Research Article
An Event-Driven Object Localization Method Assisted by Beacon Mobility and Directional Antennas

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An event-driven object localization method based on directional antennas is proposed in this paper. First the event occurrence spot is divided into four sections. Then low altitude UAV (Unmanned Aerial Vehicle) is employed to deploy DAWSN (Wireless Sensor Networks for Disaster Assistance) for urgent observation and communication. By means of a mobile anchor with four directional antennas and a GPS module, obstacle avoidance traverse in DAWSN is realized and the locations during mobility are broadcast. Unknown nodes take these locations as virtual anchors and project them onto a virtual motion path, and then the coordinates of unknown nodes are solved with extended directional localization method. This range-free method does not require plenty of anchor nodes and complicated computation. With small positioning error and large positionable node ratio (PNR), it allows the virtual anchor to move along any curve path and can be utilized under the event-driven scenario to provide self-localization for DAWSN.

1. Introduction

When a disaster happens, urgent help from rescue and relief team is desperately needed. For this purpose, the precise localization systems must be available first. Besides, to make correct decisions and reduce secondary disasters, the spatial-temporal situation of disaster field must be known well during relief by means of continuous observation tools [1, 2]. Therefore, in catastrophic event locale there are multiple requirements: first, to locate the victims so as to rescue and treat them timely; second, to locate the observed events to capture the exact positions of the events; third, to locate the rescue persons and vehicles to dispatch relief resources reasonably.

A DAWSN (Wireless Sensor Networks for Disaster Assistance) is a common and powerful tool for continuous positioning on event field [3, 4]. In such a network, a proportion of anchor nodes are required. Theoretically, the more the anchor nodes are, the more accurate the localization results will be, but the deployment cost rises sharply with the increase of anchor number [5]. Meanwhile, upon the localization process completion, the anchors will have no further use except for data transmission like ordinary nodes, so it is wasteful to lay out more anchors than necessary. In such a case, a mobile anchor which moves in DAWSN and broadcasts its own coordinates periodically can best serve the above two purposes, and those broadcasted coordinates can be treated as virtual anchors [6, 7].

In such a target positioning method based on virtual anchor, we must provide capability of obstacle avoidance for the mobile anchor and ensure the simplicity of the localization algorithm, which will determine the success or failure of this method. Compared with general WSNs (Wireless Sensor Networks), the LOS (Line of Sight) between nodes of DAWSN is frequently interrupted due to the huge rocks (comparing to the volume of the virtual anchor) in the disaster field, which results in the variation of node number in the range of communication, channel fading, and
This variation further depresses the result of localization and even leads to failure [8, 9]. In addition, the roads are often damaged by disasters, and the locale situations also change from time to time. All these characteristics make the static path planning impossible, which in turn justifies the mobile anchor choosing motion paths accordingly. Although there have already been some methods based on virtual anchors, none of them can provide obstacle avoidance capability as DAWSN does.

This paper concentrates on the self-localization problem of DAWSN nodes and proposes a positioning method based on four directional antennas. This proposed method can identify the coordinates of randomly planted DAWSN nodes handily and quickly and provide localization and tracking services for other objects in the disaster filed. Unlike the traditional method based on directional antennas, which can only follow chessboard motion path [10], the proposed algorithm can abide by an arbitrary curve motion path.

It is noteworthy that the motion path of mobile anchor is a critical factor to ensure the successful self-localization. In general, the path planning methods can be divided into two types [11–13], namely, static planning and dynamic planning. Different trajectories [14], such as Perimeter, Sinusoid, Hexagon, LMAT, and Spiral, have different performances in terms of localization precision and required time, but this study will not focus on the path planning and any planning method can be employed in this research. However, static planning methods are not recommended, because they often assume a uniform node distribution, which is no longer true in disaster regions [15].

