RSS-Based Source Localization

When Path-Loss Model Parameters are Unknown

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INTRODUCTION

Commonly used measurement methods

- Time-Of-Arrival (TOA) [2]
- Time-Difference-Of-Arrival (TDOA) [3]
- Angle-of-Arrival (AOA) [4]
- Acoustic Energy [5]

Received Signal Strength (RSS) [6]

- Not require time synchronization or use of an antenna array
- An effective and cost-saving method in terms of both software and hardware.

Two categories

- By whether the coordinates of receivers are needed or not

Method	Refer to
Physical Localization	RSS measurements of receivers and their known coordinates
Symbolic Localization	Only RSS measurements but more complicated [Reference7 and reference8]

Physical Localization Algorithms

Algorithm	Principle	Advantages	Disadvantages
Centroid [9]	Take all the receivers within the transmission range of the source node as its location	simple to implement	low in localization accuracy
Gradient [10]	1. Use the local signal strength distribution to estimate the direction of the access point 2. acquires its location by combining multiple directional estimates	overcome sampling bias and reduce non-uniform signal propagation effect	requires extensive RSS measurements
Trilateration [11]	1. converts the RSS measurements to distances between the source node and receivers using a path-loss model 2. combines these distances to obtain the location of the source node	requires the path-loss model parameters, which usually are assumed to be known *a priori* through a calibration phase	in anonymous environments, it is **impractical** to know this path-loss model information in advance

Previous Works in References

[12] considers path-loss exponent as an unknown parameter and estimates it simultaneously with the unknown location coordinates of the target node

[13] utilizes differential RSS measurements to eliminate the transmitting power uncertainty.

[14] linearly approximates the exponential relationship between RSS measurement and distance, making it possible to estimate the location of the source node when both transmitting power and path-loss exponent are unknown.

While both approaches compensate for where one or other of the path-loss model parameters are unknown, neither method can be employed unless at least one model parameter is known.

But the localization error is relatively large when the geometric conditions are poor.

METHOD DESCRIPTION

Method Description

Terminology	
(x, y)	the coordinates of the source to be estimated
m	the number of receivers, $m \geq 3$
(x_i, y_i)	the known coordinates of the i_{th} receiver, $(1 \leq i \leq m)$

The first step is to convert the measured RSS at the i_{th} receiver $\mathrm{R_i}$ to a distance $\mathrm{d_i}$ between the source node and the i_{th} receiver.

Theoretical and practical tests indicate in [15] that measured RSS decreases logarithmically as the distance increases.

RSS values can be modeled

$$R_i = R_0 - 10n\log_{10}(d_i / d_0) + X_i \quad (1)$$

Terminology	
R_i	the measured RSS at the i_{th} receiver
R_0	The received signal strength in dBm at a reference distance d_0 from the source node (usually $d_0 = 1\ m$)
n	the path-loss exponent of the environment
X_i	the shadow noise modeled as an uncorrelated zero-mean Gaussian variable with standard deviation σ dB .

$$\hat{d}_i = d_0 10^{(R_0 - R_i)/10n} \quad (2)$$

Method Description

$$f(R_i / d_i) = \frac{1}{\sigma} \exp\left[-\frac{(R_i - (R_0 - 10n\log_{10}(d_i / d_0)))^2}{2\sigma^2} \right] \qquad (3)$$

- R_0 is a source transmitting power-related constant,
- Path-loss exponent n is environment-dependent and usually can be assumed constant in a particular environment for a certain period of time,
- $\mathrm{R_i}$ can be modeled as a Gaussian random variable.

Therefore the probability-density function of $\mathrm{R_i}$ conditioned on the distance d_i between the source node and the receiver is expressed.

Method Description

However, in an anonymous environment, parameters R_0 and n are usually unknown in advance, therefore $\mathrm{R_i}$ cannot be directly converted to distance $\hat{d}i$ from the source to the receiver. To address this, (2) is modified as follows:

$$\hat{d}_i = d_0 10^{(R_0 - R_i)/10n} \qquad (2)$$

$$\hat{d}_i = d_0 \left(10^{\frac{R_0}{10}} / 10^{\frac{R_i}{10}} \right)^{1/n} \qquad (4)$$

Simplifying Terminology
$P_0 = 10^{R_0/10}$
$P_i = 10^{R_i/10}$

Using the first receiver R_0 as the reference, a ratio approach, that is divide distances of other receivers by the distance of the first reference receiver, is used to eliminate the uncertainty of the source transmitting power.

$$\hat{d}_1 / \hat{d}_i = (P_i / P_1)^{1/n}. \qquad (5)$$

Method Description

As $\hat{d}_i \approx \sqrt{(x_i - x)^2 + (y_i - y)^2}$, we rearrange (5):

$$\hat{d}_1 / \hat{d}_i = (P_i / P_1)^{1/n}. \quad (5)$$

$$\left(P_1^{\frac{2}{n}} - P_i^{\frac{2}{n}}\right)\boxed{\left(x^2 + y^2\right)} + 2\left(P_i^{\frac{2}{n}} x_i - P_1^{\frac{2}{n}} x_1\right) x + 2\left(P_i^{\frac{2}{n}} y_i - P_1^{\frac{2}{n}} y_1\right) y = P_i^{\frac{2}{n}}\left(x_i^2 + y_i^2\right) - P_1^{\frac{2}{n}}\left(x_1^2 + y_1^2\right) \quad (6)$$

