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Summary

Limited spacecraft communication links call for users to investigate the potential use of video compression and multimedia technologies to optimize bandwidth allocations. The objective of this study was to determine the transmission characteristics of multimedia data—motion video, text or bitmap graphics, and files transmitted independently and simultaneously over an ethernet local area network. Commercial desktop video teleconferencing hardware and software and Intel's proprietary Digital Video Interactive (DVI) video compression algorithm were used, and typical task scenarios were selected. The transmission time, packet size, number of packets, and network utilization of the data were recorded. First, each data type—compressed motion video, text and/or bitmapped graphics, and a compressed image file—was transmitted independently and its characteristics recorded. The results showed that an average bandwidth of 7.4 kilobits per second (kbps) was used to transmit graphics; an average bandwidth of 86.8 kbps was used to transmit an 18.9-kilobyte (kB) image file; a bandwidth of 728.9 kbps was used to transmit compressed motion video at 15 frames per second (fps); and a bandwidth of 75.9 kbps was used to transmit compressed motion video at 1.5 fps. Average packet sizes were 93.3 bytes for graphics, 498.5 bytes for the image file, 345.8 bytes for motion video at 15 fps, and 341.9 bytes for motion video at 1.5 fps.

Secondly, simultaneous transmission of multimedia data types was also characterized. The multimedia packets used transmission bandwidths of 341.4 kbps and 105.8 kbps. Bandwidth utilization varied according to the frame rate (frames per second) setting for the transmission of motion video. Packet size did not vary significantly between the data types.

When these characteristics are applied to Space Station Freedom (SSF), the packet sizes fall within the maximum specified by the Consultative Committee for Space Data Systems (CCSDS). The uplink of imagery to SSF may be performed at minimal frame rates and/or within seconds of delay, depending on the user's allocated bandwidth. Further research to identify the acceptable delay interval and its impact on human performance is required. Additional studies in network performance using various video compression algorithms and integrated multimedia techniques are needed to determine the optimal design approach for utilizing SSF's data communications system.

Introduction

Methods for remote coaching and oversight of the onboard SSF crew members' activities by the ground-based Principal Investigators (PI) may require the exchange of science procedure checklists and data files. Science payload experimenters on SSF will also require video monitoring of their life science subjects. The number of video cameras and the amount of imagery that must be supported for science payloads exceeds the currently allocated data communications bandwidth of SSF. The transmission of these data types along with command and controls of environmental and engineering parameters in the payload facilities requires enough bandwidth to support two-way communication in order to facilitate high-quality performance. Transmission bandwidth will be limited because of the large numbers of payload functions required. An effective method to manage SSF's engineering, science, and payload command and control data transmission requirements must be found. It is necessary to investigate advanced technologies, such as video compression and methods for networking multimedia, to determine their feasibility for SSF.

Previous studies have shown that compressed remote video imagery is acceptable to the life sciences user community (ref. 1) and frame rates as low as 4 to 6 frames per second are acceptable for remote monitoring of small animals (ref. 2). The life sciences user community, comprised mostly of animal and plant physiologists and biologists, determined the acceptance levels of compressed imagery; they found that video compression technologies using a Joint Photographic Expert Group (JPEG) algorithm and a proprietary Discrete Cosine Transform (DCT) algorithm by Compression Laboratory Inc. (CLI) can support their scientific requirements. However, the engineering requirements to implement such a system call for weight, power, volume, and data bandwidth to be within SSF's engineering constraints.

Method

Experiment Design and Variables

This experiment used a two-node point-to-point configuration and transmitted three types of data: a two-way compressed motion video, a compressed video image file, and two-way text and graphics. A step-by-step procedure was designed for each data type and was systematically repeated during data collection. Data collection was done first by transmitting each of the data types independently, then simultaneously with another data type. For example, two-way motion video was transmitted at the same time a file was being transferred between workstations. Finally all three data types were transmitted simultaneously.

