

# Satellite Network Resource Association Analysis and Collaborative Optimization Method

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**Abstract.** With the continuous development of satellites, the number and types of satellites continue to grow, people are increasingly demanding satellites, and the demand for satellite networks is increasing. Due to the wide coverage of the satellite, the long distance from the ground, the high dynamics, and many types, the difficulty of satellite network resource management is increased, resulting in a series of problems such as improper resource management and idle resources in the satellite network. In view of the above problems, this paper firstly uses the coarse-grained method to classify the satellite network's multi-dimensional resources and uses the characteristic parameters of the resource elements to perform fine-grained characterization and analysis of the satellite network resources; then, because the single resource element can't meet the needs of various tasks of the satellite network, a multi-dimensional resource element association algorithm for satellite networks is proposed; finally, for the multi-dimensional resource collaborative optimization problem, a resource conversion strategy is proposed to solve the problem of resource shortage in satellite network communication. After simulation verification, the resource conversion strategy is better than the traditional method under the shortage of satellite network communication resources.

**Keywords:** Satellite network; resource management; characterization analysis; correlation algorithm; resource conversion.

## 1. Introduction

With the establishment of the integrated network of heaven and earth, the network is extended to the ground system to the space system. The satellite network complements the ground network by virtue of its wide coverage and geographical conditions. In the future space system, the number of satellites will continue to increase and the types will become more and more complex. Due to the increasing demand of people, the satellite mission is heavy, and the management of satellite networks is becoming more and more complicated. Therefore, targeted network resource management is required for a variety of space mission requirements. From a management perspective, all useful information in a satellite network can be considered as a resource in the network, and unified/local or single planning can improve the local or overall performance of the network. The management object of the satellite network is represented as a resource in the network, and there are also multi-dimensional and multi-standard resource representation methods, and the goal is to optimize the local or overall performance of the network [1].

For effective resource management of a network, you need to understand the resource categories in the network. In terms of satellite network resource classification, satellite network resources are classified into two categories: substantive and functional, that is, classified according to whether they have definable entities[1], among them, physical resources mainly include weight, time, storage space, computing power, etc., while functional resources mainly include connectivity, congestion, stability, reliability, sensitivity, security, and so on. In [2], the SIGSO satellite communication system is designed, and the network resource management strategy and allocation method are described. The satellite communication system is divided into four resource types: satellite payload, frequency, power and spreading code. In [3], a distributed satellite network (DSN) cooperative architecture is proposed, which divides DSN resources into communication and network resources, processes and stores resources and application resources, and proposes a three-layer resource management architecture, which is a physical resource layer and resources. Visualization layer and application layer, which are used to describe the service process of resource management and user requirements.

In [4], due to the heterogeneity of satellite networks (multi-type networks), resulting in the lack of unified organizational planning and its complex and difficult to describe problems, the underlying resources of satellites are divided into four categories, namely processor resources, orbit resources, and communication resources, load resource class. The above-mentioned literature analyzes the resource classification of satellite networks in a coarse-grained manner, and does not perform fine-grained description and analysis on various resources, and they all target satellite communication tasks without considering satellite remote sensing, processing and other tasks. In this paper, in view of the diversified characteristics of satellite network missions, combined with the characteristics of satellite network resources, resulting in different types of resources selected, the satellite network is coarsely analyzed and classified into communication resources, remote sensing resources, etc.

Based on the above analysis, Section 1 of this paper will analyze the multi-dimensional resources in satellite networks. After this analysis, because the single resource element can't meet the requirements of satellite network communication, a multi-dimensional networked resource element association algorithm is proposed. Finally, on this basis, the problem of collaborative optimization between resource elements is analyzed, and a resource conversion strategy is proposed.

## 2. Classification and Characterization of Satellite Network Resources

A satellite network is a dynamic network consisting of satellite nodes and links with nodes [5], as shown in Figure 1, the expression is expressed as:

$$SN = \{\text{node, link}\}$$

where, node represents a satellite node, link represents a communication link.

