The Research on an Algorithm of Three-Dimensional Topology Control of Wireless Sensor Network

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Abstract

Nowadays, the research about three-dimensional topology control has focused on ensuring the connectivity of the networks, and has seldom considered the balance between neighbor node degree and energy consumption minimum path. In order to solve this problem, this paper proposes an adjustable topology control algorithm in three-dimensional wireless sensor networks, and this algorithm can dynamically adjust the network topology control structure through changing the adjustment factor r(0<r<1), and make the network has good neighbor node degree while retaining some energy consumption minimum paths. The simulation experiment data shows that the algorithm can make the network topology with good adjustability and sparsity, and also proves that the algorithm has good effect on prolonging the network's lifetime and saving the node power.

Keywords: *wireless sensor network, three-dimensional, topology control algorithm*

1. Introduction

With the wide application of wireless sensor networks, more and more research in this area [1][2]. Topology control algorithm for wireless sensor networks, by means of partial adjustment the transmission range of a node, select the appropriate neighbor node communicating, maintaining a structure that can improve network performance 3][4] for CBTC is the 3D-CBTC (Cone Based Topology Control) in three-dimensional space expansion, the algorithm ensures that each node within any cone of angle α u have at least one neighbor node, when $\alpha \leqslant 2\pi/3$ ensures connectivity, $\alpha \leqslant 2\pi/(3k)$, to ensure that the k-connected.[5] the first two-dimensional RNG (Relative Neighborhood Graph) and GG (Grbrlel Graph) expanded to three-dimensional space, proposes a new three dimensional topology based on Yao. These studies focus primarily on ensuring network connectivity, and no good taking into account the neighbor node and minimum energy consumption path for tradeoffs between the two. In addition in the actual deployment of wireless sensor networks in three dimensional network of neighbor nodes is often better than a two-dimensional network of large, nodes of high degree would lead to redundancy of information and interaction between nodes, influence of neighbor nodes that are too low you will choose the path to lower energy consumption, increase the energy consumption of the nodes [6]. Therefore, weigh between neighbor nodes and minimum energy consumption path for issues to be regulated according to the actual demand.

This article can be applied to three dimensional topology control algorithm for wireless sensor networks, by adjusting the factor r (0<r<1) dynamic network topology, while retaining some of the minimum energy consumption path with good neighbor nodes. Simulation and experimental data show that this algorithm construction of network topology has a good adjustability and sparse, and algorithm for optimized network lifecycle and node power with a more pronounced effect.

2. Network topology control algorithms

Adjacent diagram with good geometric characteristics, especially the extension factor 1 GG3D has the lowest energy consumption, while RNG3D has a lower-neighbor node [6]. This article first of all structural elements of the combination GG3D and RNG3D, r-Neighborhood Graph[8] extension applied to three dimensional space, and define an adjustable adjacent graph..

2.1 Defined network model

In three dimensional space R3, the collection of all sensor nodes for v, u the whereabouts of v, v the whereabouts for any network node V,uv node, (u,v) for the u and v components; path (u...v) represents the path from node u to v; ||uv|| Represents the Euler distances between nodes u and v, b (u,||uv||) Said to u for the sphere, sphere diameter ||uv|| Ball; spend (u...v) from node u to v consumes energy when communicating from reference [6] node for direct communication with the UV energy consumption when you spend(u...v)=||uv||A, where α≥2.

Define 1：In three dimensional space R3 given for u the whereabouts of any network node v, v the whereabouts of v, corresponding to three dimensional r-Neighborhood (Three-Dimensional r-Neighborhood Graph) is defined as:, where m is not a network node (u,v) halfway between. Sphere b (u,||uv||) And b (v,||uv||) Represent the diameter of a sphere of u and v, the ball is ||uv|| Ball; b (m,Luv) to m-sphere, sphere diameter-luv the ball; the area for the three spheres intersect, as shown in Figure 1. Points in the region to:

$$NR_r^{3D}(u,v)=\left\{x\in R^3 \,\middle|\, \|ux\|<\|uv\|, \|vx\|<\|uv\|, \|mx\|<l_{uv}\right\} \quad (1)$$

Define 2：Node set v of a given three dimensional space R3, three dimensional r-Neighborhood zone is defined as: any network node u the whereabouts of v, v the whereabouts of v If and only if ||uv|| Provides maximum transmission distance is less than the wireless sensor network, posed to the uv region and any node a network node that does not contain any other w. In other words, if, be sure there is no w the whereabouts of vw network node located within the region, namely $w\notin NR_r^{3D}(u,v)=B(u,\|uv\|)\cap B(v,\|uv\|)\cap B(m,l_{uv})$ .Where m is the midpoint of the uv , $l_{uv}=(\|uv\|/2)(1+2r^2)^{1/2}$,and $0\le r\le 1$.

