing the efficiency of the WSNs, identifying the location of an event of interest, facilitating numerous application services and assisting in various system functionalities [8].

Most of the sensor nodes rely on short life-time batteries, which might be impossible to replenish, and so the

sensor node life-time is mainly dependent on battery life-time [9], [10]. Therefore, an energy-aware localisation algorithm, such as [11]–[15], should employ several techniques to reduce the computation and communication overheads, thus reducing energy consumption [3], [10].

Attaching a GPS receiver to every sensor node is one option for determining the node location. However, this option will increase the cost and complexity of the sensor node. Moreover, it will increase the energy consumption because GPS is based on one of the energy-hungry communication technologies. Therefore, equipping all the nodes with GPS receivers is not a practical solution. A manual location configuration is another possible solution that can be used only with static wireless sensor networks. In large scale WSN this will increase the operational overhead significantly.

Localisation algorithms can be considered as a practical solution to identify sensor nodes' location. Instead of attaching every sensor node with a GPS receiver, only a few sensor nodes will be equipped with GPS receivers. These sensor nodes are called "beacons". Initially, the rest of the sensor nodes do not know their location yet, therefore they are called "unknown". "unknown" uses a localisation algorithm to estimate its position, then its status will change

to “known”. Some of these “knowns” can also be used by other “unknowns” to estimate their position. Therefore, the term “references” is used in the literature to refer to the “beacons” as well as other “knowns” that contribute to the estimation of the position of “unknowns”.

The authors of [16] have introduced a new localisation algorithm called ALWadHA (An efficient Localisation algorithm for Wireless ad hoc sensor networks with High Accuracy). Compared with other algorithms, ALWadHA performs better in terms of accuracy, robustness, energy efficiency and even security [16], [17]. Various experiments and a comprehensive comparison with several localization algorithms have been conducted in [16], [17]. Therefore the focus of this paper is not to compare ALWadHA with other algorithms, but rather to investigate the impact of using three methods to improve the energy efficiency of the ALWadHA algorithm.

The rest of this paper is organized as follows; Section II briefly explains the ALWadHA algorithm and highlights the main techniques used by this algorithm to enhance the energy efficiency. Section III describes the three methods that could be used for making ALWadHA more energy efficient, which are the single-estimation approach, dynamic power control and incremental and exponential requesting rate. The Network Simulator (ns-2) is used to compare the performance of the original ALWadHA algorithm and ALWadHA that uses these new methods. Simulation results are presented and discussed in Section IV. Section V concludes the paper.

## II. ALWadHA ALGORITHM

The aim of developing ALWadHA [16] (shown in TABLE 1) was to enhance the performance of the localisation algorithm and achieve several objectives such as improving the accuracy and robustness of the position estimation, reducing energy consumption [16] and providing a security mechanism against malicious nodes that try to compromise the localisation system [17]. Position estimation accuracy is one of the main objectives in localisation systems. To achieve this objective, ALWadHA considered the main three major errors that could affect the accuracy of the position estimation, which are the computational error, position estimation error and distance estimation error. To deal with these three errors, ALWadHA requires simple computation and eliminates those references with a high location estimation error and a high distance estimation error.

To start the process of location estimation, a node broadcasts a “location request” packet. The neighbour references respond with their location information. A novel smart reference selection method (Fig. 1) will select a subset of the available references, where those references with a possibility of a high location estimation error will not be selected. The node will use the selected references to estimate its initial position. To improve the position estimation, the node filters out some of the used references in the first round, but this time by eliminating those references with high distance estimation error and then estimates its position again. The node accepts

TABLE 1. ALWadHA algorithm [17].

