FUTURE TRENDS IN NASA SPACE OPERATIONS

N94-23836

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It is a great privilege for me to address my colleagues at SPACEOPS 92. Today, I would like to share with you some current directions we are pursuing in NASA's Office of Space Communications (OSC).

The space agencies of the world have produced some remarkable achievements in conducting our missions. It is also true that we consume significant resources in controlling and operating our spacecraft. In these challenging economic times, the degree to which our agencies can develop new missions will depend on our ability to reduce operating costs. I believe that there are many opportunities for doing this, and I will explore some of our plans in this regard. First, I will review the business of "space operations."

WHAT ARE SPACE OPERATIONS?

We use spacecraft as our agents to collect information on our behalf. This implies the ability to communicate and to interact with our agents using some form of radio transmission. The ability to interact with spacecraft implies that a piece of the total system resides on Earth. The functions and complexity of the Earth-piece determine its cost.

For example, Hubble Space Telescope and Voyager are quite different missions, yet they are similar in operational complexity. Each requires about 10,000 commands to define a day's worth of activities. This process is labor intensive for both missions.

We can generalize — independently of specific systems — the operations functions needed by every mission in a reference model for OSC services, shown in Figure 1. The model is similar to the OSI reference model. It is hierarchical with well-defined interfaces that isolate the internal details from one layer to the next.

The components of the OSC reference model are as follows:

- Radio-link service – TDRSS, DSN, GSTDN.
- Digital bit-level functions – Bit synchronization and convolutional decoding.
- Frame-level functions – Recognizing and removing the transport structure.
- Packet functions – Recognizing and separating data substructures.
- Data processing
  - Removing artifacts of communication to recover original instrument data; error detection and correction; time reordering and overlap removal.
  - Generation of user data sets.
  - Correlation of data with spacecraft position and attitude.
- Mission control (easy to say, harder to do)
  - Assessing spacecraft performance.
  - Detecting and responding to problems.
  - Planning mission activities and scheduling radio-link services.
  - Creating the operations program and certifying its safety.
- Tracking measurement – Measuring spacecraft position (distance, angle, velocity) as a function of time.
- Tracking data processing – Removing artifacts; conversion to engineering units.
- Orbit determination – Estimating position and velocity as a function of time relative to a model and a coordinate system.
- Attitude determination – Estimating the orientation and rate of change of the spacecraft as a function of time.

Moving up the stacks of the reference model, we see that the systems reflect increasing knowledge of how individual spacecraft are built and how they work. The lower level services readily accommodate new customers with little preparation, if they meet the interfaces and capacity exists. Higher level services require the development of systems based on individual spacecraft.