During each data-collection trial, the total number of packets, the total number of ethernet data bytes, the total transmission time in milliseconds, the packet size, and the percentage of bandwidth utilized were measured and recorded. A preliminary data-collection run was done with motion video in order to understand the effects of frame rate on the variability of network traffic. It confirmed that five trials per frame rate setting were sufficient, given that the variance between each trial was minimal; this finding allowed us to save time by reducing the number of data-collection trials per run. Therefore, five trials were performed for motion video data transmission, and ten trials were performed for file and graphical data in order to calculate a mean value.

Apparatus

All video imagery, graphics, and files were presented on a 16-inch (diagonal) computer screen of the IBM PS/2 model 80-321 computer. The computer has 10 megabytes (MB) of RAM and a 320 MB hard disk. The video compression hardware consisted of Intel's ActionMedia II board set, an ActionMedia II Capture module with the ActionMedia II Delivery Board (attached as a daughter board) used to digitize and compress the National Television Standard Committee (NTSC) signal "on the fly" for display on the VGA monitor.[1]

IBM's video teleconferencing software, *Person-to-Person* (P2P), was used in conjunction with the ActionMedia II boards for this study. *Person-to-Person* runs with IBM's OS/2's Presentation Manager and permits live video to be displayed locally, remotely, or in video conference mode. For this study, P2P was configured for the video conference mode. In addition to the video capability, the software also provides utilities such as "chalkboard" and "file transfer." The chalkboard utility provides a shared graphical workspace that participants can use to view, create, edit, point to, and share items from their computers. It has a drawing space, equipped with a set of tools for the production of simple colored graphics and text. The drawings done on the chalkboard appear on both participants' computer monitors simultaneously. The file transfer utility sends files between both *Person-to-Person* users, provides progress information for file transfers, and informs users of incoming file transfers.

A network-analyzer software package, *Netminder*, was installed on a Macintosh II attached to the same ethernet network as the two IBM PS/2 workstations (fig. 1). There were no other nodes on this ethernet segment. *Netminder* was used to collect data and to measure the traffic on the network; it recorded the number of total packets transmitted, the packet size, the total number of ethernet data bytes, the total transmission time in milliseconds, and the percentage of bandwidth utilized.

Video Data Traffic

Prerecorded video segments, described below, were played on a four-head, Heliquad II Model JR4500 VHS video cassette recorder whose video output was connected to the composite RS170 input connector of the ActionMedia II boards. The following video settings were configured through the P2P software: Tint = 50%, Saturation = 76%, Brightness = 66%, Contrast = 50%, and View = single.

An onscreen frame rate control was used to set the frame rate in discrete steps between 15 fps and 1.5 fps. The local and remote video scene was displayed in two video windows—128 by 120 pixels resolution—side by side on the computer monitor. The VGA monitor subtended 12.5 degrees (horizontally) by 9 degrees (vertically) of the user's visual field.

All video imagery was compressed by using a nine-bit hardware-based compression algorithm Digital Video Interactive (DVI) developed jointly by IBM and Intel Corporation. This compression algorithm divides each video frame into four-by-four pixel blocks and allocates each block one pixel representation. Each word consists of five bits for luminance, two bits for hue (color) and two bits for saturation. The algorithm is applied within each frame, i.e., there is no interframe encoding. Since the scenes presented were identical, the only parameter that changed from trial to trial was the frame rate.

Description of video scene– When video data collection was in progress, two-way video was transmitted between the PS/2 workstations. Each PS/2 workstation displayed its local video scene and the remote video scene in adjacent windows. The video scenes were prerecorded on color VHS and ran for two minutes. The recorded VHS images consisted of two white rats moving within a small enclosure similar to the animal holding habitats that may be used on SSF. The scenes consisted of both fast-motion and slow-motion activities. The slow-motion scene consisted of typical grooming activities (e.g., licking fur, scratching with a hind leg at about 6–10 Hz, playfully biting each other). Neither animal walked around very much during the scene, but they exhibited typical slow

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[1]ActionMedia II boards digitize and compress a video signal for display on a monitor and/or storage on a hard disk. The boards used here employed a dual-chip, B-series i750 Video Display Processor.

