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DELA: A displacement estimated localization algorithm in the opportunistic communication based wireless sensor network

***Abstract**. Localization is one of the key problems in our system to collect the data of movement rule of sediment transport by wind for the desertification research. We designed a full covered deployment scheme of base station for providing the basic service of data forwarding and localization first. Then we proposed a displacement estimated localization algorithm (DELA), which can help node to measure its displacement during each movement and then calculate the position. The experiment proved that the DELA is better than the trilateration in this scene.*

Streszczenie:** Przy badaniach pustynnienia i zbieraniu danych w warunkach ruchu osadów porywanych przez wiatr, jednym z kluczowych problemów jest lokalizacja. W opracowaniu, po pierwsze, dla zapewnienia podstawowej obsługi przekazywania danych o przemieszczaniu i lokalizacji, zaprojektowano układ stacji bazowych, całkowicie pokrywający rozmieszczenie węzłów pomiarowych. Następnie, zaproponowano algorytm szacunkowej lokalizacji przemieszczania (DELA), który pomaga węzłowi zmierzyć przemieszczenia podczas jego ruchu i następnie obliczyć pozycję. Badania eksperymentalne wykazują, że DELA daje lepsze wyniki niż trilateracja.* ***DELA: Algorytm szacunkowej lokalizacji przemieszczenia z oportunistyczną komunikacją, oparty o bezprzewodową sieć czujnikową

Keywords: displacement estimated, localization algorithm, opportunistic communication, WSN.
Słowa kluczowe: Szacunkowe przemieszczanie, Algorytm lokalizacji, Komunikacja oportunistyczna. WSN

Introduction

The character of WSN (wireless sensor networks) makes it wide foreground in the environment monitoring scopes. In our system, we need to deploy a WSN to collect the data of sediment transport under the desert condition and analyze the regular pattern of it for the desertification research. However, to dispose a large-scale static WSN in the desert is a high cost way, and due to the complex environment here, the transmission path of the WSN would be destroyed frequently(sensors' damage, energy consumed, buried by sand, signal interference from strong wind etc.). In this situation, the whole network will be divided into some individual parts without the communication. Based on the above considerations, we proposed to use the framework of opportunistic network [1] in the WSN for this scene.

In this way, the sensor nodes (equipped temperature, humidity and acceleration sensors) will move randomly like sand driven by the wind instead of settled position and record their movement data under the appropriate condition. While the nodes encounter any base station, which is deployed in the desert at first with solar cell and GPS, within a forwarding permitted speed, sensors will transmit the carried data to the base. Here, one of the primary works is to locate the sensors scattered in the desert, because the lack of location information can result in an incorrect interpretation of data.

Large numbers of researches has been focused on the WSN localization. There are three basic localization techniques that are used as a base to a more advanced techniques [2, 3]: trilateration, triangulation and maximum likelihood multilateration. Several localization or ranging techniques that are used to localize the position of sensor nodes have been proposed in the literature, including Time of Arrival (ToA), Received Signal Strength Indication (RSSI), Radio Hop Count, and Angle of Arrival (AoA) [2, 4, 5, 6, 7]. Based on these techniques above, the localization algorithms can be categorized into two main types: centralized and distributed algorithms.

Centralized algorithms require plenty of computational power in order to run their operations on central machines. Such algorithms include Semidefinite Programming (SDP) [8] and Multidimensional Scaling (MDS) [9].

Distributed algorithms, which are considered more efficient than centralized ones, run their operations using the computational power of each node. This type requires massive inter-node communication and parallelism to be able to perform similar to centralized systems. Diffusion [10], gradient [11], and Approximate Point In Triangle (APIT) [12] algorithms uses anchor nodes to find the position of unknown ones. The relaxation-based distributed algorithm [13] uses an optimization technique that will change nodes position in every iteration, until all nodes have zero forces acting on them. In the coordinate system stitching algorithm [14], there are three main steps. The first step is to split the network into small overlapping sub-regions which are usually a single node and its one-hop neighbors. In the second step a local map of each sub-region is computed. Finally, it places all the sub-regions into a single global coordinate system using a registration procedure. Another algorithm [15] combines two existing techniques to get a better performance, such as using both multidimensional scaling and proximity based map. The literature [16] proposed an interferometric ranging based localization algorithm, which requires a considerably larger set of measurements. The basic idea of the error propagation aware algorithm [17] is that nodes use the available information to transform into anchors in an iterative method, taking in consideration the minimization of position error and error propagation.

Considering several factors affecting the localization algorithm such as the amount of resources available in the network (e.g. memory, processing power, and battery life), the node density, the structure of the network, and the environment where sensor nodes are going to be deployed, the high precise localization algorithm is not necessary. Thus in this paper, we proposed a new distributed localization algorithm based on the displacement estimated of senor nodes called DELA, which is coarse but more suitable for our scenario.