The rest of this paper is structured as follows. Section 2 studies the characteristics of event-driven scenario and sets up the DAWSN model. Then, in Section 3, we introduce the traditional localization method based on directional antenna proposed by [10] and extend it to the motion path of arbitrary straight lines. In Section 4, the path is further extended to arbitrary curves to resolve the obstacle avoidance problem. The performances of this method are evaluated and analyzed in Section 5. Finally, the conclusion of the whole paper is presented in Section 6.
temporary treatment region, and temporary rescue paths between them.

Although some nodes for disaster observations may have already existed in the event occurrence region before the accident, most of them are quite likely to be damaged during the disaster. Furthermore, even if some nodes (denoted as Nodeₘ) survive, they are very likely to be deviated from original positions due to the accident. Thereupon, it cannot be taken for granted that their current locations must be the locations they are supposed to be, since the current coordinates of Nodeₘ are unknown.

To deploy the DAWSN, a helicopter is sent out to randomly plant WSN nodes (named as Nodeₛ). At the same time, an emergency communication command vehicle (ECCV) is driven to the temporary treatment region to act as the temporary scheduling command center and communication platform. Nodeₛ, ECCV, and Nodeₘ form the DAWSN (see Figure 3). Except for ECCV, all the coordinates of DAWSN nodes are not known. The positioning of the victim, rescue personnel, and materials is dependent on DAWSN, which in turn depends on the coordinates of DAWSN nodes. In other words, the coordinates of the DAWSN nodes are what needs to be set first. A method is here proposed to solve the self-localization problem, in which DAWSN nodes are unknown nodes to be localized.

Upon the deployment process completion, a rescue robot (or a low altitude UAV) is employed as the mobile anchor moving in networks, during which it broadcasts its own coordinates and produces a series of virtual anchors [17]. Here we assume the following: (1) the energy of the mobile anchor is unlimited; (2) the mobile anchor is equipped with a GPS module and can perceive its position in time; (3) the coverage of an unknown node is a circle, whose center is the DAWSN node itself, and the radius is the antenna transmitting range.

Figure 3: DAWSN model.

3. Extended Localization Method Based on Directional Antennas

3.1. Traditional Localization Method Based on Directional Antennas. An object localization method based on mobile anchor with 4 directional antennas, named D₁, D₂, D₃, and D₄, is addressed in [10], which is range-free and needs no complicated computation. Among those 4 antennas, D₁, D₃ and D₂, D₄ are parallel to the horizontal axis and vertical axis, respectively; see Figure 4.

The mobile anchor follows a chessboard path and makes uniform linear motions, during which its own coordinates are broadcasted, forming some equidistantly distributed virtual
Prior to the detailed exploration of this new method, it is worth investigating some important features of localization method based on directional antennas.

(1) A directional antenna has a longer transmission range than omnidirectional antenna with the same transmitting power. Because the mobile anchor and DAWSN nodes are, respectively, equipped with directional antennas and omnidirectional antennas, the mobile anchor transmits longer than DAWSN nodes do, which means that the mobile anchor can locate outside of coverage circle of DAWSN nodes.

(2) Even though the mobile anchor locates within the coverage circle of DAWSN nodes, if the DAWSN nodes locate outside of coverage of all directional antennas, they cannot get their positions due to the limitation of beam width of directional antenna. This means the line segment between the first and last virtual anchors cannot be seen as a chord of the coverage circle of DAWSN node, so the method of [7] will fail in this case.

(3) If the beam width of directional antennas has different values, the anchor node may get different number of virtual nodes even if it moves along the same motion path.

(4) Among the four directional antennas, the $D_1$, $D_2$ are parallel to the motion direction, and the $D_3$ and $D_4$ are perpendicular to the motion direction. Actually, the traditional method follows the same rule. For extended method here, all that needs to be done is just to fix the 4 antennas on mobile anchor as shown in Figure 4. When the mobile anchor moves along the oblique line, this condition can be met naturally.

The time period during which the virtual anchor goes into the coverage of mobile anchor and goes out again is called one entrance of the DAWSN node. The traditional method requires at least two entrances: one horizontal entrance for horizontal coordinate and one vertical entrance for the vertical coordinate. Similarly, at least two entrances are needed in the extended method for horizontal and vertical coordinate, respectively.

