A TELEMETRY AND SPACE COMMUNICATION NETWORK SIMULATION FOR TRAINING

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ABSTRACT

Telemetry and data communications network simulation training devices are used to train mission controllers and spacecraft flight crews to manage the space network’s resources for consistent and reliable data flow between a user’s spacecraft and control center. A Space Communication Network simulation for communication controller training contains models for; network configuration, resource scheduling, simulation of tracking data blocks, data quality monitoring (DQM), responses and interaction, malfunctions, and a communication environment to control the flow of data. The goal of the simulation is to train in the management of the Space Communication Network utilizing real-world formats and real-world protocols thus enabling the simulator to appear to the trainees as the real-world network.

INTRODUCTION

The purpose of this paper is to describe telemetry and data communications network simulation for training of spacecraft crews, ground controllers of spacecraft on-board systems, and spacecraft control center communications network support personnel. The widely accepted definition of “network simulation” in the data communications, engineering, and information science communities is “a simulation of network traffic loads given some protocol and amount of information to be transmitted over a network”. These types of simulations are useful to predict network loading for formulation of requirements and design of communications networks, but are not used for training. The purpose of the simulation described in this paper is training of personnel who control network resources or use data transported by the network. In this sense the simulation being described in this paper is more similar to an aircraft flight simulator or spacecraft vehicle simulator, than to a network traffic analysis simulation. Hereafter in this paper a telemetry and data communications network simulation will be referred to as the “network simulation”.
Network simulations have been in use by the United States space program for many years. As the world enters an era in which there will be more than two (the US and USSR) nations with a manned presence in space, it is hoped that the international community will be able to recognize the need for network training. An understanding of the reasons for this training in the US space program will help bring about this recognition.

The descriptions in this paper of personnel trained by a network simulation will be generic to maximize the readers ability to draw parallels between the tasks performed by these personnel and those performed by similar personnel at the readers facility. Descriptions of telemetry and data network services, network system interaction with mission control centers, and status information produced by the network will be kept generic for the same reason.

TYPICAL SPACECRAFT TELEMETRY AND DATA COMMUNICATIONS NETWORK SERVICES, SCHEDULING, CONTROL, STATUS, AND ARTIFACTS

NETWORK SERVICES

Figure 1 shows data flow and interaction with a telemetry and data communications network. Typical services provided by a telemetry and data communications network include the following:

1. Transportation of telemetry data from a spacecraft to the spacecraft mission control center, spacecraft systems engineering support centers, and spacecraft payload control centers. Typically data transport involves use of a relay satellite in geosynchronous orbit coupled with a ground station for the relay satellite. This function may also involve direct downlink from the spacecraft to a ground site. In either case, it is the responsibility of the network to:

   a. Receive the telemetry from the spacecraft
   b. Transport the telemetry minimizing the number or errors introduced during transport
   c. Maximize the convenience to the end user of the telemetry by delivering it packaged in an easy to process form (if cost effective)
   d. Deliver the telemetry with a minimum delay time from receipt by the first element of the network
Figure 1 - Network Data Flow and Interaction
e. Correct any errors which occur at any point in transmission if possible

f. Report any errors which occur at any point in transmission

2. Transport uplink command data to the spacecraft. Typically this function is a mirror image of the telemetry transport function. All of the same functions are provided by the network with the source and destination reversed

3. Tracking of the spacecraft is usually performed by the network. It is convenient for the network to perform this function because Doppler, Pseudo Noise coding, and antenna angle information is immediately available to the network at a ground station. This information is readily convertible into spacecraft position and velocity. Often it is necessary for the network to remain cognizant of the spacecraft position and velocity so that data transmission and reception antennas can be pointed, transmission frequencies can be Doppler compensated prior to transmission, and reception signal frequency windows can be adjusted for optimum reception of the signal. The tracking data is usually transported to the spacecraft control center, over the network

4. Recording of telemetry data during periods of interface outage, or for users who do not require immediate real-time delivery. Typically a mechanism is provided by the network to allow playback through the network to the control center so that delayed delivery of the data can be accomplished.