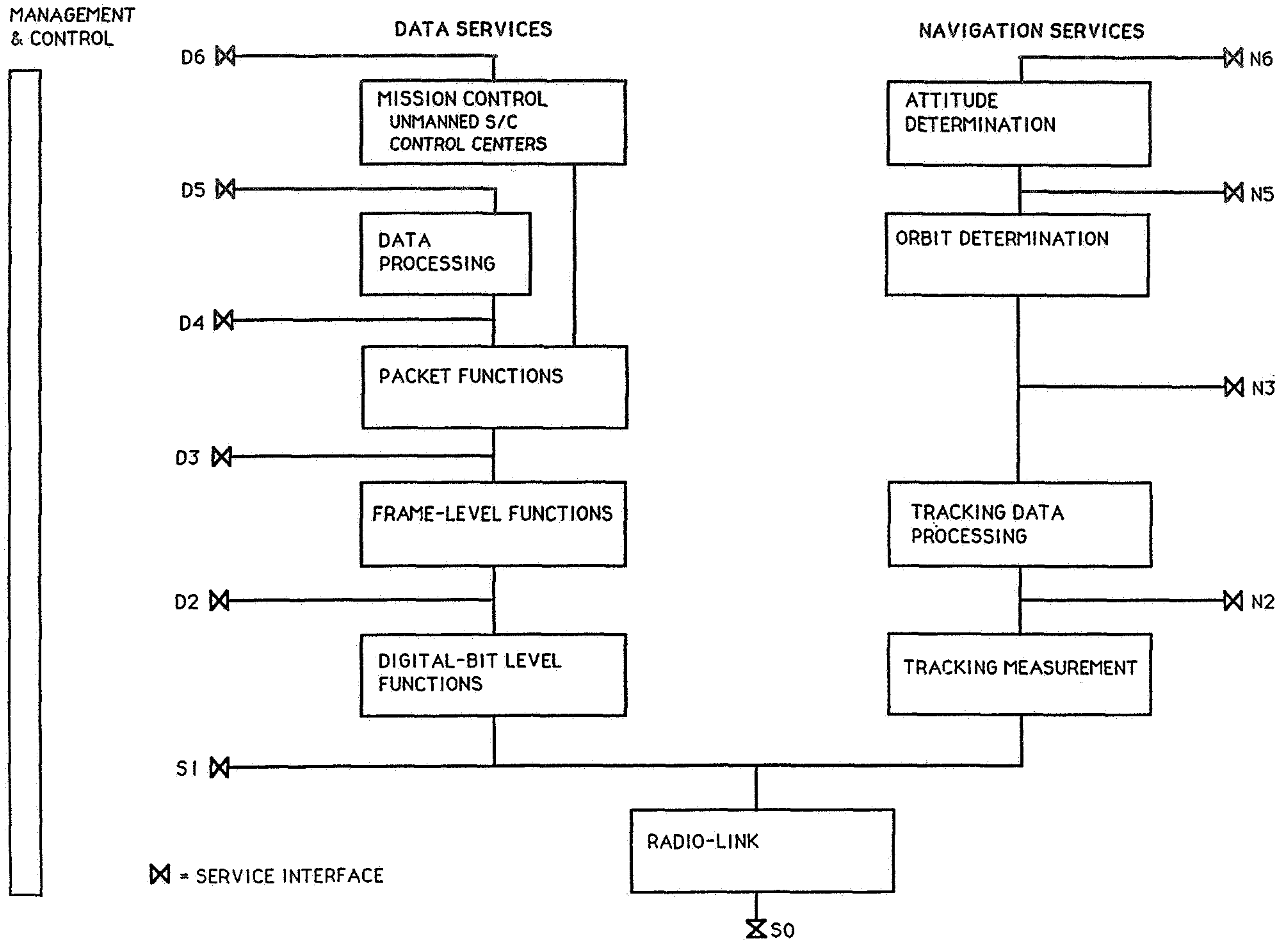

Figure 1. Reference Model for OSC Services.

Economics of Space Operations

Our challenge is to provide operations services more economically — every space agency is currently faced with this. The cost of operations directly competes with the ability to develop new missions.

One way to achieve economy is to provide common solutions for recurring mission needs: for example, the Deep Space Network and the Space Network. This has been recognized for a long time and many space agencies are organized with this in mind. OSC within NASA is an example. It does not in itself minimize total cost — for example, the cost of spacecraft can be reduced by assigning more functions to the ground system. Minimal cost is achieved only if spacecraft designers are accountable for the total cost of their missions.

In order to reduce costs, we need to know where our costs are incurred.

- Lower level services: The incremental cost for a new mission is negligible, unless new capacity is required. In this case, the cost is known and can be associated with the requirement.
- Higher level services (mission control, data processing, and flight dynamics): The incremental cost for a new mission is significant, because ground systems must reflect the design and functions of the spacecraft. There is a system development cost and an operations staff cost associated with each mission. System capacity is frequently an issue.

There is the significant possibility that spacecraft design decisions will adversely affect development and startup costs.

Our experience indicates that, for unmanned Earth-orbiters, on average:

- Development and startup costs are about twice the yearly operating cost.
- Development is quickly overtaken by operations and the latter is the biggest payoff.

Opportunities for Cost Savings

Lower Level Services

- Automation: same services operated by fewer people
  - STGT for spacecraft monitor and control and status reporting automation; reduce operations staff required for current capacity by one-third.
  - Ground networks: a new generation of low-cost transportable stations with semi-automated operations.
- New technology: modern equipment, commercial products
  - Deep Space Network: increase data rates by a factor of ten and simultaneous capacity from three to five links.

Higher Level Services

- Major thrust to standardize the services and their interfaces, so that customers can design their spacecraft accordingly. This will have a significant effect on development costs, and to some extent on operations. Currently, we frequently need to tailor systems to "as-built" spacecraft.
- Data processing
  - Flight systems now under development use standards recommended by the Consultative Committee for Space Data Systems (CCSDS).
  - Significant economies on the flight and ground sides of the data system are resulting. This is enabling the development of a new ground data processing system that will service a large number of different missions. The development activity for a new mission will consist of creating a control table to identify the virtual channels and specify processing options.
- Mission control
  - With standard services and interfaces, the development cost will be sharply lowered through reuse of systems and software.
  - This implies building our spacecraft to a similar concept of operations, representing stored command programs; even building our spacecraft to a common architecture and using common components.
- Opportunities for future mission control systems
  - Develop "power tools" for operators: i.e., new mission planning system.
  - Greater autonomy of spacecraft can produce substantial cost savings. We are beginning to do this with the new generation of spacecraft called "small explorers" that require only one operations team shift per day.

Role for Technology

- Standards
  - Packet data systems.
  - We need standard ways of representing data products to ease the job of interdisciplinary data analysis. The CCSDS is working on this with their Standard Formatted Data Unit.
- Modern computing machinery
  - We are moving away from large, mainframe computers in favor of distributed systems and custom-designed VLSI hardware processors where appropriate.
  - We need more capable flight computers to achieve higher levels of automation on board.
- Maximizing reuse of software
  - New software environments enable porting software across different vendors' hardware.
  - Significant reuse will come only if we can make the functions and data structures similar from mission to mission.
- Automation
  - Many tasks in control centers are routine and deterministic: ripe for automation.
  - Expert systems are currently used as advisors to operations personnel — in an off-line sense. It's time to go further. Examples are Cosmic Background Explorer (COBE), Johnson Space Center mission control, and STGT fault-isolation and recovery.
  - As we gain more experience and confidence, expert systems can be used more directly in the command and control process. In the future, they might be on board the spacecraft, free from the uncertainties of the communications process.

Conclusion

I have described the operations services provided by NASA's Office of Space Communications and discussed our common need for reducing the cost of operations. I have noted some economies we have realized, and explored a number of opportunities for further economies.

The key point is that economies in space operations can be achieved — especially if we change the way we build spacecraft and how they operate.

Standard services and interfaces can be expected to shorten the preparation time for the ground system. A similar benefit should be achieved on the flight element, since there is less "re-invention."

I suggest that we use this conference to share ideas and experiences in reducing space operations costs, so that our respective space agencies can pursue more exciting and productive missions.