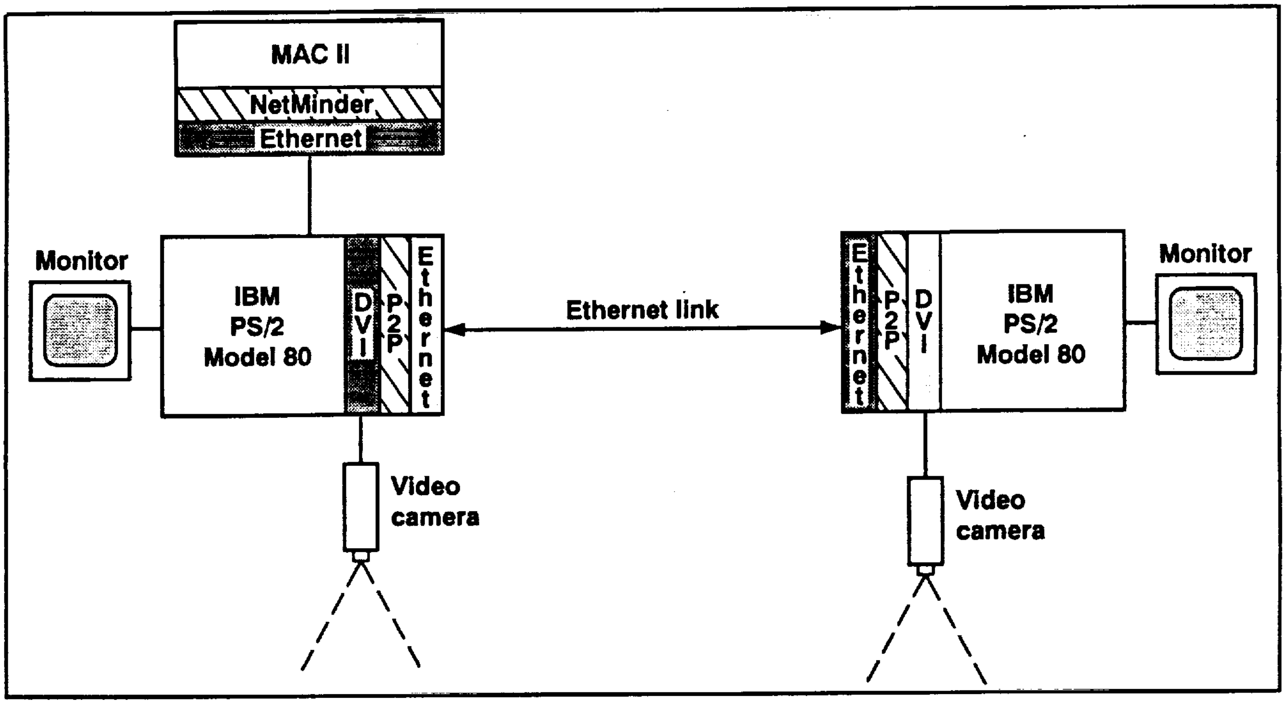

Figure 1. HW system diagram.

limb and body movement and exploratory behavior such as sniffing. The fast motion activity consisted of playful behavior such as tumbling, chasing and rolling over each other, and mock fighting. The angular rates of movement were so great that they appeared to be almost at the edge of blurring when viewed at 15 fps.

Procedure for video data collection– The video frame rates were varied from 1.5 fps, 5 fps, 10 fps, and 15 fps while in the video conference mode. Five trials were performed for each frame rate and measurements were recorded.

Results– The measurements for the transmission of two-way motion video are tabulated in table 1. The means and standard deviation values were calculated from the five-trials-per-frame-rate run. The network bandwidth is shown as a function of frame rate in figure 2.