Take the $j$th entrance as an example. Denote the first and last virtual anchors as $B_1^j$ and $B_{N_B}^j$, respectively, where $N_B$ is the number of virtual anchors. Select a point $C_j$ from the motion path (denoting Path $j$), whose coordinates are

\[
\begin{align*}
x_C & = \begin{cases} x_{(B_{n_B}+1)/2}^j, & \text{if } N_B \text{ is odd} \\ \frac{1}{2} (x_{B_{n_B}/2}^j + x_{(B_{n_B}+1)/2}^j), & \text{if } N_B \text{ is even}, \end{cases} \\
y_C & = \begin{cases} y_{(B_{n_B}+1)/2}^j, & \text{if } N_B \text{ is odd} \\ \frac{1}{2} (y_{B_{n_B}/2}^j + y_{(B_{n_B}+1)/2}^j), & \text{if } N_B \text{ is even}, \end{cases}
\end{align*}
\]

3.2. Extended Localization Method Based on Directional Antennas. To overcome the shortcoming of traditional method, that is, following only chessboard motion path, the chessboard path is extended to straight lines with arbitrary slope and this method is called extended localization method based on directional antennas or extended method for simplicity; see Figure 5.
where \((x_{Bi}^i, y_{Bi}^i)\) is the coordinates of the \(i\)'th virtual anchor. Then line \(V\text{Line}_i\) perpendicular to \(Path_j\) can be drawn through point \(C_j\).

Similarly, point \(C_j\) can be chosen from the \(i\)'th motion path \(Path_i\) and line \(V\text{Line}_i\) perpendicular to \(Path_i\) can be drawn. \(V\text{Line}_i\) and \(V\text{Line}_j\) will meet on one intersection which is seen as the estimated position of the unknown node; see Figure 6. For the solution of this intersection, we need know the equations of \(V\text{Line}_i\) and \(V\text{Line}_j\), which in turn can be obtained through the equations of \(Path_i\) and \(Path_j\). Because line \(Path_i\) and \(Path_j\) have the same form, we only need the equation of \(Path_j\). Select any two virtual anchors from the \(j\)'th entrance, for example, the first and the last ones, and the following formula can be obtained:

\[
y = \frac{y_{Bi}^j - y_{B1}^j}{x_{Bi}^j - x_{B1}^j} \cdot (x - x_{B1}^j) + y_{B1}^j, \tag{3}
\]

where \((x_{Bi}^i, y_{Bi}^i)\) and \((x_{Bi}^{1 \rightarrow j}, y_{Bi}^{1 \rightarrow j})\) are the coordinates of \(B_i^j\) and \(B_{N_a}^j\), respectively; \(y_{B1}^{1 \rightarrow j} \neq y_{B1}^j\) and \(x_{B1}^{1 \rightarrow j} \neq x_{B1}^j\) (if \(y_{B1}^{1 \rightarrow j} = y_{B1}^j\) or \(x_{B1}^{1 \rightarrow j} = x_{B1}^j\), then just use the traditional method), similarly hereinafter.

Let \(k_j = (y_{B1}^j - y_{B1}^{1 \rightarrow j})/(x_{B1}^j - x_{B1}^{1 \rightarrow j})\); then the equation of \(V\text{Line}_j\) can be archived according to the perpendicular relation between \(Path_j\) and \(V\text{Line}_j\):

\[
y = -\frac{1}{k_j} \cdot x + \frac{1}{k_j} x_C^j + y_C^j, \tag{4}
\]

where \((x_C^j, y_C^j)\) are the coordinates of point \(C_j\).

And then, the intersection point of \(V\text{Line}_i\) and \(V\text{Line}_j\) (the estimated position of unknown node) can be obtained as

\[
x = \frac{k_j k_i}{k_i - k_j} (X_C^j - X_C^i),
\]

\[
y = \frac{k_j}{k_i - k_j} (X_C^j - X_C^i) + X_C^i,
\]

where \(X_C^i = (1/k_j)x_C^i + y_C^i, X_C^j = (1/k_i)x_C^j + y_C^j\).

