Resource Allocation Based on Auction Game of Satellite Avionics System

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Abstract. Along with the development of spacecraft technology, the demands for intelligence and autonomy of future satellites are promoting. However, the operational capability of processor and transmittability of bus are mainly the factors against the promotion in existing satellite avionics system. Moreover, the efficient allocation method for computing and storage resource based distributed architecture is also the valid measures to improve the efficiency of satellite avionics system. In this paper, we focus on the resource limitation of processing units, and mention the resource allocation based auction game of satellite avionics system, advance the use ratio of free resource and optimize the power consumption.

Keywords: Auction game · Satellite avionics system · Resource allocation

1 Introduction

The avionics system is popularly known as the generic terms of spacecraft electronic system, which have the characteristics as based on computer networks, advanced micro-electronic designing and manufacturing technique, and using systematic, integrated and optimized designing in electronic equipment of different subsystem and their function, to improve the performance and reliability. Since 21st century, the avionics system is defined as the complicated electronic system base on progressive large scale integrated circuit, hybrid integrated circuit, and realized in using satellite information network architecture. The avionics system is applied in designing of GEO (Geostationary Earth Orbit) communications satellites of our contrary, and its bearer function is mainly satellite data management [1].

The existing avionics system of GEO satellite communications satellite and subsequent platforms is mainly constitute by SMU (Satellite Management Unit) and ISU (Integrated Service Unit), and connected to the other subsystems and equipment by data bus. It bears the operating system and application software, and in charges of the

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telemetry data collection and tele-command distribution, autonomously thermal control and energy management, FDIR (Failure Detection, Isolation and Recovery) and so on. The SMU and ISU have independent processer, software and storage, could realize the function like software updating and recovery, important data preservation [2, 3].

Along with the development of spacecraft technique, the progressing and carrying capacity improving, application of large-scale reconfigurable satellite platform, the performance enhancement of operating system and application software, the mature of autonomously system optimization and failure detection, means the remarkable promotion of satellite autonomy and intelligence. In the future space-based networks, the avionics system could process basic works and preservation of satellite system even whole space-based networks like data collection, storage and distribution, management of distributed computing resource, contingency plan of failure conduction and recovery by prestored handling mechanism as the satellite programming and management center. The operation of these prestored mechanisms makes independently management of resource and basic function preservation possible.

However, the operational capability of processor and transmittability of data bus are the principal factors which affect the further development of autonomy and intelligence. The insufficient of progressing capacity makes operating complicate resource management and distribution algorithm occupy high range of computing resource, and reduces the operating efficiency of avionics system. The lacks of transmittability of data bus restricts the data exchanging rate among the center progressing unit and distributed processing unit, makes most of distributed progressing unrealizable.

Against upper problems, in following design of communications satellite avionics system, it contains the solution of operational capacity of processor and transmittability of data bus. At the same time, it also needs corresponding resource allocation method, which mainly contains efficient resource allocation method designing for calculation and storage resource in distributed system, to avoid the influence of efficient promotion of avionics system with the improvement of hardware condition.

In this paper, we design a method of resource allocation in satellite avionics system. And the rest of the paper is organized as follows. After introducing the system model and auction game algorithm in distributed satellite processing unit in Sect. 2, the process of resource allocation is discussed in Sect. 3. In Sect. 4, we give the numerical results and analysis. Finally, conclusions are drawn in Sect. 5.

2 System Model

At this stage, the main architecture of satellite avionics system is in Fig. 1. In this figure, the satellite management unit, platform integrated unit and payload integrated unit are equipment of avionics, and connected to the other equipment by data bus (1553B) to exchange telemetry data and tele-commands. Except satellite management unit, the other equipment also has the function of important data storage and recovery. But restricted by the storage space, they could not save too much data. And the 1553B data bus only support 1 Mbps bandwidth, it cannot satisfy the demand to storage and distributed processing. In future communication satellite platform designing, the high-speed bus system is applicative, like SpaceWire. Different from the bus topology of

1553B bus, SpaceWire bus is in architecture of star topology include router [4–6]. As the initiator and participant of resource allocation, the integrated service units have the same configuration performance. And the method in this paper could be implemented not only in distributed system but also in system have central management unit.

