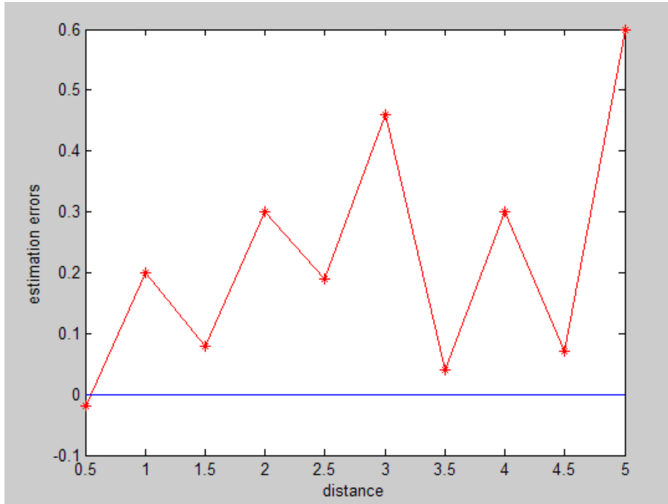

Figure 6. Distance and localization errors (beacon nodes are 30%)

In figure 6, the red star point represents destination node localization estimation errors in three-dimensional, the blue one represents true localization estimation errors. We can get that the distance estimation error is increasing with the distance, which as the relationship between RSSI and distance in formula (7).

b. localization errors

Table 2. The result of distance d and localization errors within 5m(beacon nodes are 30%)

Distance *d*	Estimation errors of localization
0.5	0.178
1	0.301
1.5	0.256
2	0.315
2.5	0.315
3	0.372
3.5	0.369
4	0.432
4.5	0.401
5	0.413

The left column is actual value between destination node and beacon node, the right column is localization errors. In table 2, the localization errors are theoretical errors. Making the localization algorithm for the node which distance is 3m in randomly, and the simulation as shown in figure 8.

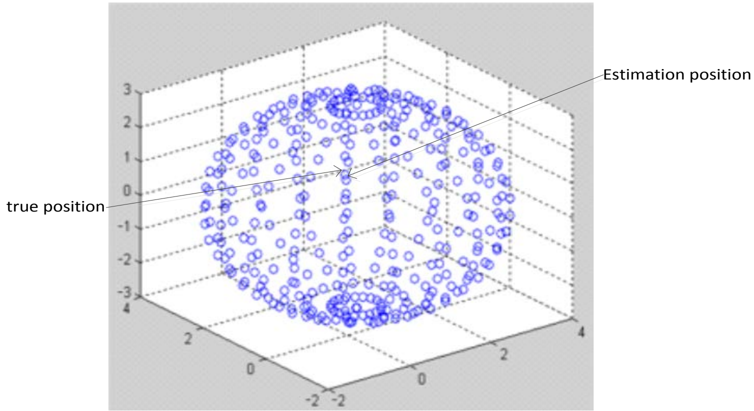

Figure 7. Sphere coverage of destination node (beacon nodes are 30%)

As we can see from the figures, the estimation error interval of localization estimation errors and truth localization errors are reduce not obviously.

2) beacon nodes are 40%

a. distance estimation errors

Table 3. Test result of d and RSSI within 5m(beacon nodes are 40%)

Distance d	The measurement of RSSI	The estimation errors of distance
0.5	-18, -18.5, -18, -19, -19.2	0.02
1	-20, -22, -21.5, -20.5, -28	-0.2
1.5	-35, -25, -24, -32, -32.5	0.08
2	-35, -30, -34.5, -33, -32.5	0.01
2.5	-34, -35, -34.5, -34.8, -35	0.01
3	-35, -36.8, -36.6, -37, -37.2	0.2
3.5	-37.6, -37.9, -33.3, -38.6, -38.3	-0.05
4	-42, -41, -41.5, -35, -35	0.07
4.5	-42.4, -41.3, -41.5, -36, -38	0.07
5	-42, -39.5, -40.8, -41.3, -43	0.2

In table 3, the left column are actual values between destination node and beacon nodes, the middle column are RSSI measurement values, and right column are distance errors. When the beacon nodes are 40%, we can see the estimation errors are slightly difference in -0.2m ~ + 0.2m, And from above formula (4), the average of RSSI values are

$\mu \leftrightarrow \{-18.54, -22.4, -29.7, -33, -34.66, -36.52, -37.14, -38.9, -39.84, -41.32\}$, From the formula (3) It shows that the measured RSSI values meet the threshold probability. Thus RSSI weighted average is

$RSSI \leftrightarrow \{-18.54, -22.4, -29.7, -33, -34.66, -36.52, -37.14, -38.9, -39.84, -41.32\}$. The estimation errors of distance simulation as shown in figure 9.

