Connecting Remote Systems for Demonstration of Automation Technologies

R. M. Brown and R. Yee
Systems Autonomy Demonstration Project Office
NASA/Ames Research Center
Moffett Field, CA

ABSTRACT

Work will begin this year on the development of the second of four demonstrations of automation technology under the Systems Autonomy Demonstration Project (SADP). This demonstration will involve elements of four NASA Centers: ARC, JSC, LeRC, and MSFC. Intercenter digital data communications will be a vital element of this demo.

This paper presents an initial estimate of the communications requirements of the SADP development and demonstration environments, a proposed network paradigm is developed, and options for network topologies are explored.

INTRODUCTION

The Systems Autonomy Demonstration Project (SADP) was established to conduct a series of demonstrations of the use of advanced automation technology in solving problems applicable to the Space Station. The first demonstration, scheduled for 1988, will use expert system technology and model-based reasoning to monitor and control the operation of Johnson Space Center's Thermal Test Bed.

Work will begin this year on the second SADP demonstration, this one scheduled for completion in 1990. Unlike the 1988 demonstration, intercenter digital data communications will be a vital element of the 1990 demo. To accomplish the 1990 demo, elements of Lewis Research Center (LeRC) and Marshall Space Flight Center (MSFC) will be included in the SADP. The demonstration itself requires the interaction of systems located at LeRC and JSC, and cannot be accomplished without intercenter data communications.

Within NASA, intercenter data communications are provided through the Program Support Communications Network (PSCN). The PSCN employs terrestrial and satellite transmission facilities to support all elements of the agency and provides a wide variety of services, including intercenter telephone, FAX, voice and video teleconferencing, electronic mail, and digital data communications. The PSCN is based on a foundation of equipment and leased lines tying together all sixteen major NASA locations.

SADPNET REQUIREMENTS

In designing a network like SADPnet, the first step is to define the overall network goals, including functions, connectivtivity, interfaces, operational quality and cost, expansion capability, and implementation cost.

Hardware capabilities

To understand the limits posed by the systems at each site, a study was made of the file transfer capabilities between a Symbolics 3600 system and two other computers on a 10-Mbit/sec Ethernet LAN. These measurements were made using the TCP-IP protocol and FTP service. The results are shown in Table 1.

Table 1 -- Measured file transfer rates

Path	No of trials	File size (bytes)	Av time (sec)	variance (sec)	transfer rate (bytes/sec)
1 -> 2	7	0	0.780	0.003	n/a
1 <- 2	6	0	2.345	0.738	n/a
1 -> 2	10	1210	1.165	0.010	1039
1 -> 2	5	1209 KB	214.1	10.2	5647
1 -> 3	1	1209 KB	111.0	0.0	10892

System 1 is a Symbolics 3600 running Genera 7.1
System 2 is a DEC microVAX II running Ultrix 2.0-12
System 3 is a DEC VAX 11/780 running VMS 4.5

It is clear that the measured transfer rates are relatively low, reflecting in part the overhead posed by the Symbolics operating system. However, the transfer rate between the Symbolics and the VAX for a large file was double that to the microVAX for the same file, showing that the microVAX also limited the transfer rate. These data are preliminary, and tuning of the systems may provide improvements. However, they suggest that the overall performance of the SADPnet may be strongly constrained by the computers at each end of the link.

End-user functions

For SADPnet, three major end-user functions dominate the design: process-to-process communications services; virtual terminal services; and file transfer services.

The links that will be needed between expert systems are examples of process to process (p-p) communications. Figure 1 shows one possible requirement for links between JSC and LeRC to connect testbeds at each site. When connected, the expert system controllers will share information and coordinate actions in a manner similar to that needed in a Space Station environment.