<b>1. Initialisation</b>	
If ( <i>final = true</i> ) then exit	
Broadcast “location request” messages	
Receive “location response” messages from neighbouring references ( $R_i$ )	
If ( $C(R_i) < 3$ ) then exit.	
<b>2. Initial position estimation</b>	
Select a subset of references $S_i$ from $R_i$	
Measure distance to the references in $S_i$	
Apply MMSE to determine an initial position $\hat{z}_i^0$ .	
<b>3. Refined position estimation</b>	
for ( $j=1$ to $C(S_i)$ )	
$\hat{e}_{i,j}^d = \left  \left\  \hat{z}_i^0 - \hat{z}_j \right\  - \hat{d}_{i,j} \right $	
if ( $\hat{e}_{i,j}^d > e_{max}^d$ ) then ( <i>enhancement = true</i> ); break.	
If ( <i>enhancement = true</i> )	
for ( $j=1$ to $C(R_i)$ )	
$\hat{e}_{i,j}^d = \left  \left\  \hat{z}_i^0 - \hat{z}_j \right\  - \hat{d}_{i,j} \right $	
if ( $\hat{e}_{i,j}^d > e_{max}^d$ ) then eliminate $r_j$ .	
Estimate refined position $\hat{z}_i$ , as shown in 2	
Else	
$\hat{z}_i = \hat{z}_i^0$ .	
<b>4. Position update</b>	
$D_{acc} = \sum \left\  \hat{z}_i - z_j \right\  - \hat{d}_{i,j}$	
if ( $D_{acc}^k < D_{acc}^{k-1}$ )	
$\hat{z}_i$ will be accepted	
if ( $D_{acc} < T_{acc}$ ) then ( <i>final = true</i> ).	

$C(\cdot)$  is the cardinality, MMSE=minimum mean square estimate,  $D_{acc}$ =degree of accuracy,  $T_{acc}$ =accuracy target.

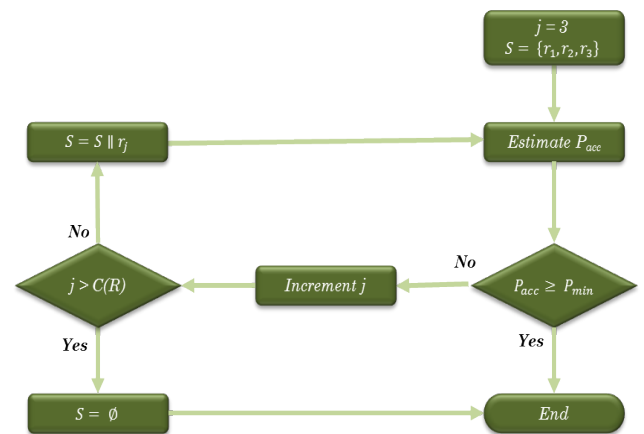


FIGURE 1. The smart reference-selection method [16].

this estimation only if it is more accurate than the previous estimation. Finally, the node checks if there is a possibility to improve the accuracy of the node position estimation in the future iterations, otherwise it will consider the current estimation as a final one and stops sending location request.

ALWadHA algorithm uses several techniques to enhance the energy efficiency. For example [16]:

- Response mechanism reduces the communication cost by reducing the number of response packets, where

only references with certain level of accuracy will send response packets to the location request. Also it reduces the computation cost by minimising the number of iterations.

- Smart reference-selection method reduces the computation cost because of its simplicity and using the minimum possible number of references. This method specifies the time of estimation without any extra message broadcasting between nodes, which reduce the communication cost.
- Termination criteria reduces the computation and communication cost by reducing the number of iterations required to get an accurate position estimation. Nodes that surrounded by references with high position accuracy (for example beacons which have more position accuracy compared to knowns) needs lower number of iterations before they reached an acceptable level of position accuracy. Without termination criteria, such nodes will keep re-estimating their position without improving their position accuracy and waste their energy.

The focus of this paper is to evaluate the impact of using three methods to improve the energy efficiency of the ALWadHA algorithm. Therefore for more details about the ALWadHA algorithm, the various techniques considered by ALWadHA and the performance evaluation of the algorithm, we refer the readers to [16].

### III. TOWARDS MORE ENERGY EFFICIENCY

This section investigates the impact of using three techniques to improve the energy efficiency of the ALWadHA algorithm and how they could affect the position estimation accuracy.