By introducing a variable $\boxed{S = x^2 + y^2}$ and substituting it in (6), we can stack all equations from (6) in a matrix form:

$$\mathbf{A}\boldsymbol{\theta} = \mathbf{b} \qquad (7)$$

where:

?

$$\mathbf{A} = \begin{bmatrix} 2\left(P_2^{\frac{2}{n}} x_2 - P_1^{\frac{2}{n}} x_1\right) & 2\left(P_2^{\frac{2}{n}} y_2 - P_1^{\frac{2}{n}} y_1\right) & P_1^{\frac{2}{n}} - P_2^{\frac{2}{n}} \\ 2\left(P_3^{\frac{2}{n}} x_3 - P_1^{\frac{2}{n}} x_1\right) & 2\left(P_3^{\frac{2}{n}} y_3 - P_1^{\frac{2}{n}} y_1\right) & P_1^{\frac{2}{n}} - P_3^{\frac{2}{n}} \\ \cdots & \cdots & \cdots \\ 2\left(P_m^{\frac{2}{n}} x_m - P_1^{\frac{2}{n}} x_1\right) & 2\left(P_m^{\frac{2}{n}} y_m - P_1^{\frac{2}{n}} y_1\right) & P_1^{\frac{2}{n}} - P_m^{\frac{2}{n}} \end{bmatrix}$$

?

$$\mathbf{b} = \begin{bmatrix} P_2^{\frac{2}{n}}\left(x_2^2 + y_2^2\right) - P_1^{\frac{2}{n}}\left(x_1^2 + y_1^2\right) \\ P_3^{\frac{2}{n}}\left(x_3^2 + y_3^2\right) - P_1^{\frac{2}{n}}\left(x_1^2 + y_1^2\right) \\ \cdots \\ P_m^{\frac{2}{n}}\left(x_m^2 + y_m^2\right) - P_1^{\frac{2}{n}}\left(x_1^2 + y_1^2\right) \end{bmatrix} \qquad \boldsymbol{\theta} = \begin{bmatrix} x \\ y \\ S \end{bmatrix}.$$

$$\boxed{S = x^2 + y^2}$$

$$\hat{d}_1 / \hat{d}_i = \left(P_i / P_1\right)^{1/n}$$

$$\hat{d}_i = d_0 \left(10^{\frac{R_0}{10}} / 10^{\frac{R_i}{10}}\right)^{1/n}$$

$\cancel{R_0}$

Fortunately, there is a constraint to the path loss exponent—it always lies between a minimum $N_{\min}$ and a maximum N_{max} —with typical values between two and four [17]. This constraint can be used to search for the optimum path loss exponent n_{opt} .

For a given path-loss exponent nj under the constraint $N_{min} \leq n_j \leq N_{max}$, distance ratios can be calculated using the RSS measurements R_i according to (5).

$n_j \rightarrow$

$$\hat{d}_1/\hat{d}_i = (P_i/P_1)^{1/n}. \quad (5)$$

$\rightarrow A_{n_j}$ *and* $b_{n_j} \rightarrow$

$$\mathbf{A}\boldsymbol{\theta} = \mathbf{b} \quad (7)$$

$$\hat{\theta}_{n_j} = \left(A_{n_j}^T A_{n_j}\right)^{-1} A_{n_j}^T b_{n_j} \quad (8)$$

$\rightarrow \hat{\theta}_{n_j} \rightarrow \left(\hat{x}_{n_j}, \hat{y}_{n_j}\right) \leftarrow$

$$\boldsymbol{\theta} = \begin{bmatrix} x \\ y \\ S \end{bmatrix}$$

$$d_{i,n_j} = \sqrt{(\hat{x}_{n_j} - x_i)^2 + (\hat{y}_{n_j} - y_i)^2}. \quad (9)$$