4. Localization Method Based on Directional Antennas along Curve Motion Path

4.1. Coordinates Determination Based on Virtual Projection.

Due to the corrupted roads and numerous obstacles in the disaster field, a mobile anchor is not likely to move always along straight lines but a curve motion path as in Figure 7(a). Apparently, neither the traditional method nor the extended method can deal with such type of localization problem, so the extended method is further extended to make it settle localization problem along arbitrary curve paths.

Before the detailed discussion, some attention should go to the following characteristics.

1. The mobile anchor may locate outside of, on, or within the coverage circle of the DAWSN node.

2. Among the four directional antennas, the \(D_1\) and \(D_3\) are parallel to the instant tangent of curve path, and the \(D_2\) and \(D_4\) are perpendicular to the instant tangent of curve path.

3. The beam covering the DAWSN node may come from any one of four directional antennas; for example, first and second virtual anchors of Figure 7(a) come from \(D_2\), while the third and fourth come from \(D_3\).

Assume there are six virtual anchors distributed as shown in Figure 7(b), and take the straight line segment \(B_1^iB_{N_a}^i\) as a virtual motion path (denoted by \(V\text{Path}\)) of the mobile anchor; then a series of auxiliary lines parallel to the \(x\)-axis (denoted by \(L_{pi}^j\)) can be drawn through virtual anchors. Every auxiliary line will meet with the \(V\text{Path}\) on an intersection point, which is called the virtual projection anchor, denoted as \(B_{pi}^i\) \((i = 2, \ldots, N_{B1} - 1)\). It is clear that the \(B_{pi}^1\) and \(B_{pi}^N\) can be seen as overlapping with \(B_1^i\) and \(B_{N_a}^i\), respectively. For convenience of description, the above process is called virtual projection of virtual anchors.

As can be seen from Figure 7(b), so long as the coordinates of virtual projection anchor \(B_{pi}^i\) can be determined, the localization problem of unknown nodes can be solved through the extended method. So the question now is how to solve the \(B_{pi}^i\) \((i = 2, \ldots, N_{B1} - 1)\).

Because the coordinates of \(B_1^i\) and \(B_{N_a}^i\), that is, \((x_{B1}^i, y_{B1}^i)\), \((x_{B_{N_a}i}^i, y_{B_{N_a}i}^i)\), have already been known, the \(B_{pi}^iB_{N_a}^i\) can be
described by formula (3). As for \( L_{pi}^j \), it can be easily known that \( y_{pi}^j = y_{B_i}^j \); thus its equation is

\[
y = y_{B_i}^j,
\]

(6)

Then the coordinates of \( B_{pi} \) can be obtained in accordance with formulas (6) and (3):

\[
\begin{align*}
x_{pi}^j &= \frac{1}{k_j} \cdot (y_{B_i}^j - y_{B_1}^j) + x_{B_1}^j, \\
y_{pi}^j &= y_{B_i}^j,
\end{align*}
\]

(7)

It must be noted that the above virtual projection is implemented with auxiliary lines parallel to the \( x \)-axis and adapted to the condition \( |k_j| \geq 1 \). To avoid the overcrowding of the virtual projection anchors this projection operation should be better implemented with auxiliary lines parallel to the \( y \)-axis when \( |k_j| < 1 \). Under this case the coordinates of virtual projection \( B_{pi} \) are computed as

\[
\begin{align*}
x_{pi}^j &= x_{B_i}^j, \\
y_{pi}^j &= k_j \cdot (x_{B_i}^j - x_{B_1}^j) + y_{B_1}^j.
\end{align*}
\]

(8)
4.2. A Full Description of the Localization Method Based on Directional Antennas. Here are the full steps of object localization method based on directional antennas under event-driven scenario; see Figure 8.

Step 1. The mobile anchor makes obstacle avoidance movement in the disaster field and forms virtual motion paths, during which it periodically broadcasts its own coordinates and forms virtual anchors.