#### A. SINGLE-ESTIMATION APPROACH

One of the simplest approaches used by localisation algorithms is called the “single-estimation” approach [17], [18]. In this approach the sensor node estimates its position only once, i.e. as soon as the sensor node receives location information of at least three references it will estimate its position and stop the localisation process. This approach is easy to implement, does not require termination criteria, it requires one iteration and it is very energy efficient. However, it could fail to achieve other objectives of localisation systems such as good estimation accuracy. There are some attempts to improve the accuracy of localisation algorithms based on this approach but that could increase the complexity of these algorithms [18]. Moreover, some of these algorithms can only operate in certain scenarios. For example, the algorithm proposed in [19] requires a triangular placement of beacons in certain locations.

Estimate the node position only once may not achieve good accuracy, especially in a noisy environment. Therefore, several localisation algorithms, for example [21], [22], follow another approach called the successive-refinement approach. In this approach, to improve the position estimation accuracy,

a sensor node estimates its position several times. However, this approach increases the computational and communication overhead, therefore increases the energy consumption. One of the critical components of localisation algorithms based on this approach is the termination criteria, which plays an important role in improving the energy efficiency of the localisation algorithms. Termination criteria identify when the node stops re-estimating its position and considers the current position as a final estimation. Termination criteria could be simply based on the number of estimations or elapsed time. However, careful implementation of the termination criteria would enhance the energy efficiency of the localisation algorithms without compromising the estimation accuracy.

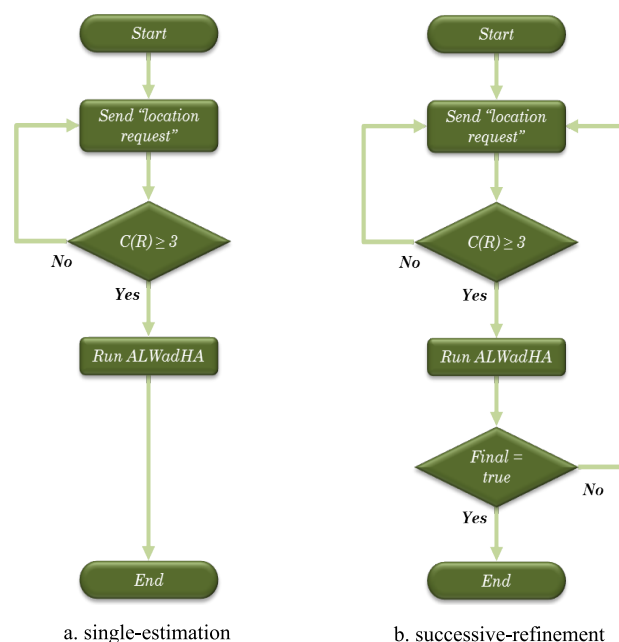


FIGURE 2. The flowchart of the single-estimation and successive-refinement approaches.

ALWadHA is based on the second type; i.e. the successive-refinement approach, where the node repeats the estimation to enhance the accuracy of positioning. To consider the single-estimation approach, the fourth phase (position update) will be ignored. Therefore, the node estimates its position only once. Fig. 2 depicts the two approaches: single-estimation and successive-refinement.

Generally speaking, in the single-estimation approach, when the node receives location information from more than the minimum number of required references ( $C(R) \geq 3$ ), then it estimates its position. In ALWadHA, this is not the only condition for the node to estimate its position. The smart reference-selection method (Fig. 1), which is responsible for selecting the best possible accurate sub-set of references, evaluates the accuracy of the available references. If the probability of accuracy of the references satisfies a certain value of accuracy, then the node estimates its position, otherwise

the node will not estimate its position but rather try to do so in the next iteration [16].

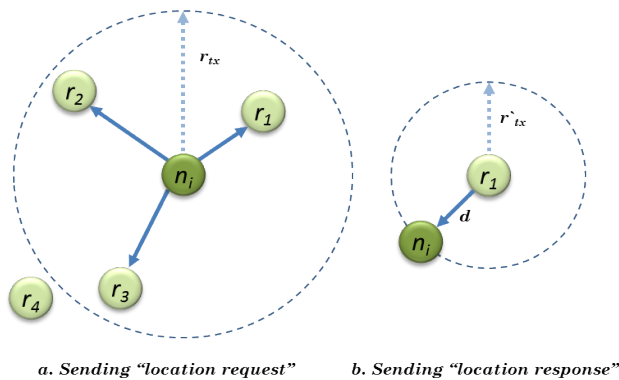
**B. DYNAMIC POWER CONTROL**

The dynamic power control technique can be used to adaptively change the level of transmission power based on the distance between the transmitting and receiving nodes. Instead of continuing to send the packets using the maximum transmission power to cover the entire range, the node dynamically specifies the required transmission power to enable the packet to reach the destination node [3].

