Cassini Science Operations and Planning Computer design

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ABSTRACT

The Cassini Science Operations and Planning Computers (SOPC) are meant to give Cassini investigators and the Huygens Probe Operations Centre (HPOC) more direct control of and responsibility for their instruments and their data and to reduce mission operations cost. SOPCs give the investigators the ability to command their instrument directly, but also the responsibility to do so correctly. The SOPCs help reduce mission operations cost by allowing the instrument designers also to be the operators. The SOPCs allow the operators to participate directly even though they ate. at a distance from JPL.

The SOPCs are direct extensions of the Cassini Ground System to the investigator's home institution. They provide links to the rest of the. Cassini Ground System for both uplink and downlink functions. The SOPCs use the same software as the rest of the Ground Data System. They also provide a platform for project and investigator provided planning and analysis tools.

The current SOPC design is targeted toward Cassini Assembly Test and Launch Operations (ATLO) and cruise. Improvements planned during cruise include hardware upgrades, changes in software architecture, changes to the data communication systems and enhanced security features. The SOPCs, without proper precautions, could pose a security liability. The philosophy of the security requirements and some particular measures will be discussed.

Keywords: Cassini, ground system, space exploration, planetary science, distributed operations, SOPC.

1. INTRODUCTION

The funding environment for planetary science and space exploration has changed. Budgets for mission operations and data analysis are being cut. At the same time, science instruments are becoming more capable and complex and investigators desire more direct control of the.ir instruments and quicker access to their data. The SOPC is designed to address these needs.

The SOPC is a computing platform that serves more functions than any other single computer in the Cassini Ground System. The SOPC uses a combination of JPL, investigator, public domain and commercial software. It is used for both development and mission operations. The SOPC is capable of performing both uplink and downlink functions. It provides a platform for everything from mission planning and command sequencing to telemetry retrieval, display and data analysis. There are currently nine SOPCs, six in the United States and three in Europe.

Dedicated communications lines and hardware are used to connect each SOPC to JPL. This is both an advantage and a difficulty. It allows the investigator to have a Ground System machine at his or her home institution and imposes the burden of remote system administration, configuration management and maintenance. This is further complicated by export and maintenance issues when the SOPC is located in another country. Because of their multifaceted role and remote location, special care must be taken to keep the SOPCs and the rest of the Ground System computers secure.

Mars Observer was the first JPL mission to use the SOPC concept. The Cassini SOPC design is based heavily on the Mars Observer model. Every effort has been made to make the SOPCs as much like the other machines in the Cassini Ground System as possible. However, the SOPCs serve a combination of functions that makes them unique..

This paper will explore the system engineering of the SOPC as well as the ways the SOPCs allow investigators to participate directly in mission operations. All things described in this paper apply to the ATLO and cruise phases of the mission. That is, from about January 1996 unt it Saturn orbit insertion minus two years, June 200?. " The exception is the uplink process that is not used until post launch. With one or two small exceptions, there are no science activities planned for cruise. Design, implementation and planning for the tour phase will fake place after launch. It is fully expected that the tour SOPC design will be strongly based on the cruise SOPC design.

The ultimate goal of the SOPCs is to empower scientists. The added cost of maintaining a computer system at a distant site will be more than offset by the increased efficiency of having science investigators participate more directly ia mission operations.

2. CASSINI GROUND SYSTEM OI<GANI7,A"I'1ON

The Cassini Ground System (GS) is divided into two parts. The Mission Operations System (MOS) is made up of people and procedures and the Ground Data System (GDS) is made up of computers, hardware and software. The Cassini Ground System is divided into eight elements. Each develops and operates its pail of the MOS and the GDS. As much as possible each element develops what it operates, although there are cases where a function developed by one element is also used by another. The elements have authority to decide to make or buy the components that they develop. They have this authority for both the MOS and the GDS portions. SOPCs are different ia large part because almost all the tools and procedures are developed by or interface with other elements. This discussion will concentrate on SOPC related functions of four of the elements, two virtual teams and the science investigators. Figure 1 shows the relationship among the organizations listed here and their contributions to the Virtual Teams. It is not mean to be a comprehensive description.

