Using Space Internet to Implement Spacecraft Automatic Operation and Control

Jing LI，Pei-jun YU，Jian-ping LIU and Jian BAI
State Key Laboratory of Astronautic Dynamics
Xi'an Satellite Control Center
Xi'an, China，710043

In order to resolve the problems of the operating mission being more complex, the servicing range being wider, the demand of air - space – ground TT&C (Tracking, Telemetry and Control) being stronger and stronger in the future, the idea of automatic operation and control for spacecraft based on space internet is proposed. The architecture and operating flow for integrated space – ground TT&C network are designed, simultaneously. The key techniques needed to study for implement automatic operation and control are discussed, finally. The idea of automatic operation and control for spacecraft is to share the data resource through the space internet. The cooperated work of multi-system and multi-mission is implemented by means of TT&C mission integrated scheduling technique. The integrated space – ground TT&C network is composed of GEO/MEO /LEO spacecraft, constellation and ground TT&C network. The purpose of space – ground united TT&C is to save ground TT&C resource. The key techniques include: the integrated planning technique of TT&C mission, the centralizing scheduling technique for mission operating center, the conflict automatic inspect technique, the managing technique for inter-satellite link. The researching production will be applied to enhance the level of mission planning and to reduce the dependent on ground TT&C station in the future.

Nomenclature

TT&C	=	Tracking, Telemetry and Control
GEO	=	Geostationary Earth Orbit
LEO	=	Low Earth Orbit
MEO	=	Medium Earth Orbit
ORS	=	Operationally Responsive Space
TDRSS	=	Tracking and Data Relay Satellite System
ISL	=	Inter Satellite Link
USB	=	Unified S – Band
UCB	=	Unified C – Band
SA	=	Single Access
MA	=	Multi – Access
RF	=	Radio Frequency
LEOP	=	Launch and Early Orbit Phase

I. Introduction

THE main space activities of mankind in future twenty years include: the Earth mission, the Moon mission and the Mars mission. There into, the Earth mission includes: exploration, surveillance, navigation and communication mission for all kinds of Earth orbit spacecraft; the near space vehicle mission for various usages; the unmanned aerial vehicle mission; the space range mission. There are three characteristics for the future TT&C development trend which is introduced by different mission. That is, the operation missions are more and more complex, the serving range is wider and wider, and the requirement for air-space-ground TT&C is stronger and stronger. The amount of Sinic satellite will increase to 200 in 2030's. So, we will be faced with the enormous challenge for the mission operation. These include:

1) The challenge of management concept. That is, the managing pattern of low cost and high reliability should be studied. The software and hardware facilities which are easy to maintenance, upgrade and scalability should be developed.
2) The challenge of complex operational missions. That is, the frame of operation and control center should be reasonable and whit the ability of missions analysis. The TT&C ground stations can well cooperate with the operational center. The TT&C resource should be scheduled flexibly.
3) The challenge of entering into new TT&C field. That is, the near space vehicle TT&C mission, Operationally Responsive Space (ORS) mission and the air-space-ground integrative TT&C mission can be supported by the same system.

In the early 1998's, DARPA (Defence Advanced Research Projects Agency) help JPL (Jet Propulsion Laboratory) to start up the research of space internet. It means the internet will be extended to space from ground. Also, NASA (National Aeronautics and Space Administration) begin to research the project in 2002. Up to now, the research for related concept has accomplished by some countries. Ongoing works at space internet are about system simulation, ground experiment and flight experiment. The related criterion and research proposal have been proposed. The part of research has been carried on in China during past five years. But, the researching contents in China are different from other countries, and the production is not more advanced than some countries [1,2,3,4].

Aim to the above challenge, the idea of automatic operation and control for spacecraft based on space internet is proposed, firstly. Then, the architecture and operating flow for integrated space – ground TT&C network are designed, simultaneously. The key techniques needed to study for implement automatic operation and control are discussed, finally.

II. Architecture of TT&C Network Based on Space Internet

A. Composition of Chinese Space Internet

The general constructive aim for Chinese integrated space – ground space internet is to establish a integrated satellite to satellite, satellite to ground and ground to ground network system. The datum from spacecraft and the satellite operation resource will be shared. All kinds of service are not limited to one series of satellite or one kind of user, but various kinds of satellite and user[1].

Chinese space internet can be divided two sections —— space section and ground section. An integrated internet will be established with the link between space and ground. The end to end transmission service will be provided to different clients through space internet with the capable of security protection.

