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Clustering Algorithm Based on Fault Tolerance for Wireless Sensor Networks

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Abstract: The service failure ratio that the cluster heads provide for its member nodes is not considered in traditional clustering algorithms of wireless sensor networks. This study proposes a new clustering algorithm, in which the ratio of cluster-head residual energy and its initial energy is set to the service failure rate. Moreover, the elected cluster heads provide multiple coverage for the key nodes in order to ensure fault tolerance. The experiment results show that the new algorithm prolongs the network life time.

Key words: Wireless sensor networks, multiple coverage, service failure rate, fault tolerance

INTRODUCTION

At present many wireless sensor network applications rely on clustering (Zhou *et al*., 2008; Qing *et al*., 2006) logic network structure. In this structure, cluster heads perceive data fusion handing and forward to the sink node which reduces the network energy consumption. But the energy consumption of the cluster head is far greater than its member nodes (Bandyopadhyay and Coyle, 2003). Traditional clustering algorithm does not consider the residual energy of the elected cluster head, so traditional clustering algorithm will cause the entire cluster communication failures and shorten the network lifetime (Raghuwanshi and Mishra, 2003; Luo *et al*., 2006). Wireless sensor networks use wireless communication which makes communication between cluster heads and cluster members vulnerable to interference for communication failure. Moreover, wireless sensor nodes perceive sensing information asymmetrically (Liu and Yu, 2010), so clustering algorithm for wireless sensor networks must ensure that cluster heads can get sensing information of the key nodes or key areas.

This study proposes a new clustering algorithm for wireless sensor networks. In the algorithm, it considers not only the node's residual energy but also the multiple coverage to the key nodes.

CLUSTERING ALGORITHM BASED ON FAULT TOLERANCE

Network operating environments: The algorithm proposed in this study is based on the following assumptions:

- The sensor nodes of wireless sensor network are homogeneous
- Each sensor node is with GPS module in order to know its position
- All nodes are randomly deployed in the perception of the region with a unique identification (ID)
- All nodes cannot move freely after deployment
- Communication links between nodes are bidirectional symmetric
- The relationship between cluster head and its members is defined as the relationship between service and the service, namely cluster heads provide relaying services for cluster members and cluster members accept the services provided by the cluster heads

Algorithm description: It assumes that the amount of the wireless sensor nodes is Ψ and n nodes will be elected as the cluster head (n<Ψ). In practical applications, the amount of sensing information in different area is different. It also means that the amount of service requesting to the cluster head is different. So the algorithm assumes that h_k is the amount of requests that node k sends to the cluster head, the service failure rate of cluster head i is P_i, E is the residual energy of node, E is the initial energy of nodes. We set:

$$p_i = 1 - \frac{E_{current}}{E_{Initial}}$$

In the initial network state, $E_{current} = E_{initial}$, so the service failure rate of all the cluster heads is 0. In the case of cluster heads energy depletes, $E_{curmet} = 0$, the cluster-head failure rate is100%, so it cannot provide services for its members.

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In order to obtain the reliable information of the key nodes, the algorithm adopts multiple coverage to the key nodes. If m cluster heads cover the key node k, the successful service probability of the node k is:

$$1-\prod_{i=1}^{m} p_i$$

Assuming that $H_{k,m}$ is the amount of node's coverage requests (the node's id is K) when the node K is covered by m cluster-head nodes. $H_{k,m}$ is expressed as:

$$H_{k,m}=\begin{cases} h_k & \text{service success} \\ 0 & \text{service failure} \end{cases} \quad (1)$$

We can also get:

$$E(H_{k,m})=h_k(1-\prod_{i=1}^{m} p_i)\forall k,m \quad (2)$$

If the amount of the cluster heads which cover the node k increases from m-1 to m, the increasing amount of the node k 's covering requests is:

$$\begin{aligned}\Delta E(H_{k,m}) &= E(H_{k,m})-E(H_{k,m-1}) \\ &= h_k(1-p_m)\prod_{i=1}^{m-1} p_i\end{aligned} \quad (3)$$