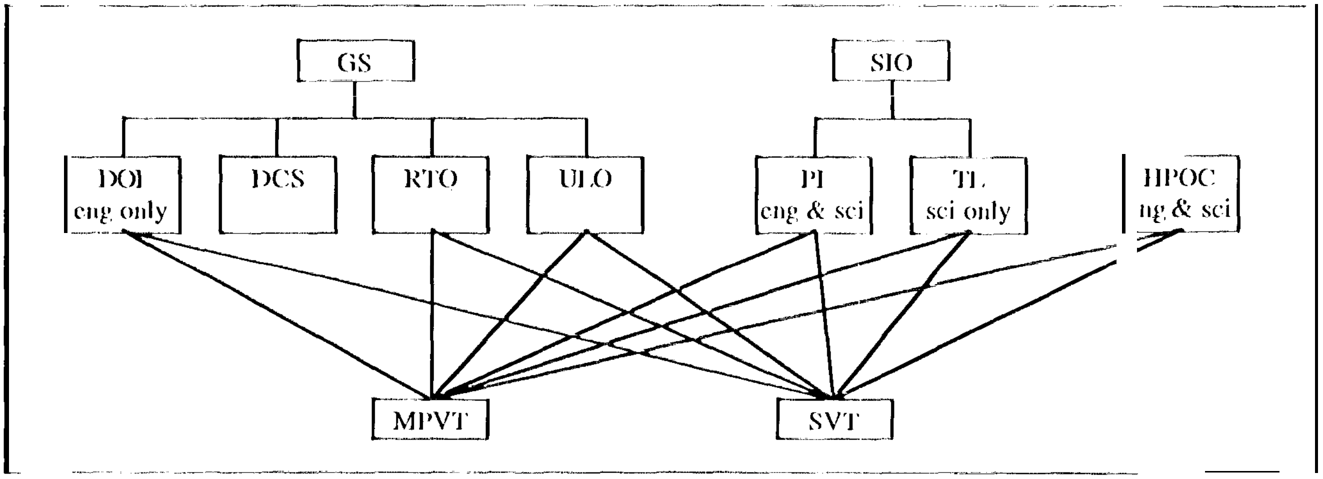

Figure 1 - Ground System organization

2.1 Mission Operations System

The Ground System MOS is a collection of people and procedures that perform Ground System functions. Both the investigators and the Ground System MOS are part of the Cassini MOS. The SOPC provides the means for the investigators to Cxc.cute many of these procedures.

2.2. Ground Data System

The GDS is the collections of computers, networks and software used to perform mission operations. From the SOPC perspective, there are three major software sets, two set vers oa tbc Cassini operations network and dedicated data and voice lines from JPL to each SOPC. The Ground System provides life of mission storage for both file and telemetry data.

2.3. Element descriptions

The investigators have aa interface with the Ground System when they perform Ground System functions. The Distributed Operations Interface (DOI) element is responsible for providing a guaranteed point of contact for the distributed operations sites, doing system engineering of the SOPCs and participating the mission planning and sequencing functions. The I Ma and Computing Services (DCS) element is responsible for maintaining the computing infrastructure of the Ground System and for maintaining the database of operational files. The Real-'l"in)c Operaliens (1{'1'0) element is responsible for coordinating real-time operations, capturing and storing spacecraft and instrument telemetry and soling commands to the spacecraft. The Uplink Operations (ULO) element is responsible for generating and integrating the command sequences. The mission planning virtual team (MPVT) and sequence virtual team (SVT) are responsible for mission planning and sequencing.

2.3.1. Principal investigators, team leaders and the Huygens Probe Operations Centre

On the Cassini spacecraft, there are eight instruments provided by principal investigators (1'1), fear facility instruments provided JPL and the Huygens Probe provided by the European Space Agency. Each of the principal investigator and the HPOC currently has a SOPC. The facility instrument team leaders (TL) receive SOPCs shortly after launch. The PIs and TLs are part of the Science Instruments Office (S10). The six instruments on the Huygens Probe do not receive SOPCs since HPOC is their sole. representative for command and telemetry interfaces. The two types of Cassini orbiter instruments and the Huygens probe interact with the. rest of the Ground System in different ways. For simplicity, they will be referred to collectively as investigators.

The principal investigators are completely responsible for all aspects of the operation of their instruments. The team leaders are responsible for the science operations of the facility instruments. DOI is responsible for the engineering operations of the facility instruments. The facility instrument science teams and DOI together perform the same functions as the principal investigator teams. HPOC is responsible for all operations of the probe and the probe instruments. The principal investigators and HPOC are responsible to develop their own telemetry and command systems for the.ir instruments. Some of that software may be installed on the SOPC in coordination with the Ground System.

2.3.2. Distributed Operations Interface

DOI is responsible for the system design of the SOPCs. DOI is also tile Ground System's liaison to the investigators for operational issues. DOI is not an intermediary, but rather a facilitator. The investigators are empowered to deal with any other element on the Ground Systc.in. DOI becomes involved if there is a question about which part of the Ground System an investigator should deal with or if having engineering representation physically at JPL, would be helpful. DOI does not have. the authority to represent the investigators on scientific issues. DOI participates in both the MPVT and SVT as part of its responsibility for engineering operations of the facility instruments. DOI is responsible for designing and participating in the, Verification and Validation (V&V) of the SOPCs. DOI also participates in Ground System V&V for the SOPCs.

2.3.3. Data and Computing Services

DCS purchases, installs, administers and maintains all the computing and network hardware used by the Ground System. As a result, the computing platform used for the SOPCs is one of the standard configurations used throughout the Ground System and Project. DCS coordinates development and maintenance of the dedicated data and voice lines that connect each SOPC to JPL and the remote communications terminal hardware (RCT) that accompanies each SOPC. DCS obtains the required export permissions for all the SOPC software and hardware.

Between JPL and each of the SOPC sites there is a data line and a voice line. The data line is either a 56 kbps or a 64 kbps NASA Communications (NASCOM) serial line.. The voice line. connects the Mission Support Area (MSA) and all of the distributed operations sites together. There is a multimission firewall that protects all of the operations networks at JPL.