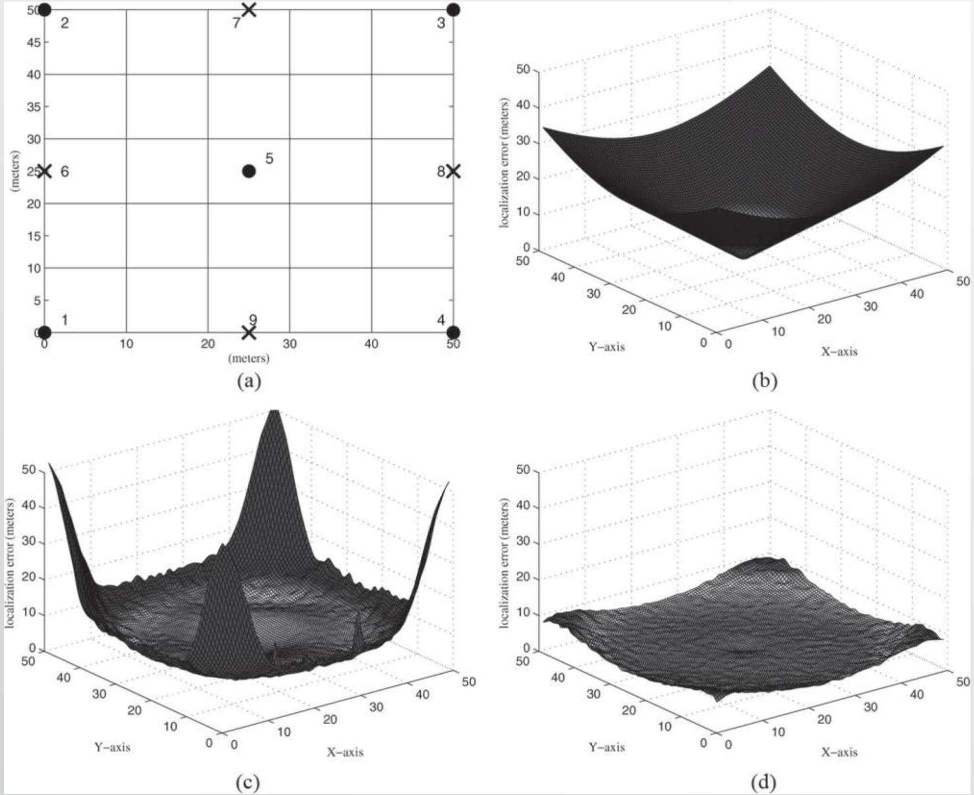
$$n_{\text{opt}} = \underset{N_{\min} \le n_j \le N_{\max}}{\arg\min} \sum_{i=2}^{m} \left[(d_{1,n_j}/d_{i,n_j}) - (P_i/P_1)^{1/n_j} \right]^2. \quad (10)$$

$$\rightarrow n_{opt} \rightarrow \hat{\theta}_{opt} \rightarrow (x, y) \leftarrow \boldsymbol{\theta} = \begin{bmatrix} x \\ y \\ S \end{bmatrix}$$

Terminology	
N_{min}	1
N_{max}	5
$step$	0.05

NUMERICAL RESULTS

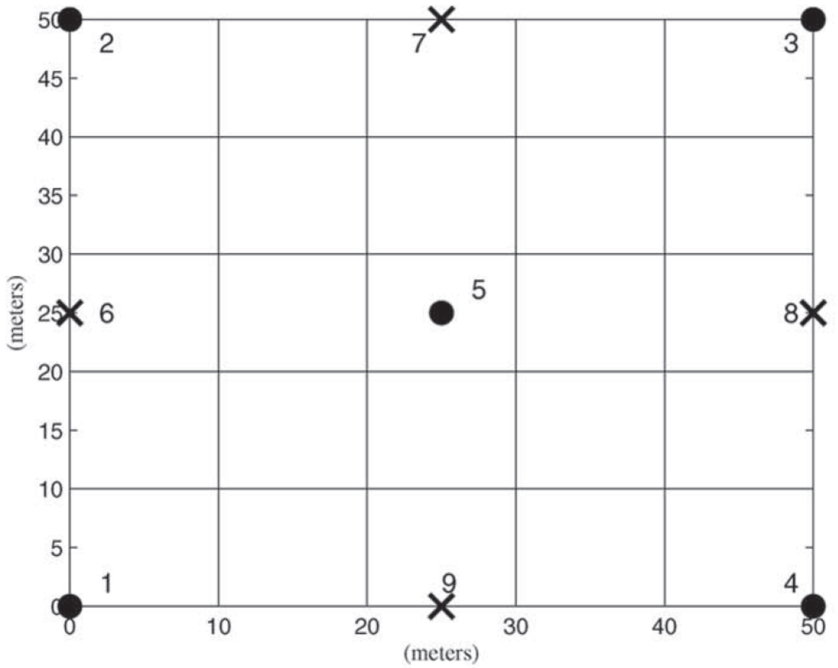
Performance comparison of different algorithms



(a) (b) (c) (d)

(a) Scenario one;
(b) centroid;
(c) Linearization;
(d) proposed.

In Scenario One

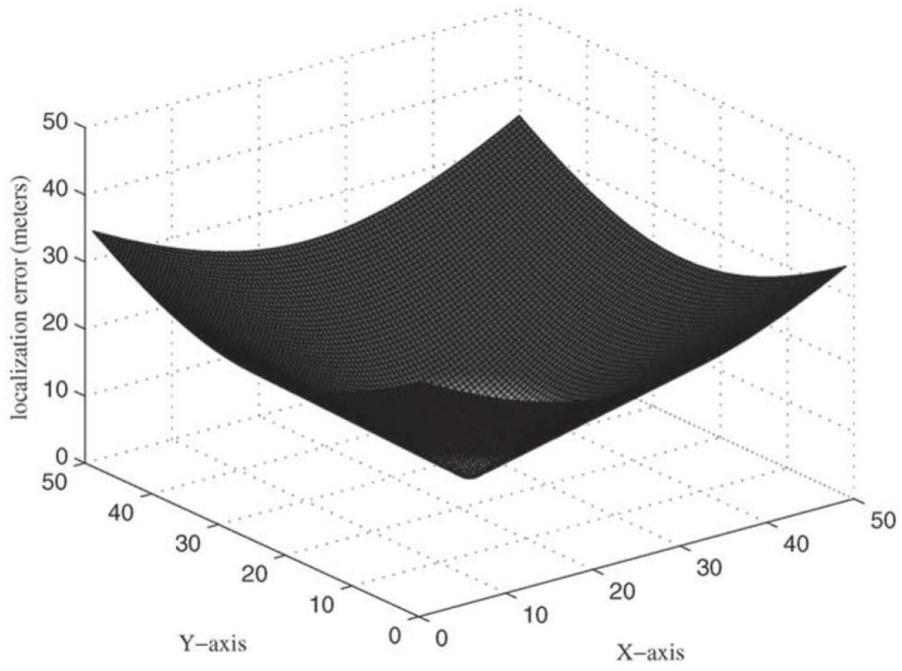


(a)