2.2 Nature of the network model

According to the definition of the network model, the network model on the construction here has the following two properties:

Property1：In three dimensional space R3, if there are any network node w located within the region, by definition2 communication between nodes on a network of uv is forwarded through the nodes w without establishing direct communication. Energy spend consumed through the nodes w (u,w,v) must be less than direct transfer of energy spend consumed between uv (u,v) times, ie：

$$spend(uwv)<(1+r^\alpha)spend(uv)=(1+r^\alpha)\|uv\|^\alpha \text{ ,其中 } \alpha\ge 2$$

demonstrate：$NR_r^{3D}(u,v)$ Any point total points u, v and w, w uv Plumb lines, intersection of o, then the path path (u,w,v), energy consumption:

$$spend(uwv)=\|uw\|^\alpha+\|wv\|^\alpha \quad (2)$$

$$\|uw\|^2=\|ow\|^2+(\|um\|-\|om\|)^2=\|ow\|^2+(\|vm\|-\|om\|)^2$$
(3)

According to the theorem of cosine:

$$\cos\angle omw=\frac{\|om\|}{\|wm\|}=-\cos\angle wmv=\frac{\|wm\|^2+\|mv\|^2-\|mv\|^2}{2\|wm\|\|mv\|}$$

$$\|om\|=\frac{\|mv\|^2-\|wm\|^2-\|mv\|^2}{2\|mv\|} \quad (4)$$

$$\|ow\|^2=\|wv\|^2-\|ov\|^2=\|wv\|^2-(\|om\|+\|mv\|)^2$$ Joint (4):

$$\|ow\|^2=\|wv\|^2-\left(\frac{\|mv\|^2-\|wm\|^2+\|mv\|^2}{2\|mv\|}\right)^2 \quad (5)$$

(3), (4), (5)-substitute (2):

$$p(uwv)=\|uw\|^\alpha+\|wv\|^\alpha=(2\|mv\|^2-\|vw\|^2+2\|wm\|^2)^{\frac{\alpha}{2}}+\|vw\|^\alpha$$

According to (1) : $\|wm\|<l=\frac{\|uv\|}{2}\sqrt{1+2r^2}=\|mv\|\sqrt{1+2r^2}$.

So the energy consumed by nodes w spend(u,w,v) is：

$$\begin{aligned} spend(uwv) &= (2\|mv\|^2-\|vw\|^2+2\|wm\|^2)^{\frac{\alpha}{2}}+\|vw\|^\alpha \\ &< \left((4+4r^2)\|mv\|^2-\|vw\|^2\right)^{\frac{\alpha}{2}}+\|vw\|^\alpha \\ &< \left(\frac{1}{4}(4+4r^2)\|uv\|^2-\|uv\|^2\right)^{\frac{\alpha}{2}}+\|uv\|^\alpha \\ &= (r^2\|uv\|^2)^{\frac{\alpha}{2}}+\|uv\|^\alpha \\ &= \|uv\|^\alpha(1+r^\alpha) \end{aligned}$$

Through the above reasoning, we can draw the property 1.

Property2：Any node set v in the three dimensional space R3, inherent affiliation: $RNG^{3D}(V)\subseteq NR_r^{3D}(V)\subseteq GG^{3D}(V)$ ； and $0\le r\le 1$ 。 specially， while r=0， $NR_r^{3D}(u,v)\equiv GG^{3D}$ ； when r=1， $NR_r^{3D}(u,v)\equiv RNG^{3D}$.

Proof ： (1) It is first of all to define ball $B(m,\frac{\|uv\|}{2})$ is $GG^{3D}(V)$ ， we can know that $B(m,\frac{\|uv\|}{2})$ is $NR_r^{3D}(u,v)$ ， s subfield from the definition 1. So if

$uv \in NR_r^{3D}(V)$, $NR_r^{3D}(u,v)$, While other network node does not exist in the region, $B(m, \frac{\|uv\|}{2})$ Inevitably there is no other network nodes, according to $GG^{3D}(V)$'s define, we can get $uv \in GG^{3D}(V)$; on the contrary, while $uv \in GG^{3D}(V)$, $uv \in NR_r^{3D}(V)$ may not be gotten . So we can get $NG_r^{3D}(V) \in GG^{3D}(V)$.

