

Response to the reviewers' comments

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- Type of manuscript: Article
- Title: An Efficient Hybrid RSS-AoA Localization for 3D Wireless Sensor Networks
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We appreciate your timely review and constructive comments. In the revised manuscript, revisions in the text are displayed in “blue” color. The numbering in the reviewers' comments and our responses will therefore correspond to the revised version unless explicitly stated.

For the purpose of convenience, we summarize overall organization of the paper as follows.

- In Section 1, we introduce the background knowledge on wireless sensor network applications and the problem of 3D RSS-AoA localization.
- In Section 2, we describe the system characteristics and the formulation of the localization problem in terms of hybrid measurement perspective.
- In Section 3, we propose a hybrid localization solution. A step-by-step procedure consisting of relate parameter calculation and target estimation is introduced.
- In Section 4, we discuss analytical and numerical simulation results for the proposed scheme and other conventional approaches.
- In Section 5, we provide conclusions and future directions.

In summary, the following major changes have been made in the revised manuscript.

1. Following Reply 2.2 and 3.5, we added more texts in Introduction section.
2. Following Reply 1.1 and 3.1, we expanded the discussion on the related works.
3. More descriptions and discussions have been included in the Simulation Results section following Reply 1.2 and 3.23.
4. Related works have been accordingly updated in the References section.
5. Typos and the grammar mistakes have been corrected throughout the entire manuscript.

Also, we would like to ask to assign the revised paper to the same reviewers.

Reviewer 1

The paper is well written and the research analysis with the corresponding findings and results are clearly presented.

Open Review	(x)	I would not like to sign my review report			
	()	I would like to sign my review report			
English language and style	()	Extensive editing of English language and style required			
	()	Moderate English changes required			
	(x)	English language and style are fine/minor spell check required			
	()	I don't feel qualified to judge about the English language and style			
		Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	()	()	()	()
Is the research design appropriate?	(x)	()	()	()	()
Are the methods adequately described?	(x)	()	()	()	()
Are the results clearly presented?	(x)	()	()	()	()
Are the conclusions supported by the results?	(x)	()	()	()	()

Comment 1.1. *The major issue is the paper novelty, as the main contribution of the paper is in joint RSS and AOA based localization, which is rather well investigated. However, this is also indicated by the authors, who provide a good list of references from the same topic. Hence, unfortunately, the novelty of the paper is at low level and the presented approach with WLS is rather straightforward and predictable. The presented location likelihood function can be solved, for example, with conventional non-linear least squares methods, which would probably give better result than the proposed approach, if they were properly configured. Of course, authors present results with Gauss-Newton method, but it remains unclear, how the algorithm is exactly implemented.*

Reply 1.1. We would like to thank the reviewer for the comment. In the original manuscript, we aimed to give a brief introduction to related works and mainly focused on the content of the propose work. In fact, we investigate on the state-of-the-art results on finding the condition for a target node being localizable. In particular, we presented several methods for solving (1) in terms of complexity and accuracy. Thus, in order to begin the background of the 3D localization for wireless sensor networks, we modify the Section 2.4 in page 4 as follows.

According to the capabilities of diverse hardwares, we may classify the conventional hybrid RSS-AoA based localization into either of two main categories: nonlinear minimization localization or convex approximation localization. In the first category, supposing that the measurements from the reference node are only corrupted by zero-mean Gaussian noise and the reference nodes are identical or much closer to each other than the target, the basic idea is solving (3) with the given information. In particular, this nonlinear minimization problem can be solved by the Newton-Gauss iteration. For instance, [16] proposed the least squares (LS) and optimization estimators using the distance and the AoA information. In [17], hybrid RSS-AoA LS and maximum likelihood (ML) estimators were derived for the emitter geolocation. The method of combining ML-LS implicitly assumes that a rough estimate range between anchor-target can be obtained. The cost function given by (3) weakly depends on this value, thus the roughness will not significantly affect the solution. It has been reported in [21] that the accuracy of such scheme suffers from the environmental dynamics. On the other hand, departing from the first category, most of the works in the

