Research on Resource Scheduling Mode of Tracking and Data Relay Satellite System

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Abstract—an efficient resource schedule mode is built to solve the conflict of multi-user effectively in Tracking and Data Relay Satellite System in this paper. Mathematical model, improved optimizing algorithm and simulation results are given. Simulation results showed that the proposed algorithm can get the global optimization scheme in acceptable calculation time, which is very important to the technical application.

Keywords-TDRSS (Tracking and Data Relay Satellite System) · Resource Scheduling · Ergodic Searching Alogrithm.

I. INTRODUCTION

The tracking and data relay satellite system (TDRSS) is an aerospace information transmission system, which utilizes the geostationary satellites or high earth orbit to track mon-aircraft customers and customer aircrafts located on the middle and low earth orbit, as well as provides data relay services [1]. TDRSS has been widely applied to observing and controlling, communication and other fields because of the advantages such as high coverage rate, wideband data transmission and high efficiency with low cost. On the other side, one satellite can only provide data transmission service to one or two customers. With the increasing of customers of TDRSS, the resource of TDRSS is getting more and more constraint. As a result, it is very necessary to research on the resource scheduling mode of TDRSS to improve system efficiency and satisfy more transmission applications for more customers.

TDRSS is consist with tracking and data relay satellite (TDRS), ground system and customer terminals. TDRS can capture and track the customer signals and accomplish forward and reward data transmission. Ground system can accomplish the observing and controlling of TDRS, system resource scheduling and data distribution to customers. Customer terminals equipped on the customer platforms can accomplish forward and reward data transmission. TDRS, ground system and customer terminals work together to compose the entire data transmission link.

As a multi-customer shared space data transmission resource, the resource scheduling mode directly affects the application of TDRSS. So building a highly efficient resource scheduling mode of TDRSS is a key problem to be resolved. Macro Adinolfi adopted the heuristic scheduling based algorithm on knowledge and develop TDRSS resource scheduling system of ESRO [2]. Rojanasoonthon adopted the parallel scheduling theory to solve the TDRSS resource scheduling problem, in which the customer priority level is not considered in the mode [3]. Fan Yanshen adopted the constraint satisfaction theory to build the CSP mode, but the solving algorithm is not given [4]. Chen Lijiang proposed a scheduling algorithm based on time flexibility [5]. But it is possible that some customer with low priority level is always refused in the schedule mode. Chen Yingwu proposed the genetic algorithm based on the effective genic path to solve the single link scheduling of TDRS, which is too complex to practical application [6]. Wang Zhilin proposed the antenna scan route optimizing algorithm which can achieve the optimization time of the TDRS antenna setout[7]. The fusion algorithm is proved to be a good way to solve the relay satellite scheduling problem in [8].

II. Resource Scheduling Mode of TDRSS

A. *Resource Scheduling Flow*

Resource scheduling of TDRSS is to allocate antenna resource of TDRS according to the application of customers, which is executed by the ground system of TDRSS. The reasonable resource scheduling mode should try to satisfy the application of customers farthest and improve the working efficiency of TDRSS. The typical resource scheduling flow is given in Fig.1.

As illustrated in Fig.1, the resource scheduling rules decides the constrain conditions of resource scheduling, which can assure the reasonability and efficiency of resource scheduling. As the quantity and capacity of TDRS are limited, the application of customers can not all be satisfied, which leads to the resource conflict. The resource conflict should be solved in the mode. The evaluation of scheduling result is based on the optimizing targets. As a result, this paper designed the three important factors of resource scheduling mode.