DCS develops and operates the Central Database (CDB). The CDB is used by elements in the. Ground System and other groups within the project as a repository for and a means to exchange operational files. Some of the files are downlink related. They are used to describe telemetry, define telemetry displays or describe the performance of the spacecraft. Processed data products may also be stored on the. CDB. Other files are used in the uplink process. They are related to mission planning, sequence generation, sequence integration and command file creation. Unlike some previous JPL missions, there is no telemetry stored in the. CDB. DCS is responsible for providing lilt of mission storage of all files in the CDB.

The CDB server resides on the Cassini operations network and the CDB clients reside on the SOPCs. The CDB uses Kerberos as its user authentication system. The CDB stores files in groups by type and has the capability to grant read, write and delete privileges to users based on file type. DCS provides other services including the Cassini electronic library (CEL) and the solutions-oriented-services (SOS) user help desk. DCS performs systems and network administration to support the computing infrastructure.

2.3.4. Real-Time Operations

RTO develops, administers and operates the telemetry and command systems for the Cassini Ground System. The telemetry system interfaces to the Deep Space Network (DSN), takes the telemetry from the spacecraft and makes it available to the users on a central server. The command system takes the spacecraft command files and sends them to the DSN for radiation to the spacecraft. RTO is responsible for providing life of mission storage of all telemetry.

The Telemetry Delivery System (TDS) server is a read only database that contains all the telemetry generated by the spacecraft, instruments and probe. The TDS server resides on the Cassini operations network and the TDS clients reside on the SOPCs. The output can be stored in a file. on the SOPC, sent to a display program, or sent to an external program (typically written by an investigator team).

RTO monitors spacecraft and science instrument health and safety telemetry. RTO does this to check for alarm limit violations and to identify and respond to spacecraft and instrument anomalies. On most previous JPL projects, there was a team in the Ground System that analyzed all the telemetry for data quality during tracking station overlap or telemetry replay and made only the best quality data available to investigators. There is no such capability in the Cassini Ground System. The investigators make these sorts of judgments themselves about their own telemetry.

The Command (CMD) system is a multimission facility. RTO performs the commanding function for Cassini. The input to CMD is the integrated spacecraft command sequence or real-time command. CMD formats the sequence for transmission to the DSN and radiation to the spacecraft. RTO sends instructions to the DSN indicating how to control its antennas, transmitters and receivers.

2.3.5. Uplink Operations and Virtual Teams

ULO is responsible for the uplink planning and the development of the sequencing and planning software. The Mission Sequence System (MSS) is the set of programs used to create, edit and display mission planning, spacecraft command sequence files and sequences of ground events. MSS is the primary software tool for the MPVT and SVT.

The MPVT and SVT do not exist as permanent entities. ULO leads the virtual teams, but the virtual teams and are made up of members of other elements from within the Ground System and groups from outside the Ground System. The MPVT and SVT come together only to do their work on a mission phase or sequence. The MPVT is responsible for the mission planning functions. The mission plan serves as a template for the investigators and other elements in the Ground System to develop their command sequences. The SVT takes the mission plan and uses it to develop the sequences that are loaded into the spacecraft and sequences of ground events.

The principal investigators and IPOC are direct members of both the MPVT and SVT. The team leaders are members of the MPVT for science issues only. Engineering issues in the MPVT and SVT for the facility instruments are handled by DOI.

In the Cassini architecture, instrument internal commands are not processed by MSS. Instrument internal commands are passed through the MSS as raw binary strings. Commands that may affect other parts of the spacecraft or other instruments, power commands for example, are listed individually in the command sequence file. Those commands can then be included in the sequence simulation and verification. The MSS is used to syntax and constrain check the sequence files before they are submitted to the CDB from the SOPCs. The investigators are responsible for developing whatever software is used to generate the binary loads of instrument internal commands.

2.4. Verification and validation

V&V tests the Ground Data System and the Mission Operations System on the SOPCs. There are two levels of V&V in which DOI participates. Element level V&V tests the SOPCs. Ground System V&V test the Ground System as a whole. The investigators also participate in the V&V process.

Element level V&V is done is phases. The first phase is performed in the MSA on a computer has the same software and hardware configuration as a SOPC. The tests include those systems that are on the SOPC and those systems that have an interface directly with the SOPC. The goal is not to test every feature of the software, but to test that the software is configured and installed correctly. That more detailed level of acceptance testing is done by the elements that develop the software. When the first phase is concluded successfully, the new configuration is stored on tape and sent to the investigators. Each SOPC is then tested individually using the same set of test cases.

The purpose of Ground System V&V is to test the data flows and procedures of the whole Ground System. The SOPC's and investigator's roles are to perform the. functions that it would in regular Ground System operations. DOI participates in the design of Ground System V&V and acts as a coordinator during the testing.

3. PROCESSES

The SOPCs are at the terminus of the. Ground System processing loop. The SOPCs are the last stop in the Ground System for instrument telemetry and the first stop for instrument commands. They are the transfer point between Ground System machines and the. investigator's processing system. The following subsections give a brief description of the. uplink and downlink processes in the Cassini Ground System and the way in which the SOPCs allow the investigators to participate in those processes remotely.