Terminology	
R_0	-30dBm
n	5
σ	2dB

R_0	The received signal strength in dBm at a reference distance d_0 from the source node (usually $d_0 = 1\ m$)

Centroid Algorithm

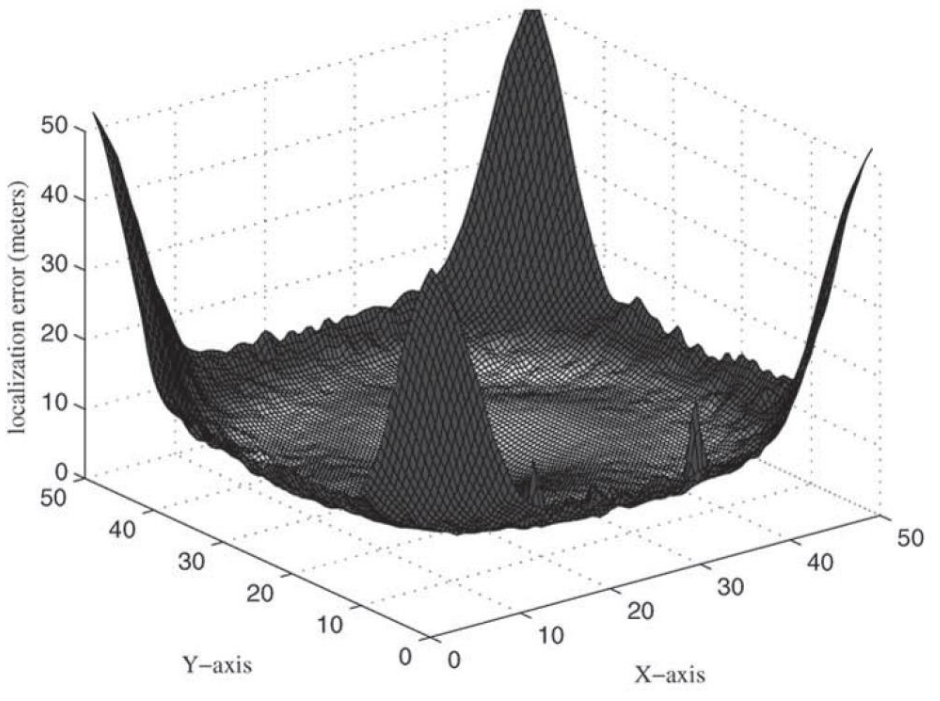


(b)

Localization accuracy is directly related to the location of the source node and RSS measurement locations. The localization error is large when the distribution of RSS measurement locations is non-uniform.

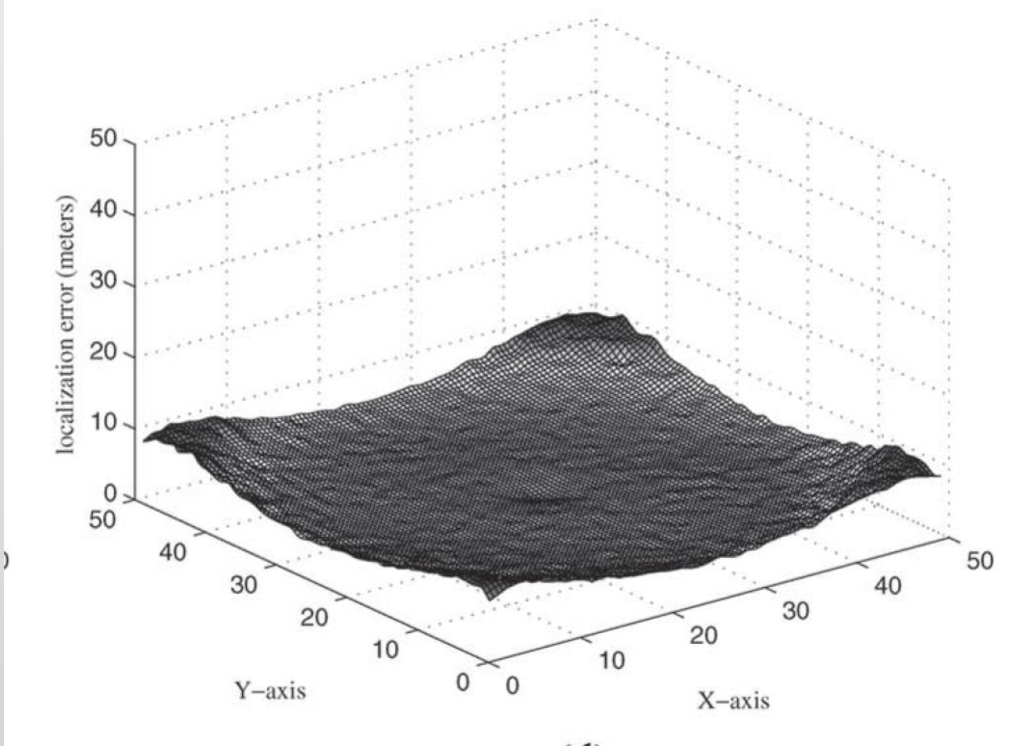
Linearization Algorithm

Small localization error in most part of the scenario, but suffers large errors at the corners when the geometric conditions are poor



(c)

The Proposed Algorithm



(d)

The localization error is relatively small across the scenario and it has better localization accuracy at the corner area compared with the linearization method.