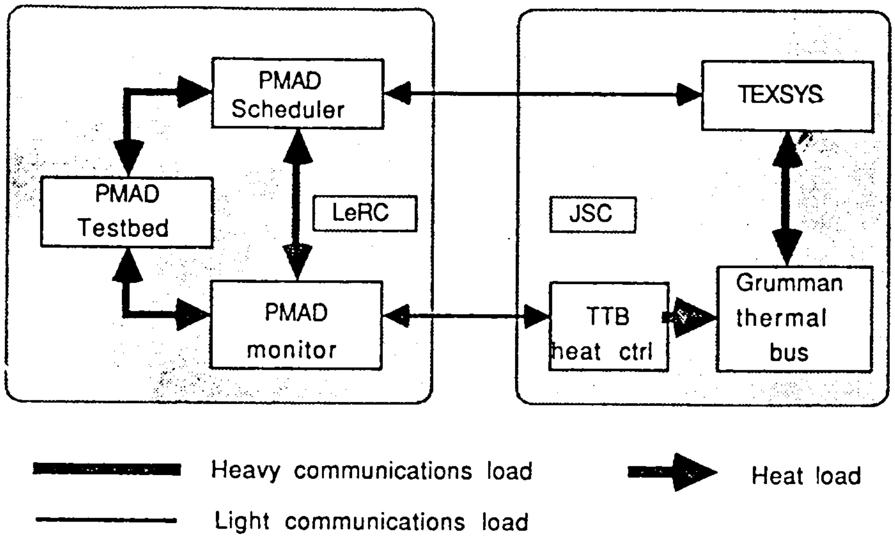

Figure 1. Possible 90 Demo p-p communications

Because these systems have little direct interaction, there is no apparent need for high data rate between the TEXSYS controller and the PMAD controller. After initial setup, the average data rate will probably not exceed one packet per second. Link periods will range from two hours, during the installation and integration activities, up to several days for the demonstrations. Outages during this period must be avoided or the demonstration activity may have to be aborted and rescheduled.

In addition to the general p-p links, SADP needs to have a virtual terminal (VT) service. VT service allows any of a wide range of terminals at one site to act as if it were connected to equipment at another site. A VT session will need to provide an equivalent to 9600 baud service with link periods of a few minutes to a few hours.

Because it is so visible to the end user, VT service will be difficult to provide. Outages, failures to connect, or other communications failures will interfere directly with the efficiency of project staff. In addition, personnel who use this service on a local area network get close to 100% availability and reliability, and will likely use this as the criterion for success when evaluating an SADPnet implementation.

The third service required for SADPnet is a reliable file transmission capability. Large file transfers will occur infrequently. The distribution of major system builds, for example, are expected to occur no more than once per month, on the average. These files are expected to be approximately 2-10 MBytes in size, and data transfer times for these large files should be accomplished in no more than a few hours.

Small files will be transferred more often. These files, less than 1 MByte in size, should be transmitted in a few minutes or tens of minutes. The transfer rate implied by the above requirements is modest, less than 15 Kbits/sec.

It is reasonable to expect file transfers to be efficient users of the provided bandwidth of SADPnet. For example, large files were recently sent between Langley Research Center and Ames Research Center over a dedicated 224 Kb/s PSCN line using TCP-IP protocols. The measured transfer rate was 219 Kb/s, exactly as predicted by the percentage of overhead in the packet.

Connectivity and Interfaces to Intra-center networks

Each center involved in SADPnet will need to communicate with at least 2 other centers via SADPnet. In fact, the only path where a need for connectivity has not yet been established is the MSFC-JSC link.

A possible configuration of the network at JSC for the 88 demonstration provides an example of the local elements of the overall SADP system. Figure 2 shows a simplified diagram of the elements of the TEXSYS system, together with other elements of the Thermal Test Bed. The configuration at ARC is similar -- an Ethernet bus with computers and controllers directly attached.

Simultaneous service

The SADPnet cannot be effectively used if it is the equivalent to a large party-line where only one connection can be supported at any moment. The number of simultaneous connections to be maintained by SADPnet for the 90 demo will be determined by further studies, but is expected to be less than ten.

Protocols

The SADP communication service will have to support several protocols. Digital Equipment Corp.'s Digital Network Architecture (DNA) and the ARPAnet TCP/IP protocols are currently used. As the SADP progresses, it may be found to be appropriate to convert to the ISO standard. Therefore, it is prudent to design a network that will simultaneously support all three. This is not an unreasonable requirement, as both TCP-IP and DNA are designed to be co-resident with multiple protocols.

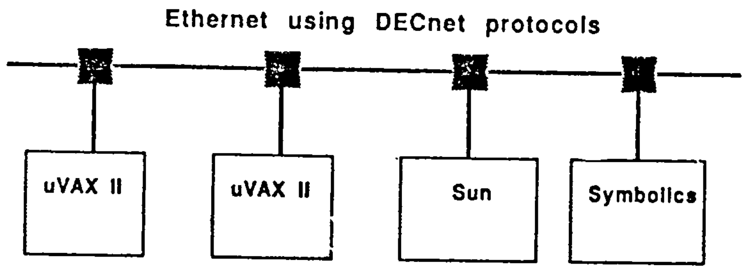

Figure 2 -- Possible network configuration for 88 demo

Reliability, Availability, and Maintainability

A basic requirement for the SADPnet is that it provide reliable service, that it be available when requested, and that an maintenance organization is available and competent to repair the service when it fails. These requirements are typically known as Reliability/Availability/Maintainability, or RAM.