The satellite nodes in Figure 1 are divided according to the height of the satellite orbit, divided into high-orbit (GEO), medium-orbit (MEO) and low-orbit (LEO). Satellites perform different tasks depending on the height of the orbit. For example, high-orbit satellites are generally geosynchronous orbit satellites, including relay satellites, and are primarily responsible for communications tasks. Low-orbit satellites include remote sensing satellites, navigation satellites, etc. These satellites are mainly responsible for some reconnaissance and observation tasks. Therefore, in a satellite network, in order to accomplish different tasks, the payload resources carried by the satellite when transmitting are different.

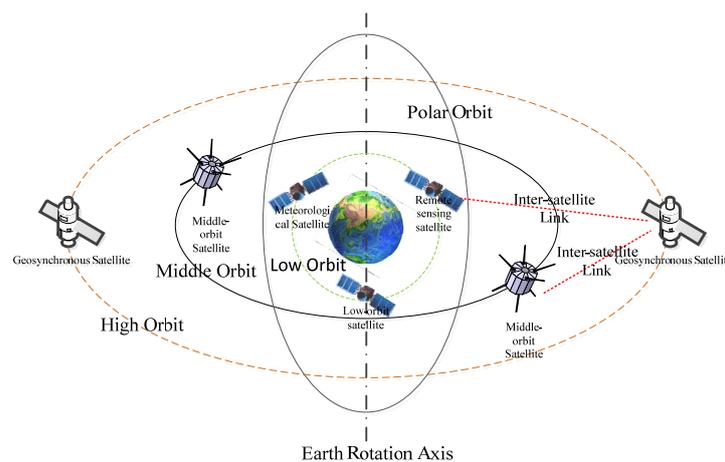


Fig. 1 Satellite network architecture

In [6], the author describes the multi-dimensional resources such as terminal resources, node resources and link resources in the wireless cognitive network as resource elements, and then analyzes the characteristic parameters of the multi-dimensional resource elements in fine-grained manner. The concept of a resource element is explained as: a resource element is a capability individual that can

function as a network communication process of a resource set and can exist independently and have a clear corresponding physical practical meaning.

Therefore, according to the types of satellite network missions and the characteristics of satellite network nodes, this paper divides the satellite's node resources and link resources into coarse-grained into resource elements in Table 1, as shown in the following table:

Table 1. Fine-grained analysis of satellite network resources

Resource Object		Description
node	Communication	Responsible for network end-to-end services
	Processor	Responsible for processing information on the network
	Storage	Responsible for storing information in the network
	Remote Sensing	Responsible for collecting and reconnaissance information
	Energy	Satellite node power problem
link	same-layer inter-satellite	Communicative link between the same track
	cross-layer inter-satellite	Communicative link between different tracks
	ground-satellite	Satellite to ground communication link

## 2.1 Node Resource

Satellite networks have a wide variety of satellites, including communications satellites, meteorological satellites, and Earth observation satellites. Various types of satellites play different roles in space. According to the tasks handled by the satellite nodes, the satellite payload resources are decomposed into communication resources, processor resources, storage resources, remote sensing resources, and energy resources, which can be expressed as:

$$R_{\text{node}} = \{R_{\text{communication}}, R_{\text{processor}}, R_{\text{storage}}, R_{\text{sensor}}, R_{\text{energy}}\}$$

where,  $R_{\text{node}}$  representing node resource,  $R_{\text{communication}}$  representing node resources,  $R_{\text{processor}}$  representing processor resource,  $R_{\text{storage}}$  representing storage resource,  $R_{\text{sensor}}$  representing sensor resource,  $R_{\text{energy}}$  representing energy resource.

