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Task allocation algorithm based on auction in WSAN

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Abstract. To solve the problem of unreasonable task allocation in WSAN, which leads to uneven energy consumption of actuators and too long task execution time, a task allocation algorithm based on auction is proposed. Task decomposition model, task efficiency model and task allocation model were established. The auction actuator node decomposes the task into a plurality of task elements according to the task decomposition model; The actuator node inputs the task element into the task efficiency model, and calculates the efficiency of the completed task element; The auction actuator node comprehensively selects the best task allocation scheme according to the task allocation model. Simulation results show that compared with other algorithms, this algorithm reduces the task completion time, balances the energy consumption of actuators and prolongs the network life.

Keywords. Wireless sensor and actuator network, Task assignment, Auction mechanism, Actuator coordination

1. Introduction

Wireless sensor and actuator network is a new type of self-organizing wireless network[1]. It consists of a large number of sensor nodes and a small number of actuator nodes. The actuator node is responsible for processing abnormal information and executing the current task. Therefore, when there are abnormal events in WSAN, se-lecting the appropriate actuator node to process ab-normal information can reduce the energy consumption of the node and improve the processing speed of the actuator node, which is of great significance to improve the real-time performance of the network, balance the energy consumption of the nodes and prolong the net-work life[2].

There are two kinds of algorithms to solve task assignment problems in WSAN: centralized and dis-tributed. Centralized algorithm means that a central node collects the information of all nodes and then assigns tasks. In literature[3], the task allocation problem is regarded as an integer linear programming problem, and the task set is traversed by tree method, and the task allocation scheme with the lowest energy consumption is found under the time constraint. In reference[4], the task attribute, the residual energy of the actuator and the event position are taken as the inputs of the fuzzy algorithm, and the final task allocation scheme is obtained. In reference[5], according to the residual energy of the actuator nodes, the hybrid simulated annealing particle swarm optimization algorithm is used to uniformly arrange tasks.

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Distributed algorithm refers to information interac-tion and decision-making between nodes. In literature[6], the execution of different tasks is regarded as a knapsack problem,and then the auction algorithm is used to achieve task allocation. In literature[7], i Mesh algorithm is used to cross-find nearby actuators, and then the localized auction aggregation protocol is used to achieve task allocation. In literature[8], the redeployment algorithm is used to deploy the actuator nodes to the network center, and then the sealed first price auction algorithm is used to assign tasks.

Compared with centralized algorithm, distributed algorithm has less computation, less energy consumption of nodes and shorter execution time. Based on distri- bution, this paper proposes a task allocation algorithm based on auction. Aiming at the problems of un- reasonable assignment of main tasks, resulting in too long task completion time, unbalanced network energy consumption and short network life. The task is divided into several task elements according to the separability, the idea of economics is introduced, the auction mechanism is adopted, and the auction is launched in the form of broadcast. The actuator node calculates the performance of the task according to the task perform- ance model, and returns the performance to the auction actuator node. The auction actuator node selects the auction actuator node according to the task allocation model, and generates the final task allocation scheme. Task allocation is completed by auction, which balances the energy consumption of nodes, reduces the task execution time and prolongs the life cycle of the network.

2. AA COLLABORATIVE MODEL BASED ON CLUSTERING STRUCTURE

In this paper, the cooperation between actuators is established based on the cluster structure with actuator nodes as cluster heads. When the sensor node detects the occurrence of an event, the sensor node only transmits information to the cluster head of the cluster, and the cluster head cooperates with other cluster heads to process the task.

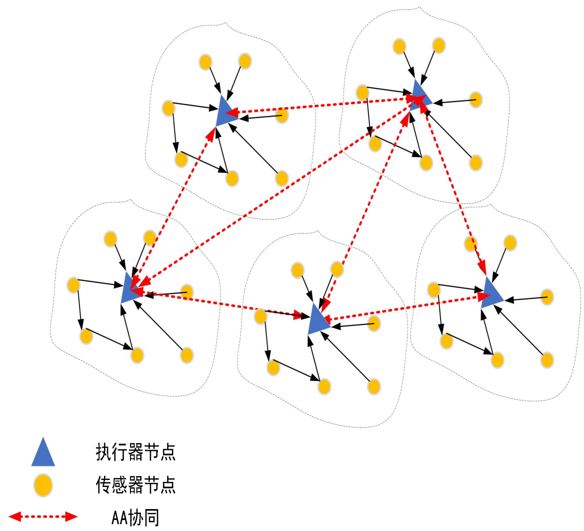

Figure 1. AA collaborative model based on clustering structure

3. MODEL ESTABLISHMENT

3.1. Task decomposition model

Assuming that the task is decomposable and multiple actuator nodes cooperate to execute task elements, it can solve the problems of unbalanced energy consumption of actuator nodes, too long task completion time and short network life caused by uneven task distribution.