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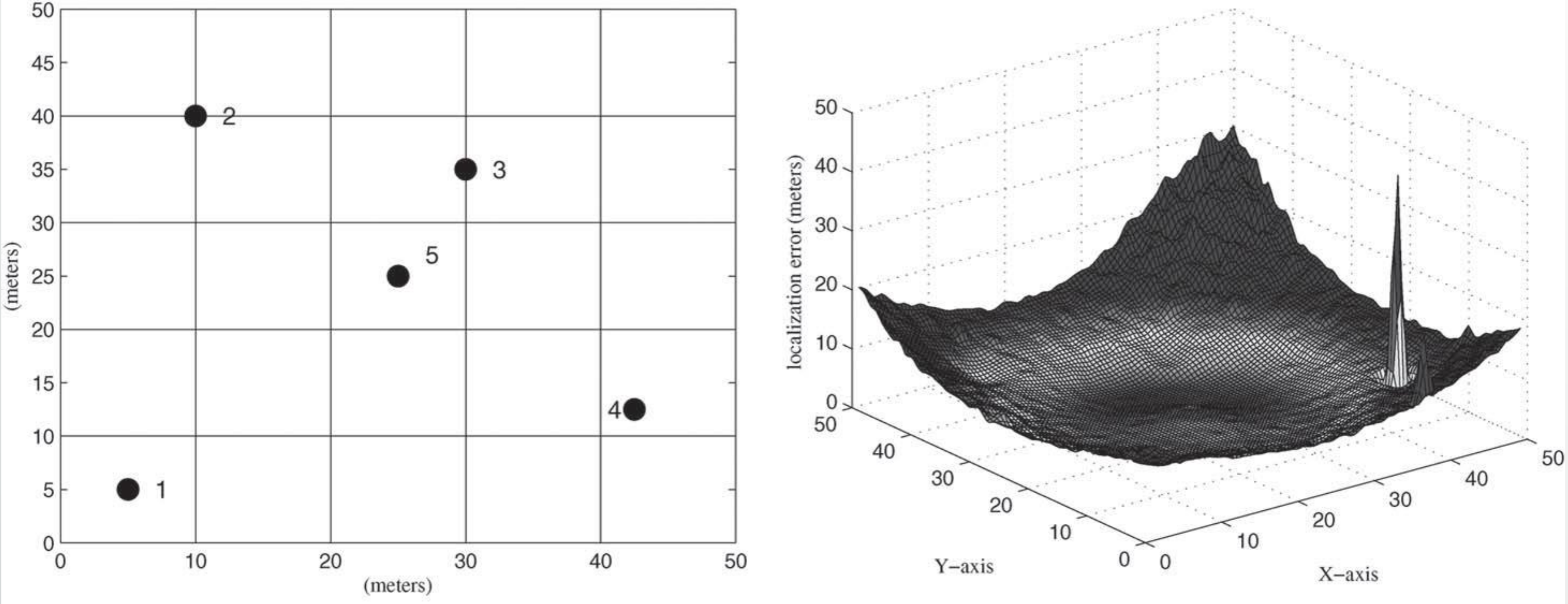
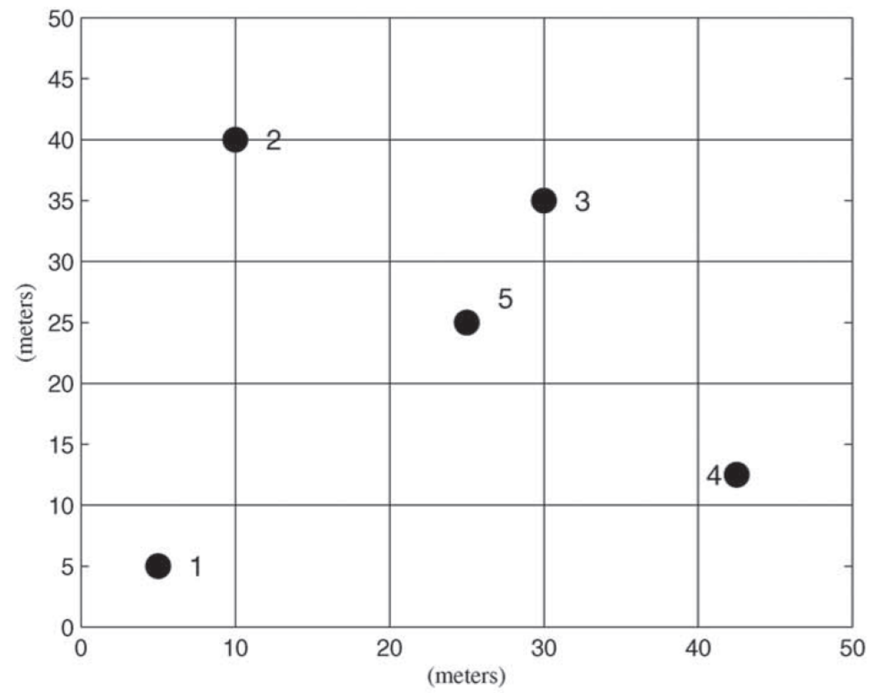
Another Scenario