Graphics Data Traffic

Procedure– The two users each sat in front of a PS/2 and simultaneously used the chalkboard utility to draw and write on a shared graphical document. The common document was displayed to both users while the collaborative task was being done in real time. Each user was given an assignment to draw a certain portion of the final document (fig. 3) with a predetermined tool and associated color. Each user announced when he/she was finished with his/her section, and the data collector stopped the network monitor and recorded the measurements when both were finished. The time to completion obviously depended on the type of task and the users' familiarity with the task at hand; this task and the rate of completion was selected to be representative of the type of interactive task that may be required in a remote coaching scenario.

Results– The measurements taken when transmitting only graphical (chalkboard) data across the network are given in table 2.

Table 1. Network traffic measurements for two-way video data between 1.5 fps and 15 fps

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
1.5 fps						
Mean	1674458	1714575	180.0	0.76	341.93	75.90
Standard deviation	35511	35817	1.2	0.02	4.89	1.85
5.0 fps						
Mean	4952737	5071405	161.7	2.51	341.89	250.50
Standard deviation	101737	103266	1.7	0.04	3.62	3.78
10 fps						
Mean	10649196	10903272	161.6	5.39	343.31	539.20
Standard deviation	215485	219022	4.8	0.11	2.86	11.12
15 fps						
Mean	14387755	14779763	161.5	7.29	345.78	728.90
Standard deviation	772357	706657	2.5	0.33	4.04	33.02

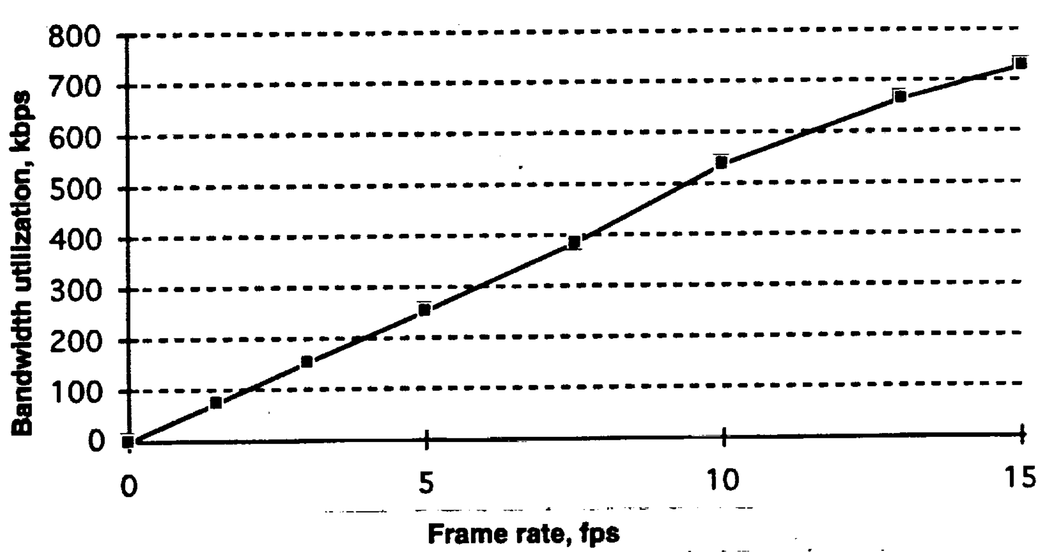

Figure 2. Network bandwidth as a function of frame rate.

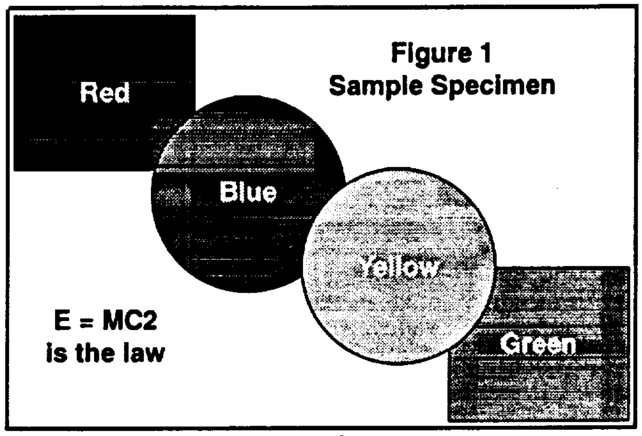

Figure 3. Representative graphics groupware document using P2P chalkboard.