second category simplify the location region update due to the target range and the network communication cost. The objective function (3) can be solved by itself or approximated by an alternative form. The approximation for (3) often makes use of the convex constraint. One typical example is [21] where the geometric constraints (distance and angle measurements) between target and anchor node are represented in linear inequalities. All of them are combined to form a single semidefinite programming (SDP) problem. For each iteration, the bounding region for each node is updated accordingly. In [18], the authors presented a hybrid weighted LS (WLS) approach to intra-cell target localization in non-line-of-sight environments, while another close-form WLS was developed in [19]. The common characteristics of those approaches are their concise problem formulation with clear model representation and refined mathematical solutions, while likely preclude themselves in practice due to their complexities. For example, the complexity of solving the SDP in [21] is at least $\mathcal{O}(N_{cv}^3)$, where N_{cv} is the number of convex constraints needed to describe the network connectivity and measurement information.

Although a lot of approaches have been proposed, a number of issues remain open. In the original manuscript, we described those issues and presented our motivation to overcome those.

Comment 1.2. *In addition, there is one technical question, which is left unclear: Why CRLB shown in Fig. 5 does not decrease when the number of anchor nodes increases?*

Reply 1.2. From Section 3.6, the CRLB is clearly dependent on the geometry of the anchors, the range accuracy and the measurement errors. In the original manuscript, since we assumed noiseless measurements, the CRLB only depends on the geometry of the anchors and the estimation ranges. In Fig. 5, the CLRb performance was not likely degraded as the number of anchor nodes increased. This phenomena may be caused by two reasons: (i) With a given number of the anchor nodes, the anchor positions are fixed to run the simulation. (ii) Errors from the estimated range d_i becomes large as N increases. Also, it is more important to see the accuracy of the proposed scheme approaches to the CRLB. In order to clearly point out this issue, we add Remark 2 in page 11 as follows.

Remark 2. *In some approaches, the accuracy may be defined as the expected distance between the actual position $\mathbf{x}$ and the estimated one $\hat{\mathbf{x}}$, i.e., $\mathbb{E}(\|\hat{\mathbf{x}} - \mathbf{x}\|)$. Thus, the evaluation metric can be indicated as the percentage of the results satisfying a predefined accuracy requirement. In this section, we only consider two metrics in (25) and (26) to validate the localization effectiveness. Based on the observation from the simulation results, there are some major factors that cause large errors during the localization process. Assuming that information on the anchor positions is obtained accurately and reliably, the error source may be caused from the distance estimation error from (13), the multipath fading and the AoA measurement noises. The same phenomenon occurs in other localization schemes.*

Reviewer 2

The method proposed in this paper overcomes the non-convexity of maximum likelihood estimation method.

Open Review	(x)	I would not like to sign my review report
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English language	()	Extensive editing of English language and style required
and style	()	Moderate English changes required
	(x)	English language and style are fine/minor spell check required
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	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	(x)	()	()	()
Is the research design appropriate?	()	(x)	()	()
Are the methods adequately described?	()	(x)	()	()
Are the results clearly presented?	(x)	()	()	()
Are the conclusions supported by the results?	()	(x)	()	()

Comment 2.1. *In logistic regression, the maximum likelihood estimation is used as a loss function because of the non-convexity of least squares. The non-convexity of the maximum likelihood estimation method corresponding to this hybrid RSS-AoA localization for 3D problem need to be demonstrated in detail.*

Reply 2.1. The maximum likelihood estimator of the location of the unknown node is given by (3). This nonlinear minimization problem can be solved by the Newton-Gauss iteration [24]. In detail, we have applied this method to obtain the MLE as Section 4 presented. The complexity of MLE has been shown in Table 1. In general, the MLE is nonlinear, nonconvex and sensitive to the given initial points, which implies that many local solutions will be obtained instead of the global ones. In Section 4, we set the actual target location as the initial point, thus RMSE performance of MLE was good.

Other approaches [13–20] approximate the ML function to obtain an alternative solvable form. Their pros and cons have been introduced in Section 2.4. We also modify this section in the revised manuscript that can be seen in Reply 1.1. The complexity analysis is also presented in Table 1.

Comment 2.2. *RSS is easy to be measured but measuring AoA requires an antenna array, the hardware configuration and cost of each anchor node would be introduced for readers to reference.*

Reply 2.2. In the original manuscript, we did mention in page 2 two key challenges for practical implementation when applying the hybrid RSS-AoA approach. At this point, we would like to show how to deal with those problems at two aspects: (i) How to detect AoA without using an antenna array; (ii) How many different AoA measurements need for locating a sensor in 3D space.