Space section includes: TDRSS (Tracking and Data Relay Satellite System), navigation constellation with ISL (Inter Satellite Link), formation flight with ISL, GEO/MEO/LEO satellite with ISL and GEO/MEO/LEO satellite with satellite to ground link.

Ground section includes: USB (Unified S — Band) TT&C equipment, UCB (Unified C — Band) TT&C equipment, deep space TT&C equipment, application equipment and user's equipment.

Chinese space internet is a kind of multi-layer and tridimensional network which is composed of various kinds of subnet[5]. Figure 1 shows its architecture. Here, the space internet is consisted of deep space explorer, the Moon explorer, GEO satellite, MEO constellation, LEO formation flight, ground / sea based TT&C equipment, launch site and ground operation center.

The architecture elements of space internet are included as: backbone network, access network and subnet. There into, inter-spacecraft network, space surveillance network, ground command & control center and ground operation center are included as backbone network. The interface of backbone network is the antenna of TT&C facility or monitoring facility and aerospace with ISL. The independent node with capable of SA (Single Access) or MA (Multi - Access) transmission, constellation and formation flight are included as subnet. Its interface is RF (Radio Frequency) facility or optical facility. The node facilities connected with backbone network and subnet are access network. The interfaces are baseband equipment, receiving equipment, transmitting equipment, antenna and matching facility of backbone network.

B. Architecture of Chinese TT&C Network

Chinese TT&C network is consisted of space based TT&C network and ground based TT&C network. The architectural elements of space based TT&C network are included as TDRSS, navigation constellation, LEO formation and the satellite with ISL. The architectural elements of ground based TT&C network are included as UCB TT&C network, USB TT&C network, LEOP (Launch and Early Orbit Phase) TT&C network, space surveillance network,

deep space network, network management center, mission operation center and application center. The architecture sketch is shown by Figure 2.