(2)We should define the intersection of $B(m,\|uv\|)$ and $B(m,\|uv\|)$ is $RNG^{3D}(V)$, then we get $B(m, \frac{\|uv\|}{2})$ to be $NR_r^{3D}(u,v)$'s subfield from definition 1. When $uv \in RNG^{3D}(V)$, $RNG^{3D}(u,v)$'s area was not exist other network node, $NR_r^{3D}(V)$ Will not keep other network node, according to $NR_r^{3D}(V)$'s define, we can get $uv \in NG_r^{3D}(V)$; on the contrary, while $uv \in NG_r^{3D}(V)$, $uv \in RNG^{3D}(V)$ may not establish. So $RNG^{3D}(V) \in NG_r^{3D}(V)$.

specially, if r=0, $l_{uv} == \frac{\|uv\|}{2}$, $NR_r^{3D}(u,v) = GG^{3D}$, if r=1, $l_{uv} = \frac{\sqrt{3}\|uv\|}{2}$, $NR_r^{3D}(u,v) \equiv RNG^{3D}$ .from $RNG^{3D}(V) \in NG_r^{3D}(V)$ and $NG_r^{3D}(V) \in GG^{3D}(V)$。

Through the above reasoning, we can draw the property 2. The expansion factor is 1of GG3D .The property 2 shows by adjusting the parameters r, topology control can guarantee ceiling expansion factors of energy consumption and energy expansion factor is constant within a certain range[6].

2.3 ATC algorithms

This topology control algorithm proposed by ATC (Algorithm of Topology Control) into neighbor discovery and topology to establish the implementation of phase 2:

(1)Neighbor discovery phase

Projection into any neighboring nodes on a sphere of RADIUS r, divided by spherical Delaunay SDT (Spherical Delaunay Triangulation) calculate the maximum blank area if the area is less than 2.72R2, make sure that the minimum 1-connected network, the algorithm terminates; otherwise continue to increase a node u-power, up to the maximum power. This borrowing [7] conclusions of the judge the condition of neighbor discovery algorithm terminates at the stage, that is, each node in a gradual process of increasing power to the surrounding nodes broadcast a unique number containing node, initialized, and residual energy message, each node according to the information received to establish a list of the information on their neighbors NL. Neighbor Discovery, the code looks like the following:

```
N̄_u ← ∅ ,  P ← P^min
FOR ( P ≤ P^max )
   u broadcast "hello" message, and collect "reply" message from neighbor v;
   N̄_u = N̄_u ∪ {v};
   Project the locations of N̄_u on the surface of the ball B(u, R);
   Construct SDT with the projected points;
   Find the largest spherical cap surface area;
   if ( Ω_u^max ≤ 2.72R^2 )
      break;
   End if
   P ← increment(P);
End for
```

(2)Topology building phase:

According to the knowledge that u has neighbor table of sorting good NLu, step through the processing of any of the neighbor node v u. There is in the first judgement to find whether NLu and NLv have some public neighbor node w located inside the area, if it means that there is a better path through w reached the v and u and v there is no direct communication links; if such a w node does not exist, u and v the establishment of direct communication links. Topology building code looks like this:

```
N_u ← ∅ , N̄_u ← ∅
FOR ( v ∈ NL_u according to W_uv )
   FOR ( w ∈ NL_v according to W_wv )
      If ∃w ∈ N_u ∪ N̄_u ∩ ∃w ∈ NR_r^3D(u,v)
         N_u = N̄_u ∪ {v}
      else
         N_u = N_u ∪ v
End for
```

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3. ATC Algorithm simulation experiment and performance analysis

3.1 Simulation Environment

Simulation experiment was done in a Matlab7.0 environment, parameters are set as follows: the cube of side length is 100m region, random dispersal 100 node n=100, 60M maximum transmission RADIUS.

3.2 Simulation of topology control

Simulation of topology control as shown in Figure 2, Figure 2 (a) was sent to max power Max Power, visible connections to the network topology is very crowded. Figure 2 (b) and 2 (f), respectively [4] GG3D and RNG3D in the topology map. Figure 2(c)~2(e) was through ATC algorithm adjustment factor of r, respectively 0.1, 0.5 and 0.9 of the network topology simulations. Simulation diagram, using the r parameter to adjust the network topology diagram node number size of the destination. When smaller r value, closer the topology map GG3D map that preserves more low energy path when the r value, the more the closer RNG3D, number of neighbor nodes also have better characteristics.

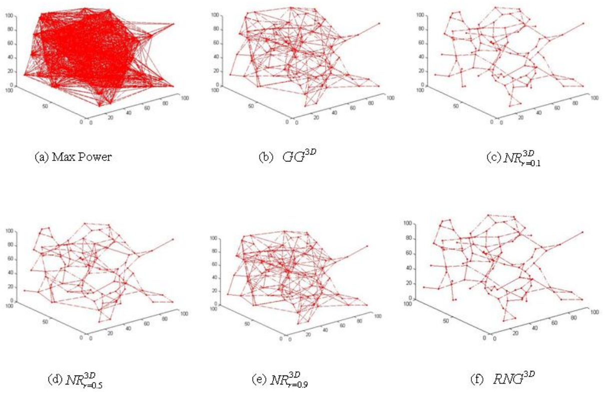

Figure2 Simulation of topology control

3.3 ATC Performance analysis of algorithms

The performance analysis of ATC algorithm mainly considers the three aspects of network nodes, and nodes of the network life cycle.