First, we agree with the reviewer that using an antenna array on each sensor node is a common approach for obtain AoA measurements. However, other techniques [R1][R2] show different ways to detect angles between sensor nodes. In this case, all anchor nodes have omnidirectional antennas. Any normal sensor is capable of detecting the angles of incoming signals from anchor nodes. Thus, we can estimate the sensor location by exploiting the AoA measurements among neighboring anchor nodes.

- [R1] R. P and M. L. Sichitiu, "Angle of arrival localization for wireless sensor networks," *Proc. IEEE SECON 2006*, pp. 374-382, Reston, USA, Sept. 2006.
- [R2] A. Nasipuri and K. Li, "A directionality based location discovery scheme for wireless sensor networks," *Proc. ACM WSNA 2002*, pp. 105-111, Atlanta, USA, Sept. 2002.

Second, according to a specific application purpose, the number of AoA measurement needed to locate a sensor depends on the corresponding required accuracy.

- Regarding the number of AoA measurements, it has been shown that minimum two AoA measurements from two different anchor nodes are necessary to the location estimation of a target in 2D space, while other time-related methods require at least three anchor nodes [6]. In [13] and [15], the procedure of solving (3) requires the AoA measurements from 4 different anchor nodes.
- Concerning the anchor location settings, the authors in [11] showed a simple technique to obtain AoA measurements by putting three rotating reference nodes at the boundary of a sensor network area to provide the related information.

In summary, we would like to reflect the comment in the revised manuscript by adding the following texts in page 2.

For the AoA, using an antenna array on each sensor node is a common approach for obtaining the AoA measurements. Other simple techniques in [7, 8] give different ways to detect the AoA between the sensors. In such settings, all anchor nodes have omnidirectional antennas and a normal sensor is capable of detecting the angles of incoming signals from anchor nodes.

The related papers are also updated accordingly in the References section.

Comment 2.3. *$L_0 = -\infty$ and $L_S = \infty$, the actual measurement range of RSS is much smaller. As an approximate processing, can it narrow the range and improve the accuracy? The geometric meaning of Quantized RSS-Based Ranging is illustrated by a diagram.*

Reply 2.3. As shown in the original manuscript, the upper and the lower quantized levels were set at $L_0 = -\infty$ and $L_S = \infty$, which are the theoretical expressions. In the simulation setting, their values were determined as the minimum and the maximum values of RSS readings over M_c runs, respectively.

According to the original manuscript, the sensor only reports the quantized value to the anchor nodes, thus the estimated range between them can be approximated by either the anchor node or the base station based on this value.

Reviewer 3

The authors proposed a weighted LS for localization estimation, in particular, while transmit power and the path loss exponent unknown. Still, there are some issues needed to address to improve the quality of the paper up to the standard as examples below.

Open Review English language and style	(x)	I would not like to sign my review report
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	Yes	Can be improved	Must be improved	Not applicable
Does the introduction provide sufficient background and include all relevant references?	()	(x)	()	()
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Are the methods adequately described?	()	(x)	()	()
Are the results clearly presented?	()	(x)	()	()
Are the conclusions supported by the results?	()	(x)	()	()

Comment 3.1. *The authors should revise the organization to ease the reader understanding; the problem, motivation, what others' limitations, what is the techniques (novel or application), simulation, comparative results, justification, conclusion/future, etc.*

Reply 3.1. We would like to assert that the proposed approach has many clear innovative features. In this paper, we are interested in the hybrid RSS-AoA localization for 3D WSNs. Although localization technique is widely used in current WSNs and 2D UWSNs, there are still open issues to be investigated, especially for 3D WSNs. We follow step-by-step paths to develop our technique. Consequently, the discussion for each part was given as separate section.

- The contribution of the paper was summarized in page 2.
- The problem formulation for hybrid measurements in 3D WSNs was given in Section 2.2.
- We first review on how to estimate the strategy for estimating channel factors and other related parameters in Section 2.3. Then, we discuss how noisy and bias ranging results affect the localization results in three aspects: ranging, propagation, and estimation errors. Thus, we presented the state-of-the-art studies on error elimination and location refinement in Section 2.4 and Section 3.2. All of which have the goal of mitigating the negative impact of errors in RSS-AoA measurements for solving (3). Their advantages and disadvantages are also discussed in this section. In the revised manuscript, we modify the Related Works section as follows.