Future communication satellites not only have traditional relay functions, but also have powerful on-board switching functions, and have the ability to directly provide access links with a large number of end users, becoming a true user-oriented "Space Switch". Combined with satellite communication characteristics, this paper divides communication resources into: exchange resources, transmission resources, spectrum resources, and antenna resources, which can be expressed as:

$$R_{\text{communication}} = \{R_{\text{exchange}}, R_{\text{transmit}}, R_{\text{spectrum}}, R_{\text{antenna}}\}$$

where,  $R_{\text{exchange}}$  representing exchange resource,  $R_{\text{transmit}}$  representing transmit resource,  $R_{\text{spectrum}}$  representing spectrum resource,  $R_{\text{antenna}}$  representing antenna resource.

For spectrum resources, not only satellite microwave communications, but also laser communications. Therefore, this paper divides spectrum resources into two categories, microwave and laser, which can be expressed as:

$$R_{\text{spectrum}} = R_{\text{microwave}}, R_{\text{laser}}$$

where,  $R_{\text{microwave}}$  representing microwave resource,  $R_{\text{laser}}$  representing laser resource.

The above analysis, the satellite node resource model can be obtained, which can be expressed as:

$$R_{\text{node}} = \{R_{\text{exchange}}, R_{\text{transmit}}, R_{\text{microwave}}, R_{\text{laser}}, R_{\text{antenna}}, R_{\text{processor}}, R_{\text{storage}}, R_{\text{sensor}}, R_{\text{energy}}\}$$

## 2.2 Link Resource

In satellite networks, the factors affecting the performance of communication links are: transmit power and antenna gain at the transmitting end, loss during transmission, noise and interference introduced during transmission, antenna gain and noise of the receiving system. Therefore, the above factors need to be considered in the computational design of the satellite link. According to the spatial distribution, satellite links can be divided into ground-satellite links (GSL) and inter-satellite links (ISL), which can be expressed as:

$$R_{\text{link}} = \{\text{GSL}, \text{ISL}\}$$

where,  $R_{\text{link}}$  representing link resource, GSL representing ground-satellite link, ISL representing inter-satellite link.

According to the orbit, satellites can be divided into high-orbit satellites, medium-orbit satellites, and low-orbit satellites. Therefore, on the inter-satellite link, it is divided into the same-layer inter-satellite links (SLISL) and the cross-layer inter-satellite links (CLISL), which can be expressed as:

$$\text{ISL} = \{\text{SLISL}, \text{CLISL}\}$$

where, SLISL representing same-layer inter-satellite links, CLISL representing cross-layer inter-satellite links.

In summary, the satellite link resource model can be expressed as:

$$R_{\text{link}} = \{\text{GSL}, \text{SLISL}, \text{CLISL}\}$$

## 2.3 Resource Characterization

The coarse-grained classification analysis of satellite networks resources in A and B is not enough for the perfect analysis of satellite network resources. It is necessary to conduct fine-grained analysis of various resources to ensure the integrity of their resource information. This section will describe the fine-grained feature parameters of the satellite network multidimensional resource elements.

A feature parameter is a physical quantity information parameter used to characterize and describe the nature and state of a resource element. Separate feature parameters do not have the full physical function meaning, and several feature parameters need to work together to reflect the actual situation of resource elements. For the feature parameters describing the resource elements, they can be divided into two categories: description attribute and description state according to the description angle and mode, which are attribute parameters and state parameters, which are interpreted as:

**Attribute Parameters:** used to indicate the fixed characteristics of resource elements, or some fixed specific settings and specification features, such as the resource element's logo, affiliation, scope of investigation, use system, observation method, and so on.

**State Parameter:** used to describe the specific use of a resource element or the characteristic information in a change. It usually needs to describe the usage and utilization status of the resource element from the quantity or proportion, which can reflect the remaining or can be the ability to use.

According to the above description of the characteristic parameters, the multi-dimensional resources of the satellite network can be characterized and analyzed by means of the phase parameters and the state parameters. This paper selects the typical resource elements in the satellite network: processor resources and remote sensing resources, and uses the characteristic parameter description method to characterize and analyze these two resources.

