A Novel Service Composition Optimization Strategy

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Abstract. In order to cope with the increasingly complex application requirements, sensors work in a cooperative and collective manner. Service-oriented Wireless Sensor Networks (WSNs) framework becomes an effective strategy to solve the cooperative work of sensors. Aiming at the key service composition optimization problem under this framework, this paper proposes a novel multi-channel directed harmony search algorithm (MDHS) algorithm after analyzing the performance of ant colony optimization (ACO), genetic algorithm (GA) and particle swarm optimization (PSO) algorithms on this problem. Based on harmony search algorithm (HS) algorithm, this algorithm adopts multi-channel, dynamic parameters, directional perturbation and other technologies, which greatly improves the excellence of service composition and solution efficiency. Extensive experiments have been carried out and the results show that our technique performs better than GA and PSO on reducing energy consumption and extending the life of the wireless sensor network.

1. Introduction

To solve complex application requirements, sensor nodes communicate with each other to complete complex tasks in a collaborative manner. This has become a research hotspot and is widely used in smart homes [1], target tracking [2], biomedical [3], electric power grids [4] and many other fields. The article [5] proposed service-oriented wireless sensor network (WSNs) framework to solve problem of sensors working together. Then, in this framework, [6] explored the WSN service composition of concurrent requests and improved the sharing of WSN services. [7] proposed a configurable WSN service composition to resolve potential conflicts between functions. However, the instantiation of a service class into a specific service has not been extensively explored by selecting the suitable service for the service class in the chain. Under the condition of considering energy efficiency, energy balance, service quality and other factors, it is a major challenge to find the best WSN service composition. This paper attributes it to the multi-objective multi-constraint problem and a novel multi-channel directed harmony search algorithm (MDHS) is proposed to solve it.

2. Preliminaries

2.1. Service-Oriented Wireless Sensor Networks (WSNs) Framework

This framework is used to solve the problem of sensors collaborating with each other to meet the needs of complex applications. Specifically, first, sensors are encapsulated as WSN services. Secondly, services with the similar function are transferred into the service classes. Then, service classes are
linked in a chain to meet the requirements of the application. Last, finding the optimal service instance(sensor) for the class on the chain that meets the requirements.

However, when selecting a specific service instance for a service class, we need to consider many goals and constraints based on the characteristics of the sensor itself and the WSN [8]. For example, the energy consumption of the node, the energy balance of the WSN, the space-time constraints caused by the geographic location and working time of the sensor node of a specific application, etc. So, this is a multi-objective multi-constraint service composition optimization problem.

2.2. Service Composition Optimization Problem
The service composition has a huge solution space, which requires a lot of work to select the optimal composition, which is also the difficulty of the current composition optimization.[9] applies the ACO algorithm, but the ACO algorithm searches for a long time when the initial conditions are not well set and it will appear stagnant and fall into the local optimum when it searches for a certain degree. The genetic algorithm (GA) and particles warm optimization (PSO) algorithm are applied[10]. However, due to the irregularity and non-directionality of the generation process of offspring in the GA algorithm, a large number of inferior individuals may be generated in the process of multiple evolutions [11]. The performance of PSO algorithm following high-quality individuals makes the whole population converge to the local optimal value, so that the best global solution cannot be discovered [12]. These algorithms cannot effectively solve the service composition problem.

HS algorithm is one of the most excellent meta-heuristic algorithms, the search range and search accuracy of the HS algorithm can be adjusted by the parameters HMCR (Harmony memory considering rate) and PAR(Pitch adjusting rate). We will build a novel service composition optimization algorithm based on HS algorithm.