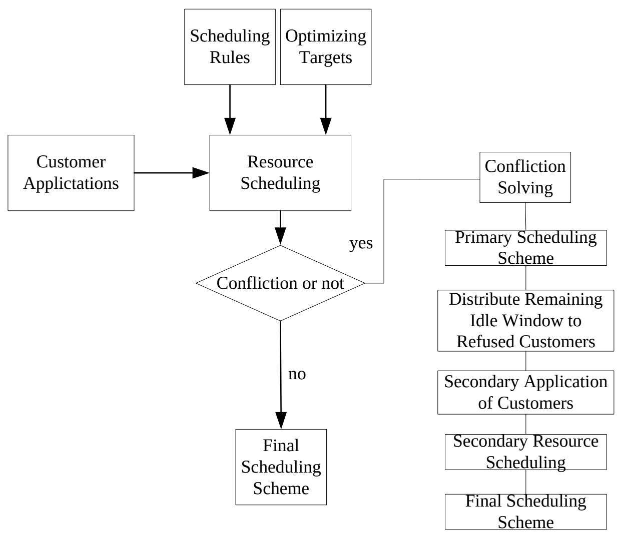

Figure 1. Resource scheduling flow of TDRSS.

B. *Resource Scheduling Rules*

Aiming at the characteristic of resource scheduling and link establishing of TDRSS, this paper proposed six constraint conditions as the resource scheduling rules. The resource scheduling rules are consist of task time window constraint, visible window constraint, shortest task time constraint, task interval time constraint, task relativity constraint and task priority level constraint. Task time window constraint means the task should be accomplished during the time window required by customers. Visible window constraint means the task should begin and finish in the visible window of customers and TDRS. Shortest task time constraint means the service time of every task should not be shorter than the shortest service time defined by the TDRSS. Task interval time constraint means the TDRSS needs switching time to configure devices status and from one task to the next task, and the interval time of two adjacent tasks should not be shorter than the switching time interval. Task relativity constraint means the application of task A should be refused if task A and task B are relative and the application of task B is refused. Task priority level constraint means every task of customers should have the corresponding priority level, and the application of tasks with higher priority level should be satisfied first.

C. *Confliction Resolving Methods*

There are two confliction resolving methods of TDRSS, which are idle window distribution and secondary resource scheduling. Idle window distribution can avoid the conflict between application of customers and maintaining operation of TDRSS, which means the ground system reduced time window of maintaining operation of TDRSS before distribution the idle window to customers. Then customers choose the application window in the idle window. Secondary resource scheduling means the system can distribute the remaining idle window to the refused customers in the first resource scheduling procedure. The customers can choose the application window in the remain idle window, which can assure the sufficient use of idle window and resolve conflict without effects on the other customers.

D. *Optimizing Targets of Resource Scheduling*

In the resource scheduling mode proposed in this paper, centralized scheduling method is adopted, which means the ground system of TDRSS collects application of customers in a period of time and process together. Multi-target optimizing method is adopted, which includes maximum satisfaction rate of customers, maximum utilizing rate of system, maximum summation of priority level of accomplished tasks, equilibrium burden of different satellites.

Maximum satisfaction rate of customers means the maximum quantity of accomplished targets during a certain period. Maximum utilizing rate of system means the scheduling result can be taken full advantage of idle window. Maximum summation of priority level of accomplished tasks means the scheduling result accomplish tasks with high priority level as many as possible. Equilibrium burden of different satellites means the tasks should be allocated to different satellites equally to utilize the whole TDRSS resource. In practical operation, we can choose different optimizing target according to different practical conditions, or we can combine different targets to output the best resource scheduling result.