**Processor Resources:** Processor (CPU) resources on the satellite can effectively handle information compression, calculation and other issues. According to the characteristics of the

processor, the attribute parameters of the processor of the satellite node are the node ID, the number of processors, the instruction set, the working frequency, and the memory (because the CPU reads the data in the memory, the memory is added to the processor resource) Such parameters, while the state parameters of the satellite node processor resources have parameters such as temperature and time. The specific feature parameters of the processor resources describe the pin analysis of the available data structures, as shown in Table 2.

Remote Sensing Resources: Remote sensing satellites can cover the entire Earth or any designated area within a specified time. When operating on geosynchronous orbit, it can continuously remotely sense a designated area on the Earth's surface. The remote sensor is one of the main payloads of remote sensing satellites and can provide mission support for remote sensing satellites. Here, the remote sensor resources are referred to as remote sensing resources. The specific characteristic parameters of the remote sensing resources can be analyzed by the hands of the data structure, as shown in Table 2.

Table 2. Processor resource characterization

<pre> Struct Rc = { // Attribute Parameter Node ID; // satellite node ID where the processor is located Number of processors; // number of processors Performance parameters; // working frequency, Cache capacity and other parameters Instruction set; // instruction system matching hardware circuit Processing technology; // number of threads, core number and other parameters Memory capacity; // processing information capacity Power; // processor power consumption indicator Time resolution ;// information processing time metric //Status parameter Temperature; // processor temperature status Time ;//processing time Processing efficiency; // processing file rate } </pre>	<pre> Struct Rse= { // Attribute Parameters Node ID; // satellite node ID where the remote sensor is located Types of remote sensing applications; //including meteorology, land, oceans, etc. Recording method; // including film, image or digital tape, etc. On-board load; // refers to the type of camera or scanner on a remote sensing satellite Power; // remote sensor consumption of energy indicators Spatial resolution; // to distinguish the size of the smallest unit of the image Time resolution; // acquisition, reconnaissance task time measurement //Status parameter Time ;//remote sensing task duration Spatial location; // spatial location of remote sensing satellites Mission status; // whether remote sensing tasks are in progress } </pre>
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In Table 2, the processor resources and remote sensing resources are characterized and analyzed in detail. Other types of resource elements (such as storage resources, energy resources, etc.) can also be analyzed and analyzed by this representation. Through the results of this characterization analysis, network resources can effectively support the establishment of the network resource management database. The resource management database can not only store resource information about the satellite network, but also allocate resources for tasks in the satellite network in real time, so that satellite network resources can be made. The utilization rate has been greatly improved. The design and research of the satellite networks resource management database will be an important research direction for the future development of satellite networks, and the resource characterization content proposed to this paper is the basic condition for database establishment.

### 3. Resource Association Research

In the previous section, the classification and analysis of satellite network multi-dimensional resources were carried out, and the typical resource elements were characterized and analyzed. This method is to reduce the problem of zero and break with one by one. However, in actual communication requirements, resource classification analysis is only the first step in order to achieve end-to-end communication purposes. Because in a satellite network, the completion of a task is the organic integration of the resource elements of these categories, any single resource element cannot be properly run separately to complete the task. It is precisely because satellite networks need to integrate multi-dimensional network resources organically in order to accomplish tasks, so we need to design a resource correlation algorithm to solve such problems.

#### 3.1 Analysis of Related Ideas

When the satellite is launched into orbit, it carries various payload resources (such as various remote sensors, memories, processors, etc.) and some logical resources (such as frequency, frequency band, etc.), which constitute the sharable resources of the entire network [7]. The ground station will make mission requests for these different types of resources according to the actual situation. For example, the completion of the reconnaissance mission often needs to be completed by including various resource elements such as remote sensing, storage, and communication. And for the characteristics of the satellite network, since the launch cost and operating cost of the satellite are directly proportional to its weight, and the resources after the orbit is usually not expandable, the resources on the satellite are limited, compared to the ground network resources. It is especially valuable. However, when the satellite network completes the task, due to the richness and timeliness of the task, the phenomenon of resource waste and low resource utilization often occurs.