The deployment of the base stations

How to deploy the base stations in the monitoring area is very important but difficult, since they will receive the data from sensors and provide localization information for sensors and it's too hard to estimate how the sensor nodes will move driven by the wind. One way is to use the cellular shape that is very similar with the deployment of base station in mobile communication. Each base station is located at the vertex of the hexagon, and all of them make up a beehive showed as fig.1. If the transmission radius is R, the side length of the hexagon is L, then $R = L$. The advantages of this method are: 1) the hexagon has the largest cover area compared with triangle and square with the same side length and smaller than the dodecagon, but the dodecagon is too complex for deploying and computing; 2) it provides almost whole cover signal in the monitoring area, which will be used for sensor nodes' localization.

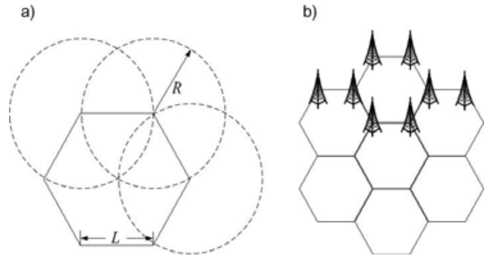

Fig.1. a) Each hexagon like deployment of the base station b) Cellular deployment made up by hexagons

These base stations then can be seemed as anchor with precise position and broadcast their location information periodically. Then the sensor nodes can calculate their positions by this related information received from the base stations.

DELA Algorithm

As taking the acceleration sensor, the node can estimate movement state of itself. Showed as fig.2, there are two different positions for sensor nodes' staying. One is shadow area, which is covered by three base stations, such as O_1B, covered by base station A, B and D. The other is blank area, which is only covered by two base stations, such as O_1AB, covered by base station A and B. Apparently, a node can calculate its location through trilateration if it is at the shadow depending on the information from three adjacent base stations, but cannot do it if at the blank, due to lack enough information, such as at position *L1*、*L2* or *L3*. However, according to the information from two base stations, the node at the blank will acquire two positions with the same value distributed symmetrically at both side of the axes between the two base stations, namely *L'1*、*L'2* and *L'3* in fig.2, which are called image position.

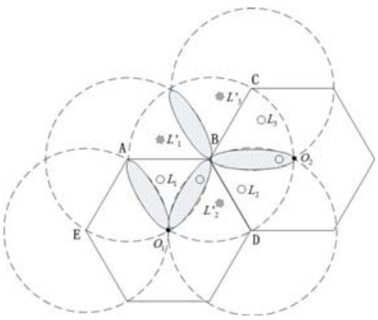

Fig.2. Types of node's possible position and image position

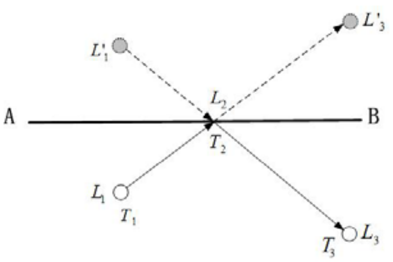

Fig.3. The change of actual and image position of the node

We analyze the two base stations covered status further. Showed as fig.3, the node at position L_1 at timeT_1 cannot confirm its actual location is L_1 or L'_1. When it moves to $L_3$from L_1 and L_2, it will not differentiate its real route. Therefore, the key of the localization algorithm is to identify which one is the true position.

Then we found while the node moves directly from one blank area to another, it must pass at least one shadow area, at which it can acquire its position. In fig.2, the node passes shadow O_1B, when it moves from L_1 to L_2. When it goes on moving from L_2 to L_3, it crosses shadow O_2B.

Based on the analysis above, we proposed the displacement estimated localization algorithm (DELA), which can locate the node by two anchors and the node's displacement.

Now, we suppose the wind speed is only two values for zero or a changeless variable during once movement of the node. When a node start moving from stationary status, it is accelerated by the wind until it becomes uniform motion. When the wind stops, the node will stop moving in a little time because of the strong friction between node and sand. Thus the displacement from deceleration to stop of the node can be ignored. The node's speed can be calculated by parameters of node's weight and measurement, wind speed, friction coefficient and so on [18]. In addition, since the node's acceleration can also be achieved, it's easy to compute the node's displacement of once movement.

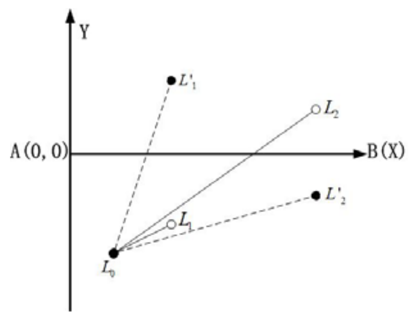

Fig.4. The actual and image position at different time

Showed as fig.4, set the connecting line between base station A and B as X axis, A as origin A(0,0), the coordinate when the node crosses the shadow area at time T_n as $L_0(x_0,y_0)$, the actual and the image coordinate acquired by RSSI technique when the node passes the blank area at time T_{n+i} as $L_i(x,y)$, $L'_i(x',y')$, i = 1,2,3…. Then the displacement of the node during a movement at time T_{n+i} is:

(1) $$S_i = \int_{T_n}^{T_{n+i}} v dt$$

where: S_i – displacement, v – speed, T_n , T_{n+i} – time.