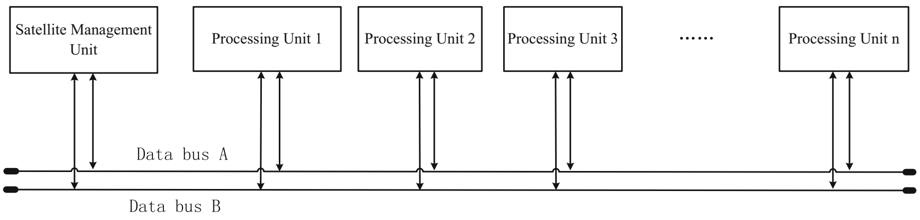

Fig. 1. Architecture of satellite avionics system-bus topology

The algorithm of resource allocation in this paper is the distributed algorithm base on first price sealed-bid (FPSB) auction game. The reason to use the game method to design algorithm is as follows:

(1) The development direction in future avionic system is modularity and intelligence. Therefore, the satellite process units have the independent module qualified computing resource, and format distributed network construction. The central resource management algorithm has poor adaptability to this construction.
(2) Restricted to the limited energy and computing resource, repeated game and iterative algorithm method are inapplicable to the environment of avionic system, waste computing resource, generate more communication overhead, and occupy the bandwidth of communication links [7–10].

The algorithm in this paper could be described as follows: first, cooperative computing means the processing units offer their own computing resource to help the other processing units. The network architecture is in Fig. 2.

Define the parameters: R_s is the computing resource of the initiator in cooperation, and R_{r_i} is the computing resource of the i_{th} participant r_i. W_i is the bandwidth in communications. p_{r_i} is the power in cooperation of participant. Q_{r_i} is the total power of participant. η is the cooperative efficiency. α_i is a function of $p_s \cdot k_i$ is a power price parameter of participant r_i, always larger than 1 and known to r_i itself. The efficiency of participant is expressed as

$$\eta = \frac{R_s}{R_{ri} W_i P_{ri}} \tag{1}$$

The initiator occupies more resource, the participant spend less. And the cooperative efficiency is inversely proportional to consumed power and occupied throughput of bus. From the relationship before, the price generated by participant could be described as

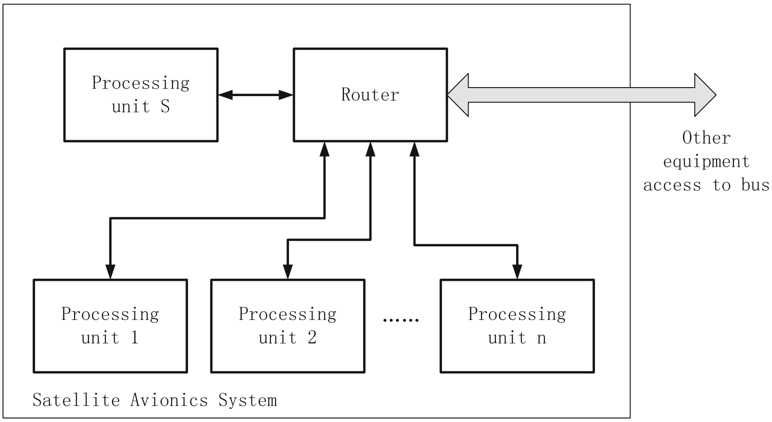

Fig. 2. Architecture of satellite avionics system-star topology

$$\alpha_i(R_s) = k_i R_{ri}(R_s) = \frac{k_i R_s}{\eta(mW_i + tP_{ri})} \quad (2)$$