SCHEDULING

If the network is used by more than one spacecraft control center, and has insufficient resources to dedicate communications paths to all users simultaneously, some mechanism for scheduling network resources must be provided. Typically scheduling will be accomplished via some electronic communications path with the network control center, if the scheduling system is an automated system. Over this communications path the spacecraft control center will request use of the network resources as described above. The user will typically specify a start and stop time for network use, and a set of resources that make sense (a “possible” support configuration). To do this the user must specify information such as a support identification code, data rates, transmission band, and frequency. If the user has an especially congenial relationship with the network management, establishment of special predefined configurations may be possible. These will allow the spacecraft control center to specify a macro configuration code.
The control center will usually have assigned personnel responsible for network scheduling. These personnel utilize a computerized means of generating scheduling messages. The nature of this function dictates that the interface between this local scheduling function and the network control center be a two way interface. This is necessary so that requests for support can be responded to with acknowledgement that the requested resources have been reserved. In cases where the requested resources can not be reserved, a dialog is necessary between the local scheduling function and the network control center so that corrective action can be taken.

NETWORK CONTROL

Modern spacecraft telemetry and data transport networks allow interaction between the spacecraft control center, and elements of the network. Those elements which interact directly with the user’s spacecraft or depend directly on spacecraft configuration to work can be configured electronically from the control center. This allows configuration of the scheduled resources to match the configuration of the spacecraft telemetry and command data transmission systems. Performance of this control from the spacecraft control center is both necessary and convenient because the area of greatest expertise on the spacecraft communications systems will be localized at the control center. The spacecraft control center is also the location which is most aware of the spacecraft condition and configuration.

The network will usually provide a means for the control center to control the transmission frequency for the uplink signal to the spacecraft, initiation of the signal acquisition sequences to lock up on the carrier, and many other of the variables involved in radio frequency communications. An example for use of this capability is a change in data rate from the spacecraft. When something like this occurs the elements of the network which require a knowledge of data rate need to be informed in real-time so that communications can continue with a minimum of interruption.

The control center will have support personnel responsible for the performance of these real-time network control functions. These personnel will monitor the configuration and performance of the network and tune the configuration for optimum performance. The means of communicating network configuration changes will be a real-time communications interface with the network control center. This interface will be two way, so that the control center network control personnel can be assured that configuration changes to the network have been received and are being acted upon.
NETWORK STATUS

Status data of all types is of primary interest to a spacecraft control center. In the case of the network, status data can be broadly divided into two primary areas. These are the status of the data being transported through the network and the status of the network systems. The status of the data being transported will include such information as the amount of telemetry and command data being processed by the network for the spacecraft and the number of errors in the data. The status of the network will consist of the network configuration and any status information gathered from supporting network systems which could be useful to resolve data transport anomalies. The network will usually supply status information in real-time electronic form to the control center. Status information will be displayed in the control center by systems viewed by the control center network control personnel. The status provides feedback about the current telemetry downlink and command uplink data transmission performance, and is a factor in the decision process to initiate network control corrective actions.

NETWORK ARTIFACTS

Network artifacts are effects on the transported data caused by the network. These include the following:

1. Acquisition of signal/Loss of signal times - These will depend on the geometric positions of the network relay satellite(s) or ground station with respect to the spacecraft position, assuming line of sight is necessary with the spacecraft. The minimum power threshold the network is configured to receive data at, as well as the maximum power level the network is able to transmit at also effect when AOS is possible. Often mission sequences for the performance of tasks aboard or from the spacecraft (like extra vehicular activity or experiments) are planned around the predicted AOS/LOS times.

2. Noise - Among the factors which contribute to the amount of noise introduced into the telemetry data during transmission are the bit error rates the network was designed to operate within. The amount of noise in the telemetry downlink and command uplink has an effect upon every control center on-board systems controller position, whether or not that controller has anything to do with the network or spacecraft communications configuration. There will be periodic losses of telemetry data due to noise. These will show up on displays in the control center, and may even trigger the annunciation of alarms in control center. Automated processes for monitoring of spacecraft systems will be affected due to total or partial lack of input. In rare cases were telemetry data
with errors gets through all the checks and error protection built into the data communications systems, noisy data will be displayed and or processed.

3. Outages and degradation due to malfunction - In cases where nominal support is not possible due to equipment failure, the network can affect the data by either disallowing it’s transmission, or artificially introducing errors. This is also possible due to misconfiguration of either the network or the spacecraft data communications systems. Noise, and it’s effects in the control center as described above, can be much greater in this situation. Often in these cases it is necessary for the control center network support personnel to trouble shoot and initiate work arounds to this type of problem. This may involve corrective action through ground control, scheduling of a new configuration, or voice interface with network control center and ground station personnel.