3.1. Uplink processes

The uplink process begins with the mission plan, and ends with the transmission of a command sequence to the spacecraft. The MPVT is responsible for taking the mission plan and producing a high level list of activities. The SVT then takes that list and produces a series of products that ends with an integrated sequence of spacecraft commands. The mission planning may start six months before the sequence is meant to be uplinked. The sequencing cycle itself is designed to last six weeks.

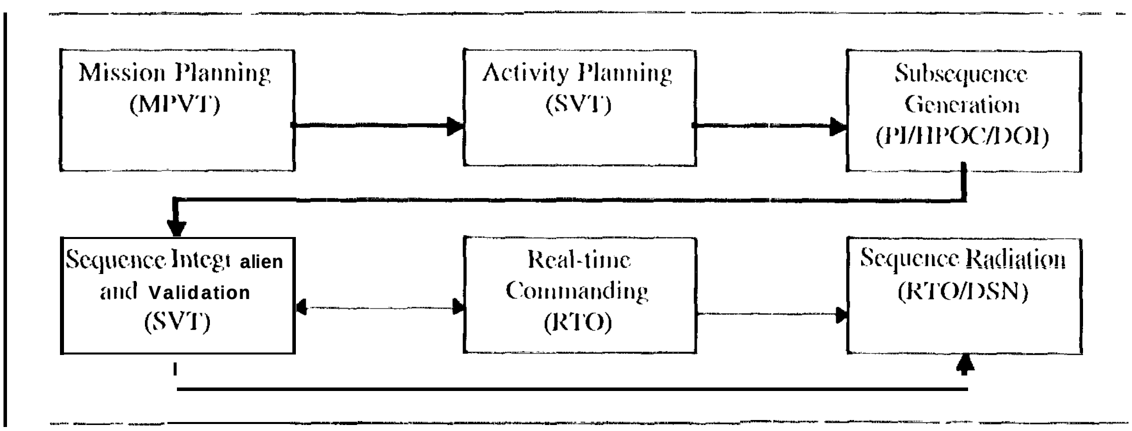

Figure 2 - Uplink Process

The MPVT takes the mission plan one phase. at a time and produces a list of key events and operational constraints specified to the resolution of about one day. This is where science priorities are set and science conflicts resolved. The list of events is passed to the SVT. The SVT then refines that plan to about one minute resolution in the activity planning, process. The observational design process next specifies the. sequence to the subsecond level of detail. Once the observational design is complete, each investigator team (either principal investigator, HPOC or in the case of facility instruments, DOI) produces the subsequence of commands for its instrument. Figure 2 diagrams this process. The bold line represents the primary flow.

Investigators must have their own systems to generate their own internal commands. These systems may consist of hardware, software, or both. If the system is made of software, at the investigator's discretion that software can be run on an investigator's workstation or on the SOPC. The file submitted is called a Spacecraft Activity Sequence File (SASF). The sequence of instrument internal commands are passed directly through the Ground System as binary strings.

An operational mode is a set of constraints on power, instruments and subsystems. As long as each instrument and subsystem on the spacecraft stays within its allowed envelope, there is much less work required of the SVT to integrate and validate sequences. No unique sequences (those that are not in any operational mode) are planned during cruise except for the instrument checkout activity at launch plus fourteen months.

Commands that might affect other parts of the spacecraft (i.e., commands that Change the power state of the instrument) are listed individually, not as part of the binary string in the sequences submitted by investigators. These commands are called system level commands and are the responsibility of the SVT to integrate and validate.

The instrument sequences are then combined with sequences from other SVT members to form the integrated sequence. That integrated sequence is reviewed and updated as needed to resolve any remaining conflicts and to stay within the assigned operational modes. Commands can also be sent to the spacecraft on short notice either to change a small part of an already uploaded sequence or to respond to anomalies. These are known as real-time commands.

This cycle of uplink activities is repeated as needed within the schedule to produce the integrated sequence. The principal investigators, team leaders and HPOC are able to participate in the MPVT and SVT activities because of the SOPCs. The spacecraft sequences and all the intermediate products used to generate those sequences are stored in and exchanged through the CDB. The SOPC gives the investigators the same level of access to the CDB as those members of the MPVT and SVT located at JPL. The SOPCs contain the software tools to examine the intermediate products produced by the MPVT and SVT and to produce the products submitted to the virtual teams.

3.2 Downlink processes

The downlink process is more linear than the uplink process. There are three types of telemetry. Housekeeping telemetry tells about the engineering status, health and safety of an instrument. Science telemetry contains the science data. Telemetry from the spacecraft itself is called engineering telemetry.

At each step, the data are repackaged, transformed or stored by the system. The first step is when the DSN acquires the raw data from the spacecraft. That telemetry is sent from the tracking station to JPL. It is unpacked from the DSN wrappers, synchronized to form the original spacecraft transfer frames and exploded into the original instrument and subsystem packets and minipackets. The intermediate steps and final results are stored in the TDS server for use by the investigator teams and Ground System elements. Figure 3 shows the downlink process. The lines in bold show the primary path.

RTO monitors the instrument housekeeping telemetry, along with spacecraft engineering data, for alarm limit violations. RTO can detect possible instrument and spacecraft anomalies. RTO notifies the appropriate investigators or elements in the Ground System, and responds with real-time command sequences if needed to put the spacecraft or instrument in a safe state. The investigators use the TDS clients on the SOPCs to retrieve their science and housekeeping packets and route them either to display software on the SOPC or to their own telemetry processing systems. They can monitor the telemetry for instrument alarm limit violations in near real-time from their SOPCs. During the ATLO phase of the mission there has been only a one or two minute lag between when the data are available in the Spacecraft Assembly Facility (SAF) and at the SOPCs.