It has the following properties: while $k_i = 1$, r_i gains no profit from helping the initiator but only cover the cost caused due to the consumed power for cooperation. While $k_i > 1$, r_i make the profit of $(k_i - 1)R_{ri}$. Therefore, r_i has a minimum value of k_i given as

$$k_i^{\min} = 1 + a\exp(-b(Q_{ri} - P_{ri})) \quad (3)$$

Where $a > 0$, $b > 0$, this function denotes that the minimum value of price is increasing with the improving of power of participant in cooperative computing, and reduces the success rate of this participant in auction. While the participant success in auction, its profit is $(k_i^{\min} - 1)R_{r_i}$. The occupied resource of cooperation computing of initiator could be expressed as

$$C_i = R_s + \alpha_i \quad (4)$$

Combined to function (2), we can get

$$C_i = R_s + k_i R_{ri} = R_s(1 + \frac{k_i}{\eta(mW_i + tP_{ri})}) \quad (5)$$

From function (5), we can find that C_i is linear function of R_s, so C_i is continuous of R_s in given data field, and have the minimum value in this field. According to Kakutani fixed point theorem, it exists at least one Nash equilibrium point. The participants based on FPSB auction game algorithm could choose the auction strategy with best profit. Follow this strategy; the system will in a steady state after the participant adjust their strategy self-adaptively.

3 Process of Auction Game Algorithm

In satellite, the processing unit S which initiates the auction game (resource allocation initiator) implement the demand of resource allocation based on its margin of computing resource (or the margin of storage resource, which means the idleness of CPU/storage space, and so on. They have the same variation trend. The increasing of margin reduces the demand of cooperation. We only use computing resource for instance). The initiator computes the resource R_s in cooperation, and allocates it by broadcasting on bus to the other n processing units which are the potential participant of the auction game (resource allocation participant).

The potential participant r_i receives the broadcasting message and gets the information of initiator includes R_s, and calculates W_i, R_{r_i} and p_{r_i}. Based on the result, mentions the price α_i and join the auction by feedback message on bus to the initiator.

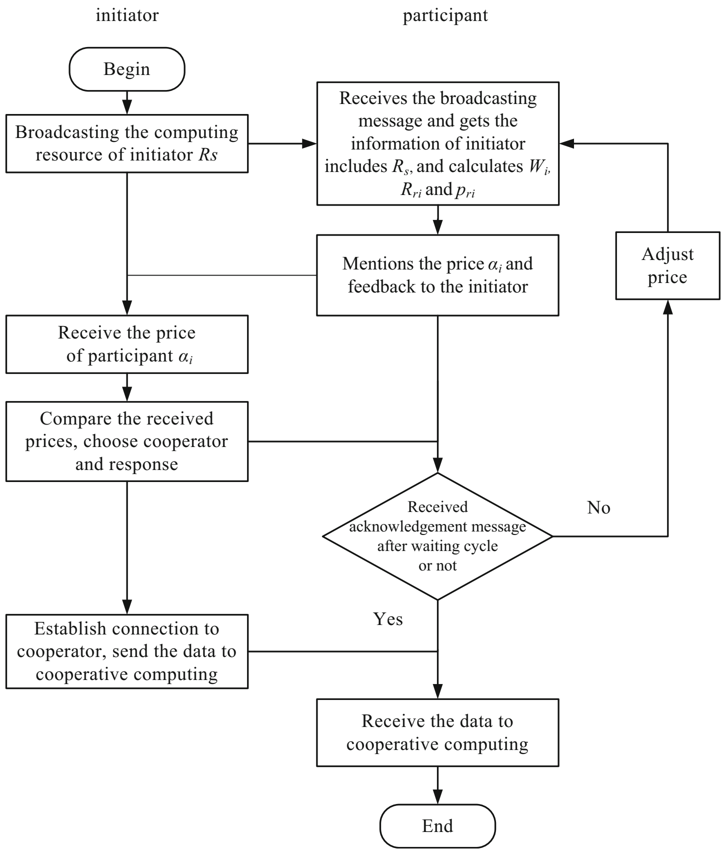

Fig. 3. Process of auction game algorithm

The initiator gets the price from participant in given waiting cycle, then confirms the participant which given the lower price as the bid winner, and establishes the link to it. And send the cooperative data as the proportion of occupying resource, finish distribution.