Step 2. After receiving the first virtual anchor $B_i^j$, the unknown node keeps storing the virtual anchor $B_i^j$ of this entrance.

Step 3. Compute the slope of line $B_iB_j$ according to $k_j = (y_{B_j}^i - y_{B_i}^j)/(x_{B_j}^i - x_{B_i}^j)$; then calculate the coordinates of virtual projection anchor $B_{pi}$, that is, $(x_{B_{pi}}^i, y_{B_{pi}}^i)$, with formula (7) when $|k_j| \geq 1$ or formula (8) when $|k_j| < 1$.

Step 4. Choose any two entrances, say the $i$th and $j$th ones; then, respectively, substitute the coordinates of their virtual projection anchors into (2) to obtain responding foot points, that is, $C_i(x_{C_i}^i, y_{C_i}^i)$ and $C_j(x_{C_j}^j, y_{C_j}^j)$.

Step 5. Substitute $k_i, k_j, x_{C_i}^i, y_{C_i}^i$, and $x_{C_j}^j$ into formula (5) and get the coordinates of the unknown node.

5. Performance Simulations

In this section the performance of the proposed localization method is evaluated and compared with the method addressed in [10] according to localization error and positionable node ratio (PNR) under different influential factors, such as motion speed of mobile anchor, beam width of directional antenna, transmission range of directional antenna, and number of unknown nodes in network. The localization error refers to the Euclidean distance between the estimated position and the real position, and the PNR means the proportions of the number of unknown nodes below the given threshold to the total number of unknown nodes. As is expected, a larger localization error usually means a poorer positioning precision.

5.1. Simulation Settings. The mobile anchor broadcasts its coordinates once a second, which means the production frequency of virtual anchors is also once a second. Unless otherwise defined, the simulation network size is 100 m x 100 m distributing 20 unknown nodes randomly. To ensure the reliability of the simulation results, 50 Monte Carlo runs are performed for each set of simulation conditions, and the average values are obtained as final results.

The following works need to be done to generate the motion paths: First, divide the whole networks into some equal grids; then let mobile anchor move from bottom to up or up to bottom, during which vertical motion paths will be produced. The motion path between two neighbor grids is no longer a straight line, but a random curve dependent on obstacles. With this similar procedure, the horizontal curves can also be produced. To simulate the influences of obstacles on localization performances, three rectangular obstacles of 10 m x 10 m are placed in the network, whose coordinates of the bottom-left point are (20, 20), (50, 40), and (70, 70), respectively, as shown in Figure 9.

It is noteworthy that the number of the divided grids of the whole network is closely related to the transmission distance of the mobile anchor. The larger the transmission range is, the longer the coverage radius is, and the smaller the number of grids is. For example, the transmission range of part (a) and part (b) of Figure 9 is 20 m and 40 m, respectively, which makes it obvious that the number of motion paths of part (a) is much less than that of part (b). Besides, every step of the mobile anchor is random and it can avoid obstacles. Following this method, the motion paths in each run of the 50 Monte Carlo simulations are different, not constant.

Let $\theta$ be the beam width of the directional antenna. Because the 4 directional antennas have equal beam widths, $\theta \in (0, \pi/2]$. When $\theta = \pi/2$, 4 directional antennas are equivalent to an omnidirectional antenna.

5.2. The Impact of Beam Width on Localization Error. The beam width of directional antennas determines its transmission range and coverage area, which further determines coverage capability on unknown nodes. A wider beam will result in more virtual anchors, and the more virtual anchors, the more precise positioning.

The speed of the mobile anchor is 1 m/s, and the triangle, diamond, square, and circle in red in the above
5.3. The Impact of Motion Speed and Transmission Range on Localization Error. The motion speed of the mobile anchor determines the generation frequency and spacing of virtual anchors. The slower the mobile anchor moves, the more the virtual anchors are produced and the smaller the spacing is, and then the higher positioning precision can be obtained. As can be seen in Figure 11, the motion speed has a remarkable impact on the localization error: the higher the motion speed is, the lower the positioning precision will be.