According to the capabilities of diverse hardware, we may classify the conventional hybrid RSS-AoA based localization into either of two main categories: nonlinear minimization localization or convex approximation localization. In the first category, supposing that the measurements from the reference node are only corrupted by zero-mean Gaussian noise and the reference nodes are identical or much closer to each other than the target, the basic idea is solving (3) with the given information. In particular, this nonlinear minimization problem can be solved by the Newton-Gauss iteration.

For instance, [16] proposed the least squares (LS) and optimization estimators using the distance and the AoA information. In [17], hybrid RSS-AoA LS and maximum likelihood (ML) estimators were derived for the emitter geolocation. The method of combining ML-LS implicitly assumes that a rough estimate range between anchor-target can be obtained. The cost function given by (3) weakly depends on this value, thus the roughness will not significantly affect the solution. It has been reported in [21] that the accuracy of such scheme suffers from the environmental dynamics. On the other hand, departing from the first category, most of the works in the second category simplify the location region update due to the target range and the network communication cost. The objective function (3) can be solved by itself or approximated by an alternative form. The approximation for (3) often makes use of the convex constraint. One typical example is [21] where the geometric constraints (distance and angle measurements) between target and anchor node are represented in linear inequalities. All of them are combined to form a single semidefinite programming (SDP) problem. For each iteration, the bounding region for each node is updated accordingly. In [18], the authors presented a hybrid weighted LS (WLS) approach to intra-cell target localization in non-line-of-sight environments, while another close-form WLS was developed in [19]. The common characteristics of those approaches are their concise problem formulation with clear model representation and refined mathematical solutions, while likely preclude themselves in practice due to their complexities. For example, the complexity of solving the SDP in [21] is at least $\mathcal{O}(N_{cv}^3)$, where N_{cv} is the number of convex constraints needed to describe the network connectivity and measurement information.

- In order to clearly present potential applications of the proposed approach, we give an example to demonstrate the localization procedure in Section 3.1. Following that, we concern the development of the localization scheme with hybrid measurements. In fact, we adopt the quantized model (5) for radio signals to obtain the distance information, then the location of a point can be determined by the trigonometry and geometry rules with the help of measuring angles from a number of the anchor nodes. We also provide a method to control the channel errors in the section of linear approximation and channel factor refinement. The complexity analysis of the proposed work and other approaches is given in Remark 1.
- Numerous simulations have been shown to compare many localization schemes (MLE, SOCP, WLS and the proposed method).

In summary, please understand that the current structure of the manuscript has been already organized properly to ensure a suitable workflow. Thus, we would like to keep as itself but with some modifications to improve the readability.

Comment 3.2. *Please provide a comprehensive state of arts for any claims and assumptions as the citations.*

Reply 3.2. We did carefully review the citations which appeared in the manuscript. Otherwise, those sentences without citations were discussion and analysis statements made by the authors.

Comment 3.3. *Note that while claiming others may have low precision or high computation, recent state of the arts can mitigate those and so please provide some justification and details.*

Reply 3.3. We agree with the reviewer that the proposed approach still has its limited. However, we have considered this approach in this paper for the following two reasons:

- As we presented in Section 2.4 and Section 3.2, two main problems have not been considered yet, which are (i) how to handle the nonconvexity of network deployment with low computational complexity; (ii) how to quickly extract the location information to keep lower maintenance. It is not easy to solve both problems in 2D space, but much more difficult in 3D space.

- Apparently, it is not often to have enough number of the anchor nodes for localization process, which can be considered as the worst-case. Thus, in order to overcome this issue, we proposed a location refinement under the uncertainty condition. Also, the channel factors (e.g., transmit power and PLE) have been kept updated from raw measurements to improve the localization accuracy.
- Related works have been updated accordingly in the revised manuscript.

Comment 3.4. *Please provide some cost analysis for the proposed one.*

Reply 3.4. The complexity analysis was given in Table 1 in the original manuscript.