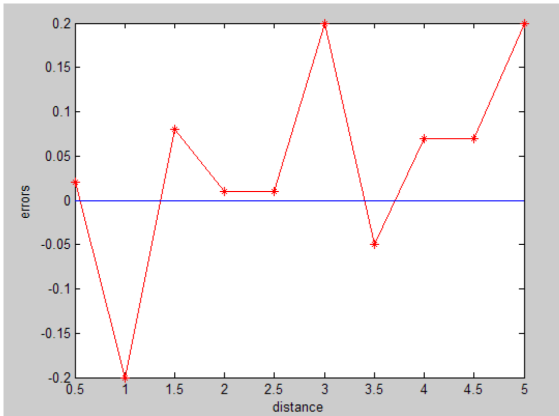

Figure 8. Distance and localization errors (beacon nodes are 40%)

In figure 8, the red star represents the destination node localization estimation errors in three-dimensional, the blue represents the true localization estimation errors. From the figure 9, we can get that the distance estimation error is changed not obviously with the distance.

b. localization errors

Table 4. Result of d and localization errors within 5m(beacon nodes are 40%)

Distance d	Estimation errors of localization
0.5	0.176
1	0.219
1.5	0.259
2	0.295
2.5	0.327
3	0.364
3.5	0.36
4	0.406
4.5	0.401
5	0.396

The left column is actual values between destination node and beacon nodes, the right column is localization errors. We make the localization algorithm for the node which distance is 3m in randomly, and the simulation as shown in figure 9.

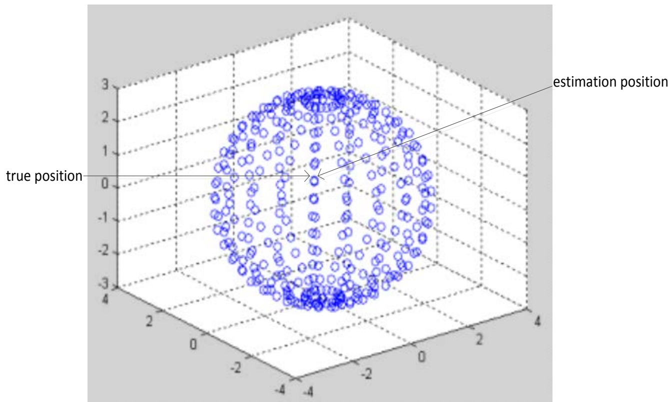

Figure 9. Sphere coverage of destination node(beacon nodes are 40%)

As we can see from the figure 9, the estimation error is reduced between localization estimation and truth localization with the higher repetition. When beacon nodes are 40%, the localization estimation error is reduced as few as possible. Therefore, beacon nodes are 40% in the networks, which would be a significant number to get the destination node localization.

3) beacon nodes are 50%

a. distance estimation errors

Table 5 Test result of d and RSSI within 5m(beacon nodes are 50%)

Distance d	Measurement value of RSSI	Estimation errors of distance
0.5	-18, -18.2, -17, -18.9, -20	0
1	-21, -21.8, -22, -21.7, -22	0.3
1.5	-30, -28, -27, -27.9, -29	0.1
2	-32, -32.8, -33.2, -35, -33	0.25
2.5	-34, -34.8, -34.4, -35.2, -36	0.29
3	-37, -36.8, -37.2, -37, -37.1	0.1
3.5	-38, -37.2, -36, -37.4, -37.8	0.05
4	-38.7, -39.2, -39.1, -40, -38.1	-0.1
4.5	-40.4, -39.1, -40.2, -40, -39.9	0.07
5	-42, -41.8, -42.1, -41.8, -40	0.3

In table 5, the left column are actual values between destination node and beacon nodes, the middle column are RSSI measurement values, and right column are distance errors. When the beacon nodes are 50%, we can see the estimation errors are slightly difference in -0.1m ~ + 0.3m, And from above formula (4), the average of RSSI values are

$\mu \leftrightarrow \{-18.42, -21.7, -28.38, -33.2, -34.88, -37.02, -37.28, -39.02, -39.92, -41.54\}$,

From the formula (3), it shows that the measured RSSI values meet the threshold probability. Thus RSSI weighted average is

$\mu \leftrightarrow \{-18.42, -21.7, -28.38, -33.2, -34.88, -37.02, -37.28, -39.02, -39.92, -41.54\}$

The estimation errors of distance simulation as shown in figure 10.