Error rate is generally the metric used when considering reliability. Based upon recent studies of seventeen PSCN links, a reasonable expectation for packet error rate is that it will not exceed one packet in a thousand. The PSCN goal for packet error rate -- based upon ATT standards -- is that it not exceed 0.5 packets per hundred.

Availability is the probability that the service will be available for use when needed, and that no outages (as opposed to burst errors) will be encountered once the connection is established. An appropriate availability goal is that the system be available for use at least as often as telephonic access to the same location. This implies that a request for connection to another site should be satisfied with an 0.99 probability at an 0.50 confidence level.

Finally, the maintainability of the service should approach that provided by most long distance digital common carriers. Though the PSCN is a new network, the service provided by PSCN operations staff is approaching the level needed.

Expandability

Expansion of the SADPnet is a distinct possibility. It therefore should be designed now to allow this expansion -- adding sites, services or levels of performance. Expansion should be possible without hurting the existing service and without unusual cost impact.

PSCN RELIABILITY

Accurate data are available to judge the PSCN performance in terms of error rate. These come from an unpublished study[1] of NASnet, a communications network using PSCN that ties computers at ARC to 17 other sites, including all of the sites associated with SADP. These links include dedicated T1 services, switched 56 Kb/s services staying on the PSCN backbone, switched 56 Kb/s service with tail circuits from the backbone, and dedicated 224 Kb/s lines through the PSCN backbone. All of these links are provided through terrestrial, rather than satellite, services.

Table 2, below, summarizes the NASnet measurements of the PSCN error-rate on 15 of the 17 circuits over a 30 day period. Two of the 17 sites had no traffic during this period.

Table 2 - NASnet traffic statistics

Site	up time	MBytes sent	MBytes rcvd	% CRC errors	Circuit type
1	736.0	253.3	155.0	0.00	Ded. ATT T1
2	720.5	5740.2	1272.4	0.02	Ded. 224 Kb no tail
3	699.5	50.2	10.5	0.92	Sw. 56 Kb
4	517.9	1965.0	83.2	0.18	Ded. 224 Kb no tail
5	445.5	14.2	15.2	0.00	Sw. 56 Kb no tail
6	226.0	30.1	18.0	0.00	Sw. 56 Kb
7	90.3	32.8	10.5	0.01	Sw. 56 Kb
8	82.8	21.1	6.8	0.02	Sw. 56 Kb
9	58.7	38.2	13.8	0.01	Sw. 56 Kb
10	44.3	74.1	19.3	0.01	Sw. 56 Kb
11	41.5	13.3	5.7	0.05	Sw. 56 Kb
12	37.8	69.3	56.2	0.50	Sw. 56 Kb
13	34.6	42.6	44.2	0.01	Sw. 56 Kb
14	16.7	12.2	40.0	0.02	Sw. 56 Kb
15	4.3	0.0	0.0	0.00	Sw. 56 Kb no tail
16	2.8	0.2	0.1	0.58	Sw. 56 Kb no tail
17	0.0	0.0	0.0	0.00	Sw. 56 Kb

One conclusion that can be drawn from this study is that the dedicated and switched 56 Kb/s PSCN lines can provide error rates that are acceptably low when measured against SADPnet requirements. Eleven of the fifteen sites demonstrated packet error rates less than one in a thousand, and all had error rates less than one in a hundred. The PSCN goal for error rate is 1 in 200, limited by the commercial carrier offering.

---

[1] Data here were provided by Judy McWilliams, General Electric Corp, from studies covering the 15 week period from May 24, 1987 through Sep 4, 1987.

However, the study reveals some problems in terms of availability. The three dedicated line circuits in this network should have had 100% availability; only one of these lines achieved that goal.

That line (to Site 1) provides a standard by which the others can be judged. It is a dedicated T1 service running over ATT lines that had an uptime of 100%. No packet errors were seen on this line under moderate to heavy system loads.

On the other hand, site 2 had over 15 hours of downtime and a resultant availability of 98%, while site 4 achieved only 70% availability. The level of service was reported to be considered 'good' by the users at site 2 and 'poor' at site 4.

SADPNET OPTIONS

Since the switched and dedicated line services of PSCN can provide connectivity with acceptably low error rates, the design process now involves establishing a network paradigm, topology, and channel speed; then fleshing these out with hardware and software options.

SADPnet Paradigm

Because the goal of SADPnet is to connect LANs at each site, the basic network paradigm proposed is that it be an extended Ethernet service, though one that has a lower bandwidth for inter-center traffic than that provided intra-center. This paradigm permits the use of existing hardware, software, and protocols, and allows for the addition or removal of computer equipment at each site without coordination problems. In addition, experience with this approach has shown it to be both feasible and economical.