Based on the task-oriented thinking of satellite networks, completing a task may invoke different resource elements. According to the different types of tasks, the combination of resource elements is calculated, and the task requirements of the user are completed by the combined resource element sets. This calculation process is called resource element association analysis. The purpose of this design is to effectively prevent other tasks from occupying resources other than their own tasks, resulting in wasted resources.

#### 3.2 Association Algorithm

This section will design a resource element association algorithm for the problem of satellite network multi-dimensional resource element association and combination. The data flow chart of the association algorithm is shown in Figure 2 (only the communication task, reconnaissance task and storage task are listed, and other task analysis methods are similar), and the associated algorithm is shown in Table 3.

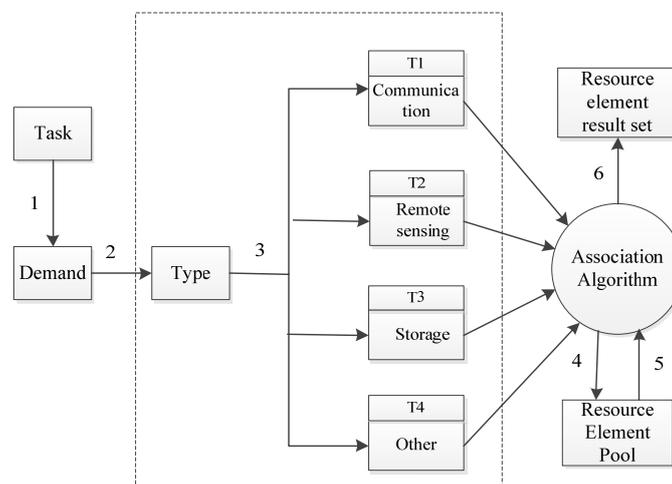


Fig. 2 Association algorithm data flow diagram

**Table 3. Resource association algorithm**


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1 At some point, the satellite needs to complete some tasks.
2 BEGIN Task requirements analysis, prioritize tasks
3 SWITCH (Satellite Network Mission)
4 CASE: Communication Task
5   A:Find resource pools in the satellite network resource management system
6     if Delay sensitive communication task
7       then Emergency mission plan
8     else Non-delay sensitive communication task
9       then Joint storage resources, energy resources, communication resources, etc.
10    break
11 CASE:Remote sensing mission
12 go A
13 default: go A
14 END

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Steps 6 and 8 in Table 3 are collections of resource elements designed according to past experience, that is, result sets of association algorithms. The design of this part comes from human intervention. Through the artificial regulations, the resource elements of various tasks can be set up, and the result set is used to allocate resources to complete the satellite network task. The artificial regulation can avoid the waste of resources of the satellite network due to other reasons. For example, an urgent image acquisition task requires the remote sensing satellite to collect the image and directly transmit it back to the ground without storing the image information collected by the remote sensing satellite. In the storage hard disk, since the image information is not allowed to be stored in the storage hard disk in advance, the satellite networks saves the image information about the task to the storage disk, which results in waste of storage resources of the remote sensing satellite node in the satellite network. The phenomenon occurs. With regard to the analysis of resource association algorithms, the following focuses on the analysis of resource element set analysis methods of reconnaissance tasks.