2.3. Objective and Constrained
Services Composition has multiple goals and constraints, respectively: energy consumption $E(cp(chn))$, load balancing factor $lbf(cp(chn))$, time constraint $tpr(cp(chn))$, space constraint $spc(cp(chn))$[5]. In order to comprehensively measure these indicators, we defined fitness. The fitness function indicates how good the selected services composition is to the application in the current situation. The smaller fitness, the better composition.

$$fitness(cp(chn)) = \alpha \times E(cp(chn)) - \beta \times lbf(cp(chn)) - \gamma \times tpr(cp(chn)) - \delta \times spc(cp(chn))$$ (1)

3. Multi-channel Directed Harmony Search Algorithm
Multi-channel directed harmony search algorithm (MDHS) is based on HS algorithm and combines the characteristics of services composition. MDHS adopts multi-channel HS algorithm for service classes chains, and uses dynamic parameter setting and directed disturbance in the iterative process to solve services composition problems efficiently.

3.1. HS Algorithm
The HS algorithm is a smart algorithm proposed by Korean scholar Geem to simulates the process of music creation in which musicians rely on their own memories to correcting the tone of each instrument again and again to achieve a wonderful harmony state. Each instrument represents a variable, and each instrument's different pitch represents a different assignment to the variable. The whole process uses the fitness function to evaluate the excellent level of harmony. The musician will repeat the creation until a satisfactory result is achieved. This is the optimization process of HS algorithm. For details, please refer to the literature [13].

3.2. Multi-channel
We have noticed that selecting services composition is based on a multitude of service class chains rather than a single service class chain, which will make our search space particularly large and the
algorithm subject to a large number of constraints. Therefore, we construct HS for each service class chain that meets the conditions, and then select the optimal services compositions generated by each class chain. This will effectively improve the algorithm search speed and reduce the complexity of the algorithm.

3.3. Dynamic Parameter

In HS algorithm, parameters HMCR and PAR are fixed values. In order to search more efficiently, we will use dynamic HMCR, PAR. The larger HMCR, the higher probability of selecting the solution from HM, which speeds up the convergence and easily leads to local optimization. And the smaller HMCR can enrich HM and obtain global optimization, but the search accuracy is not enough. A small PAR facilitates the transfer of tone information to the next generation, while a large PAR make the new harmony to expand the search area by disrupting the values of the corresponding dimensions in the harmony memory. We believe that the smaller HMCR and the larger PAR should be used in the early stage to avoid local optimization, and the convergence can be accelerated; the larger HMCR and the smaller PAR should be used later to improve the accuracy of the search. Therefore, we designed the HMCR, PAR function with the independent variable being the number of iterations (equations 2 and 3). At this time, the changes in HMCR and PAR with the number of iterations are shown in Figure 1 and Figure 2.

\[
HMCR(t) = \ln \left( \frac{t^{t-1} \times \text{GENmax}}{\text{HMCRmax} \times e} \right) + e
\]

\[
PAR(t) = \text{GENmax} \times \text{PARmax} \times \text{PARmin} / (t \times (\text{PARmax} - \text{PARmin}) + \text{GENmax} \times \text{PARmin})
\]

\(\text{HMCR}_{\text{max}}, \text{HMCR}_{\text{min}}, \text{PAR}_{\text{max}}, \text{PAR}_{\text{min}}\) are the upper and lower limits of HMCR and PAR, and \(t\) is the number of current iterations. \(\text{GENmax}\) is the maximum number of iterations.

**Figure 1.** HMCR with the number of iterations, \(\text{HMCR}_{\text{max}} = 0.9, \text{HMCR}_{\text{min}} = 0.2, \text{GENmax} = 200.\)

**Figure 2.** PAR with the number of iterations, \(\text{PAR}_{\text{max}} = 0.9, \text{PAR}_{\text{min}} = 0.5, \text{GENmax} = 200.\)

3.4. Directed Disturbance

At the same time, when adjusting the harmony in Harmony memory (HM), we do not randomly, but adopt a directional disturbance. We believe that the harmony in the HM is relatively good, and as the number of iterations increases, the harmony in HM becomes more and more excellent. And the degree of superiority of the services composition depends on the energy consumption and space-time constraints, both of which are related to the distance between the nodes, so we are more inclined to the nodes that are closer to the current node when we are adjusting. In particular, when we adjust the current node, we calculate the distances between the current node and surrounding nodes, and then generate the corresponding probability according to the distances. The closer the node is, the higher the probability of replacing the current node with the node. This process is carried out in the form of roulette.
4. Experimental Verification
In order to test the performance of MDHS algorithm, GA, PSO and MDHS algorithm were used to conduct experiments, and each core index affecting the energy efficiency of wireless sensor network was studied.