Further more, we define as below:

$$y_k=\begin{cases} 1 & \text{node k is coverd by a cluster head} \\ 0 & \text{otherwise} \end{cases}$$
$$X_i=\begin{cases} 1 & \text{exist a cluster head near the cluster head i} \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

$$a_{ki}=\begin{cases} 1 & \text{node k is in the range of the covering radius of the cluster i} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

The variables above satisfy the following conditions:

$$y_k-\sum_i a_{ki}X_i \le 0 \quad k=1,\ldots,\Psi-n \quad (6)$$

$$\sum_i X_i \le M$$

$$X_i=0,1 \quad i=1,\ldots,\Psi-n$$
$$y_k=0,1 \quad k=1,\ldots,\Psi-n$$

The algorithm makes the amount of covering request maximum by selecting appropriate nodes as cluster heads. By derivation, we get the clustering algorithm:

$$\text{Maximize}\sum_{k=1}^{\Psi-n}\sum_{j=1}^{n}(1-p_j)h_k y_{jk}\prod_{i=1}^{j-1} p_i \quad (7)$$

In the clustering algorithm proposed in this study, some nodes may be covered by more than one cluster heads. So the nodes choose to join the cluster which cluster head is closest to it and other clusters will be alternative. When the communication between the node and the cluster head fails, the node selects the closest candidate cluster head as its cluster head and sends data to it.

THEORETICAL ANALYSES OF THE ALGORITHM

[Theorem]: If cluster-head covering radius increases from CR_1 to CR_2, the maximum coverage requests meets $RequestNum(CR_1)\le RequestNum(CR_2)$ [Proof]:

Supposing that it contains **Ψ** sensor nodes and n cluster heads in the wireless sensor network. When the covering radius is CR_1, we set $CoverageNum=\{cnm_1,cnm_2,\ldots\ldots cnm_\Psi\}$ and the position sets of cluster heads are $L'=\{l(1),l(2),\cdots,l(n)\}$. When the covering radius is CR_2, the covering number sets are $CoverageNum'=\{cnm'_1,cnm'_2,\ldots\ldots cnm'_\Psi\}$ and the position sets of cluster heads are $L'=\{l'(1),l'(2),\cdots,l'(n)\}$. It is known that $CR_1 < CR_2$, we will prove $RequestNum(CR_1)\le RequestNum(CR_2)$.

When the covering radius increases from CR_1 to CR_2, it maybe cause the node's coverage status changed. If any node's coverage status doesn't change, the entire network coverage sets will not change. It means $CoverageNum=CoverageNnm'$. So the successful service probability within the covering radius of each node does not change, that is:

$$k=1,2,\cdots,\Psi \quad (8)$$

We calculate the coverage requests of each sensor node, we get:

$$\sum_{k=1}^{\Psi}h_k(1-\prod_{i=1}^{cnm'_i}p_i)=\sum_{k=1}^{\Psi}h_k(1-\prod_{i=1}^{cnm_i}p_i) \quad (9)$$

That is:

$$RequestNum(CR_1)=RequestNum(CR_2)$$

If some nodes' coverage status change, the entire network coverage sets will change. It means $CoverageNum\ne CoverageNum'$. According to the model, not only the coverage sets may vary with the increasing covering radius but also the optimal location sets may also be affected:

- If the optimal position sets do not change, there will be at least one node k which makes $cnm'_k>cnm_k$. So the successful service probability within the covering radius meets

$$1-\prod_{i=1}^{cnm_i'} p_i > 1-\prod_{i=1}^{cnm_i} p_i$$

Both sides of the inequality multiply the amounts of requests h_k, we get:

$$\sum_{k=1}^{\Psi} h_k (1-\prod_{i=1}^{cnm_i'} p_i) > \sum_{k=1}^{\Psi} h_k (1-\prod_{i=1}^{cnm_i} p_i)$$