Comment 3.5. *Please provide some justification over the applicability of RSS-AOA, say, with limited resource on sensors but with antenna array? Also, what about the precision of the way to map RSS to distance.*

Reply 3.5. To answer the first question, we agree with the reviewer that using an antenna array is a common approach for obtaining AoA measurements. However, other simple techniques in [7, 8] give different ways to detect AoA between sensors. In such settings, all anchor nodes have omnidirectional antennas and a normal sensor is capable of detecting the angles of incoming signals from the anchor nodes. In order to reflect this comment in the revised manuscript, we add the following sentences in the revised manuscript.

For the AoA, using an antenna array on each sensor node is a common approach for obtaining the AoA measurements. Other simple techniques in [7, 8] give different ways to detect the AoA between the sensors. In such settings, all anchor nodes have omnidirectional antennas and a normal sensor is capable of detecting the angles of incoming signals from anchor nodes.

Regarding the second question, for a given S -level the estimated range can be quickly obtained by applying the mapping rule in (6). Using the other techniques like the RSS fingerprinting, the location of the unknown node can also be estimated but it takes more cost for storing the retrieved data. Thus, the accuracy of such scheme often suffers from the environmental dynamics.

Comment 3.6. *Please be specific how to overcome the two limitations of RSS-AoA based approach here?*

Reply 3.6. Regarding these issues, we suggest the solutions as follows.

- First, the reviewer can refer Reply 3.5 on obtaining the AoA without deploying an antenna array.
- Second, we admit that, in order to extract the hybrid information, it is important to design a hybrid receiver. However, in this paper we assume that the receiver is able to determine the direction from a transmitter. The investigation on hybrid antenna structure is out of scope of our paper.

In order to reflect the comment, we add the following sentences in page 5 of the revised manuscript.

Moreover, given the combined RSS-AoA measurements, our localization scheme is proposed based on the following assumptions. The first one is that the AoAs can be measured and calibrated from the omnidirectional antennas. The ambiguities in the hybrid receiver architecture and its sensitivity are neglected in this paper. We also do not address the noise uncertainty issue over fading channel factors through the localization problem formulation.

Comment 3.7. *Please revise the motivation leading to the contribution (not clear), in particular, with unknown PLE.*

Reply 3.7. As we described in page 5 of the original manuscript, only few studies considered the transmit power as an unknown parameter [17, 19, 21, 22], while in practice these two parameters (transmit power and PLE) may vary significantly in different times and places. To our best knowledge, there is no existing work that derives a solution for hybrid RSS-AoA in 3D space when both transmit power and PLE are unknown variables. Therefore, in the paper we derive a suboptimal solution for this case.

Comment 3.8. *Please justify the contribution a bit against the previous paper by the same authors [18].*

Reply 3.8. We now point out the different between our work and the work [18] in the below table.

Content	[18]	This paper
Workspace	2D space WSN	3D space WSN
Method	The authors proposed a selective hybrid weighting RSS-AoA approach for NLOS intra-cell localization.	We proposed a WLS for quantized RSS-AoA measurements.
Main contribution	The scheme uses only two best RSS measurements of the localized nodes to serve the localization process with the help of AoA.	Our scheme used the online readings of RSS and AoA to locate the unknown node. The bias factor between RSS-AoA has been taken into account to improve the accuracy.
Pros and Cons	The scheme is simple but requires channel information and antenna array at receiver.	Channel factors are predicted and updated during the localization process. Also, when the number of anchors is not enough, the location refinement will be performed at the BS to obtain a coarse solution for the unknown node.
Complexity	Medium. $\mathcal{O}(2N + K_{\max}N)$ where $K_{\max}$ is the maximum number of iterations for solving WLS	Medium. $\mathcal{O}(MN + K_{\max}N)$ where M is the number of the anchor nodes
Accuracy	RMSE: 3.5-7.5 m, bias: 1-7m over $100 \times 100\text{m}$ area at each direction	RMSE: 2.5-6.5 m, bias: 0.5-2m over $100 \times 100\text{m} \times 100$ area at each direction

In the revised manuscript, we modify the Related Works section according to Reply 3.1.