Other elements within the Ground System perform engineering analysis on the spacecraft telemetry. DOI, PIs and HPOC perform engineering analysis on the instrument and probe telemetry respectively. PIs and HPOC perform science analysis on their science telemetry. DOI may perform some level of processing on facility instrument telemetry before that telemetry is passed on to the team leaders.

Unlike engineering and housekeeping packets, the telemetry processing system understands nothing of the internals of science packets. Like the instrument internal commands, the science packets are simply transported by the Ground System. Telemetry from the Huygens probe is treated similarly. The exception is that DOI knows how to process science packets for the facility instruments. DOI process the science telemetry before it is sent to the team leaders.

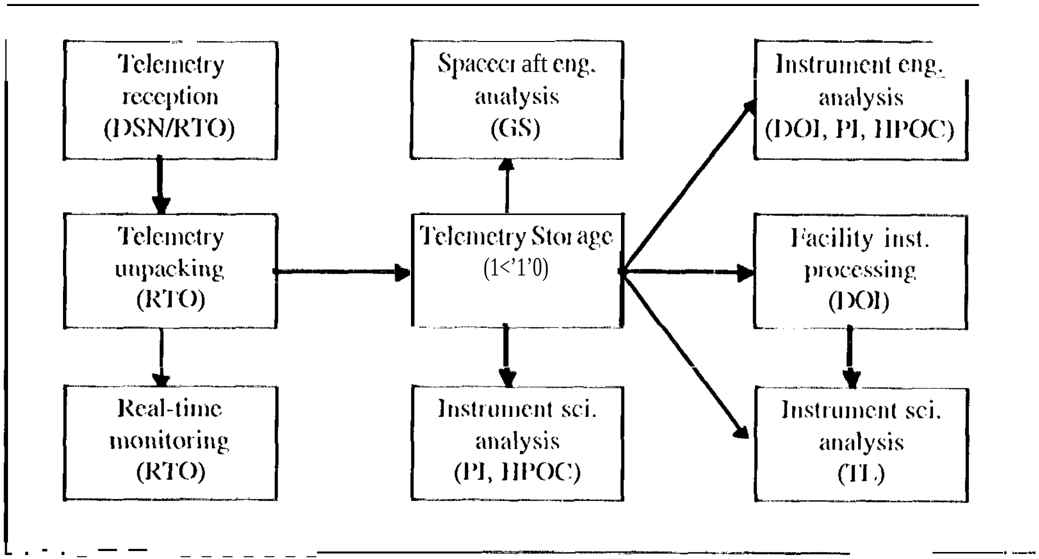

Figure 3 - Downlink processes

Ancillary files are used to configure the telemetry processing and display software on the SOPCs and to interpret the telemetry by an investigator's own processing system. These ancillary files are retrieved using the same CDB software that is used in the uplink process described in the previous section. The CDB is also the mechanism by which the investigators will return science data products to the Ground System for collection and submission to the Planetary Data System.

4. GROUND SYSTEM TO SOPC DATAFLOW

As discussed earlier, there are two basic types of data in the. Ground System. File data moves back and forth to the CDB server. Telemetry stream data are stored by the Ground System in the TDS server and retrieved by the users. The results of the sequencing process are taken as command data and sent to the. spacecraft. It should be emphasized that the programs and data flow paths used on the SOPCs are the same as those used on the. Cassini operations network.

4.1 File data

Figure 4 shows the relationship between CDB server and client and Kerberos server and client. The CDB uses Kerberos to perform user authentication. The Kerberos system performs user authentication without sending passwords across the network in the clear. The bold line shows the primary data flow.

The user must have a valid Kerberos ticket before the CDB server will transfer a file. All files stored in the CDB server must be wrapped in Standard Format Data Unit (SFDU) headers. The headers contain catalog information about the file. There is a special toolkit that takes care of wrapping, and unwrapping files. The CDB server checks to make sure that the headers are in the correct form when the. file is submitted.