III. MATHEMETICAL MODEL AND OPTIMIZING ALGORITHM

A. *Mathemetical Model of Resource Scheduling*

Aiming at the resource scheduling of TDRSS, resource is defined by $\Omega = \{\omega_1, \ \omega_2, \ \cdots, \ \omega_n\}$, task is defined by $E = \{\varepsilon_1, \ \varepsilon_2, \ \cdots, \ \varepsilon_m\}$, constraint relationship is defined by $C = \{c_1, \ c_2, \ \cdots, \ c_k\}$, $\Omega_{j,k} = \{\omega_{j,k,1}, \ \omega_{j,k,2}, \ \cdots, \ \omega_{j,k,L(j,k)}\}$ is a resource scheduling scheme to accomplish , the quantity of resource is $L(j, k)$. To accomplish the task ε_j , there are N resource scheduling schemes, $\Omega_j = \{\Omega_{j,1}, \Omega_{j,2}, \cdots, \Omega_{j,N}\}$, in which every scheme can accomplish the task ε_j. Assumed that the beginning time of task ε_j is $T_{j,k,s}$,the finishing time is $T_{j,k,e}$ in the scheme . Resource scheduling of TDRSS is to choose the best resource scheduling scheme for task $\varepsilon_j \in E$ with the constraint collection C.

(1) Task Time Window Constraint. Assumed the application time window of task ε_j is $[START_j, END_j]$,task time window constraint can be illustrated by: $\forall\Omega_{j,k} \in \Omega_j$, $T_{j,k,s} \geq START_j$ and $T_{j,k,e} \leq END_j$.

(2) Visible Window Constraint. Assumed that the visible window is $[STW_j, ETW_j]$,the duration time of task is D_j, visible window constraint can be illustrated by: $\forall\Omega_{j,k} \in \Omega_j$, $D_j \leq ETW_j - STW_j$.

(3) Shortest Task Time Constraint. Assumed that the shortest service time defined by TDRSS is $T_{\min}$,and $T_{j,k,s} = \infty$ means the refused task, the shortest task time constraint can be illustrated by: $\forall T_{j,k,s} < \infty, D_j \geq T_{\min}$.

(4) Task Interval Time Constraint. Assumed that the shortest switching time of adjacent tasks defined by TDRSS is $\Delta T_{\min}$, ε_1 and ε_2 are adjacent tasks, task interval time constraint can be illustrated by $\max_{\Omega_{1,k}\in\Omega_1}\{T_{1,k,e}\} + \Delta T_{\min} \leq \min_{\Omega_{2,k}\in\Omega_2}\{T_{2,k,s}\}$.

(5) Task Relativity Constraint. Assumed that ε_1 and ε_2 are relative tasks, task relativity constraint can be illustrated by : if $\max_{\Omega_{1,k}\in\Omega_1}\{T_{1,k,s}\} < \infty$,then $\max_{\Omega_{2,k}\in\Omega_2}\{T_{2,k,s}\} < \infty$.

(6) Task Priority Level Constraint. There are ten levels of priority, 10 is the highest priority level, and 1 to 5 means the tasks of normal mode, 6 to 10 means the tasks of emergency mode.

(7) Maximum satisfaction rate of customers can be illustrated by $\max\left(\frac{M}{N}\right)$, in which N is the quantity of tasks to be scheduled, M is the quantity of tasks that have been scheduled.

(8) Maximum utilizing rate of system can be illustrated by $\max\left(\frac{\sum_{i=1}^{N} C_i D_i}{L}\right)$, in which $C_i \in \{0, 1\}$ means the decision value, $C_i = 1$ means resource needed by the task is scheduled successfully, $C_i = 0$ means the task is refused. And D_i is the service time length of task ε_i, L is the total time length of the idle window.

(9) Maximum summation of priority level of accomplished tasks can be illustrated by $\max\sum_{i=1}^{N} C_i P_i$, in which $P_i (P_i = \{1,2,\cdots,10\})$ is the priority level variable.

(10) Equilibrium burden of different satellites means the tasks should be allocated to different satellites equally to utilize the whole TDRSS resource. Let us define X_j is the utilization ratio of the TDRS j, and $X_j = \frac{T_{uj}}{T_{wj}}$, in which T_{uj} is the total time length of the scheduled tasks of TDRS j, T_{wi} is the total time length of the idle window of TDRS j. $\bar{X}$ is defined as the average utilization ratio of TDRSS, which can be calculated by $\bar{X} = \frac{\sum_{j=1}^{K} X_j}{K}$, in which K is the quantity of TDRS. Mean square error is introduced in to measure the equilibrium of every TDRS, which can be calculated by $\sigma_X^2 = \sum_{j=1}^{K}(X_j - \bar{X})^2 / K$, $\bar{\sigma} = \sqrt{\sigma_X^2}$. As a result, equilibrium burden of different satellites can be illustrated by $\min(\bar{\sigma})$.

