TELEMETRY DATA STORAGE SYSTEMS TECHNOLOGY FOR THE SPACE STATION FREEDOM ERA

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ABSTRACT

NASA'S Space Station Freedom and the Earth Observing System, due to be operational in the mid-1990's, will provide scientists the vehicles to deploy an unprecented number of data producing experiments, including advanced imaging instruments with high spatial and spectral resolution. Peak down-link data rates are expected to be in the 500 megabit per second range, and the daily volume of science data could reach 2.4 terabytes. Such startling requirements have stimulated development efforts in high rate on-board recorders, and inspired an internal NASA study to determine if economically viable data storage solutions are likely to be available to support the ground data transport segment. This paper summarizes the mission and system drivers for telemetry data recording and storage capabilities, and provides an overview of NASA efforts to prototype advanced storage systems.

INTRODUCTION

The manned base and polar orbiting platform elements of the Space Station Freedom will create a number of data storage and delivery challenges for flight and ground information systems:

- operation of high rate imaging instruments in the 100 to 300 Mbps range;
- capture of high resolution video at high frame rates for microgravity experiments;
- near-real-time delivery of data for telescience operations;
- data driven operations, based on variable length packets embedded in fixed length transfer frames;

- on-board reconfiguration of experiments, requiring adaptation of telemetry processing operations; and

- operation of platforms over a long lifetime.

The storage subsystems and technology needed to meet these requirements are dependent to some extent on the architecture of the end-to-end information system and on specific storage functions within the system architecture. The data transport system from spacecraft/platform to the final archive destination is simplified in Figure 1. With the operational Tracking and Data Relay Satellite System (TDRSS), on-board storage is primarily required to buffer data during periods of TDRSS link unavailability due to the Zone of Exclusion and scheduling conflicts in servicing multiple spacecraft. Ground processing involves capture, staging, and routing of data streams from multiple spacecraft to the appropriate mission data handling centers. Additional processing stages are required to eliminate artifacts introduced in the space-ground link (e.g., reversed data from tape recorder playback, duplicated data from handover between TDRSS spacecraft) and to convert telemetry units to scientific data, merging orbit/attitude and other ancillary data. Recording functions are required at each stage of this system for link buffering, data capture, rate conversion, working storage, and data delivery. Using projected mission manifests, analysis of worst case data flows from alternative architectures, and data system models, performance requirements have been estimated for classes of storage devices to determine the technology options. Figure 2 represents these storage functions and the storage media alternatives for each.

ON-BOARD STORAGE

The primary applications of on-board data storage to date have been buffering of instrument and engineering data during periods when the spacecraft is not within line of sight or within scheduled support periods of ground tracking stations or TDRSS. On-board tape recorders have provided reliable service for what has been primarily a sequential access problem. However, the higher data rates produced by future imaging instruments will result in longer delays in playing back engineering data and other instrument data, possibly impacting experiments being operated in an interactive “telescience” mode or those requiring near-real-time data delivery for correlative field observations. Figures 3 and 4 show the results of a discrete event model of Earth Observing System payload data flows through the on-board recorders, with link availability based on orbit models of the ZOE and on shared link schedules. Figure 3 shows the storage used vs. time for one of the four tape recorders, with the peak capacity used at approximately 250 gigabits. Figure 4 shows the latency vs. time for three low rate payloads. In each case, delays of up to 100 minutes are routine.

In addition to the recording latency, high data rate instruments will complicate the reversal process on the ground for tape playback. For these reasons, NASA's Office of Aeronautics and Space Technology has been sponsoring the development by Langley Research Center and GE Aerospace of the Space Optical Disk Recorder, a storage subsystem based on 160 gigabit erasable optical disk units, each capable of operating at 300 M bits per second (1). In order to meet link buffering needs of moderate rate instruments, NASA's Office of Space Operations is investigating the ruggedization and radiation hardening of 5-1/4" optical disk devices (2).

Other trends indicate future needs for direct access recorders on-board. The increasing complexity of science instruments will require on-board storage for control processor programs, calibration data, and, potentially, working storage for on-board processing to reduce downlink bandwidth in routine monitoring operations. Higher levels of autonomy in spacecraft systems and robotic exploration and servicing will require storage of knowledge bases, reference maps, and schematics. However, the advantages of direct access recording must outweigh the contribution of science instruments also competing for the increased power and mass required when compared to tape recorders (3).