It means that the maximum coverage requests exists the relationship:

$$\text{RequestNum}(CR_1) < \text{RequestNum}(CR_2)$$

- (b) If the optimal position sets change, it means that $L' \neq L$ L' is the optimal layout scheme when the covering radius is CR_1. So the coverage requests of other scheme must be less or equal to $\text{RequestNum}(CR_2)$ when the covering radius is CR_2. In other words, when the covering radius is CP_2, the coverage requests in the layout scheme $\angle$ meets:

$$\text{RequestNum}'(CR_2) < \text{RequestNum}(CR_2)$$

According to (a), The layout scheme of $\text{RequestNum}(CR_1)$ and $\text{RequestNum}'(CR_2)$ is $\angle$ and the covering radius meets. CR_1<CR2 We get:

$$\text{RequestNum}(CR_1) < \text{RequestNum}'(CR_2)$$

Combining two points above, the inequality $\text{RequestNum}(CR_1) < \text{RequestNum}(CR_2)$ is founded in the current assumption. Based on (a) and (b), we conclude that when the coverage sets change, $\text{RequestNum}(CR_1) \leq \text{RequestNum}(CR_2)$ is founded.

SIMULATION ANALYSIS

In the simulation model, 100 nodes randomly distribute in 100m * 100m and 10 cluster heads in a network. Each node's initial energy is 0.5 J. Sink node is located at (10, 20).

Figure 1 is the relationship of election rounds and the amount of nodes alive in the network. It shows that it keeps 778 rounds in Leach, while it keeps more 1200 rounds in the algorithm proposed in this study. This is because that during the election of cluster heads, the new algorithm considers residual energy of nodes making the network node's energy consumption relatively uniform.

Figure 2 shows that in the initial conditions, the new algorithm and Leach have little difference in the amount of data transmitted to the sink because the service of failure rate that the head provided is very low. But with the energy of the nodes consuming gradually, the service failure rate of cluster heads increases and the amount of data that the sink received reduced significantly in LEACH. Although the amount of data in the algorithm proposed in this study is also reduced, the performance of network is still better than LEACH because the new algorithm considers good service that the head node provides to its members as the primary condition. Moreover, cluster heads adopt multiple coverage strategy to the members in the algorithm, so it also ensure that the data can be send to the sink even if the service that the cluster head provides fails.

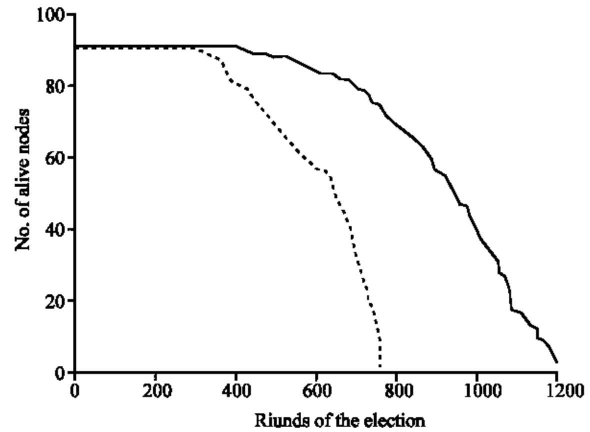

Fig. 1: Diagram of election times and survival node numbers

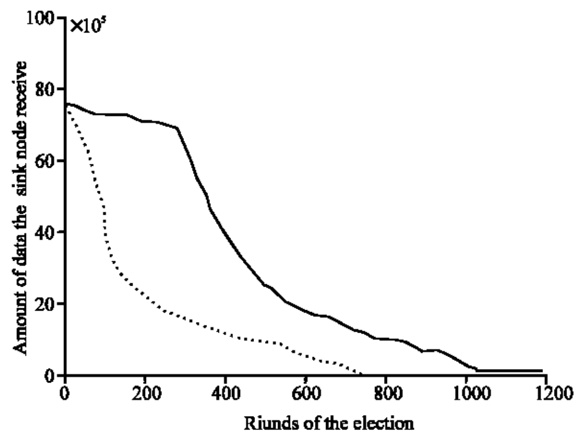

Fig. 2: Diagram of the data sink received and election times

CONCLUSION

Clustering algorithm proposed in this study makes the cluster head provide reliable service to its members. During the cluster head election, it considers the residual energy of the nodes and service failure rate. In the process of clustering, cluster heads provide multiple coverage to the members improving the correctness of data transmission. The simulation results show that compared with the traditional clustering algorithm, the algorithm proposed in this study prolongs the network life time effectively and improves the fault tolerance of the network.

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