Definition1:Set of tasks to be performed $T = \{t_1, t_2, t_3, \cdots, t_n\}$,Among them,T is a task execu- tion unit, referred to as task unit; If it exists $T = \bigcup_{i=1}^{n} t_i$, $t_i \cap t_j = \emptyset$,and$\forall$ $i, j \in \{1, \cdots, n\}, i \neq j$, call task T separable.

Definition 2:Collection of actuator nodes $A = \{a_1, a_2, a_3, \cdots, a_n\}$,A task element t_i is executed and completed by at least one actuator node a_i.

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3.2. Task effectiveness model

Suppose that when the actuator nodes are randomly deployed, each node can acquire its own position by being equipped with a GPS receiver, or provided by a local service period, or by other positioning technologies.

Suppose the communication range of actuator nodes is a circle, and the cluster head is located in the center of the cluster.

The performance of the actuator to complete the task is equal to the benefit minus the cost. It is the expected revenue of the revenue actuator node after completing the task $\mathrm{Reward}_i(T_j)$,The cost is the cost that the actuator node needs to pay to complete the task Cost_i,then:

$$U_i(T_j) = \mathrm{Reward}_i(T_j) - \mathrm{Cost}_i(T_j) \quad (1)$$

The expected revenue of the node after completing the task $\mathrm{Reward}_i(T_j)$, including the value of the main task itself $\mathrm{Value}_i(T_j)$ and the success rate of task completion by the actuator node is as follows $S_i(T_j)$. The expected revenue of the actuator node after completing the task is:

$$\mathrm{Reward}_i(T_j) = \mathrm{Value}_i(T_j) \cdot S_i(T_j) \quad (2)$$

The success rate of the actuator node task is equal to the times $S_i(T_j)$,when the actuator completes the task/the times$C_i(T_j)$,when the actuator becomes an auction actuator:

$$P_i(T_j) = \frac{S_i(T_j)}{C_i(T_j)} \quad (3)$$

The costs incurred by the actuators in performing tasks mainly include:energy consumption, time and event distance required by the ith actuator node to complete the jth task element,energy consumption cost of establishing actuator nodes $E_i(T_j)$, the time cost $TM_i(T_j)$ and The cost of distance from the event center $D_i(T_j)$.

The energy consumption cost $E_i(T_j)$ of the actuator node is equal to energy consumed by a node to perform a task E_{action}/Residual energy of actuator nodeE_{rest}:

$$E_i(T_j) = \frac{E_{action}}{E_{rest}} \quad (4)$$

When $E_{action} \geq E_{rest}$, it shows that the residual energy of the actuator node can't support the actuator node to complete the task cost $TM_i(T_j)$, including comm-unication time TM_c, calculation time TM_s and expected task completion time $TM_e$of the actuator node:

$$TM_i(T_j) = TM_c + TM_s + TM_e \quad (5)$$

The cost of distance from the event center $D_i(T_j)$,Suppose the communication radius of the actuator node is R_A:

$$D_i(T_j) = \sqrt{(i_1 - i_2)^2 + (j_1 - j_2)^2} \quad (6)$$

When$D_i(T_j) > R_A$,the task is beyond the communication range of the actuator node, so the actuator node does not consider executing the task.

Based on the above three indicators, the cost of the actuator node to complete the task $\mathrm{Cost}_i(T_j)$:

$$\mathrm{Cost}_i(T_j) = \alpha \cdot E_i(T_j) + \beta \cdot TM_i(T_j) + \gamma \cdot D_i(T_j) \quad (7)$$

Where α, β and γ are scaling factors. The final task allocation scheme is to reduce the execution time of the actuator, balance the energy consumption of the actuator and prolong the life of the network. So set the ratio of the three scaling factors α:β:γ to 3:2:1.

The performance of the execution task of the actuator node is:

$$U_i(T_j) = \mathrm{Value}_i(T_j) \cdot P_i(T_j) - (\alpha \cdot E_i(T_j) + \beta \cdot TM_i(T_j) + \gamma \cdot D_i(T_j)) \quad (8)$$

When the efficiency is greater than 0, it indicates that the actuator node has the ability to participate in the auction, and sends the calculated efficiency to the auction actuator node to participate in the auction; Otherwise, the actuator node waits for the next auction.