The dynamic power control technique can be used by the ALWadHA algorithm as follows: the node uses the maximum transmission power to broadcast the “location request” packets, to make sure all the references within its transmission range will receive this packet. The references that received this request estimate the distance to the requesting node using the Friis free space equation (1) and then estimate the required transmission power to enable the “location response” packets to reach the requesting node [3].

$$d = \sqrt{\frac{P_t \times G_t \times G_r}{P_r}} \times \frac{\lambda}{4 \times \pi} \tag{1}$$

where  $d$  is distance between the reference node and requesting node,  $P_t$  is the transmission power,  $P_r$  is the received power,  $G_t$  is the transmitter antenna gain,  $G_r$  is the receiver antenna gain and  $\lambda$  is the signal wavelength.



**FIGURE 3.** Dynamic power control method, where  $n_i$  is an unknown node,  $r_j$  is reference node and  $r_{tx}$  is the transmission range.

Fig. 3 illustrates a simple scenario to elaborate the concept of the dynamic power control method. The unknown node ( $n_i$ ) broadcast a “location request” packet to all references within its transmission range ( $r_{tx}$ ). The transmission range is the maximum distance that the transmitted signal can propagate, where only nodes located within this range can receive the transmitted signal. Therefore, only  $r_1$ ,  $r_2$  and  $r_3$  references will receive the packet that was sent by the node ( $n_i$ ) (Fig. 3.a). If, for instance,  $r_1$  need to send its location information back to node  $n_i$ , it first estimates the distance ( $d$ ) to the node  $n_i$  then it adjusts its transmission power based on this distance and finally send the “location response” packet to node  $n_i$ .

Therefore, the transmission range of  $r_1$  is now  $r_{tx}'$ , where  $r_{tx}' \leq r_{tx}$  (Fig. 3.b).

**C. INCREMENTAL AND EXPONENTIAL REQUESTING RATE**

One target of a localisation system is to minimise the number of beacons used because of the cost or the difficulty of installing these nodes, which means only some of the nodes will be neighbours of these beacons. Initially, the nearby unknown nodes will be able to determine their position and they could act as references for other unknowns. Therefore, the unknown nodes far from the beacons need more time to determine their position compared with the ones close to them. Using a fixed requesting rate will lead to wasting the energy of sensor nodes, mainly those that are far from the beacons, because at first these nodes will keep sending “location request” packets without getting enough “location response” packets back. Therefore, in this approach, the requesting rate ( $\Delta t_{req}$ ) is updated after each iteration; either incrementally or exponentially, as shown in Fig. 4. If the node has determined its position at a specific iteration (or enhanced the accuracy of the current position), it will increase the requesting rate by one ( $\Delta t_{req} = \Delta t_{req} + 1$ ), otherwise it will multiply the requesting rate by two ( $\Delta t_{req} = 2 * \Delta t_{req}$ ) [3].

**IV. SIMULATION RESULTS**

The Network Simulator (ns-2) has been used widely in the literature to evaluate various protocols, algorithms and techniques of WSN. However, the original ns-2 does not provide an easy way to implement localisation algorithms. Thanks to open source, the authors of [20], [21] added extra modules to the ns-2 to enable the simulation of WSN localisation system in ns-2 and open the door to implement and simulate various localisation algorithms. Therefore, we used ns-2 to evaluate the new techniques proposed in this paper. In our simulation we deployed 76 sensor nodes randomly in an area of 200m x 200m. Out of these 76 sensor nodes there are only 12 beacons, while the rest of the sensor nodes do not know their location (unknowns).

Initially, ALWadHA’s performance is compared with another two localisation algorithms, called Single and Successive. Single follows the single-estimation approach while Successive follows the successive-estimation approach. After that we evaluate the performance of the new techniques and compare them with the original ALWadHA algorithm.