Comment 3.9. *Please justify “fast” scheme say that depends on many factors/setup/testbed OR the author meant low complexity?*

Reply 3.9. In the original manuscript, we proposed a “fast” localization scheme in two aspects: (i) low complexity; (ii) how quickly to obtain an accurate ranging information. In fact, localization task often consumes a large amount of computation resource. It only makes sense when the network is localizable. Thus, testing the localizability (e.g., checking the number of the anchor nodes required) before estimation of the unknown node as considered in this paper, can save unnecessary and meaningless computation as well as reduce the power consumption over the network.

Comment 3.10. *Related work should be comprehensive and intensive study.*

Reply 3.10. We did carefully revise the Related Works section and update the references accordingly.

Comment 3.11. *In terms of derivation and analysis, with one additional axis say z , what makes it so different from the 2D analysis?*

Reply 3.11. In 3D space, it is more difficult to determine an unknown node for given measurement information. For instance, solving the nonconvex optimization problem (3) takes lots of efforts because there are many unknown parameters, i.e., higher dimensional search space. Also, the derivation of CLRB in 3D space is more complex than 2D one.

Comment 3.12. *If correctly understand, there is no “ x ” in (3).*

Reply 3.12. Since we denoted $\mathbf{x} = [x, y, z]^T$ and $\boldsymbol{\theta} = [x, y, z, P_0, \beta]^T$, the reviewer can see that $\boldsymbol{\theta} = [\mathbf{x}^T, P_0, \beta]^T$, which is totally related to (3).

Comment 3.13. *What is “initial guessing intervals”?*

Reply 3.13. In theory, we often consider an iterative method under the prerequisite that the initial guess is close to the true solution to avoid local minima. However, the selection of such a starting point is not simple in practice. Thus, we preset the value in a certain “range” instead. For example, the transmit power P_0 was randomly generated in the interval $[-15, -5]$ dBm. For each iteration, its value is updated according to (14).

Comment 3.14. *How to define the range say min and max; and any sensitivity analysis?*

Reply 3.14. Their values are selected according to the environment scenario. For instance, the PLE varies between 2-5 in indoor environment. We realize that one of critical limitations is the issue of matching the observation with the learned elements from the environment. It can be done by either designing a test for a hypothesis verification or extract the characterizing features from the raw sensor data. In summary, in our work the range of P_0 and β can be evaluated from persistent learning of the area.

Comment 3.15. *The evaluation shouldn’t be contribution; there is a need to perform the evaluation to state the superiority of the algorithm.*

Reply 3.15. Following the reviewer’s suggestions, we modify the main contribution of this paper in page 2 as follows.

In simulation results, we compare our work with other existing localization approaches under some likely-practical conditions in terms of root mean square error and bias.

Besides the computation cost, we realize that a good localization algorithm must ensure a low RMSE and a stable bias under the same setting scenario. In the revised manuscript, we add the following sentences in page 10.

Given a localization algorithm, the RMSE and the bias show how well the estimated target location matches the actual one. More specifically, besides the computation cost, a good localization algorithm must ensure a low RMSE and a stable bias under the same setting scenario. In this section, we will evaluate and compare those aforementioned algorithms under different noise conditions to make accurate validation.

Comment 3.16. *It’s not quite clear why the assumption is over just 1 unknown node OR this is just the formation and further, the model should not limit the unknown nodes.*

Reply 3.16. In our paper, since the BS only runs the localization algorithm when it receives a localization request from the user, we consider the unknown node as a random point in the area of interest. Through the simulation results, it can be seen that the proposed scheme works well for a single request (i.e., single target) at one time. For the multiple localization, the BS may set up a localization queue and handle one by one.

Comment 3.17. *Since the authors claimed on the real-environment testbed; details of all related setups are required including detailed characteristics of each component. Also, any specific protocol used in this model?*

Reply 3.17. We would like to clarify that we did not claim the proposed scheme works well in the real-environment testbed. In fact, we build a localization algorithm under some likely-practical conditions, for examples, unknown path loss and PLE, not having enough number of anchor nodes required, noisy measurements, etc. For the inspiring example in page 5, we think that the proposed localization scheme can be appropriate for that kind of applications with such level of complexity and accuracy.