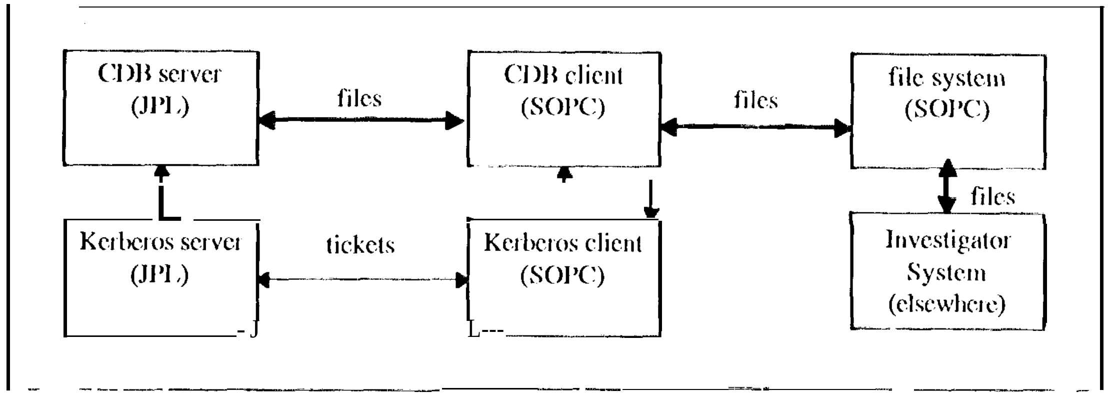

Figure 4 - File dataflow

4.2. Uplink data

Figure 5 shows the flow of files among the different program sets in the uplink process. The steps in the process are: an investigator's own instrument commanding system, Sequence Generator (SEQGEN), Sequence Translator (SEQ_TRAN), Command subsystem (CMD), the DSN and the spacecraft. The Sequence of Events Generator (SEG), High Speed Simulator (HSS) and the Integration and Test Lab (ITL) are branches off the main dataflow. Although it is omitted from this diagram, all files are exchanged through the CDB. The bold line shows the primary data flow.

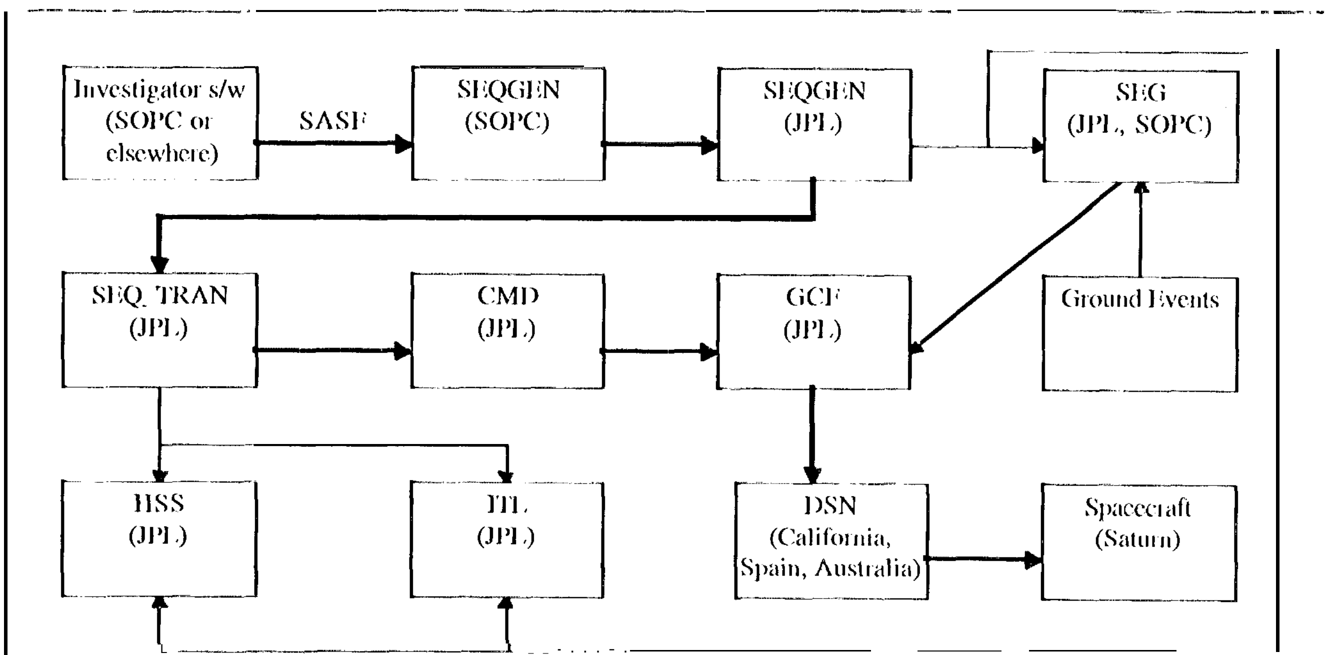

Figure 5 - Uplink dataflow

For the instruments, the uplink process starts with investigator developed software and hardware. That system creates the instrument internal sequence and packages it in an SASF. Investigators may create the SASF with a text editor if they wish. SEQGEN on the SOPC checks the SASF for syntax errors before submission to JPL. SEQGEN at JPL merges the subsequences from all the instruments and elements into an integrated sequence. SEQ_TRAN then produces the binary code that is sent to the spacecraft. CMD sends the binary code to DSN, which then radiates it to the spacecraft. The HSS and ITL take input from both SEQ_TRAN and SEQGEN and validate the sequence. SEG takes input about the spacecraft from

SEQGEN and input about ground events and produces an integrated list of both spacecraft and ground events and commands for RTO and DSN. SEG is used to view these products.

4.3. Downlink data

Figure 6 shows the ways in which telemetry is routed through the Ground System and to the SOPC. This diagram shows the data flow starting at the spacecraft and ending at the investigator's own processing system. The steps in the process are: spacecraft, DSN, Ground Communication Facility (GCF), Telemetry Input System (TIS), Telemetry Delivery System (TDS), Telemetry Output Tool (TOT) and Data Monitor and Display (DMD). Beyond TOT and DMD, the telemetry can be sent to the investigator's own processing system. The bold line shows the primary data flow.