The transmission range of virtual anchor reflects its maximum transmission distance and has great influences on both localization error and PNR; see Figure 11. As it can be seen, our method greatly outperforms the traditional one. When the motion speed increases, the number of virtual anchors decreases gradually, and the localization precision reduces.

As observed from Figures 10 and 11, the transmission range of the mobile anchor has great effects on the localization precision. A greater transmission range will result in a smaller localization precision of the unknown nodes, especially for those that are far from the mobile anchor but within the coverage of the directional antennas. The traversal time to the entire network, however, will decrease with the increase of the transmission range. Therefore, except for extending the transmission range to accelerate the self-localization process, we can also raise the speed of the mobile anchor or divide the whole disaster area into some subareas and localize these subareas separately by different mobile anchors. Having taken the special needs of the disaster scenarios, our method, with a transmission of 40 m, can even get almost identical precision as the traditional method with a transmission of 10 m; see Figure 10. From the foregoing, we can see that our method can complete self-localization process more quickly under the same precision or get more accurate localization results under the same time.

5.4. The Impact of Unknown Node Number on Localization Error. The number of unknown nodes, which has been proved a great factor of localization error, implies the distance between the virtual anchor and unknown nodes. To further verify this deduction, a series of simulation experiments with motion speed of 1 m/s are conducted. Starting from 20 unknown nodes, we add 20 unknown nodes in each experiment until the number reaches 200; see Figure 12.

As can be seen from Figure 12, all localization errors are about 10% of the transmission range, and this precision can
Figure 11: The impact of motion speed and transmission range on the localization error (a) with omnidirectional antenna \((\theta = \pi/2)\); (b) with directional antenna \((\theta = \pi/3)\).

Figure 12: The impact of unknown node number on the localization error \((\theta = \pi/3)\).

fully meet the needs of disaster rescue. Besides, the variation of the unknown node number has little influence on the localization error, so the proposed algorithm is robust to the change of the node number. The reason is that when the directional antenna can basically cover the unknown nodes within a grid, continuing to increase nodes fails to change the coverage area. Therefore, we can draw a conclusion that once a steady localization is obtained, the positioning precision cannot be improved only through the increase of transmission range.

5.5. The Change Characteristics of PNR. The PNR refers to the proportion of unknown node whose localization error is lower than a threshold to the total number of unknown nodes. The bigger this ratio is, the more the nodes can be localized in DAWSN. Actually, this metric can be represented by the cumulative distribution of localization error (CDLE); see Figure 13.

As shown in Figure 13(a), if the error threshold requirement is 2 m, the PNR is lower than 30% when motion speed is 4 m/s, but this value is about 65% when the speed of the motion is 1 m/s. If full localization (the PNR is 100%) is to be achieved, only less 5 m error threshold is required for the speed of 1 m/s, while this error threshold is larger than 10 m for the speed of 4 m/s. Thereupon, the PNR decreases as motion speed increases.

Figure 13(b) shows that the distribution curves with larger transmission range (by decreasing the beam width while preserving the same power) are steeper than those with smaller transmission range, which declares that the PNR rises rapidly. If a full localization is needed, the error threshold reaches up to 5 m when the transmission is 10 m, but this threshold is larger than 10 m for transmission range of 40 m. As a result, the positioning precision of an unknown node can be improved through increasing the beam width of the directional antenna while preserving the same transmission power, but the distant unknown nodes cannot be covered, and this leads to a smaller PNR. Therefore, in terms of beam width, the case is not the wider the better.