Table 2. Network traffic measurements for graphics data

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
Mean	31029.40	33605.00	34.6	0.07	93.27	7.40
Standard deviation	2361.49	2555.96	5.3	0.01	2.70	0.84

File Data Traffic

Procedure– Each user invoked the SEND FILE and RECEIVE FILE commands in P2P to transfer files between the two PS/2 workstations. The file was an image of a plant leaf with necrosis in one corner magnified 20X through a microscope. The image displayed a range of chrominance vectors. It was captured at high resolution (640 wide by 480 high), digitized at DVI's 9-bit plane, compressed by using the JPEG algorithm, and resulted in a file size of 18.9 kB with a compression ratio of 51:1.

The SEND FILE command allowed one user to select the file to be sent, specify the destination, and then transmit the file over the network. The destination station would then receive a visual message on the computer monitor indicating that a file had been sent. The message also prompted the user to use the RECEIVE FILE command to store and access the transmitted file. The send/receive procedure for a file of 18.9 kB took approximately 25 seconds. The length of transmission time may change, depending upon the file size.[2] *Netminder* collected data throughout the SEND FILE/RECEIVE FILE procedure.

Results– The measurements taken while sending a file are given in table 3.

Integrated Multimedia Data Traffic

The results are presented in tables 4–7 for aggregated multimedia data; combinations of graphics, video, and file data are varied systematically.

[2]Because the same two users performed the tasks, these SEND and RECEIVE FILE commands were completed in minimal time. Less experienced users may require more time.

Table 3. Network traffic measurements for file transfers

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
Mean	228331.30	23204.10	2.5	0.87	498.52	86.80
Standard deviation	1375.47	1402.00	1.3	0.34	12.28	34.05

Table 4. Network traffic measurements for simultaneous video and graphics data transmissions

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
1.5 fps						
Mean	258301.6		25.7	0.83	245.85	82.6
Standard deviation	17034.08		2.2	0.03	3.81	2.97
5.0 fps						
Mean	876484.20		29.8	2.42	285.82	241.6
Standard deviation	106753.94	2555.96	4.4	0.07	2.75	6.91
10 fps						
Mean	1583937.60	1628593.60	30.6	4.24	292.24	424.40
Standard deviation	94257.76	96920.77	1.4	0.18	4.54	18.35
15 fps						
Mean	1676776.80	1725583.20	33.3	4.14	283.26	413.60
Standard deviation	114942.63	118371.69	1.4	0.14	3.03	14.19

Table 5. Network traffic measurements for simultaneous video and file data transmissions

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
1.5 fps						
Mean	265546.6	2771633	25.3	0.86	356.88	85.60
Standard deviation	20161.83	20374.49	1.0	0.09	15.14	9.02
5 fps						
Mean	671723.80	689002.20	26.5	2.07	319.08	207.00
Standard deviation	95694.14	98001.84	2.7	0.11	2.90	10.91
10 fps						
Mean	1278063.60	1284417.40	25.8	4.06	306.90	406.00
Standard deviation	108238.40	102532.96	2.1	0.13	14.26	13.34
15 fps						
Mean	1938703.00	1989768.60	31.3	5.08	312.51	507.80
Standard deviation	310490.40	319538.88	5.1	0.11	6.89	11.39

Table 6. Network traffic measurements for simultaneous graphics and file data transmissions

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
Mean	98830.8	102566.8	27.7	0.29	216.17	29.4
Standard deviation	11496.06	11451.23	2.5	0.05	22.07	4.55

Table 7. Network traffic measurements for simultaneous video, graphics, and file data transmissions