GROUND TRANSPORT RECORDING

Storage systems for data capture, buffering, processing, and delivery on the ground (4) may be categorized as:

<u>First In-First Out (FIFO) Storage</u> - Very high rate capture of large data volume to protect against data loss due to system or communication line outages (System Outage Protection and Line Outage Protection in Figure 2).

<u>Fast Random Access Storage</u> - High speed block addressing of telemetry frames and packets to support reordering and reversal of playback data in Level Zero Processing and to buffer data bursts for transmission over lower bandwidth communication links (Rate Buffer and Working Store in Figure 2).

<u>Slow Access with Staging</u> - Hierarchical storage providing moderate (10's of gigabytes) direct access storage for scheduled or demand delivery of experiment data and extremely large volume off-line storage for reprocessing requests or for media transfer to processing centers and archives (Deferred Delivery in Figure 2).

(Note - Long term storage systems and media for archives are not considered here.)

Based on projected mission manifests and data rates, worst case requirements were developed for the these three storage architecture functions. The data rate vs. capacity was plotted for 2 years, 1996 and 1998, at which the mission data rates are expected to reach new plateaus, and the rates vs. capacities of alternative technologies and storage devices, again for each function category, were plotted on the same chart. Specific devices were considered if their performance was within a reasonable factor of the data rate and volume requirements, such that the requirements could be met through multiple devices. The capability of future devices was based on vendor projections, however an additional period of at least 4 years was added to allow for technology maturity and system integration. The results of the analysis are shown graphically in Figures 5 through 7 for the sequential, fast access, and slow access with staging functions, respectively. Requirements for key years are shown as squares on the peak data rate vs. volume plot. Selected subsystems and projected year of availability are plotted with vectors drawn to the appropriate "requirement" year based on projected development time. Each vector is labelled with the number of drives and/or media units needed to meet the requirement (assuming operation of parallel drives to meet data rate requirements).

The analysis indicates that the D-1 digital video cassette technology appears to be the most promising for data capture, line and system outage protection, large volume operations, and data delivery. It also indicates that parallel disk farm systems are the most promising at this time for high rate Level Zero Processing working storage and rate conversion operations. Based on this analysis, a prototype data storage system for meeting the high rate data capture operations for the Space Station Freedom era is being developed. In order to meet initial 150 Mbps data rate of a TDRSS I or Q channel, telemetry frames will be written in parallel across two disk farms through a high performance "data mover" card based on semi-custom VLSI devices (5).

Discrete event modeling of the end-to-end system is continuing as the designs of the various Space Station Freedom era information system elements evolve from concept to detailed definition. Trade-offs with communications costs will be a major factor in the final storage configuration. For example, Figure 8 shows the data storage utilization modeled at the Data Interface Facility (Figure 2) assuming one of six communication links in the model is buffered to reduce the maximum rate to 50 Mbps. The result is a maximum buffer size requirement for the modeled mission data sources of 80 gigabits (10 gigabytes). Similar analyses are being performed for the more demanding Level Zero Processing working storage functions.

CONCLUSION

Current projections of Space Station Freedom era science mission data rates vs. technology trends indicate that media and storage devices will be available to meet the data transport challenge, however relatively large configurations of parallel devices will be required to meet peak data rates. Opportunities exist for further improvements in on-board storage systems to allow priority delivery of near-real-time and engineering data and to avoid the need for some ground processing operations.

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REFERENCES

1. Shull, Thomas, “NASA Spaceflight Optical Disk Recorder Development”, Proceedings of the Symposium on Spaceflight Data Storage Technology, Jet Propulsion Laboratory, Pasadena, California, July 19-21, 1988.

2. Hockensmith, Richard, “5-1/4 MO Drive Development”, Proceedings of the Symposium on Spaceflight Data Storage Technology, Jet Propulsion Laboratory, Pasadena, California, July 19-21, 1988.

3. Dalton, John, “NASA Spaceflight Data Storage - Trends and Requirements”, Proceedings of the Symposium on Spaceflight Data Storage Technology, Jet Propulsion Laboratory, Pasadena, California, July 19-21, 1988.

4. Dalton, John, et. al., “Data Storage Systems Technology for the Space Station Era”, AIAA/NASA International Symposium on Space Information Systems in the Space Station Era, Washington, D.C., June 22-23, 1987.