**Delay-sensitive reconnaissance mission:** The general delay-sensitive mission is an emergency mission. It can directly call the available satellites to directly perform reconnaissance operations on target area, and then directly transmit the image information back to the ground station. Among them, it may involve overseas reconnaissance, and the image cannot be directly transmitted back to the domestic ground station, but the data is transmitted to the relay satellite. Because it is an urgent task, the time is as short as possible, and it is better to use a laser to make it transfer faster. Therefore, the resource elements that may be required are remote sensing resources, cross-layer inter-satellite links, satellite link resources, processor resources, spectrum resources (laser), transmission resources, and exchange resources. These seven resource elements are combined with a set of elements. Used to complete delay-sensitive remote sensing tasks, as shown in Table 4.

**Non-delay-sensitive reconnaissance mission:** Generally, the non-delay-sensitive mission is a general-level mission. After the reconnaissance of the target area is over, the image can be compressed and processed in the satellite hard disk, waiting for a suitable time to be transmitted back to the ground station. Because it is a non-emergency task, in order to save costs, it is natural to consider satellite power consumption and transmission speed issues, and also consider using microwave transmission and minimizing satellite power consumption. Therefore, the required resource elements are remote sensor resources, inter-satellite link resources, cross-layer inter-satellite link resources, satellite link resources, processor resources, spectrum resources (microwave), antenna resources, transmission resources, and exchange resources, energy resources, these 10 resource elements are also combined with a set of elements, used to complete non-delay-sensitive reconnaissance tasks, as shown in Table 4.

The above analysis of the reconnaissance task, these two examples reflect the results of the resource element association, through the different tasks to complete the combination of resource elements, so that the original independent resource elements in the network are all together, forming

a collection of resource elements, for the satellite the network completes the necessary tasks. For communication tasks, storage tasks, and other tasks, the analysis method is like the above method.

Table 4. Reconnaissance task instance

Task Type	Resource Element Collection
Delay sensitive reconnaissance mission	Remote sensing resources, spectrum resources (laser), transmission resources, exchange resources, cross-layer inter-satellite links, ground-satellite link resources, processor resources
Non-delay sensitive reconnaissance mission	Remote sensor resources, antenna resources, transmit resources, exchange resources, energy resources, inter-satellite link resources, cross-layer inter-satellite link resources, ground-satellite link resources, processor resources, spectrum resources (microwave)

#### 4. Research on Resource Synergy Optimization

Due to limited resources on the satellite, resulting in small system memory, low CPU processing power, limited power supplies, etc., satellite node resources in satellite networks have great limitations, and once in heaven, due to on-orbit hardware it is difficult to upgrade, so it is difficult to upgrade and replace node resources. In addition, the inter-satellite links are relatively fragile, making it difficult to work together between nodes [8]. Since the load resources in the satellite network are sharable, a method called resource conversion strategy is proposed to these satellite network problems.

As shown in Figure 3, if the data is not compressed using computing resources, only the data of tasks b and c can be returned under given communication conditions. If the data is compressed, under the given communication conditions. The data onto tasks a, b, and c can be returned. This method of using computing resources to reduce the burden of communication resources is a resource conversion strategy.

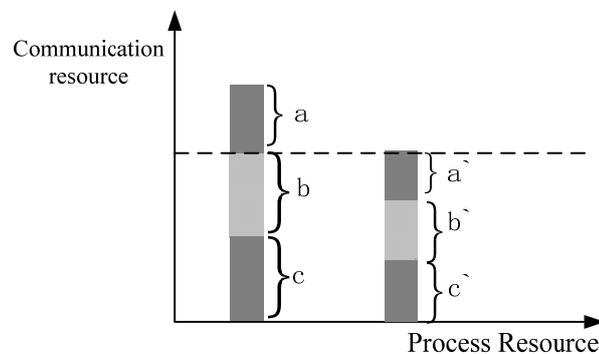


Fig. 3 Computing resource and communication resource conversion

According to the analysis of FIG. 3, the importance of the resource compression processing is to improve the network transmission efficiency. In satellite networks, the computing resources of a single satellite are limited. When a remote sensing satellite needs to transmit the collected image back to the ground station, many problems may be encountered. For example, the resources of the satellite link are not sufficient, and the remote sensing satellite itself has insufficient computing resources. In this situation, the following two methods can be adopted: The first method is to continuously consume a large amount of remote sensing satellite's own computing resources, compress the image and then transmit it back to the ground station. The second way are to transmit part of the image information to other satellite nodes (herein referred to as idle satellite nodes). After the other idle satellite nodes process the compressed image information, the information is transmitted back to the ground station.