	Ethernet data bytes	Total bytes	Total time (sec)	Percent bandwidth utilized	Packet size (bytes)	kbps
1.5 fps						
Mean	471559.80	484380.60	36.5	1.06	302.07	105.80
Standard deviation	46294.22	47315.77	3.9	0.03	5.94	3.35
5.0 fps						
Mean	1172541.40	1202811.80	36.6	2.63	317.97	262.80
Standard deviation	87963.71	90180.55	3.3	0.15	5.16	15.45
10 fps						
Mean	1560939.60	1601035.60	37.4	3.41	319.37	341.40
Standard deviation	160962.14	164715.61	2.2	0.18	6.62	18.11
15 fps						
Mean	1254710.20	1286689.40	34.3	2.97	320.97	297.00
Standard deviation	291431.49	298024.78	2.4	0.51	8.29	50.99

Discussion

Application to Space Station Freedom Operations

Currently, the planned SSF communications downlink using the Tracking and Data Relay Satellite System (TDRSS) is 50 megabits per second (Mbps) through the Ku band and 192 kbps through the S-band. The S-band uplink is 72 kbps. These communications links between the SSF and the ground use 4 kB maximum CCSDS packets (ref. 3). This study of the multimedia network throughput indicates that compressed two-way video can be transmitted by using between 729 and 76 kbps, depending on the frame rate settings. Previous studies (ref. 4) have shown that frame rates of 4 to 6 fps are acceptable for the life sciences community. Using simple arithmetic, we can expect one-way compressed video transmission to utilize about one-half of this bandwidth. The compressed video uses 343 bytes per packet, which is relatively small, and it fits within SSF uplink and downlink packet allocations. These small packets obviously need to be aggregated into larger CCSDS packets by the payload developers for compliance with SSF's communications guidelines.

The small-packet-size implementation of this video transmission algorithm has two advantages: digitized voice can also be synchronized and packetized per video data packet; and jitter can be reduced by spreading out jitter delays across more packet intervals.[3] On the other hand, small-packet-size implementation has disadvantages because there is a higher probability of frame data loss in transmission. In the Fiber Distributed Data Interface (FDDI) protocol on SSF, dropped video frames are assumed to be permanently dropped.

Graphics and shared chalkboard tests determined an average data packet size of 93 bytes per packet and these packets can be accommodated within SSF uplink and downlink packet sizing. This sample task took an average of 34 seconds and used an average of 7.4 kbps bandwidth. This work speed is typical of a ground-based PI working with an onboard crew member, so the bandwidth used was representative of the bandwidth allocation that would be needed for task completion in the future on SSF. If the PI and the crew member can work faster, then increased

[3]Maximum (inter-arrival delay) / # of intervals in the data frame; max. (inter-arrival delay) is a function of FDDI token passing parameter.

bandwidth may be needed to reduce the frustration caused by communication delays.

Transmission of the image file used an average data-packet size of 498.5 bytes, well within the maximum CCSDS packet size of 4 kB. Space Station Freedom can support image file transmissions if the user can sustain the transmission delay. In this test the average bandwidth was 86.8 kbps and the average send and receive completion time was 2.5 seconds. The transmission delay will vary, depending on the percentage of the 72 kbps uplink bandwidth that is available to the transmission of the image file. It is not clear what would be an acceptable delay duration. Further human-factors research is needed to understand the impact of delay on science productivity.

Conclusions

We conclude from these findings that transmission of multimedia data across an ethernet local area network provides evidence that the compression techniques used by commercial multimedia vendors can be adopted for SSF applications. A packet network can support aggregated multimedia data by using bandwidths as low as 729 kbps for two-way transmission. A bandwidth of 310 kbps would be needed for video transmission at frame rates of 4 to 6 fps, which have been shown in previous studies to be acceptable for the life sciences community. The question of delay also enters into the bandwidth equation. The acceptable delay interval and its impact on human performance will have to be defined and quantified empirically in order to request SSF bandwidth allocations and then optimize network usage.

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