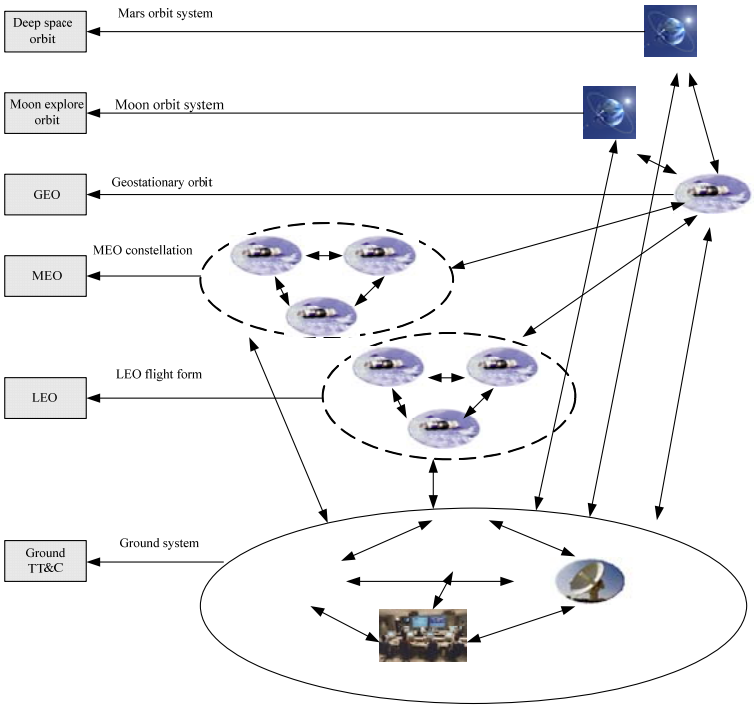

Figure 1 Space internet architecture

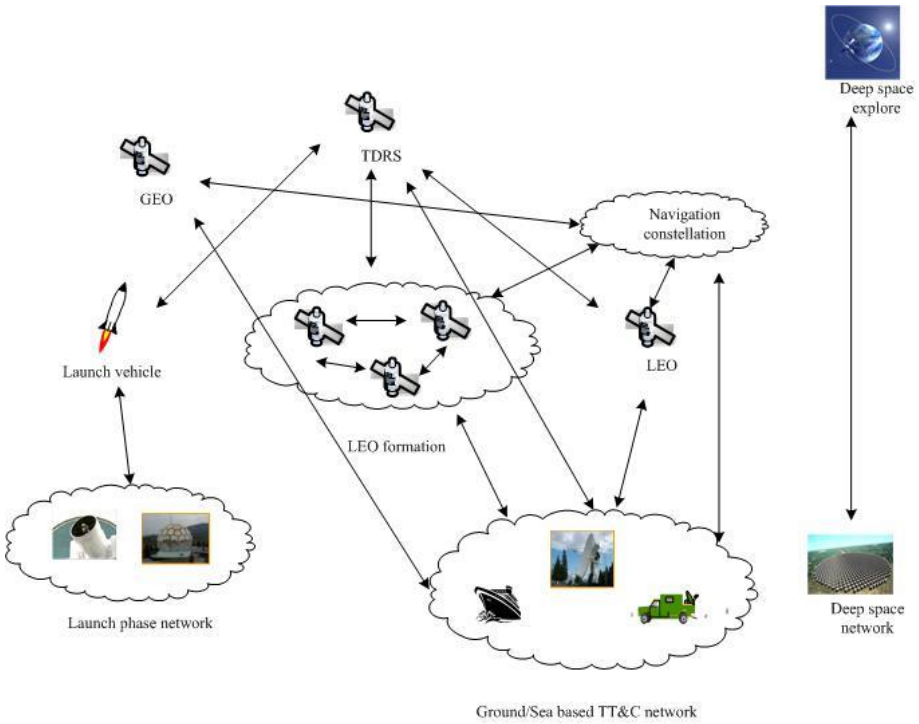

Figure 2 Chinese TT&C network architecture

According to Figure 2, we can know that launch vehicle, GEO satellite, navigation constellation and LEO formation can be operated by integrated satellite to ground mode.

III. Requirement Analysis for Missions Automatic Operation and Control

A. Frame of TT&C Missions Automatic Operation

Let's assume that the automatic operation for space internet is divided into four levels, they are separately automatic operation of ground TT&C facilities, automatic operation of ground TT&C system, automatic operation of TT&C missions and automatic operation of TT&C network.

The automatic operation of ground TT&C facilities means that the parameters and function can be set through the method of centralize and remote operation. Stations are now remotely operated on a routine management [6,7].

The automatic operation of TT&C system means that the TT&C facilities, calibration facilities, time/frequency facilities, data transmission facilities and communication facilities can be remotely and centrally operated. The ESOC (European Space Operations Center) has developed the EMS (ESTRACK Management & Scheduling System), and the automatic operation of the ESTRACK (ESA (European Space Agency) Tracking Network) has been achieved[8]. Figure 3 is a sketch of Chinese station automatic operation.