Two ways are shown in Figure 4, where the solid red line indicates the first mode and the dashed line indicates the second mode.

Both the first and second approaches reflect the resource conversion strategy. But the second way uses the idea of distributed transformation strategy. As can be seen from FIG. 4, the distributed resource conversion strategy can play its role when it has idle resources. However, how to know that there is satellite nodes have idle resources required for the conversion strategy, which involves the application of the database. The two resource conversion strategies have their own advantages and disadvantages. If the amount of resource information is small, but the communication requirements are also not met, the first resource conversion strategy is recommended as this case. If the amount of resource information is large, the second resource conversion is recommended. The strategy can reduce the burden on a single satellite node and optimize the processing delay of satellite network tasks.

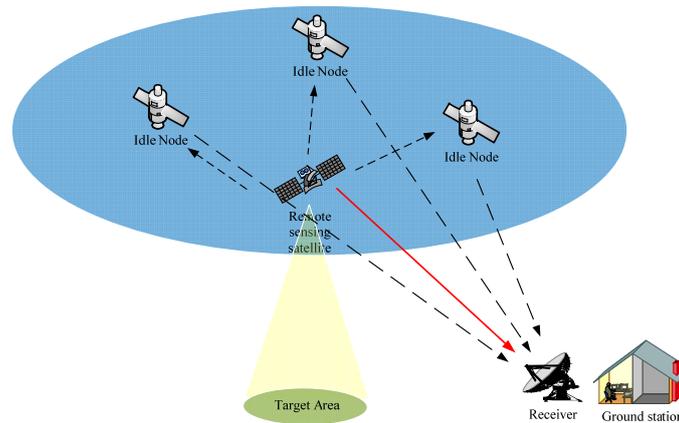


Fig. 4 Resource conversion diagram

## 5. Simulations

### 5.1 Simulation Environment

#### 5.1.1 Hardware Platform

The host hardware parameters used in this simulation are as follows:

CPU: Intel®Core™i7-4790 CPU@3.60GHz

RAM:16G

Hard Disk: Samsung SSD 750 EVO 250G SCSI Disk Device (250G)

#### 5.1.2 Software Platform

The software environment used in this simulation is as follows:

OS:win7-64

Software:Matlab

### 5.2 Modeling

Table 5. parameter settings

Parameter	Description
$T_1$	The first way to consume time
$T_2$	The second way to consume time
$\tau$	The second way to consume time
$n$	Number of idle satellite nodes
$G$	The size of information capacity
$V$	CPU processing rate

The first way data modeling: This method consumes a large amount of computing resources of the satellite itself to compress the data. Therefore, it can be expressed as:

$$T_1 = \frac{G}{V} + \tau \quad (1)$$

The second way data modeling: this method is to transfer data to other idle satellite nodes, to obtain computing resources at the expense of communication resources. Therefore, it can be expressed as:

$$T_2 = \frac{G}{nV} + 2n\tau \quad (2)$$

### 5.3 Simulation Analysis

Simulation data: (1)The  $V$  in Equation 1 and Equation 2 uses the CPU processing rate of the local experimental environment, which is set to 3.6 GHz. (2) The communication link loss time  $\tau$  is the same, and both use microwave communication, that is, set to 3.7ms (where the microwave transmission speed is  $3 \times 10^8$ m/s, and the distance is the low-orbit satellite average height of 1100km). (3)The  $n$  is 3, 5, and 7, which means there are 3, 5, and 7 idle satellites.