5. Shi, J., G. Grebowski, W. Horner, and J. Chesney, “Prototype Architecture for a VLSI Level Zero Processing System”, International Telemetering Conference, San Diego, California, October 30 - November 2, 1989.

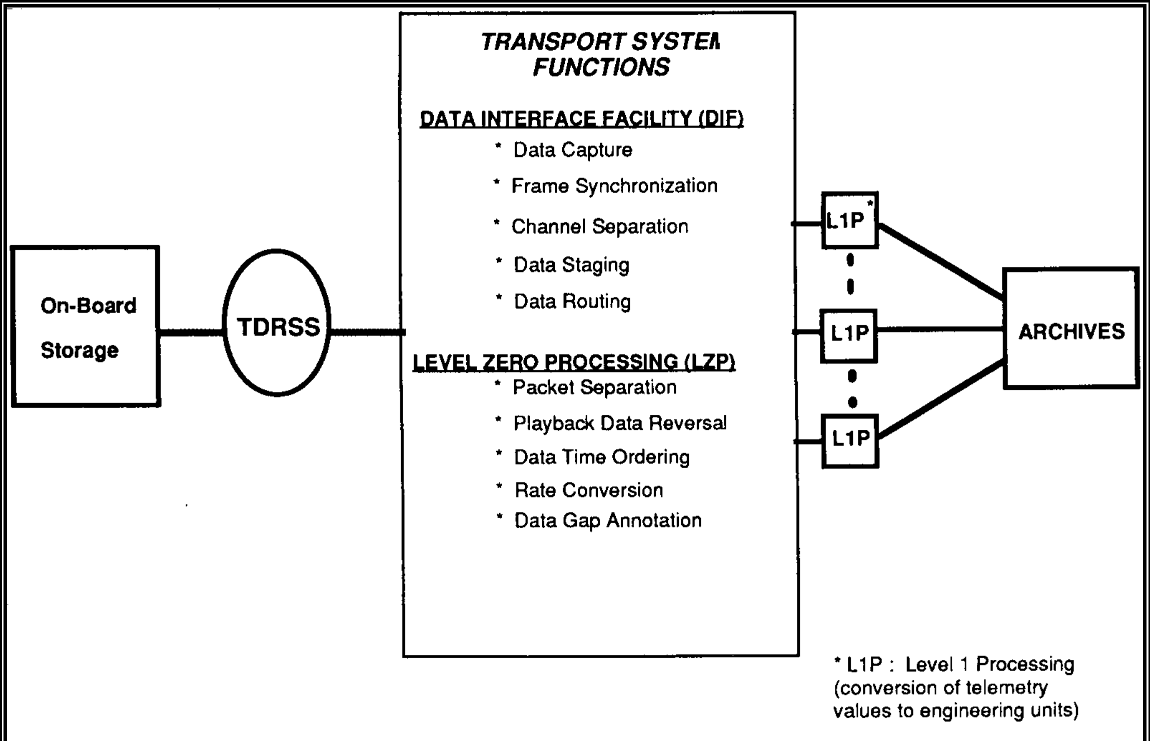

FIGURE 1. DATA TRANSPORT SYSTEM

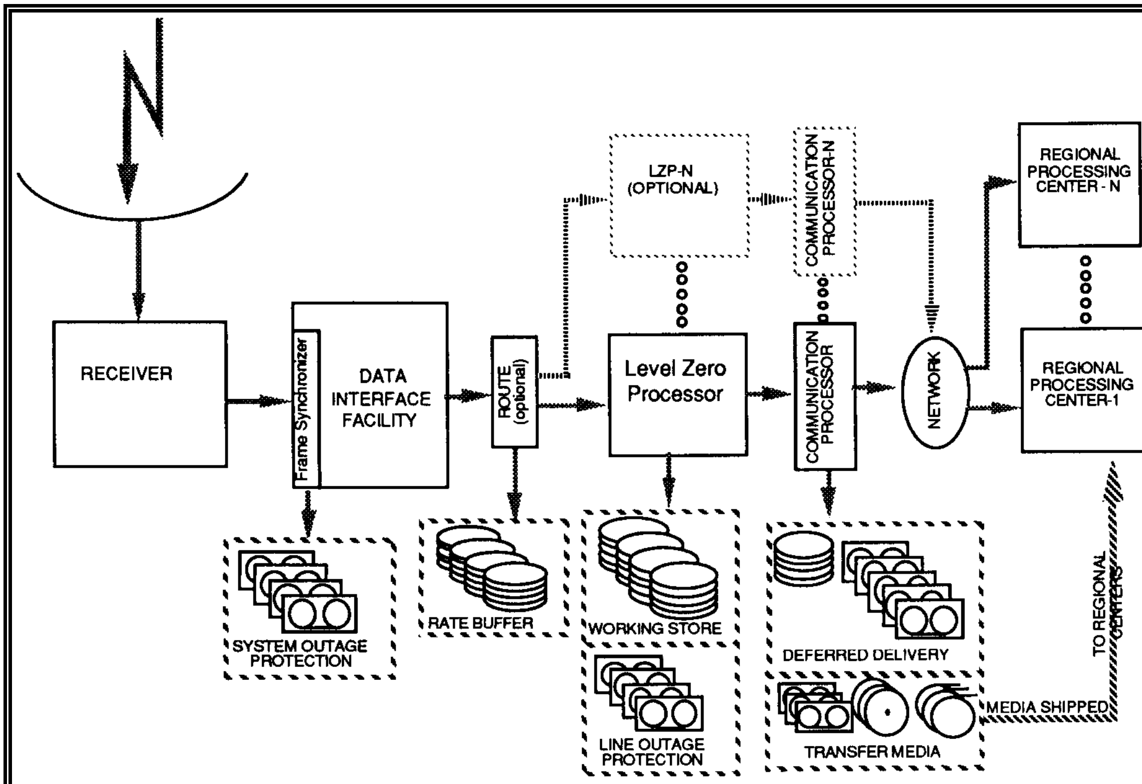

FIGURE 2. STORAGE FUNCTIONS IN THE DATA TRANSPORT SYSTEM

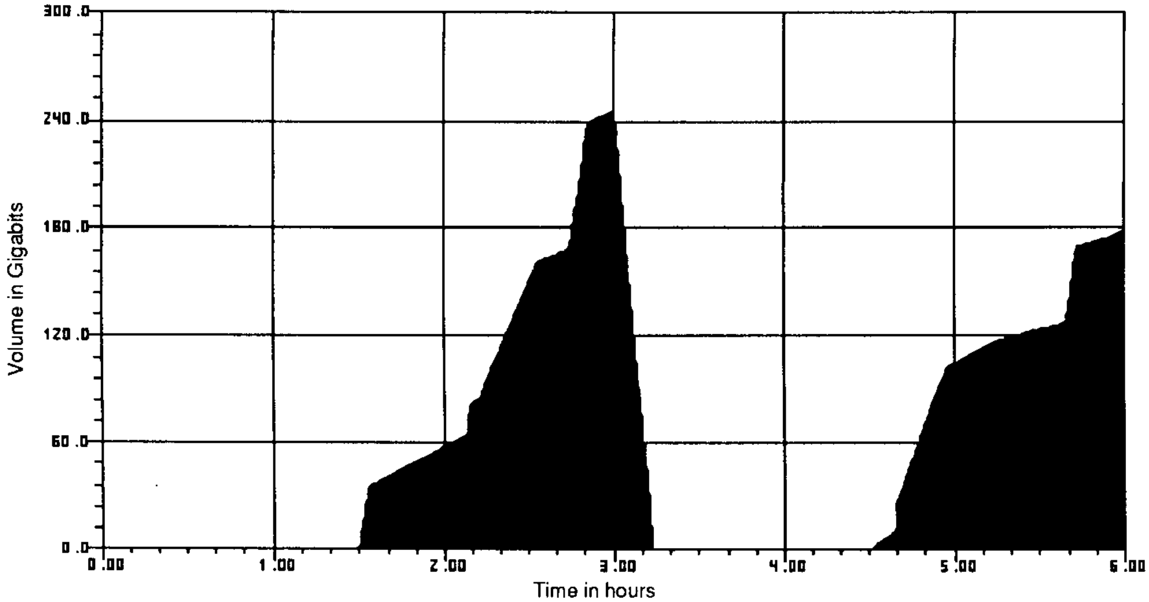