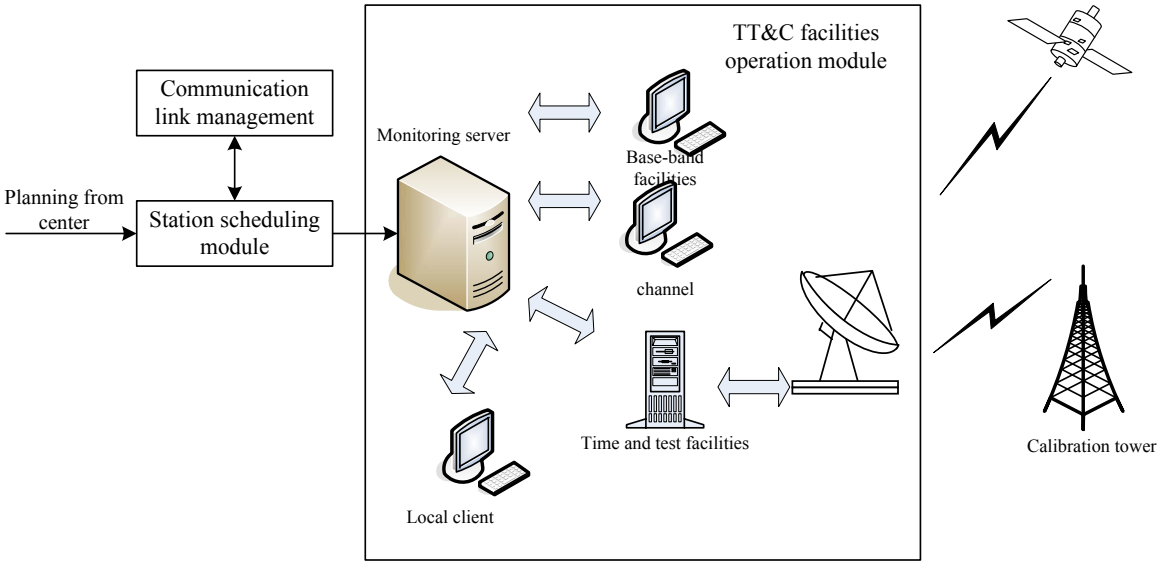

Figure 3 A sketch of Chinese station automatic operation

The automatic operation of TT&C mission means that the function of TT&C mission analysis, TT&C mission preparing, TT&C resource scheduling, TT&C mission planning, TT&C mission operation, TT&C strategy simulation, orbit prediction and determination, TT&C mission evaluation and malfunction diagnosis can be achieved through developed management system. Figure 4 is a sketch of mission operation center.

The automatic operation of TT&C network means that the space based TT&C network cooperates with ground based TT&C network to operate satellite through space internet. The main function includes as automatic schedule of TT&C network, automatic plan of integrated space — ground TT&C mission, automatic conflict detection and optimization of integrated space — ground TT&C resource, TT&C support for emergency TT&C and coordinated operation. Figure 5 is a sketch of TT&C network automatic operation.

The automatic operation priority for space internet is: automatic operation of ground TT&C facility → automatic operation of ground TT&C system → automatic operation of TT&C mission → automatic operation of TT&C network. The automatic control priority for space internet is: automatic operation of TT&C network→ automatic operation of TT&C mission → automatic operation of ground TT&C system → automatic operation of ground TT&C facility.