The GCF takes data from the DSN and separates it into its original transfer frames. The TIS breaks apart the spacecraft transfer frames into the subsystem and instrument packets. TIS performs the channelization of the housekeeping and engineering packets. In channelized telemetry packets, the channel values are labeled with the channel identifier. Channel identifiers are a string of a letter followed by four numbers (i.e., A-1234). Unchannelized telemetry contains no channel identifiers. Science telemetry packets are never channelized. The packets from the Command Data System (CDS) and Attitude Articulation and Control System (AACS) spacecraft subsystems are broken down further into minipackets.

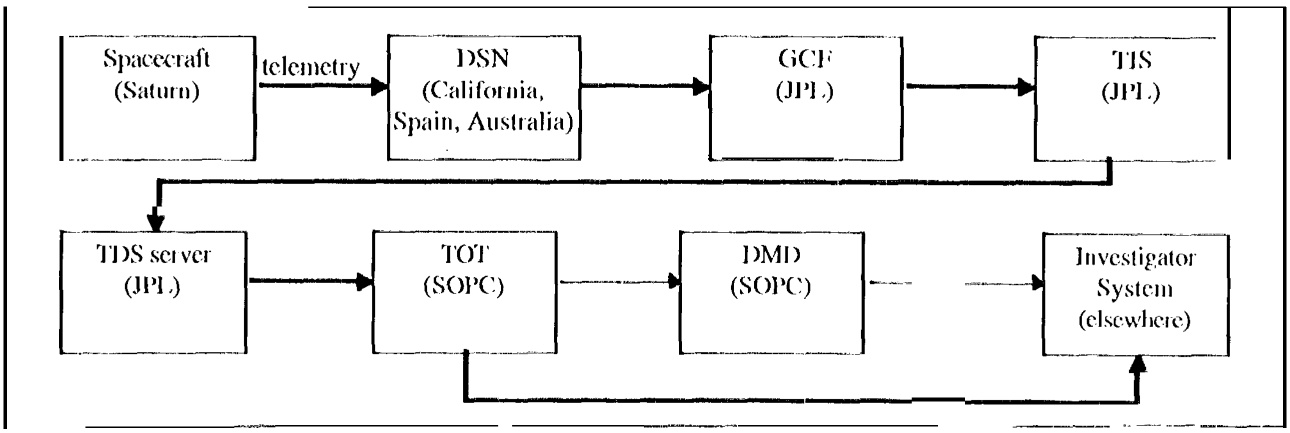

Figure 6 - Downlink dataflow

The packets and minipackets, both channelized and unchannelized, from TIS are then loaded into the TDS server. From the TDS server they can be queried in a variety of ways by TOT. TOT can then send the packets to any one of several destinations including a file, DMD or investigator processing system.

DMD requires channelized telemetry as its input. DMD can further process the channelized telemetry to create extended channelized telemetry. Extended channelized telemetry contains both data numbers (DN) to engineering units (EU) and alarm limit flags. DMD can further process channelized telemetry to create derived channels by performing calculations on existing channels.

5. COMPUTERS AND NETWORKS

The computer hardware configuration used for the SOPC is one of the standard computer configurations used throughout the Ground System. In addition, the SOPC has a Remote Communications Terminal (RCT) that contains all the networking, test and serial communications hardware.

SOPC hardware	RCT hardware
111'735 CPU (80 Mb RAM)	Cisco 4000 router
1 Gb internal disk	Bit Error Rate Tester
2x2 Gb external disk	CSU/DSU (NASCOM line modem)
19" color monitor	Uninterruptable Power supply
CD-ROM drive	Auxiliary modem
8mm tape drive	
4mm tape drive	
600 dpi laser printer	

Table 1.

The SOPCs contain AMMOS software supplied by JPL. AMMOS requires some public domain software to operate.. The investigators may add other software that is part of their own processing system. This software may be public domain, commercial or investigator developed. The following table summarizes what types of software can be placed on which machines.

Software type	Supplier	on SOPC	On investigator W/S
telemetry processing	JPL	required	prohibited
file processing	JPL	required	prohibited
sequence	JPL	required	prohibited
Sequence	investigator	optional	optional
engineering telemetry display	JPL	required	prohibited
engineering telemetry display	investigator	optional	optional
science data processing/analysis	investigator	optional	optional
science planning	JPL	required	prohibited
science planning	investigator	optional	optional
long term data storage	investigator	optional	optional
commercial	third party	optional	optional
public domain	third party	optional	optional

Table 2

6. SECURITY

The SOPCs are just one part of the Cassini Ground System. They are covered by the same security requirements as the rest of the Ground System computers. The security requirements for the SOPCs are to provide user and system level authentication, privacy, integrity and continuous service.

The SOPCs present a unique security problem for the project. They have to support a wide variety of functions including simultaneous development and mission operations. They are located remotely from JPL, although the Ground System still has responsibility for maintaining security. They must communicate with the Cassini operations network at JPL as well as investigator processing systems at the distributed operations sites. The Cassini operations network is protected by a firewall, but the SOPCs do not necessarily have such protection.