The performance of each algorithm was evaluated based on two metrics: The first was the localisation error, which reflects on the location accuracy. The mean error is estimated every second for all knowns as a ratio of transmission range ( $r_{tx}$ ). The mean error at a specific time  $t$  is equal to the sum of the location error of all knowns, divided by the number of these knowns, and then it is divided by the transmission range as shown in (2) [16]. The reason for estimating the mean error as a ratio of transmission range is to make it comparable with other works, regardless of the transmission range used in their experiments. For example, if the mean

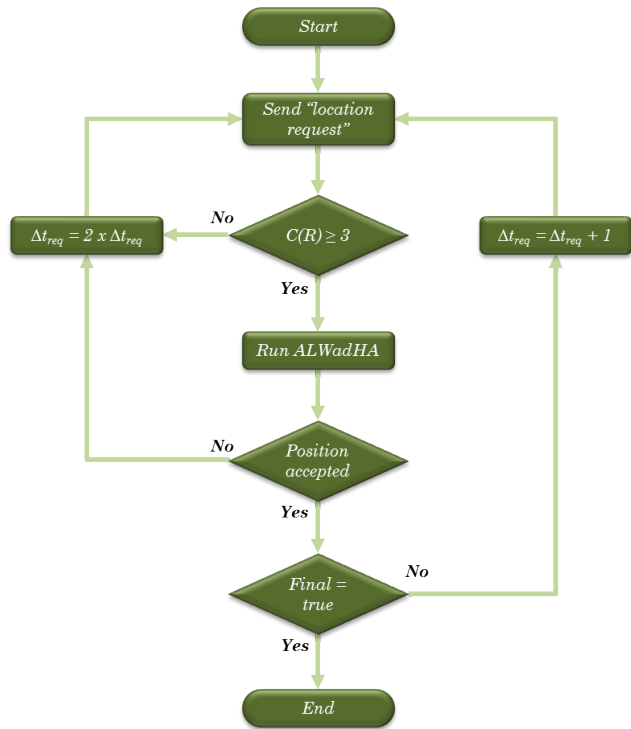


FIGURE 4. Incremental and exponential requesting rate method.

error is 3m for a transmission range of 50m, this is not equivalent to the same mean error if the transmission range is 100m.

$$Mean\ error_t = \left( \frac{1}{n} \sum_{i=1}^n \|\hat{z}_i - z_i\| \right) \frac{1}{r_{tx}} 100\% \quad (2)$$

In (2),  $n$  represents the total number of knowns at a specific time  $t$ ,  $z$  is the actual node location and  $\hat{z}$  is the estimated position using the localisation algorithm

The second metric is the energy consumption only due to communication.

**A. ALWadHA ALGORITHM**

In the first simulation, the position estimation accuracy has been evaluated for the ALWadHA, Single and Successive algorithms. Fig. 5 shows the mean error as a function of time for these algorithms. As expected, Single could not achieve a good accuracy level as compared to the other two algorithms. Successive performs better than Single because the nodes keep re-estimating their position to improve the position accuracy. The position accuracy of ALWadHA is better than Single and Successive due to the various techniques considered by ALWadHA to deal with computation errors, position estimation error and distance estimation error. The authors of [16] explain these techniques and conduct several simulations to evaluate the accuracy of ALWadHA in different scenarios. Therefore, discussing these techniques is not within the scope of this paper.

We also evaluate the energy efficiency of the above localisation algorithms. As shown in Fig. 6, Successive consumes

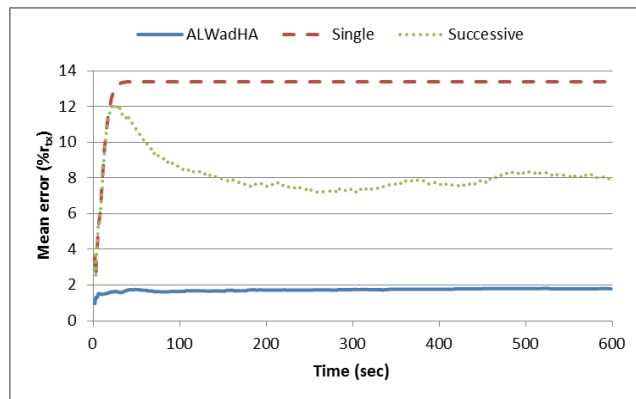


FIGURE 5. Mean error as a ratio of transmission range for ALWadHA, Single and Successive algorithms.