REQUIREMENTS OF A NETWORK SIMULATION

Typical requirement of a network simulation for training are to simulate each of the network functions described above, providing the same inputs to the real world mission control center as it receives from the communications network in the real world. Data interfaces typically utilize the same formats and data rates as are used in the real world. The goal of the network simulation is to create the illusion that the control center is interfacing with the real world network communicating with the actual spacecraft. The uplink commands produced by the control center in the real world are received by the network simulation and provided to the spacecraft vehicle simulation (the same simulation used for crew training). The spacecraft vehicle simulation also provides all telemetry to the network simulation. Figure 2 shows the data flow and interaction with a network simulation. Detailed network simulation requirements include the following:

1. Physical receipt and transportation of telemetry and command data between the spacecraft control center and the spacecraft simulation. Data is only processed and allowed to pass though the simulation if the simulated network conditions and configuration is one that would allow data communications in the real world

2. Simulation of tracking by the network. This involves transformation of the state vectors and velocity information maintained by the spacecraft vehicle simulation into the format of tracking data messages produced by the network. These messages are then transmitted to the mission control center
Figure 2- Data Flow and Interaction with a Network Simulation
3. Simulation of line outage recording is provided by recording the telemetry produced by the spacecraft vehicle simulation. This data is then played back to the control center, if requested in the manner utilized by the real world.

4. Simulation of the network scheduling function by having the simulation play the role of the network control center. This involves receipt of scheduling messages from the spacecraft control center scheduling system, maintenance of a schedule database, and response to spacecraft control center scheduling data messages. Once valid schedule requests are transmitted to the simulation and added to the simulated network schedule, the schedules are used to automatically configure the simulated systems in the network simulation to match the configuration requested by the spacecraft control center. This automatic network configuration occurs when the appropriate support start time is reached as specified in the schedule.

5. Simulation of network control. This involves receipt of control messages from the mission control center, and altering the configuration of simulated network systems in the manner commanded by the control center. As with scheduling, no attempt is made by the simulation to insure that the commanded configuration will allow communications. This provides the trainees with an opportunity to make the same mistakes which are possible in the real world.

6. Simulation of network status. This involves collection of the same statistical data provided in network status messages in the real world. This data is collected based upon measurements taken from the simulated telemetry received from the spacecraft vehicle simulation, and measurements taken from the command uplink received from the control center. This data is then formatted into data quality status messages and provided to the control center in electronic form.

7. Simulation of network artifacts. This involves accurate AOS/LOS computations. These are based upon line of sight calculations using the simulated positions of the spacecraft, the relay satellites, and ground stations. The current scheduled network configuration is also considered in these computations, to insure network systems have been configured correctly to allow data to flow. The configuration of the spacecraft vehicle simulation on-board data communications systems is also considered. Transmission frequencies, polarization, data encoding, and any other variable which has a possibility of manual configuration mismatch between the spacecraft and the network relay satellite or ground station is checked for compatibility. If all conditions allow, data is allowed to flow between the spacecraft vehicle simulation and the control center.
8. Introduction of noise. This involves intentionally introducing errors into the telemetry data produced by the spacecraft vehicle simulation, prior to the simulation of data reception by the network. A random noise generation algorithm is utilized, which is seeded by the bit error rate characteristics of the network for nominal noise simulation. The simulation instructor is also allowed to increase this level of noise to simulate degraded conditions. Similar noise is introduced on the command uplink data prior to it’s presentation to the spacecraft vehicle simulation, as well as to all other simulated real world data links including the scheduling, ground control, data quality, and tracking. In each case realistic “seeds” are used for the random noise generation, based upon the bit error characteristics of the respective data link.

9. Simulation of outages and degradation due to malfunction. This is accomplished by simulating the systems which are used to transport data, and creating the set of symptoms which would appear in the control center if that system were degraded or completely broken. The instructor of the simulation is allowed to introduce malfunctions into the simulation. Malfunction symptoms may manifest themselves in any or all outputs to the control center including telemetry, tracking, ground control response, scheduling response, and data quality messages. In this manner it is possible for control center personnel to recognize the particular set of symptoms which accompany numerous permutations of anomalous situations.

PERSONNEL TRAINED BY A NETWORK SIMULATION

Assuming the simulation requirements were to simulate all typical network services, interaction, and artifacts as described above, candidates for training include the following:

a. Spacecraft crews - The crew has opportunity to practice configuration of the communications systems aboard the spacecraft. This is especially important in practice for recovery from anomalous situations in which communications with the ground has been lost and must be recovered to continue the mission. Often, loss of communications is due to misconfiguration, either of network, or of the spacecraft. The fact that the network simulation is present and simulating the network configuration makes misconfiguration possible. Without a network simulation, the training cues which manifest themselves during a misconfiguration will never be experienced by the flight crew in a realistic manner.