The winner participant will receive the acknowledgement message and establish link, receive cooperative data from initiator, finish distribution.

The loser participant will not receive the acknowledgement after given waiting cycle, and then consider bidding failure in auction. It will change its auction strategy and improve price when the resource condition permitted, present in the next auction.

The process of auction game algorithm could be expressed in Fig. 3.

Following the program of initiator and participant, the resource allocation could be established. And the course could be finished by satellite processing units autonomously without overall planning and management of central management unit.

4 Simulation Analysis

In this section, we give the simulation results and demonstrate the property of our proposed method. The method we proposed is indicated as MRAF (Method of Resource Allocation based on FPSB), and the contrast algorithm is CPS (Centralized Planning Scheme), which distribute useful resource to satellite processing units have redundant resource for cooperation averagely. In this scheme, the central management unit is necessary. The information of redundant resource of different processing units should be collected before allocation. Therefore, this scheme is not adaptive to distributed architecture. In our simulation, there are less than 10 potential participant except initiator in networks and connected by bus. The bandwidth of bus is set as 100 Mbps, and the maximum consumed power in cooperation is 5 W.

The profit of MRAF in different biding strategy compare to CPS is shown in Fig. 4. The node mention a minimum value of price in function (3), ensure the price satisfied criteria gets positive earnings. The value of a is larger, the node mentions higher price, and the parameter because the opposite effect. At the same time, the lower biding price decreases the opportunity to cooperation and profit; the higher biding price means the participant have strong willing to cooperation. But if participant spend higher price to get the chance to cooperation, it will occupies more redundant resource or exceeds limitation, then the cooperation could not be finished. Therefore, adjusting the biding strategy based on the consequence of auction is efficiency to cooperation based on useful resource. From the simulation result, when $n = 10$, the higher profit is acquire while setting a as 20–70. Adjust $n = 5$, the range of a to get higher profit is 10–40. We can find that, at first, using the resource allocation method in this paper and adjusting the biding strategy and price could get higher profit than distribute directly. Secondly, the increasing of number of participant intensifies competition in networks. If the participant spend same biding price, the success rate of biding decreases along with the participant increasing.

In Fig. 5, we evaluate the profit of MRAF aim a compare to CPS under different number of participants. When $a = 30$, the profit of participant increases with the increasing of number of participants, and get extreme point at $n = 6$ then decreases, but always higher than the profit of CPS. When a = 60, the growth is slow and average profit is higher. We can find that MRAF could get higher profit and the positive strategy get lower profit than passive strategy while the network contains fewer nodes. It means the increasing number of nodes intensifies competition in networks.