This paradigm involves three major elements, as shown in Figure 3. The top element is the communications network provided by PSCN lines, whether dedicated or switched. The bottom element is the local network, containing the existing and planned development and testbed computers. In between is an Ethernet bridge device and communications interface.

The bridge is the critical element in this network. It transmits to the other sites only those packets being sent to remote systems. This keeps local Ethernet traffic from being transmitted through the network, a feature that reduces network bandwidth requirements enormously. The bridge makes use of configuration information to manage the network traffic, and to provide network statistics and security.

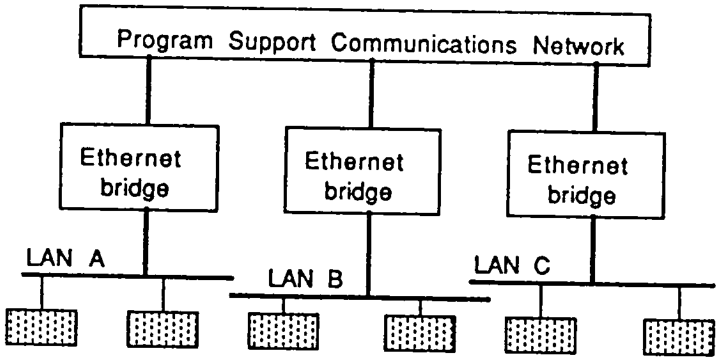

Figure 3 -- Basic SADPnet paradigm

Possible Topologies

The network topology can be a star, a bus, or a series of point-to-point links. Figure 4 shows four possibilities.

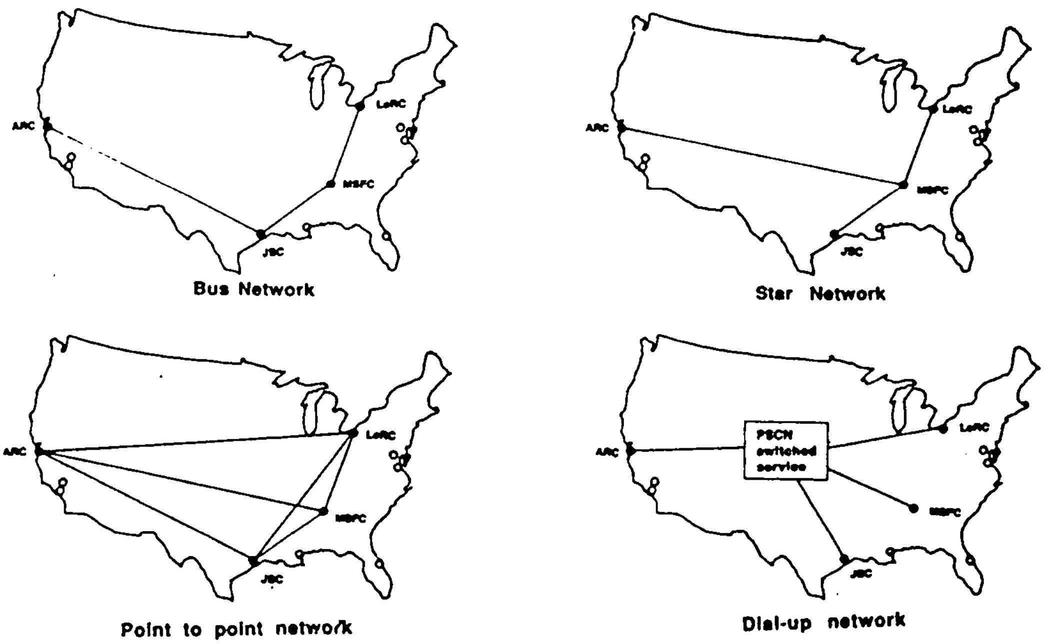

Figure 4 - SADP Topology Options

The bus, star, and point-to-point options shown in Figure 4 can meet all SADPnet requirements; the dial-up option can meet them under conditions of very light load. Choosing among these options will require cost/performance tradeoffs, and a complete analysis of these tradeoffs is beyond the scope of this paper.

CONCLUSIONS

This study has focussed on communications requirements for the SADP 1990 demonstration. The next step is to validate the requirements, explore the network options, and select a design. A project team, including members from each site, should then be formed to implement the network, a schedule and budget for this project established, and implementation begun.

SADPnet will be the first within NASA to be used to connect interacting automated controllers, and to do so over long distances. The SADPnet has every chance of meeting technical requirements, cost constraints, and schedule requirements, if the steps noted above are initiated promptly.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the help provided by the NASA/ARC NAS Systems Division by making available the unpublished results of the tests of PSCN reliability and transfer rates.