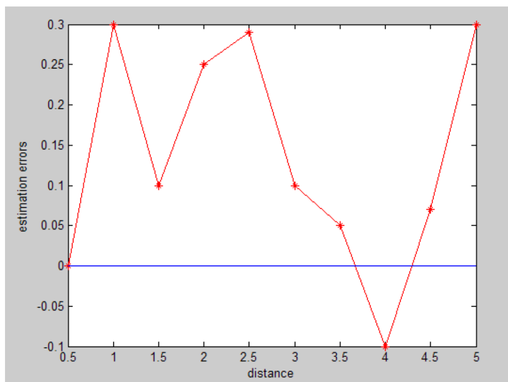

Figure 10. Distance and localization errors(beacon nodes are 50%)

In figure 11, the red star represents the destination node localization estimation errors in three-dimensional, the blue represents the true localization estimation errors. Compared with the figure 7 and figure 9, we can get that the distance estimation error is changed gently with the distance.

b. the localization errors

Table 6. Rresult of d and localization errors within 5m(beacon nodes are 50%)

Distance d	The estimation errors of localization
0.5	0.179
1	0.219
1.5	0.259
2	0.315
2.5	0.357
3	0.424
3.5	0.362

4	0.412
4.5	0.401
5	0.406

The left column is actual values between destination node and beacon nodes, the right column is localization errors. We make the localization algorithm for the node which distance is 3m in randomly, and the simulation result is as shown in figure 11.

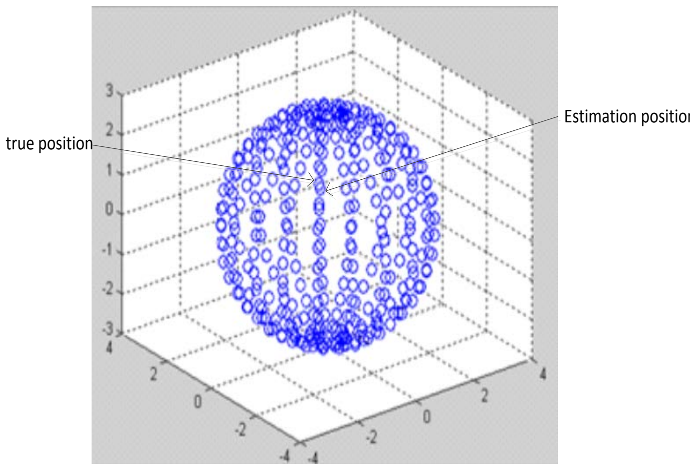

Figure 11. Sphere coverage of destination node(beacon nodes are 50%)

In figure 11, estimation localization and the truth localization error is small. While comparing with figure 10, the estimation error interval of localization would not reduce obviously, then the beacon nodes are 50% , which is not the best choice to estimate destination node localization.

D. **Complexity analysis**

As we can see from the figures by comparing, in three-dimensional space when packets transmitted more, the communication overhead is higher and the error is smaller. While when transfer data packets reach a certain number, the estimation error interval of distance would not reduce obviously. Moreover beacon nodes have much functions and high power consumption, with the number of beacon nodes increasing, total costs of network would be higher. Therefore, it needs to select a certain transmit packages and nodes number to get the destination node localization based on the environment parameters. In the experiment, beacon nodes are 40% of total nodes number is help to reduce unnecessary communication overhead and localization estimation.

By making Comprehensive analysis of the above situation, a summary can be got of beacon nodes selection method:

(1) Gently changed of distance estimation error can reduce accuracy of error estimation.

When distance estimation error value is changing very small between beacon node and destination node (errors change gently), estimation of localization errors would reduce based on 3DCSPR, as shown in table 3 and figure 10.

(2) It’s uncertain that more beacon nodes number is help for getting accuracy localization.

In three-dimensional space, the more the beacon nodes are, the more the data computational need, but estimation error interval would not reduce obviously. Therefore, it’s better to select a certain beacon node number to compute destination node localization based on the environment parameters.

Ⅳ. CONCLUSIONS

In this paper, 3DCSPR algorithm is proposed based on perception radius model and centroid algorithm principle, The simulation results show that the algorithm can get node localization in three-dimension effectively, which based on the weighted radius perception and centroid algorithm. Finally the experiment is tested to verify validity. In practical application when adopted 3DCSPR algorithm to handle node localization problem, it needs more data computational and workload, so how to improve work efficiency and reduce operation cost is still the focus of future research work. This work was supported by Research Foundation of Xi’an Science Technology Bureau of China (Grant No. CG201578), and supported by key science and technology program of Shaanxi province of China (Grant No. 2015GY041).

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