The most important operational control is limiting who has access to the machines. Each SOPC must be kept in a locked room. Every user account must be approved by the Ground System. System logs are regularly monitored and any unusual activity investigated. Connections from the SOPCs to the servers on the Cassini operations network are also logged.

The Ground System must protect not only the SOPCs, but also the Cassini operations network. Only the SOPCs are allowed to connect through the firewall to the servers on the operations network. In turn, only a short list of investigator machines are allowed to connect to the SOPCs. As already mentioned, the CDB uses Kerberos on the Cassini Operations network to provide authentication. All passwords must be protected from compromise by both operational procedures and technical means.

Apart from disconnecting the SOPCs entirely from the outside world, there is no single satisfactory secur i t y solution. We have adopted a mixed, multi-layered approach. A serious enough security violation from one of the SOPCs will result in that SOIT being disconnected from JPL until the problem is investigated and resolved. The SOPCs, like the rest of the operational computers are part of the Ground System risk management plan.

7. DESIGN TRADEOFFS AND CONTINUOUS IMPROVEMENT POSSIBILITIES

This section will examine some of the design tradeoffs that were made when designing the current system architecture. Some of these tradeoffs were governed by decisions made in the Ground System design before the details of the SOPC design were determined. Some of the capacities and capabilities of the system were based on the Mars Observer experience with SOPCs.

During ATLO, the current phase that runs approximately from January 1996 through launch in October 1997, there is a high level of SOPC activity. A lot of data are generated during spacecraft and instrument testing. After launch, the level of science activity in the Ground System falls off. There is a burst of science operations acti vity during the instrument checkout at launch plus fourteen months. Apart from that, the majority of interplanetary cruise is simply periodic instrument maintenance, once every three months. At Saturn Orbit Insertion (S01) minus two years, 2002, science data collection begins and the level of instrument and SOPC activity increases dramatically.

The computing hardware for the SOPCs was purchased in 1994. All the computers in the Ground System, including the S01'('s, will be upgraded twice before the end of the mission. The upgrades will take place in 2000 and 2005. The upgrade dates fall shortly before the beginning of science data collection in 2002 and shortly after SOI in 2004. The decision to use HP computers was made when an independent source evaluation board reevaluated JPL's purchasing contract in light of competitive bidding rules. At the time the SOPCs were purchased, they were top of the line]]}' 735s. Whew the time for upgrading the machines comes, wc may consider purchasing two lower end (by 2000 standards) machines instead of a single high end machine. This will allow separate operations and development environments and/or a redundant system for operations.

The Ground System has chosen to use dedicated NASCOM serial data lines to send data between the SOPCs and J]']... The arrangement was made between Code O and Code S at NASA HQ at no direct cost to the project. The NASCOM lines provide privacy, site authentication, guaranteed bandwidth and accountability for maintenance. The disadvantage is that dedicated lines are expensive. This configuration was installed in late 1995 and early 1996 and will last at least through launch. After launch, one option would be to use. the Internet. An Internet solution would still have to meet the assured bandwidth, maintenance and security requirements. Another option would be to use a dial up connection. An Integrated Services Digital Network (ISDN) dial up connection running Asynchronous Transfer Mode (ATM) protocol would provide both data and voice on the same tine. The bandwidth of the line is expandable. That would allow the instruments that generate greater volumes of telemetry to have higher data rate connections to JPL. It would also allow multiple voice lines to each site rather than a single voice line if wc found the need ever arose.

The AMMOS software on the SOPC can be used in three broad configurations. The choice is up to the investigator which mode is used. The choice is governed in large part by what investigator developed software the investigator chooses to install on the SOPC. The first anti simplest mode is to use the SOPC simply as a way to send telemetry to the investigator's processing system and exchange files via the CDB. in this mode, the SOPC is simply a communications mechanism. The next option takes advantage of the JPL supplied display and processing software. Since this software is the same that is used in the. rest of the Ground System, there is a great advantage to having the same displays available in both places. Ground system engineers and science operations personnel can view and work with the same displays remotely. Finally, the SOPC can be used as a platform to run the investigator's own processing software. Typicall y, that software has been developed on another platform. Some instruments may prefer to use the SOPC for that purpose for convenience or processing power. The goal is to make the configuration management and security systems flexible enough to accommodate a wide range of end user system designs.

8. CONCLUSIONS

The SOPC is not an isolated system. For both hardware and software, the SOPC must be consistent with the rest of the. Ground System. la addition, the SOPC is constrained by physical distance, time zone difference and a limited bandwidth link to JPL. At the same time that the SOPC has these. limitations, it must be more flexible than other machines in the Ground System. It performs both uplink and downlink roles and must be capable of performing investigator specific functions including scientific analysis.

The SOPCs provide the basis for distributed operations. The Cassini mission lasts over ten years and the investigators are scattered across six states, two foreign countries and six time mats. The SOPCs empower investigators to operate their instruments directly, reducing the need to have representative at JPL and for travel to JPL. The SOPCs have performed well during ATLO. The SOPCs have given the investigators timely access to their telemetry. The SOPCs also support the. concept that the investigators should be given more control and responsibility for the operation of their instrument. The SOPCs, in combination with teleconferencing, make the interaction between investigators and Ground System personnel less dependent on location.

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