(a) (b)

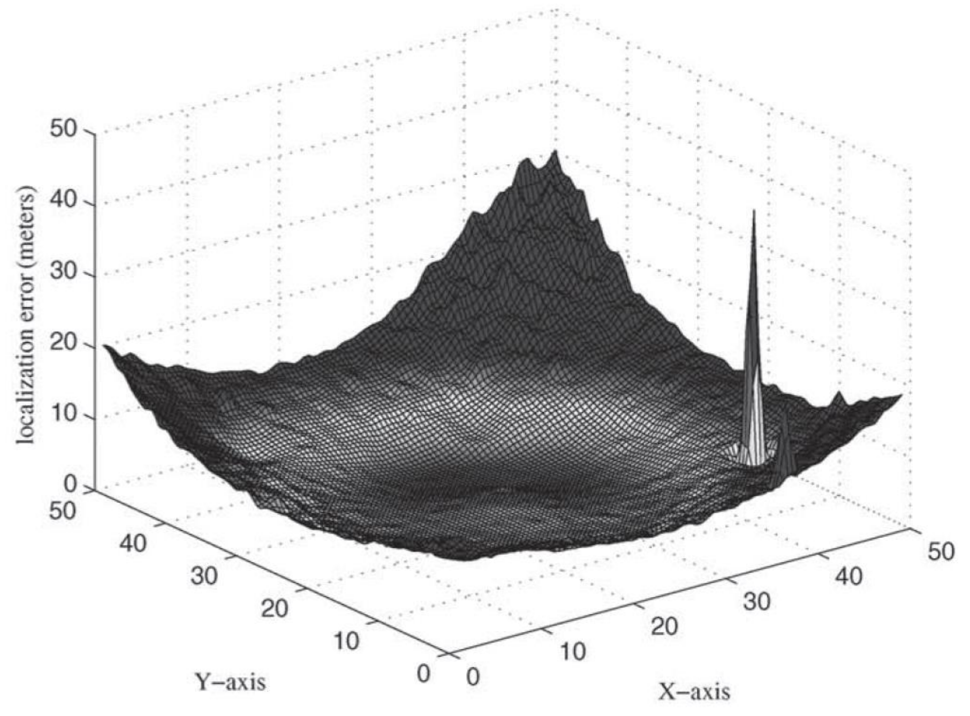
In Scenario Two



(a)

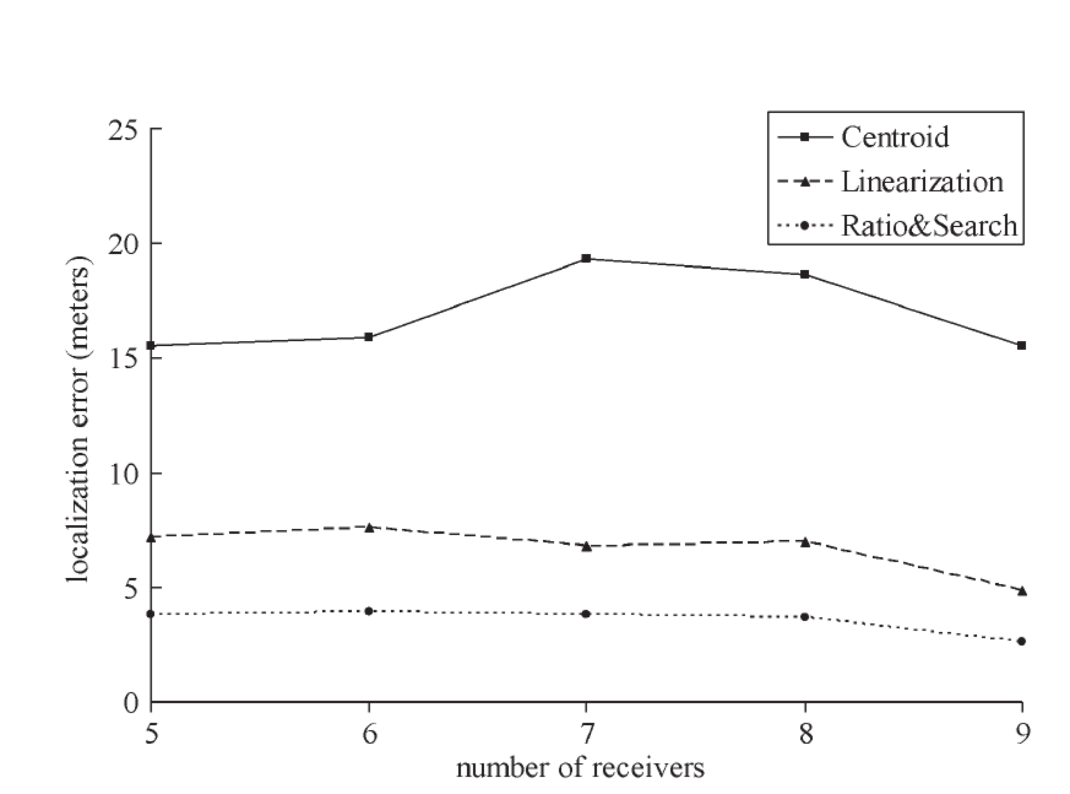
Terminology	
R_0	-30dBm
n	5
σ	2dB

The localization error is relatively small across the scenario and it has better localization accuracy at the corner area compared with the linearization method.