Comment 3.18. *Whether is any coverage and routing used here? It's a bit confusing when the authors stated the real example applied in this proposal.*

Reply 3.18. We would like to say that the localization system runs based on an event-driven mechanism, i.e., a sensor only collects the RSS-AoA measurements when it receives a localization request. The quantized RSS helps the sensor to know quickly their ranges to neighbor anchors/relay nodes and to indicate AoA of the incoming signals. Thus, until the localization packet (sensor ID, RSS-AoA measurements) reaches the neighbor anchor nodes, they collect and deliver back to the BS with their locations. Finally, the localization algorithm can be executed by the BS to obtain the sensor location on the received packets. We also assume that the shortest path distance between two sensor nodes corresponds well to their Euclidean distance. Regarding some practical settings, please refer to Reply 3.17.

Comment 3.19. *Based on Table 1, the complexity (most) is O of N , isn't it? Please be specific on the superiority of the proposed scheme.*

Reply 3.19. According to Table 1, our localization scheme has a lower complexity compared to the MLE and the SOCP, while exhibiting comparable complexity to the LE and the WLS. Beside the pros and cons discussed in Section 2.4, the proposed scheme also achieves a good RMSE and a stable bias under some mild conditions compared to those ones.

Comment 3.20. *The authors claimed on "high computational cost" and "measurement errors"; please provide some analysis against the state of the arts.*

Reply 3.20. Regarding the computational cost, please refer to Reply 3.19. In terms of measurement errors, we would like to draw the attention on Section 3.4 and Section 3.5. In fact, we develop a bias reducing constant (8) for the RSS-AoA measurements and the refine location estimation in (11) and (12).

Comment 3.21. *The authors should perform the comparative analysis against the state of the arts.*

Reply 3.21. As we pointed out in Reply 3.15, we compare the effectiveness among localization schemes in terms of complexity cost, RMSE and bias performance.

Comment 3.22. *Detailed configuration/setup/testbed are required in the evaluation section.*

Reply 3.22. Concerning the statement of evaluation, please refer to Reply 3.15. Other simulation parameters were described in the first paragraph of Section 4.

Comment 3.23. *Please provide some discussion on the performance; say, it seems there is not much trend on the RMSE over all; very close to each other.*

Reply 3.23. In order to reflect this comment, we add Remark 2 in page 12 of the revised manuscript as follows.

***Remark 2.** In some approaches, the accuracy may be defined as the expected distance between the actual position $\mathbf{x}$ and the estimated one $\hat{\mathbf{x}}$, i.e., $\mathbb{E}(\|\hat{\mathbf{x}} - \mathbf{x}\|)$. Thus, the evaluation metric can be indicated as the percentage of the results satisfying a predefined accuracy requirement. In this section, we only consider two metrics in (25) and (26) to validate the localization effectiveness. Based on the observation from the simulation results, there are some major factors that cause large errors during the localization process. Assuming that information on the anchor positions is obtained accurately and reliably, the error source may be caused from the distance estimation error from (13), the multipath fading and the AoA measurement noises. The same phenomenon occurs in other localization schemes.*

Comment 3.24. *The authors claimed “..problem with the constraints in energy consumption and communication bandwidth.”; please provide some analysis on the latter (comm. BW).*

Reply 3.24. In the original manuscript, in terms of communication bandwidth it can be seen that the proposed scheme can reduce the number of messages required for localization per unknown node. Instead of continuously reporting the measurements to the neighbor anchors, a sensor only collects the RSS-AoA measurements when it receives a localization request. In order to address the reviewer’s comment more clearly, we also added more description in the revised manuscript as follows.

- We add two new reference papers [1, 2] to support the statement.
- We make a new remark in page 12.

***Remark 3** It has been seen that localization system runs based on an event-driven mechanism, i.e., a sensor only collects the RSS-AoA measurements when it receives a localization request. The quantized RSS helps the sensor to know quickly their ranges to the neighbor anchors/relay nodes and to indicate the AoA of the incoming signals. Until the localization packet (sensor ID, RSS-AoA measurements) reaches the neighbor anchor nodes, they collect and deliver back to the BS with their locations. Finally, the localization algorithm can be executed by the BS to obtain the sensor location on the received packets. The unknown node only send one message for localization instead of continuously reporting the measurements to the neighbor anchors, thus the number of messages required for localization per unknown node can be reduced.*

References

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