It can be clearly seen in Figure 5 that the use of a resource conversion strategy optimizes the delay in completing a satellite networks task. And as the size of the information that needs to be processed continues to increase, the time it takes to complete the task is relatively less and less. It can also be analyzed from the figure that if the information capacity is larger, the more the number of satellites distributed over the idle satellite, the less time it takes to complete the task.

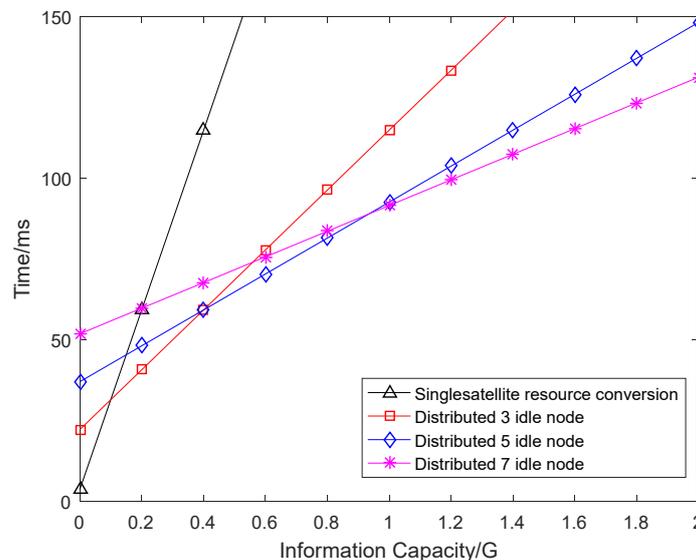


Fig. 5 Resource Conversion Comparison Chart

This paper analyzes the characteristics of satellite node resources and link resources, and establishes a node model and a link model. Characterization and analysis are carried out through the attribute and state characteristics of satellite nodes and links. The attribute parameters and state parameters of each resource element in the satellite network are introduced in detail. Since the single resource element could not complete the satellite network task, the resource association problem was discussed and the resource association algorithm was designed. Finally, the problem of resource collaborative optimization is discussed, and the advantages of resource conversion strategy are verified by simulation verification. The formation of the database can be supported by the resource information formed by the characterization. The next step is to design the satellite network database,

and then analyze the resource matching algorithm to get the best solution for completing the satellite network task.

## References

- [1]. W Rui, H Xiaodong, W Chao, Z Xi, L Jun. Resources scheduling and cooperative management of space-based information networks[J]. *Journal of Communications*, 2017, p. 104-109.
- [2]. H Zhengqun, SIGSO Satellite Communication Resources Management. 2016 Sixth International Conference on Instrumentation & Measurement, Computer, Communication and Control (IMCCC). Harbin, 2016, p. 43-46.
- [3]. X Guo, H Zhou and G. Liu. Service oriented cooperation architecture for distributed satellite networks. 2015 International Conference on Wireless Communications & Signal Processing (WCSP). Nanjing, 2015, p. 1-5.
- [4]. Q Liu and L Yao. Satellite resource description and search based on hybrid granularity. 2018 IEEE 15th International Conference on Networking, Sensing and Control (ICNSC). Zhuhai, 2018, p. 1-5.
- [5]. M Manhao, Q Dishan, W Liang. Research on Modeling Method of Network Topology Structure of Space-based Information System[J]. *Journal of Wuhan University (Information Section)*, 2009, p.606-610.
- [6]. Liu Qin, Kwak Kyung. Decomposition analysis with layered structure for cognitive network resources. *IEEE*, p.636-641.
- [7]. Xu Ke: Resources Optimization Research for Tasks in Satellite Network[D]. master's degree, Shenyang University of Technology, China, 2010.
- [8]. M Xiangli, Wu Lingda, Y Shaobo. Research on Resource Management Mechanism of Space Information Network Based on Virtualization [J]. *Journal of China Academy of Electronics Science*, 2018.p.47-52.