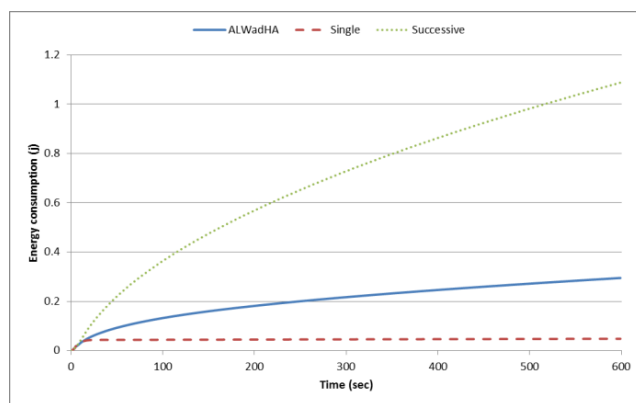


FIGURE 6. Energy Consumption for ALWadHA, Single and Successive algorithms.

more energy compared to the other two algorithms. The successive estimation approach focuses mainly on improving the accuracy of the position estimation in the cost of increasing the energy consumption. This motivates the need to consider several objectives while developing a new localisation algorithm. For example, by considering a proper termination criterion, Successive could improve the energy efficiency without compromising the position accuracy. Fig. 5 shows that after 150 seconds the mean error of Successive is around 8%. Therefore, if the nodes stop re-estimating their position at this time, then this will not affect the accuracy of the position estimation. However, this will reduce the energy consumption by more than 50% (energy consumption at  $t = 150$  sec is around  $0.5 J$  while at the end of the simulation it is  $1.1 J$ ).

ALWadHA is based on the successive estimation approach; however it consumes less energy compare to the Successive algorithm. The energy efficiency of ALWadHA is due to the various techniques considered by this algorithm to reduce the energy consumption [16]. Single consumes less energy than ALWadHA because in the Single algorithm nodes estimate their position only once, also Single neither considers any mechanism to evaluate the estimated position nor tries to reject a position of high estimation error. Therefore,

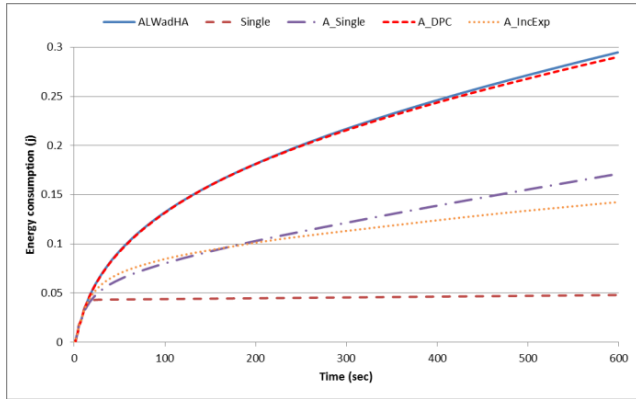


FIGURE 7. Energy Consumption for original the ALWadHA algorithm and ALWadHA with Single, DPC and IncExp techniques.

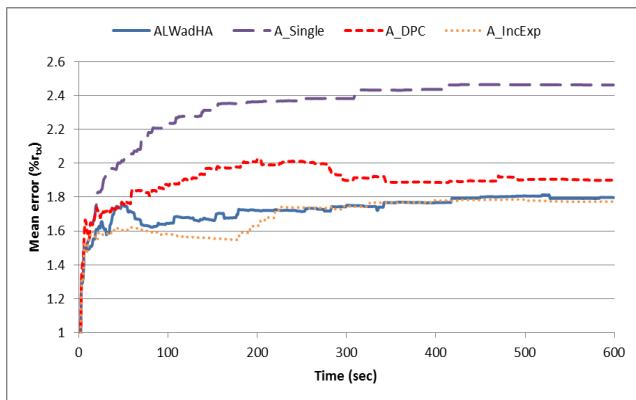


FIGURE 8. Mean error as a ratio of transmission range for the original ALWadHA algorithm and ALWadHA with Single, DPC and IncExp techniques.

the accuracy of Single is very low compare to the other two algorithms.