Network node

Node refers to the node in the network topology can communicate directly with the number of neighbors. Minimum node refers to the entire network for all nodes in the topology of the minimum values and maximum degree is the entire network topology for maximum value for all nodes, average degree of a node is the average value for all nodes of the network as a whole. Higher nodes in wireless sensor networks easier to communications interference between signals and conflicting, resulting in significant additional overhead of node energy; communications between nodes through the low end to end you need longer transmission paths, just as easily result in energy loss for the entire network. Kleinrock, who noted that the average overall network performance is the best in the static wireless sensor network with the average node 6 [5].

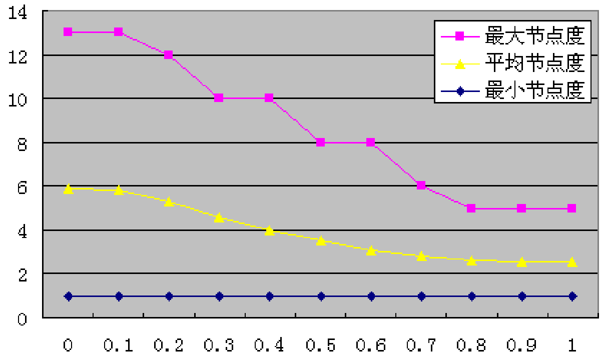

Figure 3 Change diagram node with the adjustment factor r

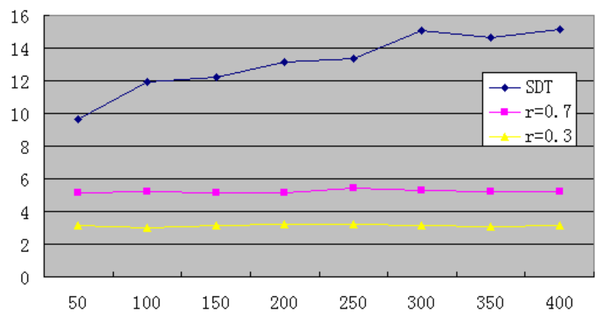

Figure 4 Nodes of network scale's node n

Figure 3 adjustment factor r is the range of values that starts 0, each step is 0.1, respectively, 11 different parameter values for simulation and experimental contrast analysis of the results. As can be seen from the diagram, with the adjustment factor r take different values, average between 3 to 6 degrees of the nodes, the maximum value at between 5 and 14. Figure 4 network size n get 50~400 each simulation network of size n increases the number 50, in different network scales used in the literature [6] SDT algorithm and algorithm of ATC this article when the adjustment factor of 0.3 and 0.7 average results of node degree of structural topology diagram. As can be seen from the figure, as the network size grows, neighbor nodes on average growth of SDT and ATC r average degree of adjustment factors determined cases remained unchanged. Therefore illustrate ATC algorithm construction of network topology has a good tone and sparse.

(2) Network Life Cycle

Network life cycle is measured from the network began its work, has to appear in the network due to not enough energy remaining the first node communicates with neighbor nodes when the network topology divided by the elapsed time. Figure 5 running ATCr=0.3, ATCr=0.7, SDT and Max Power after four different algorithms of network life cycle comparison chart. Horizontal axis is the number of nodes in n scale, vertical axis is the network life cycle. As can be seen from the diagram nodes running at maximum power the network life cycle that has nothing to do with the scale of network nodes, nodes will not increase or decrease arising from change, ATCr =0.3, ATCr =0.7, and SDT algorithm as the node size increases the life cycle of growth, on the whole, ATC increased faster than SDT.

(3) Node Power

Average power of wireless sensor network node from another perspective reflects the network energy consumption at work, greater the average power of the node, indicate that the network is more energy consumption at work and, conversely, less energy consumption during the work. Figure 6 is the ATC and SDT algorithm and maximum power average power in the same network environment compared to, ATC r adjustment factor of 0.5 in the algorithm. As can be seen from the diagram, two arithmetic mean power, maximum power is reduced as you increase the number of network nodes, but overall ATC algorithm for maximum power average power and are smaller than the SDT algorithm.

4. Conclusions

From above of contrast analysis can concluded that conclusions, this made of ATC algorithm is a can regulation of wireless sensor network topology control algorithm, through adjustment factor r $(0<r<1)$ dynamic adjustment network topology structure, makes network has good neighbors node degrees of while retained has part energy minimum path, ATC algorithm constructed of network topology figure has good of can adjustable sexual and sparse sexual, while in network life cycle and node power area are than SDT algorithm or Max Power algorithm to excellent.

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