FIGURE 3. FLIGHT TAPE RECORDER UTILIZATION ON USA POLAR PLATFORM

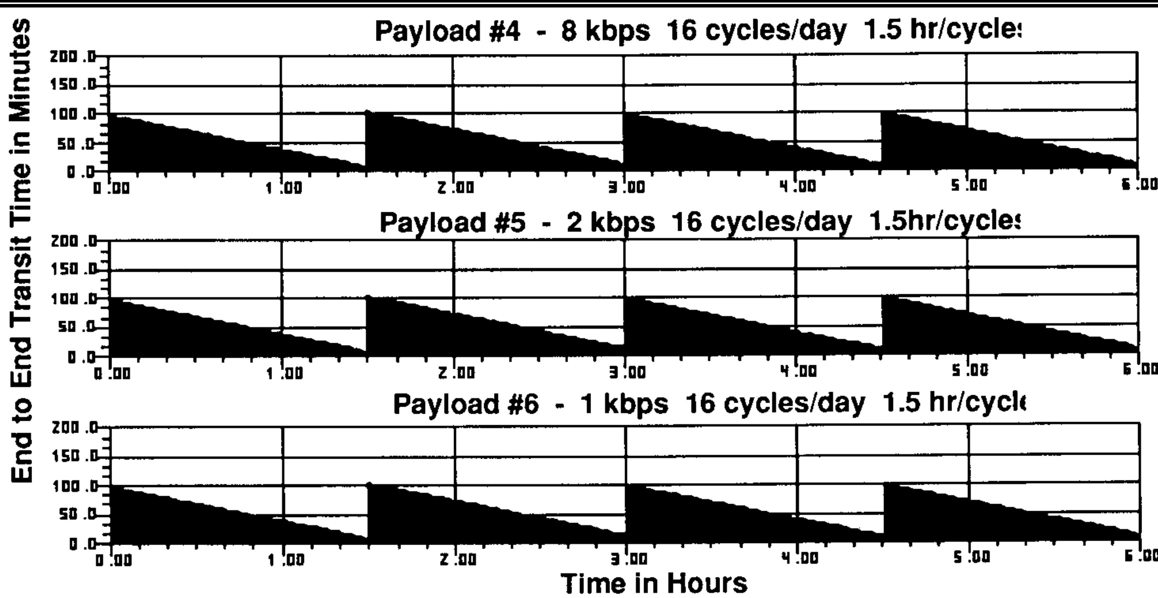

FIGURE 4. TRANSIT TIME (LATENCY) FOR 3 SELECTED PAYLOADS DUE TO ON-BOARD TAPE PLAYBACK

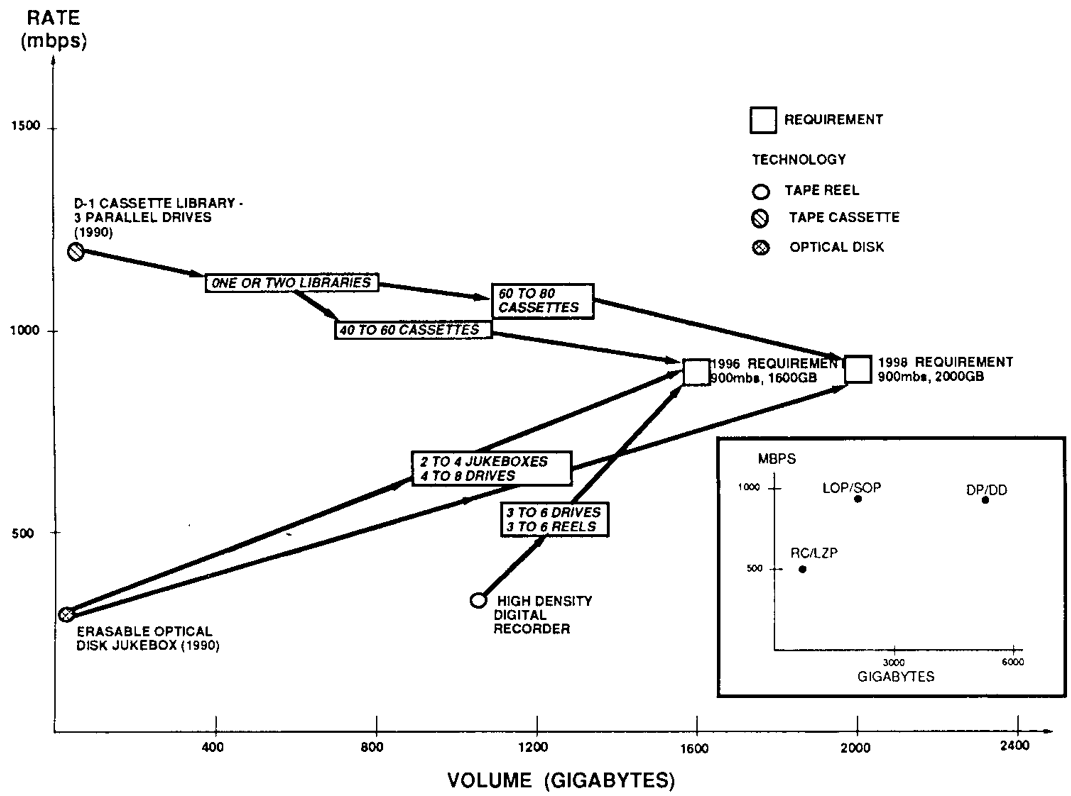