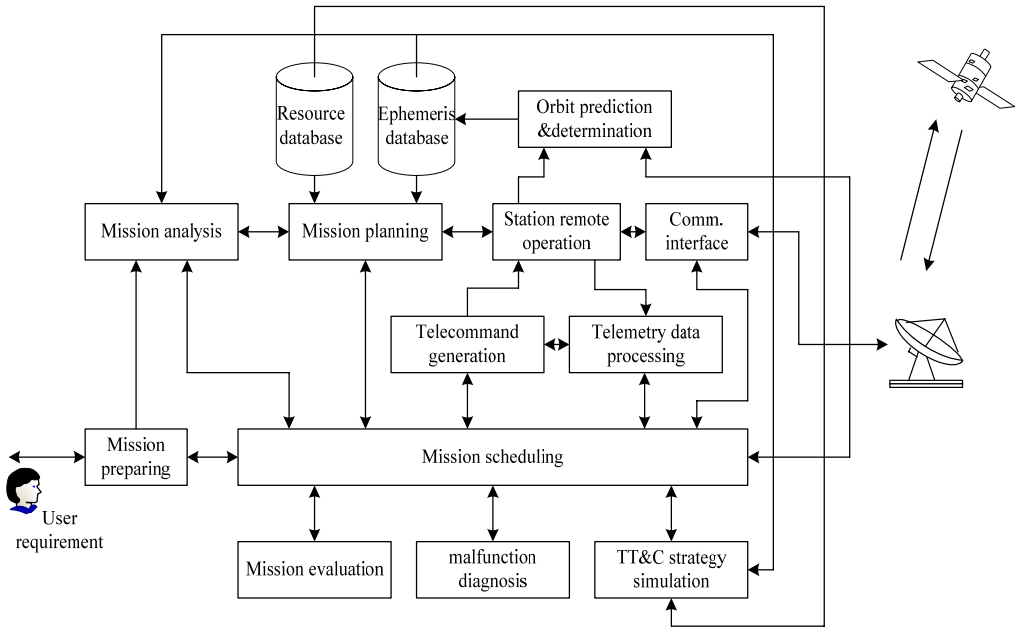

Figure 4 A sketch of mission operation center

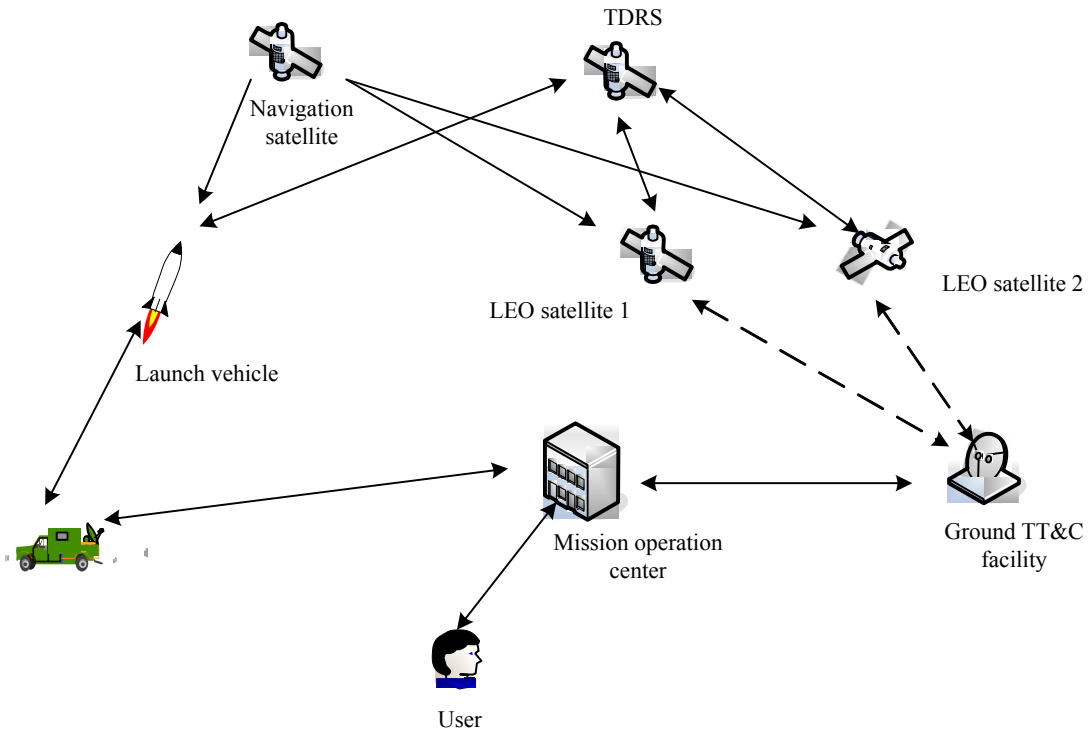

Figure 5 A sketch of TT&C network automatic operation

B. Requirements Analysis of Automatic Operation

1) Requirement of orbit prediction and determination

The orbit of all kinds of spacecraft should be predominated by ground mission operation center. The orbit information comes from GPS navigation information, ground measurement information, inter-satellite measurement information, satellite and ground united information. At the same time, the various format and time length orbit prediction will be provided according to the user requirements.

2) Requirement of mission preparing

Firstly, the user TT&C requirements will be received by ground mission operation center. Then, the mission will be classified according to the TT&C character. Finally, the TT&C planning will be mapped out after communicating with user. Also, the ability of analyzing special mission should be possessed during the requirement of emergency TT&C.

3) Requirement of mission analysis

The TT&C missions should be analyzed according to the result of mission classified. The TT&C event table will be generated. The time sequence of all events will be determined. And, the parameter setting table for ground TT&C facilities will be generated.

4) Requirement of mission planning

The missions should be ordered. The acquisition condition and ephemeris should be calculated. The TT&C resource should be optimize and scheduled.

5) Requirement of station remote operation

The parameter setting table will be received and carried out. The all facilities inside TT&C network will be operated automatically.

6) Requirement of telecommand generated and telemetry data processing

The telecommand sequence will be generated according to the TT&C event table, and the executing effect will be evaluated. The telemetry data of multi-satellites can be processed at the same time.

7) Requirement of strategy simulation

The analyzing results should be simulated, which include: orbit kinetic simulation, attitude simulation, telecommands and injecting data verification, inter-satellite link establishing verification.

8) Requirement of malfunction diagnosis and mission evaluation

The spacecraft healthy state should be prognosticated, according to the processing result of telemetry data. It also can be monitored. The effect of mission operation should be evaluated after the event.

9) Requirement of multi-mission scheduling

The information from each user should be received and sent by the TT&C mission operation center. And, the TT&C network should be scheduled automatically.