B. *Optimizing Algorithm*

Resource scheduling of TDRSS can be solved through global optimum algorithm and non-global optimum algorithm. Global optimum algorithm such as ergodic searching algorithm can get the global optimization result, which has to ergodic search all possible solving path and search for the feasible scheme that can satisfy the constraint conditions and optimizing targets. As a result, the calculation complexity of ergodic searching algorithm is exponential function of p ,quantity of tasks. In practical application, the calculation will be very complex, if p is big. Non-global optimum algorithm such as greedy algorithm can get a result much faster, but it can not assure the result is global optimization. As for TDRSS, the quantity of TDRS and tasks to be scheduled will not be too big. So we adopt partitioned method to improve ergodic searching algorithm to accomplish the searching much faster to satisfy the practical application needs.

We define the historical weight as G , and the original value is 0. To task t_i ,the sum of weight is defined by $V_i = v_{i+1} + v_{i+2} + \cdots + v_p (1 \le i \le p)$, which means the sum of weight after task t_i . During searching process, if the sum of weight of one solving path and V_i is less than G , when the solving path is getting to task t_i , which means no matter how to schedule after task t_i , the sum of weight can not be more than G . Then the solving path is not the optimizing one, and can be ignored. The algorithm flow is given in Figure 2.

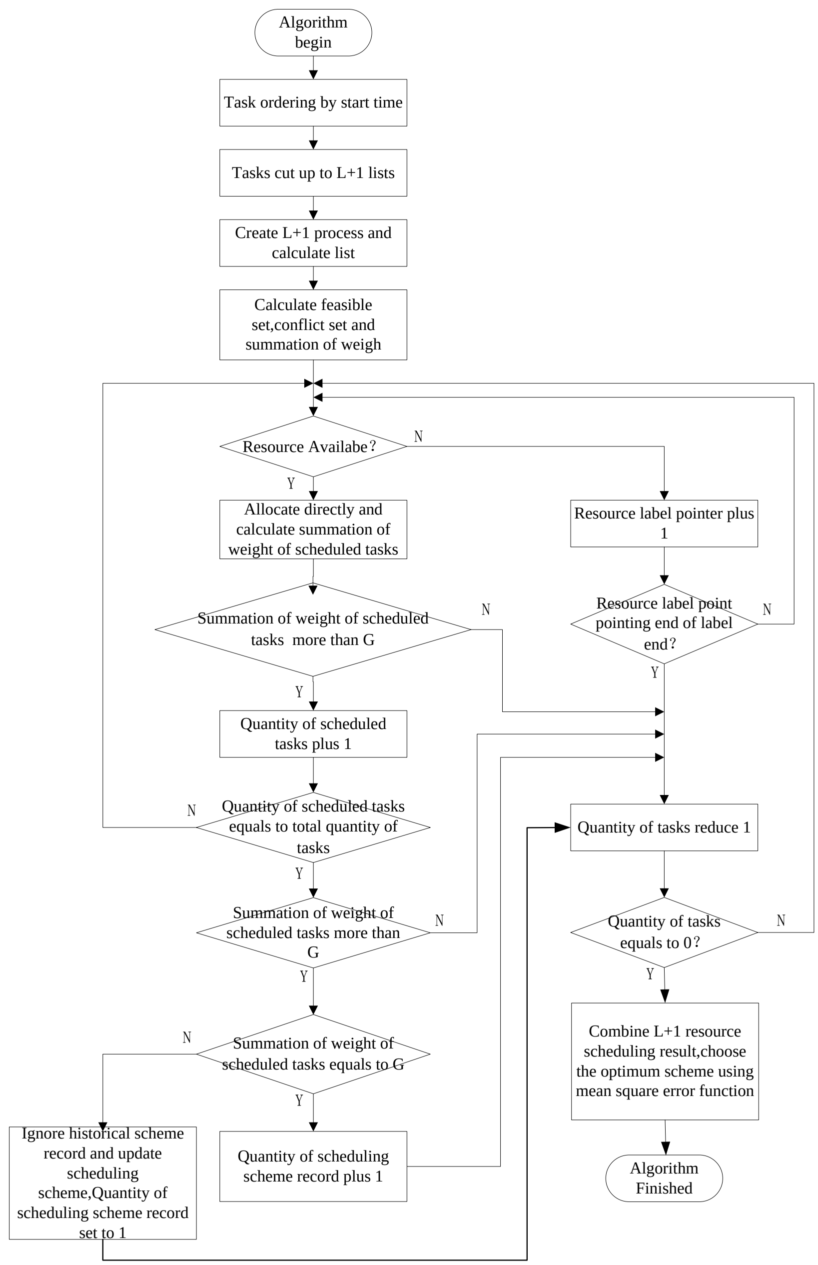

Figure 2. Resource scheduling flow of TDRSS.

In order to verify the validity of the proposed algorithm, simulation experiments are carried out. The simulation condition is that the resource scheduling period is 7 days, from 2016-08-01 00:00:00 to 2016-08-08 00:00:00, there are 5 TDRS, 100 customers, 300 tasks to be scheduled. We take maximum satisfaction rate of customers, maximum utilizing rate of system, maximum summation of priority level of accomplished tasks as the first optimizing targets, and equilibrium burden of different satellites