FIGURE 5. LINE OUTAGE/SYSTEM OUTAGE PROTECTION (LOP/SOP) POTENTIAL TECHNOLOGY SOLUTIONS

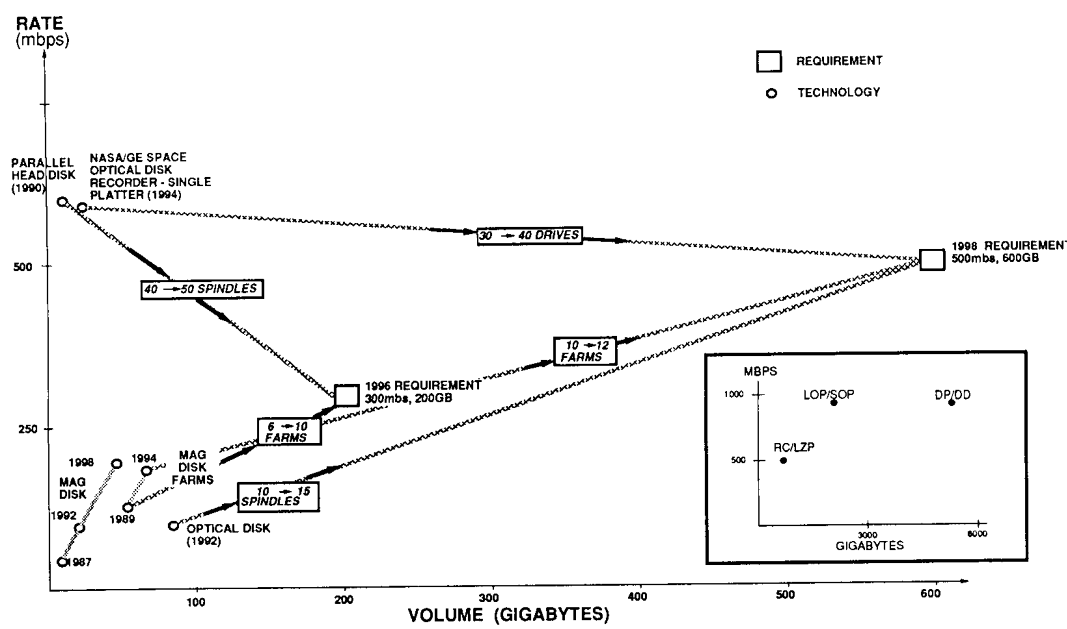

FIGURE 6. RATE CONVERSION/LEVEL ZERO PROCESSING (RC/LZP) POTENTIAL TECHNOLOGY SOLUTIONS

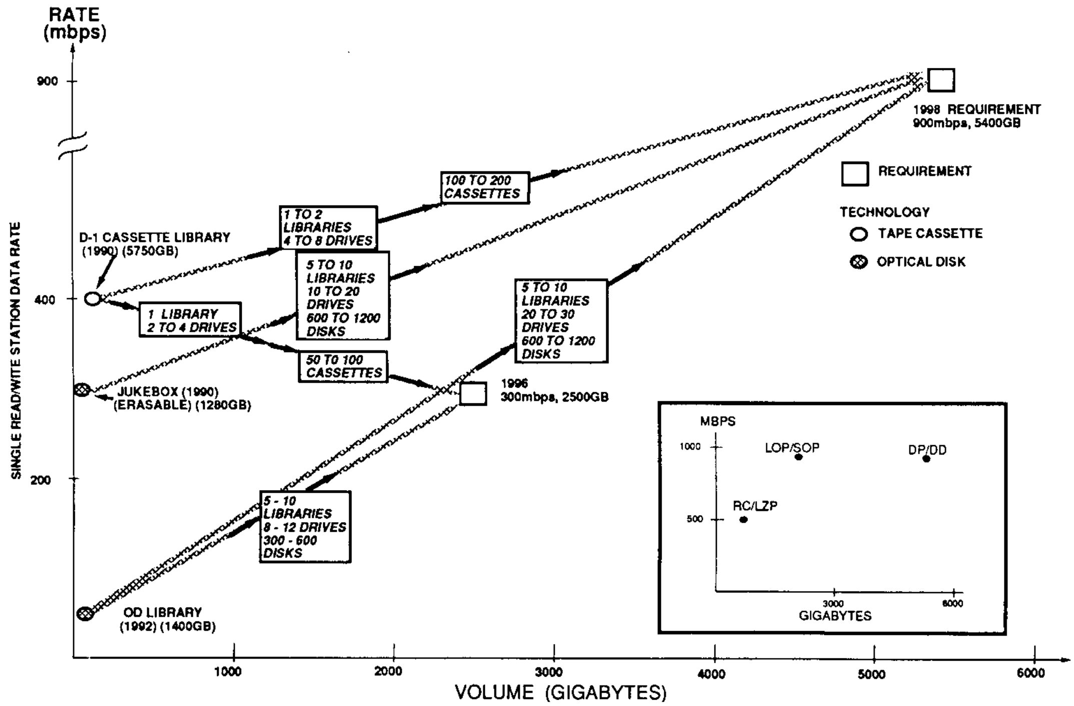