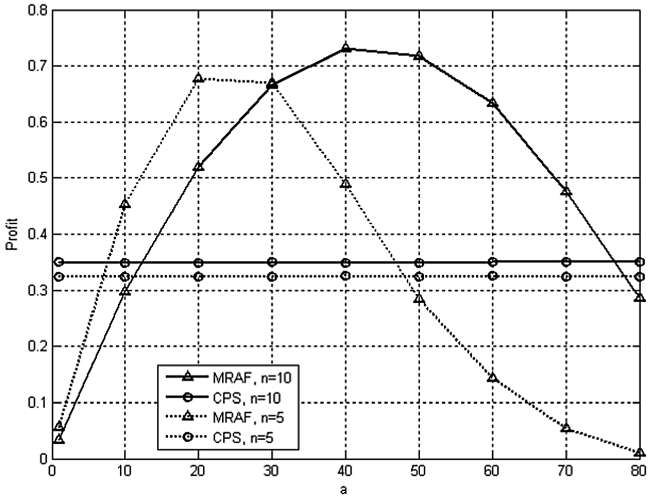

Fig. 4. The profit of MRAF in different biding strategy compare to CPS

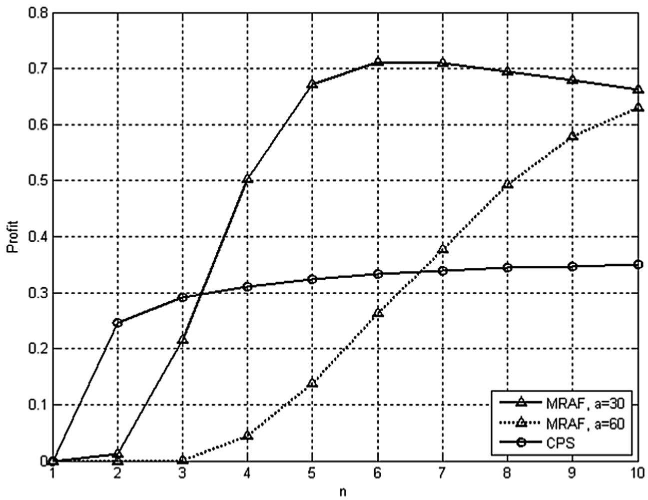

Fig. 5. The profit of MRAF aim a compare to CPS under different number of participants

Figure 6 shows the trend of average biding price of MRAF with different strategy along with the number of participant in network. We can find that fewer participants make them spend higher biding price. But too high price could not acquire profit, which is expressed in Fig. 5. When $a = 60$, $n = 2$, the high biding price makes resource to cooperation exceeds the limitation; with the increasing of number of participants, the average price is decreasing and profit increasing.

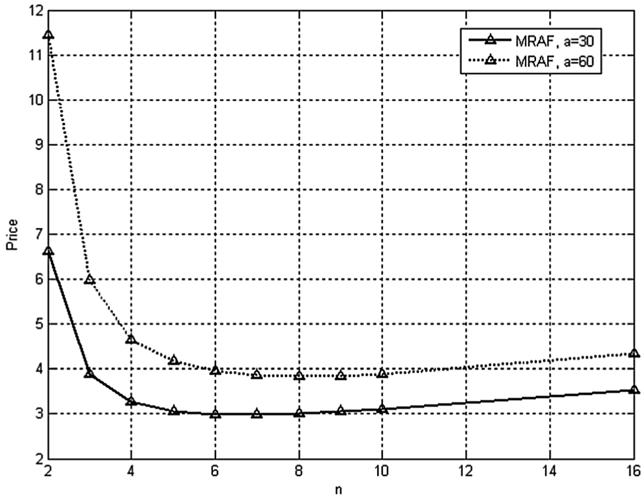

Fig. 6. The biding price of MRAF in different strategy under different number of participants

5 Conclusion

This paper depends on the demand of open avionic system to the capacity of communications, computing and storage, mentions a method of resource allocation of satellite avionic system based on research of intelligent avionic technology and resource scheduling and management. The advantage of this method is as follows:

(1) In common satellite avionic systems, because of the capacity limit in computing and data exchanging, there are not method of resource allocation in distributed network architecture. The method in this paper realizes the resource allocation in this circumstance.

(2) The method in this paper could allocate and cooperative utilize limited resource of processing unit, and improve the system resource utilization and operating efficiency.

(3) The method in this paper decrease the data exchanging on bus than the methods based on repeat game and iterative algorithm, and considered the limitation of resource in processing unit, could improve the occupation in bandwidth and power consuming.

The designing of process of resource allocation algorithm and simulation result prove the effectiveness of this method, and realize coordinating and allocation autonomously in distributed architecture of satellite avionic system, acquire higher profit than centralized planning scheme.

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