as the second optimizing targets. We compared the calculation results of proposed algorithm and greedy algorithm. The simulation results are shown in Table 1 to Table 5. We can see from the result that the scheduling results of proposed algorithm are better than greedy algorithm. The calculation time of greedy algorithm is less than 30 ms, while the calculation time of proposed algorithm is more than 10 seconds, which is totally acceptable in practical application.

TABLE 1. SATISFACTION RATE OF CUSTOMERS.

	Group 1		Group 2		Group 3	
	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm
Satisfaction Rate	98.67%	93.33%	99.00%	95.33%	98.33%	92.33%

TABLE 2. UTILIZING RATE OF SYSTEM.

	Group 1		Group 2		Group 3	
	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm
TDRS A	0.265	0.381	0.261	0.403	0.255	0.431
TDRS B	0.267	0.332	0.266	0.339	0.264	0.286
TDRS C	0.268	0.296	0.261	0.216	0.260	0.212
TDRS D	0.269	0.159	0.258	0.202	0.258	0.201
TDRS E	0.267	0.103	0.268	0.109	0.263	0.091
MSE	0.0036	0.23	0.008	0.234	0.008	0.251

TABLE 3. SUMMATION OF PRIORITY LEVEL OF ACCOMPLISHED TASKS.

	Group 1		Group 2		Group 3	
	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm
Priority Summation	1709	1594	1589	1530	1605	1509

TABLE 4. IDLE RATIO OF SYSTEM.

	Group 1		Group 2		Group 3	
	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm	Proposed algorithm	Greedy algorithm
Idle Ratio	0.732709	0.745830	0.737336	0.746186	0.739590	0.755742

TABLE 5. CALCULATION TIME.

	Greedy algorithm	Proposed algorithm
Group 1	17s328ms	21ms
Group 2	13s63ms	17ms
Group 3	30s547ms	30ms

IV. Conclusion

Aiming at the practical application characteristic of TDRSS, resource scheduling mode is designed in this paper. Resource scheduling rules, conflict resolving methods and optimizing targets are designed in detail and illustrated by mathemetical modes. The improved ergodic searching alogrithm is also proposed to solve resource scheduling mode of TDRSS. Simulation results show that the proposed algorithm can get the global optimization scheme in acceptable calculation time.

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