3.3. Task assignment model

Auction the performance value received by the actuator node $U_i(T_j)$:

$$U_i(T_j) = \mathrm{Reward}_i(T_j) - \mathrm{Cost}_i(T_j) \quad (9)$$

Node trust degree $G_i(T_j)$, The number of times the actuator node completed the task $\mathrm{Time}_{success}$, Number of times the actuator participated in the auction $\mathrm{Time}_{assigned}$:

$$G_i(T_j) = \frac{Time_{success}}{Time_{assigned}} \quad (10)$$

According to the task allocation model, the auction actuator node selects the actuator node with high efficiency to perform the task, because when the utility of the actuator node is greater, it indicates that the cost of the actuator node to perform the task is smaller, then:

$$Max(G_i(T_j)) \begin{cases} Max(Time_{success}) \\ Min(Time_{assigned}) \end{cases} \quad (11)$$

4. TASK ASSIGNMENT BASED ON AUC-TION(ATAA)

After the task decomposition is completed, when a task is separable, the auction actuator node sends the meta information of each task to other actuator nodes in the network through the auction mechanism. Here, the actuator node decomposes the task into several task elements, and sends out the auction invitation to become the auction actuator node. The auction actuator node sends out an invitation in the form of broadcast, including information such as the energy consumption, time and location of the goods to be auctioned. After receiving the broadcast information, other actuator nodes first judge whether they can participate in the auction. The nodes that can participate in the auction calculate the task efficiency and return it to the auction actuator node to participate in the auction, which is called the auction actuator node. The auction node determines the best task allocation scheme according to the received task efficiency.

4.1. Tender executor node

The executor node receiving the auction invitation information calculates the performance value of each task element according to the broadcast information. If the performance is greater than 0,it indicates that the executor node has enough ability to participate in the auction, and sends the calculated performance back to the auction executor node.Become a waiting auction ex-ecutor node.

4.2. Auction executor node

After receiving the performance of the auction executor nodes, according to the task assignment model, the auction executor node comprehensively evaluates the performance and node credibility of each executor node, selects the auction executor node, and decides the final task allocation scheme.

4.3. The executor performs the task

When the executor receives the notice of the auction result of the auction executor, the executor node will confirm the task information again and calculate according to its own situation again. If it meets the requirements, it will feed back the confirmation information of the task to the auction executor node, become the auction executor node, and start to execute the task.

4.4. Supervision responsibility of auction executor node

The auction node needs to set a timer T to ensure the successful execution of the task. When the commun-ication time of the executor is TM_c, the calculation time TM and the expected completion time TM,after the executor node successfully participates in the auction, if the auction executor node does not receive the feedback information sent by the auction executor node within $T = TM_c + TM_s + TM_e$, the auction executor node can think that the auction executor node has failed or failed. At this time, The auction executor node will send a reminder message to the auction executor node. If it still doesn't receive a reply message within $T + \Delta T$ (ΔT is the average time for the executor node to process information), it is considered that the node has lost contact, and the auction executor node will re-launch the auction for the task and reassign the executor node to perform the task.

5. TASK ASSIGNMENT ALGORITHM FLOW BASED ON AUCTION(ATAA)

In this paper, the AA collaboration based on auction mechanism is adopted, and the actuator node that receives the event information first acts as the auction actuator node, which decomposes the task into several task elements and sends the task element information to the actuator node in the form of broadcast. The received actuator node calculates the efficiency according to the task meta information,

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and if the efficiency is greater than 0, returns the efficiency to the auction actuator node; According to the efficiency and credibility of the auction node, the actuator node is selected to form the final task allocation scheme. The whole process is as follows:

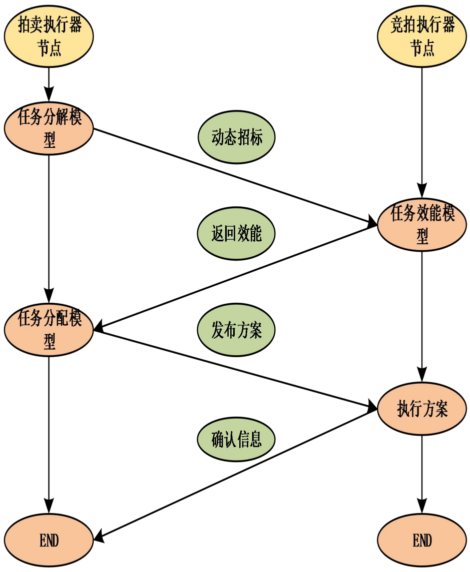

Figure 2. ATAA algorithm flow chart

6. SIMULATION AND PERFORMANCE ANALYSIS OF THE ALGORITHM BASED ON

6.1. Simulation environment

In order to verify the performance of the algorithm, this paper uses NS-2 simulation platform to carry out comparative simulation experiments with algorithm KE[9] and algorithm DADA[10], aiming at the average task completion time, energy consumption balance and life cycle of the network. The monitoring area is 250m*250m, and 210 sensor nodes and 18 actuator nodes with mobile characteristics are randomly deployed.