4.1. Environment Settings
Our experiments used 400 sensors over a test area of 350 m × 350m. Sensors are divided into 14 categories according to their functions. The spatial constraint is determined by the spatial position loc(x,y) and the communication radius. The time constraint consists of several consecutive timeslots, each of which corresponds to 2 hours in the 24-hour format. At the same time, we believe that all services have the same initial energy. We use the service network and requirement application (REQ APP) of [5]. As shown in Figure 3, the black dot is the service, the spatial constraint is specified by the red circle; 338(sc4)→33(sc3)→364(sc1)→389(sc9)→188(sc10) is an example service class chain and service composition.

![Figure 3. Example services composition by MDHS.](image)

4.2. Experimental Evaluation
![Figure 4. The fitness of GA, PSO, MDHS over 300 iteration cycles.](image)

![Figure 5. The fitness of MDHS over 300 iteration cycles.](image)

Figure 4, 5 shows the values of fitness of the GA, PSO, and MDHS algorithms with the number of iterations. The GA algorithm converges around 200 generations and the values of fitness is around -0.721. The PSO algorithm converges around 50 generations and the values of fitness is around -0.842. The MDHS algorithm converges around 70 generations and the values of fitness is around -0.874. It can be seen that the MDHS and PSO algorithms are faster and more accurate than the GA algorithm.
Figure 6. The value of the fitness over time in a continuous 50 time slots.

All of the following experimental results are the average of 10 experiments. Figure 6 shows the value of the fitness over time in a continuous 50 time slots. We can see that the fitness value of the services composition provided by the MDHS algorithm is the highest even for a long period of time. And as time increases, the fitness value continues to rise. This is due to the energy consumption and the load balancing factor are increasing. In addition, we can clearly see that the fluctuation of the fitness value of MDHS is smaller, which shows that the stability of MDHS is better.

Figure 7. The energy consumption of the WSN in 50 consecutive time slots.

We can clearly see that the energy consumption of the MDHS algorithm is about one quarter of the PSO and one sixth of the GA. That is to say, the MDHS algorithm can ensure that the energy consumption of the services composition is minimized while considering various factors. Of course, we don’t just want the least energy consumption, we must also pay attention to the balance of energy consumption.

Figure 8. The minimum remaining energy of all services in all 300 consecutive time slots.

From Figure 8, we can see that the minimum residual energy of the WSNs by the GA, PSO, MDHS algorithm is less than 10% at the 50th, 170th and 300th time slot. It is experimentally verified that the minimum remaining energy for the MDHS is less than 10% in the 1500th time slot. In this respect, the MDHS algorithm delayed the time of the first dead node by five times compared to the PSO algorithm; From Figure 9, we can see that the variance of the MDHS algorithm is the smallest, which means that the MDHS algorithm always has the largest minimum residual energy and the smallest variance. That is to say, the energy consumption of the services composition provided by MDHS is more uniform. The composition of services provided by MDHS more rationally considers the overall situation and avoids local hot spots caused by excessive consumption of individual services. This effectively reduces premature death of nodes and extends network life.
5. Conclusion
The use of service composition to complete a complex task becomes an effective means to solve the Sensor collaboration problem. Due to the energy consumption, the energy balance, and the time and space constraints, the service composition is summarized as a multi-objective multi-constraint problem. In this paper, MDHS algorithm is proposed based on the HS algorithm, which adopts multi-channel, dynamic parameters and directional disturbance to greatly improve the efficiency and accuracy of the search. After a lot of experiments, the results show that MDHS algorithm consumed less time to reach stability, and can find a services composition with higher fitness. In addition, in the long service invocation, compared with GA and PSO, the service compositions provided by MDHS algorithm consumes less energy, and the energy consumption is more balanced, so that the WSNs can live longer.

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