IV. Automatic Operation and Control Flow of TT&C Internet

The automatic operation and control flow is designed, according to the TT&C mission type. Figure 6 is a sketch of automatic operation and control flow. It can be described as follow:

1) Firstly, the mission requesting information from user should be sent to the “mission preparing module”. Then, the mission will be classified by the module. Finally, the classified result will be send to the “mission analyzing module” in the form of file. At the same time, it also will be send to the “mission scheduling module” in the form of message. The types of mission include: cooperating mission of integrated space — ground TT&C, mission of ground TT&C, LEOP mission, telemetry monitoring mission, orbit measuring mission, manoeuvre control mission.
2) The TT&C mission will be analyzed by the “mission analyzing module”. The productions include: the time sequence table of TT&C event and the parameter setting table of TT&C facilities. Two tables will be sent to the “mission planning module” and the “strategy simulation module” synchronously. Also, the message will be send to the “mission scheduling module” for the purpose of notification.
3) After the files and command being received from the “mission planning module” and “mission scheduling module”, the TT&C strategy will be verified and simulated by the “strategy simulation module”. It includes: manoeuvre point and manoeuvre parameter verification, telecommands and injecting data verification, inter-satellite link management verification. The verification results will be send to the “mission scheduling module” and “mission planning module” in the form of message.
4) The integrated space – ground TT&C resource will be optimize and scheduled by the “mission planning module”, according to the distribution state. The planning production includes: TT&C mission scheme, station management plan, communication link management plan and inter satellite link management plan. The four plans will be send to the “mission scheduling module” and the “Station remote operation module” in the form of file.

5) The telecommands and injecting data will be processed by the “telecommand generation module”, after receiving the message from the “mission scheduling module” and mission TT&C plan. At the same time, the telecommands and injecting data will be send to the “Station remote operation module” and the “mission scheduling module”.