6.2. The completion time of the task

In the first auction process of ATAA algorithm, the task is first decomposed into multiple task elements, and each task element can be executed by multiple actuator nodes in parallel. Compared with the other two alg-orithms, the average task completion time of ATAA algorithm is shorter than that of the other two algorithms. After the auction, the success rate increased, and the average task completion time decreased accordingly. And DARA algorithm have no process of task decomposition and concurrent execution of task elements, each task is completed by a single actuator node, the overall task completion time is prolonged, the energy consumption is unbalanced, and the time delay increases. Therefore, the ATAA algorithm adopts the multi-executor-node cooperation mechanism, which makes the tasks execute concurrently and shortens the overall task completion time.

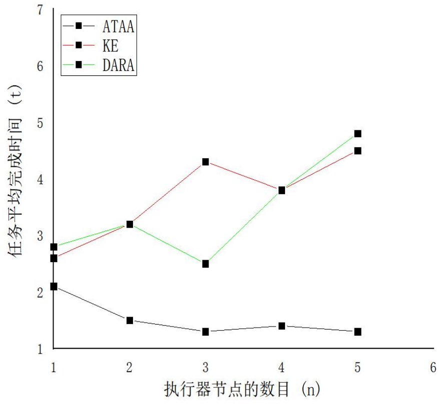

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Figure 3. Comparison chart of average task completion time

6.3. Energy consumption balance

ATAA algorithm decomposes tasks, and then multi-actuator nodes execute them simultaneously, sharing the execution energy consumption to each node to the maximum extent, so that the overall energy consumption of nodes is relatively balanced. However, for KE and DARA algorithms, the energy consumption of some actuator nodes is too fast due to the random occurrence of events, and the fluctuation of equilibrium index E is larger than that of ATAA algorithm.

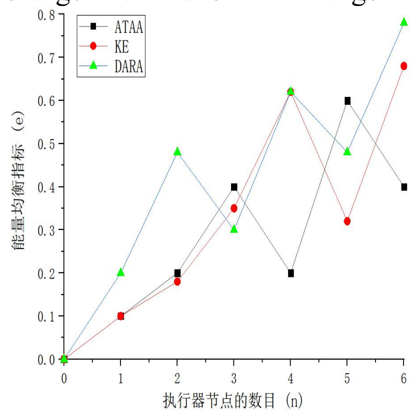

Figure 4. Energy consumption balance comparison chart

6.4. Life cycle

The network lifetime of WSAN is defined as the time from the beginning of receiving task information to the exhaustion of its own energy of the executor node with the first abnormal information. In KE algorithm and DARA algorithm, every time an actuator node receives abnormal information, it must complete the corr-esponding task independently, so that the energy con-sumption of actuator nodes in the monitoring area is uneven and the network life is shortened. The ATAA algorithm dynamically cooperates with actuators to perform tasks according to the energy consumption of actuators through the cooperation mechanism of actu-ators, and tries to keep the energy consumption balance of network nodes. In contrast, the network lifetime of ATAA algorithm is obviously improved.

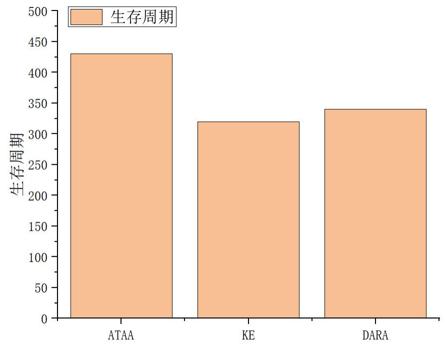

Figure 5. Life cycle comparison chart

7. CONCLUDING REMARKS

Aiming at the problem of how to allocate tasks reasonably in multi-actuator nodes, this paper proposes an actuator task allocation algorithm based on auction mechanism. The actuator node that receives the abnormal information first decomposes the task and becomes an auction actuator node. By decomposing the task into several task elements, it initiates the auction, and the actuator node that receives the broadcast information evaluates the efficiency according to the information of the task elements, and returns the efficiency value to the auction actuator node. According to the mathematical model of task assignment, the auction actuator node selects the actuator node to execute the task, and

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generates the final task assignment scheme, so that the tasks can be executed in parallel, and the task execution time is shortened. At the same time, the execution energy consumption is shared and balanced as much as possible, which solves the problem of unbalanced energy consumption of nodes and prolongs the network lifetime.

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