**B. SINGLE-ESTIMATION APPROACH**

Fig. 7 shows that this technique (A\_Single) could enhance the energy efficiency of the original algorithm (ALWadHA). On the other hand, the mean error is slightly higher than the original algorithm, as shown in Fig. 8. A\_Single estimates the node position only once. However, it still evaluates the probability of accuracy of the available references, if it is less than a specified value the node does not estimate its position and try to do so in the next iteration, where references could improve their position accuracy or other references with better accuracy will be available. This evaluation mechanism could require more time before the node estimates its position and also could consume slightly more energy compared to the Single algorithm. However, it leads to significant improvement of the estimated position accuracy as compared to Single. At the end of the run time ( $t = 600$  sec) the mean error for Single is 13.8% (Fig. 5), while the mean error for A\_Single is around 2.4% (Fig. 8)

In a noisy environment the distance measurement error will be high, which will increase the mean error of the position

estimation. Therefore, in a noisy environment it is not advisable to use the single-estimation approach, especially if accuracy is a critical issue. To improve the accuracy of the position estimation in such an environment, localisation algorithms should consider the successive-refinement approach [16].

**C. DYNAMIC POWER CONTROL**

Fig. 7 shows that the use of this technique by ALWadHA (A\_DPC) does not enhance the energy efficiency very much for several reasons. One reason is that this technique is used only to change the power level for sending the “location response” packets, while the nodes use maximum transmission power to send the “location request” packets. The nodes’ density is low, only 4.75 nodes per  $r_{tx}^2$ , which means the nodes are not close to one another and therefore the transmission power is slightly lower than the maximum transmission power. By using the response mechanism, ALWadHA reduces the number of “location response” packets, therefore this technique does not greatly affect the energy efficiency of the ALWadHA algorithm. However, this technique could enhance the energy efficiency of the other localisation algorithms and also reduce interference [3].

**D. INCREMENTAL AND EXPONENTIAL REQUESTING RATE**

As shown in Fig. 7, ALWadHA, when using the incremental and exponential requesting rate technique (A\_IncExp), consumes less energy than the original ALWadHA and A\_Single; moreover, Fig. 8 shows that the accuracy is slightly better. This technique allows the nodes close to the beacons to reach their final estimation faster, which also enhances the position accuracy of other nodes. At the same time it prevents the nodes farther away from continuing to send useless “location request” packets and thus enhances the energy efficiency of the algorithm [3].

TABLE 2. Performance comparison of the new methods.

Algorithm	Mean error (% $r_{tx}$ )	Energy consumption (J)	Energy improvement (%)
ALWadHA	1.797	0.295	-
A_Single	2.462	0.171	42%
A_DPC	1.900	0.290	1.7%
A_IncExp	1.773	0.143	51.5%

**E. PERFORMANCE COMPARISON**

TABLE 2 shows a performance comparison between the original ALWadHA algorithm and the new techniques. The mean error and the energy consumption are recorded at the end of the run time ( $t = 600$  sec). ALWadHA, using the incremental and exponential method (A\_IncExp), achieved the best result in terms of mean error as well as energy consumption. This method allows ALWadHA to reduce the energy consumption by more than 50% without compromising the position estimation accuracy. A\_IncExp still follows the successive-refinement approach, thus it is still robust, even in a noisy

environment. Evaluating these techniques using real sensor nodes or a WSN testbed [22], [23] will be conducted in the future and it will also consider the energy consumption due to computational operations.

## V. CONCLUSION

In order to make ALWadHA an energy-aware localisation algorithm, several techniques are followed to reduce computational and communication overheads. These techniques make ALWadHA consume less energy than other successive-refinement localisation algorithms without compromising the position estimation accuracy [16]. In this paper, we investigated three methods that could make ALWadHA more energy efficient. These methods are the single-estimation approach, dynamic power control and incremental and exponential requesting rate. Simulation results show that using the incremental and exponential method by ALWadHA achieved the best result in terms of energy consumption and position accuracy.

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