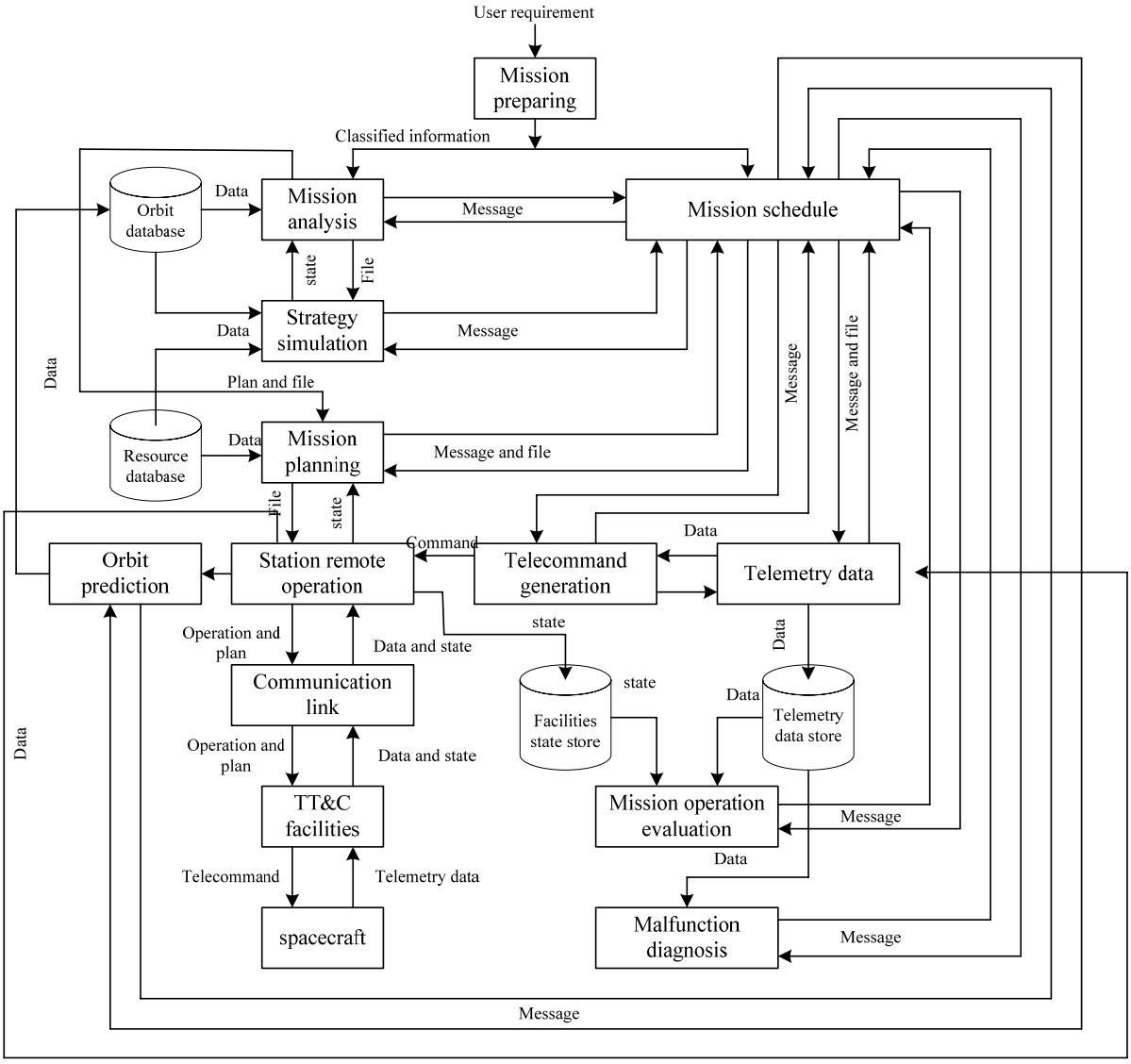

Figure 6 A sketch of automatic operation and control flow

6) After receiving the message from the “mission scheduling module”, the communication link between the TT&C mission operation center and the ground station will be established by the “Station remote operation module”, according to the communication link management plan from the “mission scheduling module”. Then, the station parameters will be set according to the station management plan. Finally, the ground TT&C facilities will be operated for satellite acquisition, tracking, control and inter satellite link establishment. Also, the measurement data will be sent to the “orbit prediction and determination module”. After the telemetry data being received by the ground TT&C facilities, it will be send to the “telemetry data processing module” through the “Station remote operation module”. And, the operating state of ground TT&C facilities will be send to the “mission planning module” for real time monitoring. It also will be stored in the “facilities state store system” for mission analyzing subsequently.

7) The satellite orbit will be determined by the "orbit prediction and determination module", according to the measuring data. And, the orbital element will be stored in the "orbit database".
8) The original telemetry data from "Station remote operation module" will be processed by the "telemetry data processing module". The related processing results will be sent to the "telecommand generation module" for control effect check-up.
9) The health state of satellite, inter satellite and ground TT&C facilities will be evaluated by the "mission operation evaluation module", according to the processing result of telemetry data and monitoring result of ground TT&C facilities operating state. The evaluating result will be send to the "mission scheduling module" in the form of file. If the malfunction for the satellite or the TT&C facility is discovered, the message will be send to the "mission scheduling module" for the "malfunction diagnosis module" activation.

V. Key Techniques of Automatic Operation and Control for Space Internet

A. Technique of Integrated Planning Based on Space Internet

There are more constraint conditions need to be considered for the integrated space — ground TT&C mission, because of obvious characteristic of multi-mission, multi-requirement, multi-system and multi-method.

Multi-mission means there are more types of TT&C mission, such as: the routine management mission for GEO/MEO/LEO satellite, the TT&C mission for launch phase, the early phase TT&C mission for GEO and MEO satellite, the cooperated mission with platform manoeuvre and payload manoeuvre and emergency TT&C mission.

Multi-requirement means there are more requirement to TT&C system from user, include: the requirement of orbit determination precision, the requirement of agility for TT&C plan and the requirement of ORS TT&C.

Multi-system means there are more systems need to be cooperated operate with TT&C system, include: launch system, operation system and application system.

Multi-method means there are more methods can be used to complete the TT&C mission, such as: ground based multi-target TT&C resource and space based TT&C resource.

B. Centralized Scheduling Technique for Mission Operation and Control Center

Scheduling modular is the central part of TT&C network. Its main function is to command and schedule each system according to the TT&C strategy.

C. Technique of Automatic Conflict Detection for Space and Ground TT&C Resource

Automatic conflict detection technique of satellite — ground TT&C resource is a fundamental of reasonable schedule satellite — ground TT&C resource. It is also one of the important techniques to meet the requirement of ORS TT&C.

D. Management Techniques of Using ISL to Support TT&C

ISL provides a possibility to realize integrated space — ground TT&C. Therefore, it is very important to monitor ISL healthy status and to reconfigure ISL.

VI. Conclusion

It is a complicated work to realize the automatic operation and control. There are many key techniques need to study. During the later work, the synthesized planning technique of TT&C mission will be researched according to the feature of multi-mission, multi-system, multi-requirement and multi-method; the integrated scheduling technique of TT&C mission will be researched aiming at the unified command and cooperated TT&C; the management technique of inter satellite will be researched to the future TT&C developing trend.

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