FIGURE 7. DATA PROTECTION/DEFERRED DELIVERY (DP/DD) POTENTIAL TECHNOLOGY SOLUTIONS

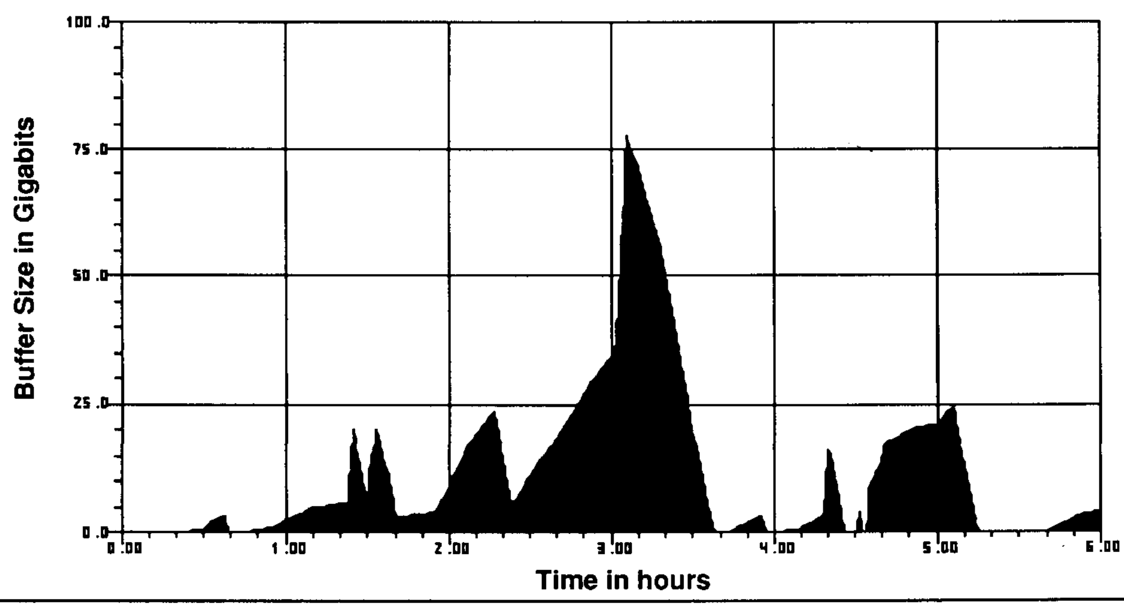

FIGURE 8. STORAGE UTILIZATION VS. TIME FOR BUFFERING LINK FOR SINGLE DESTINATION TO 50 MBPS