The distance between the position L_0 at shadow and the positions L_i, L'_i at blank is:

(2) $$\begin{cases} L_0L_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2} \\ L_0L'_i = \sqrt{(x'_i - x_0)^2 + (y'_i - y_0)^2} \end{cases}$$

where: x – the x axis, y – the y axis.

Therefore, the actual position of the node lies at blank area at time T_{n+i} can be confirmed by the formula (3):

(3) $$Location_{n+i} \sim Min(|S_i - L_0L_i|, |S_i - L_0L'_i|)$$

Although the node can calculate its position with trilateration here, the DELA is more accurate, which will be validated by the experiment.

Experiment and the analysis

We used some sensor nodes to build a small WSN at the campus environment. The nodes integrate JENIC5139 chip embedded TinyOS. The wireless communication module's working frequency is 2.4GHz with the furthest transmission around of 50m and the Maximum transmission speed around of 20Kbps.

Since nodes need measuring RSS to calculate the displacement in the DELA, we tested the RSSI of all sensors in different environment to confirm the related parameters. The fig.5 shows the RSSI's variety of measured nodes in the different environment.

a) b)

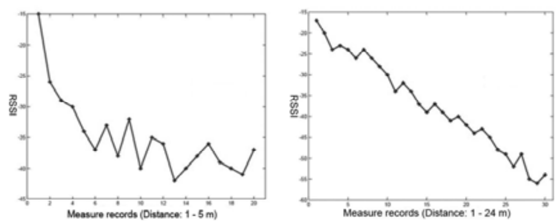

Fig.5. a) The RSSI varying from 1m to 5m indoors
b) The RSSI varying from 1m to 24m outdoors

Apparently the RSSI in room condition is disorder due to the multipath interference coming from manifold objects and bodies showed as fig.5 a). Then we changed the experiment place to the outdoor side and found that the parameter to calculate the RSSI at close quarters between two sensors is not suitable again after increasing the distance in the outdoor experiment. For instance, according to the formula of computing RSSI, the value of A is the one of RSSI when the distance between the source node and the receiving node is 1m, which was -17 in our experiment. Then if the other parameter N's value was 10 and the distance was less than 5m, we could obtain more accurate numerical, but if the distance was more than 5m, the result would be large deviation. In past research, scienstists suggested that the N's general value section was [2.3, 4.5]. However, this section could not be fit for our experiment. We believe this is because different device are also very different in hardware design. We confirmed A was -17 and N was 5 in the formula of computing RSSI at last via many groups of experiment, which are more appropriate for us and the RSSI then exhibited a better linear attenuation in fig.5 b).

In the localization experiment, we tested 10 times with trilateration and DELA under the totally same condition. The error contrast showed in fig.6. The fluctuation of green line is smaller than the blued one, which means the deviation's distribution of DELA is more average. Although the DELA is very similar with trilateration, the reason made the different result maybe is that when the node at blank starts to compute the position by the trilateration, one coordinate value cached in the node is obtained when this node is passing the shadow area, and the value is also figured out by the trilateration based on the RSSI from this node to three base stations. But in the DELA, this value is just used to calculate the displacement to distinguish the real and the image position. Then another two reference value calculated by RSSI from two base stations is enough to locate the node, which means the computing process in DELA only depends on two imprecise location values but the trilateration needs three. We still cannot sure this conjecture yet and will analyze this case in the next work.

Conclusion

In this paper, we proposed a localization algorithm used for the sand movement monitoring at the desert. Because of limited energy, there's no GPS module equipped in the sensor node. The distributing of sensor nodes is also sparse. In this situation, the traditional localization algorithm would work hardly. Therefore, we designed a full covered base stations mode to provide enough opportunity for data forwarding and location of sensor nodes. The node can measure RSSI from the base stations to itself and its displacement during each movement driven by the wind and calculate the position then, which we called displacement estimated localization algorithm (DELA). At last we tested the algorithm and compared the result with the trilateration. The result presents that the DELA is more beneficial than the trilateration in this scene.

We will try to improve the precision of the DELA in the future work, or excogitate some other way to locate the sensor nodes, which is more appropriate for this application.

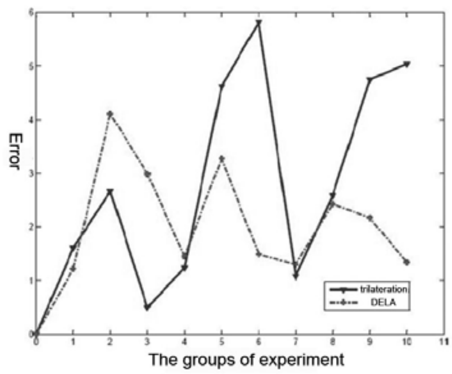

Fig.6. The error contrast of trilateration and DELA

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