Now this conclusion will be explained in theory. Without loss of generality, assume that the path fading exponent is 2. The transmission power must satisfy the following condition to receive and decode a signal correctly [18]:

\[
P_t \geq \frac{8P_0\pi^2}{\lambda^2} \cdot d^2 \cdot (1 - \cos(\theta/2)),
\]

where \(P_t\) is the transmission power, \(\lambda\) is the signal wavelength, \(d\) is the distance between the virtual anchor and unknown node, and \(P_0\) is the power threshold for correct receiving and decoding. When the left part of (9) is equal to its right part, the following formula can be drawn:

\[
d = \sqrt{\frac{\xi}{1 - \cos(\theta/2)}},
\]

where \(\xi = \lambda^2 P_t / 8P_0\pi^2\). If \(P_t\) is constant, \(\xi\) will also be constant. Given that \(\theta \in (0, \pi/2]\), according to formula (10) it can be concluded that \(d\) is a decreasing function of \(\theta\) when \(P_t\) is constant.
Allowable localization error (m)

Positionable node ratio

Virtual anchor distance: 1 m
Virtual anchor distance: 2 m
Virtual anchor distance: 3 m
Virtual anchor distance: 4 m

(a)

Transmission range: 10 m
Transmission range: 20 m
Transmission range: 30 m
Transmission range: 40 m

(b)

Figure 13: The change rules of PNR with (a) different speed; (b) different transmission range.

Virtual anchor error (m)

Localization error (m)

Motion speed: 1 m/s
Motion speed: 2 m/s
Motion speed: 3 m/s
Motion speed: 4 m/s

(a)

Transmission range: 10 m
Transmission range: 20 m
Transmission range: 30 m
Transmission range: 40 m

(b)

Figure 14: The impact of virtual anchor error on the localization error considering (a) motion speed under omnidirectional antenna \((\theta = \pi/2)\); (b) transmission range under omnidirectional antenna \((\theta = \pi/2)\); (c) motion speed under directional antenna \((\theta = \pi/3)\); (d) transmission range under directional antenna \((\theta = \pi/3)\).
Therefore, on the one hand, formula (10) indicates that a wider beam brings about a shorter transmission range, which in turn results in a higher positioning precision. But Figure 13 also shows that the PNR is inversely proportional to beam width, so as for the beam width, the wider does not necessarily mean the better. On the other hand, a narrower beam will usually lead to a lower localization precision, so in this case the narrower does not necessarily mean the better, either. In practice, we should select an appropriate beam width to strike a tradeoff between the localization precision and the PNR.

5.6. The Impact of Virtual Anchor Error on Localization Error.
All previous simulations assume that coordinates of virtual anchor are completely accurate. Actually, those coordinates obtained from such tools as GPS have more or less errors, so the coordinates of virtual anchors are not fully precise, either.

To simulate the impact of virtual anchor error, we add a stochastic disturbance between 1 m and 5 m to the real x and y coordinate of virtual anchors, respectively. Figure 14 shows the impact of virtual anchor error on localization error of which parts (a) and (c) hold a transmission range of 10 m, and parts (b) and (d) keep a speed of 1 m/s.

It can be observed from Figure 14 that (1) the localization error increases with the error of virtual anchors at any motion speed, but the increase rate is very small; (2) compared to the scenario without virtual anchor error (whose virtual anchor error is zero), the scenario with virtual anchor error only receives little impact, which illustrates that the proposed method is more robust than the traditional method in terms of the localization precision under conditions with virtual anchor errors.

6. Conclusions
An event-driven object localization method based on directional antennas is proposed in this paper. It projects the virtual anchors onto a virtual motion path and then employs the extended localization method to obtain the coordinates of the unknown node. Simulation experiments demonstrate that a greater motion speed of mobile anchor will lead to fewer virtual anchors and bigger localization error; when transmission power is constant, a wider beam will get a higher positioning precision, but the increased beam will reduce the transmission range, causing the decline of PNR. Therefore, a tradeoff must be made between positioning precision and PNR in practice; the number of unknown nodes reflects the distance between unknown node and mobile anchor, yet it cannot influence the positioning precision remarkably; the error of virtual anchor has negative effect on positioning precision, but the directional antenna possesses a more powerful capability against the error of virtual anchor. The localization precision of the proposed method can fully satisfy the needs of catastrophic event locale and can be a supportive technique for continuous event observation and real-time object positioning. As parts of our future works, we will extend our method to three-dimensional scenarios and explore its behaviors in practical networks.

Conflict of Interests
The authors declare that there is no conflict of interests with the publication of this paper.

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