The crew will also be able to experience the effects of noise on uplink. If a network simulation was not utilized, the crew would not experience the effect of
noise on uplink commands. If uplink voice data were completely error free during simulation, but noisy in the real world, negative training would result. If on-board systems never registered the receipt of noisy invalid commands, cues which contribute to realistic training would be missed. If every command sequence received from the control center was completely error free, then every mission event which is driven by control center command sequences would be less realistic than if a network simulation were present to introduce noise.

Training is also more realistic because mission time lines which require synchronization with AOS can be more accurately rehearsed. If AOS/LOS times were not accurately simulated, the practice of mission time lines would be unrealistic. Taking a few moments more than planned to perform a crew procedure is significant if the extra time causes a mission event which requires observation and cooperation from the control center, to occur during an LOS period. In space, where irreplaceable consumables can be expended when mission time lines are exceeded, this is a very important consideration in determining the need for network simulation.

b. Ground controllers of spacecraft on-board systems - All control center personnel who view telemetry get accustomed to “normal” noise. In addition, the same concerns apply here as to the crew training for mission command sequences and time line planned mission events.

Since the network simulation is required to accurately simulate the current scheduled network configuration, including transmission power levels, frequencies, and other characteristics, it is possible for the flight controllers for the spacecraft on-board communications systems to view realistic telemetry. Without network simulation the telemetry from these simulated on board systems which measure the characteristics of the uplink signal from the network can not be realistic.

c. Spacecraft control center communications network support personnel - These personnel have an opportunity to practice scheduling of “possible” network configurations for mission support. If preplanned “canned” schedules are to be utilized in the actual mission, there is opportunity to utilize these in mission simulations. If there is no scheduling training in simulations, these individuals do not have a chance to practice live.

As a side benefit, the control center personnel who view tracking data and the outputs of systems in the control center which process tracking data, are allowed to view realistic data.
d. The entire team - Every anomalous situation has a set of symptoms which will manifest themselves in different ways to each member of a mission support team. These symptoms can be thought of as a signature of the problem. If it is possible to inject likely problems during simulations, and the simulation is of sufficient fidelity to produce that problems associated signature accurately, it is possible to train the mission support team to recognize anomalous situations and take appropriate corrective action quickly. The team will see a “distributed” signature, which will require appropriate communications and dissemination of information among team members in order to formulate a collective decision on the nature of the problem and it’s solution. The distributed nature of the problem signature makes it all the harder to recognize and solve the problem. The network simulation provides a solution to training the entire mission support team to work together to recognize and solve these types of problems.

**NETWORK TRAINING IN THE PERMANENTLY MANNED SPACE ERA**

As we enter the era of permanently manned space presence, another consideration is mission support team complacency due to long periods of nominal operations. There is temptation to assume on the job training for spacecraft flight controllers will be sufficient in this era, since mission control centers will be manned full time. Whether simulation type training is necessary after an initial training “bootstrap” is accomplished is in question.

We submit, that in order to avoid complacency, proficiency training in anomalous situations is absolutely necessary. Space systems are designed with the goal that the most catastrophic problems will be least likely to occur. This means that this most dangerous class of problems are the ones least likely to be encountered on the job. It therefore is essential that mission support personnel be exposed somehow to the signatures associated with these problems. Space is a very unforgiving environment, and every possible step should be taken to prepare for all contingencies. Training is very inexpensive when compared with the expense of loss of even one average experiment or payload. We further submit, that the fidelity and realism of the simulation is of paramount importance in order to produce an accurate signature of anomalous situations. The need for this realism is magnified due to the distributed nature of problem signatures in a spacecraft control center.

**CONCLUSIONS**

High fidelity simulations of telemetry and data communications networks have been utilized by the US space program for training of flight crews and mission control center personnel for many years. These simulations provide realistic training for configuration of spacecraft and telemtry communications networks, as well as
providing benefits to all personnel who utilize telemetry and command data by introducing network artifacts into simulated telemetry data produced by the spacecraft vehicle simulation. These simulations are necessary to allow all mission team members to recognize the symptoms of anomalous situations, and are especially critical due to the distributed nature of control center designs and distributed flight controller responsibilities. As we enter the era of permanently manned space presence, network simulations become even more important for proficiency training in recognizing and solving spacecraft communications problems.

REFERENCES