(b)

More Simulations About The Number Of Receivers



- Source node location (24.5, 9.5) was chosen

- The performance of centroid does not become better with more receivers placed.
- However, the localization errors of both the linearization algorithm and the proposed algorithm decrease as the number of the receivers increases.
- The localization error of the proposed algorithm is always lower than that of the linearization algorithm.

Estimation Error

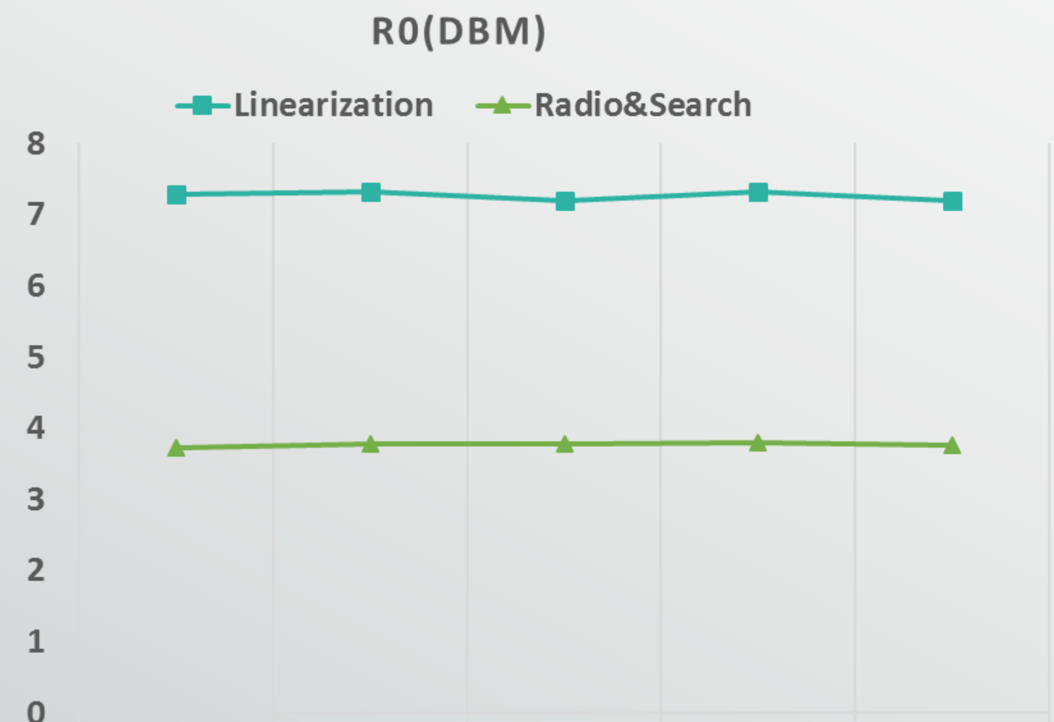
ESTIMATION ERROR (METERS) FOR DIFFERENT MODEL PARAMETERS

R_0(dBm)	-20	-25	-30	-35	-40
Centroid	15.51	15.51	15.51	15.51	15.51
Linearization	7.28	7.31	7.20	7.31	7.19
Ratio&Search	3.72	3.77	3.77	3.80	3.75

Shadow Noise σ(dB)	1	1.5	2	2.5	3
Centroid	15.51	15.51	15.51	15.51	15.51
Linearization	6.93	7.02	7.20	7.84	8.66
Ratio&Search	1.75	2.72	3.77	5.01	6.18

Path-loss Exponent n	2	2.5	3	3.5	4
Centroid	15.51	15.51	15.51	15.51	15.51
Linearization	8.39	7.70	7.20	7.12	6.94
Ratio&Search	6.04	4.71	3.77	3.18	2.72

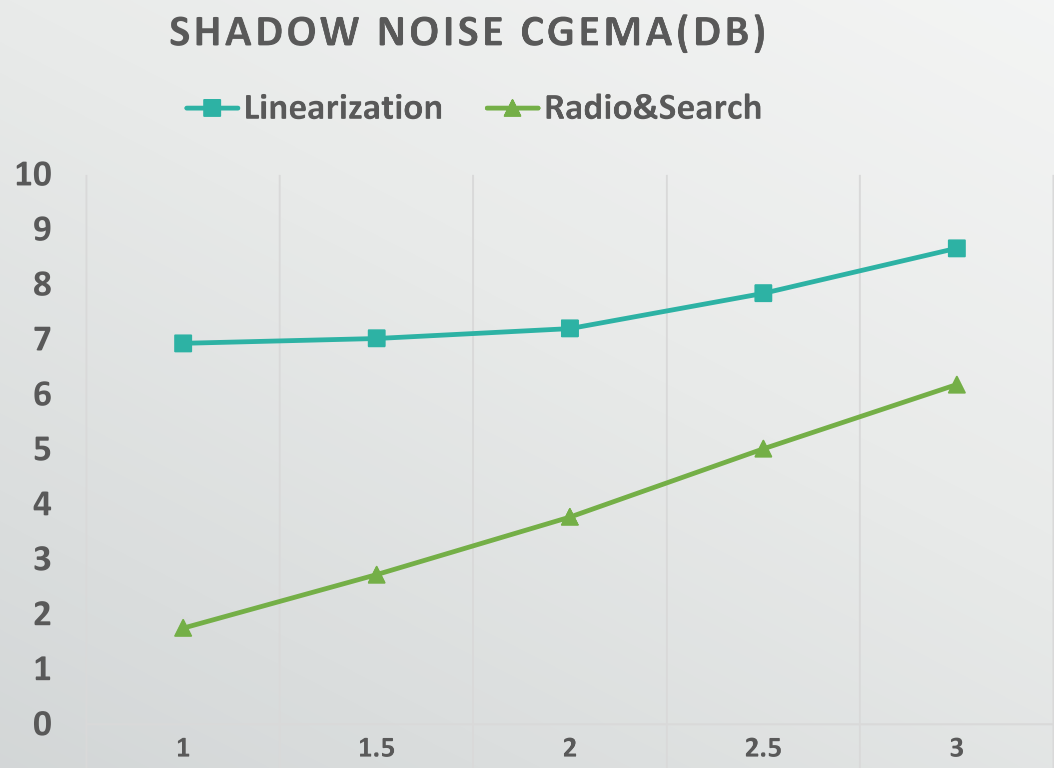
R0(dBm)



	-20	-25	-30	-35	-40
Linearization	7.28	7.31	7.2	7.31	7.19
Radio&Search	3.72	3.77	3.77	3.8	3.75

While the accuracies of both the linearization algorithm and the proposed algorithm show similar trend when a single parameter changes

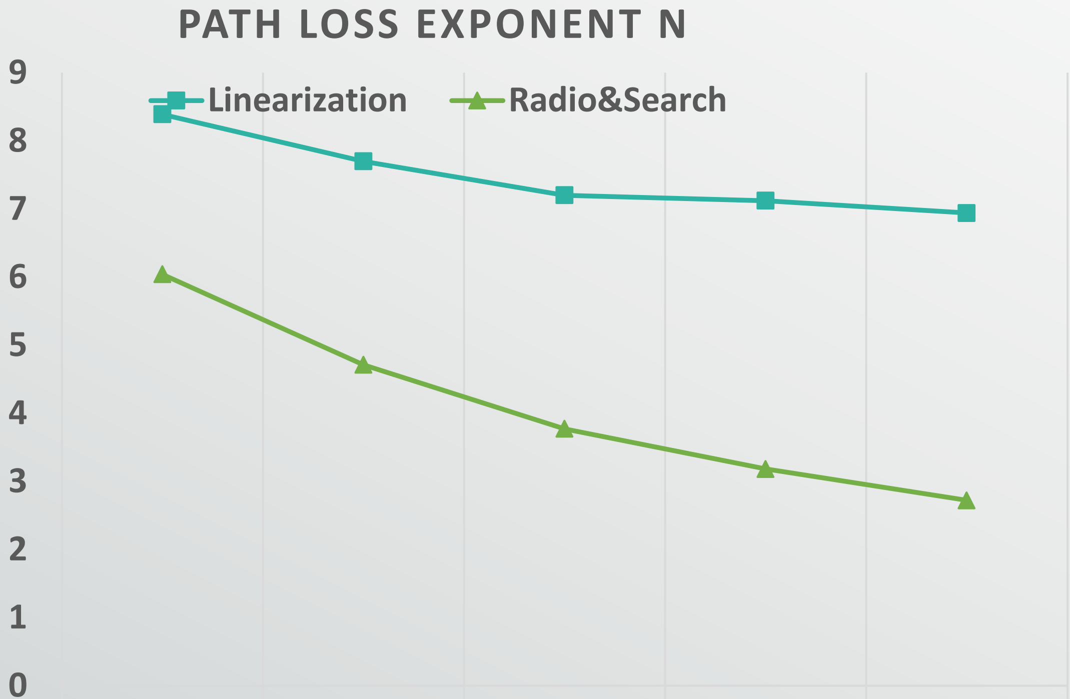
Shadow Noise σ(dB)



	1	1.5	2	2.5	3
Linearization	6.93	7.02	7.2	7.84	8.66
Radio&Search	1.75	2.72	3.77	5.01	6.18

For both the linearization algorithm and the proposed method, the localization accuracy keeps nearly constant when the transmitting power related parameter R0 changes

Path Loss Exponent n



	2	2.5	3	3.5	4
Linearization	8.39	7.7	7.2	7.12	6.94
Radio&Search	6.04	4.71	3.77	3.18	2.72

Decreases as the shadow noise σ increases and improves as the path-loss exponent n increases.

CONCLUSION

Conclusion

In summary, the simulations indicate that, for different path-loss model parameters, the proposed method results in better localization accuracy compared with centroid and linearization.

A limitation in the proposed method is that the path-loss exponent is assumed to be the same for different measurements, whereas there may be minor differences in these values [16]. This will be the basis for future research work.

THANK YOU FOR WATCHING !

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