

**An STC Proposal for  
A Widely Distributed  
Videoteleconferencing Environment**

James Ferwerda  
James A. Rose  
Terry S. Yoo

Program of Computer Graphics  
580 Engineering Theory Center  
Cornell University  
Ithaca, New York 14853

Department of Computer Science  
3190 Merrill Engineering Building  
University of Utah  
Salt Lake City, Utah 84112

Department of Computer Science  
CB 3175 / Sitterson Hall  
University of North Carolina at Chapel Hill  
Chapel Hill, North Carolina 27599-3175



## **Forward for Advanced Draft (13 May 1992)**

This document is a design specification for a proposed videoconferencing facility for the NSF Science and Technology Center for Computer Graphics and Scientific Visualization. This working draft accompanies a request for extended funds to enable the center to decisively begin this effort in a planned and organized fashion.

This design document represents the infrastructure required to support a distributed research environment such as ours. The STC's commitment to performing research in high resolution, high quality computer graphics constrains this proposal to exploring only high-end technology for the transmission and replication of images. Unlike other centers, the STC has requisitioned few funds for building space, laboratory, or other physical plant requirements. Instead, our experiment in aggregating the expertise from distributed sites in specialized subfields into a coordinated research team depends heavily on smooth, high quality intersite communication.

This center is a pilot for future research environments. Through improvements in communications technology, fast, easy communication will become more available and affordable. The future of scientific research in many fields will likely be through remote collaborations between colleagues at geographically distributed institutions. This STC has a somewhat ideal opportunity to employ its existing expertise in video technology and computer graphics to explore the boundaries a communications environment of this type.

We are committed to the development of this distributed research environment. It will enable close collaboration; it will provide a channel for the publication and distribution of information within the STC as well as to other institutions, and it will serve as an educational vehicle for STC members and those universities that are affiliated with member sites. In fact, if the communications system is available in Fall 92, principal investigators, senior investigators, and senior research associates within the STC have already pledged to conduct an advanced seminar series in computer graphics.

This document reveals the cost structure and indicates some of the technical obstacles that must be overcome. We direct the reader's attention to the section on startup costs, equipment costs, and the section on site specific issues. The requested release of previously budgeted funds is being made to address not only the significant startup threshold that these items represent, but also to defray the recurring costs of continued intersite communication.

This document remains incomplete in places since individual sites have yet to report the cost of local modifications and an inventory of available support equipment. No final request for quotes has been made, so only provisional and estimated costs are published. A pilot study has been conducted, as well as a fairly thorough comparison of the relevant commercially available products. For a cost summary, we direct the reader to the **Summary**, and for an evaluation of today's technology, see **Appendix A**.

We present here an organized approach for the deployment of this system. If the requested funds are released, all of the above stated goals will be made possible. Member institutions have pledged to devote existing personnel who have the technical background in video and telecommunications to support the deployment and startup of the network. Expertise in these areas as well as available man-power varies from site to site. It is some measure of our commitment to this effort that we will divert other sources of energy and resources to see its successful completion. The technical staff of the STC institutions have already established a cooperative relationship among themselves in pursuit of these goals. The growth of this relationship is encouraging and is a strong indication for success.

Terry S. Yoo

## **Preface**

This document is intended to outline some alternate proposals for the planned televideo network proposed earlier for the Science and Technology Center. Video and computer engineers selected from within the STC community by the executive committee comprised a technical committee to evaluate and explore the problems and solutions involved in deploying a televideo conferencing system for the STC.

This is an overview of the technology as evaluated by the STC technical committee. It includes, at the end of each section, recommendations made by the committee (recommendations endorsed by consensus). Sections detailing televideo equipment, network topologies, communications carriers, site preparation issues, and a field test evaluation comprise the body of this document. A summary including the projected costs for the entire project is also attached. For details on the findings of the committee on individual topics see the attached appendices.

We begin with establishing some standard and common definitions. The term *local common carrier* applies to the local company at each site that will take the feed from the lab to the "local" site for transmission to the *national carrier*, a company like AT&T, MCI, Sprint, or WilTel that carries the signal long distance. The local carrier would most likely be arranged through the national carrier generally at cost, or even below cost in some cases. A *codec* is an acronym for "coder/decoder", a device that does analogue to digital and digital to analogue conversion along with signal compression encoding and decoding. The *local site loop* requirements refers to how each site is routing their cameras, tape machines, scan converters, and the like, into the system for transmission from the site into the televideo system. The local site loop ends at the codec. *Interconnectivity* refers to how a site gets to the outside world from the T-1 arena to a microwave or a T-3 satellite uplink, or possibly to connect from one carrier to another in order to "drop in" on a different televideo session. This arrangement would have the advantage that, inasmuch as some of the vendors have televideo systems in place already, it might be possible to do group training all at once from a vendor teleconferencing site. Such arrangement could save the vendor and the STC money.

The *assumed* (i.e., projected) *usages* and *real usages* are the total amounts of connect time that we will be billed, typically in quarter hour increments. Since the actual communication use needs have not been established "*a priori*" it is necessary to specify a

highly flexible and elastic structure that can accommodate ongoing alterations. The assumed usage, that is the largest affordable use, can be calculated from the annual budget allocation minus local carrier fees, national carrier fees and maintenance, and dividing by the hourly connect fee to get the maximum number of hours available total for all sites.

The scenarios presented here are aimed at real-time televideo conferencing in a sound and cost effective manner for a production environment. These scenarios take into account day to day production issues such as local common carriers, national carriers, local site loop requirements, site preparation issues, interconnectivity, both real and assumed usage, and system reliability, an item of major importance.

**Contents**

Preface .....	i
Contents .....	iii
1. Introduction .....	1
Anticipated Modes of Use .....	3
Design Philosophy .....	5
2. Videoconferencing Technology .....	6
Codecs .....	6
Codec Addendum (11 September 1992) .....	8
MCUs .....	8
Recommendation .....	11
Recommendation Addendum (11 September 1992) .....	12
Estimated Costs .....	12
Revised Estimated Costs (11 September 1992) .....	12
3. Network Topologies .....	14
Ideal .....	14
Spoke and Hub .....	15
Hubless .....	16
Codeless .....	16
Recommendation .....	17
4. Network Suppliers (Common Carriers) .....	18
Hub Placement .....	18
Dedicated vs. Switched Service .....	19
Additional Costs .....	19
Additional Discounts .....	20
Choosing a Carrier .....	20
Recommendation .....	21
Estimated Costs .....	21
5. Data Networking .....	22
Estimated Costs .....	22
6. Site Specific Issues - Unenumerated Costs .....	23
7. Field Test - a status report .....	25
8. Normal Operation .....	28
Operating Costs - Site Support Personnel / Overhead .....	29
9. System Startup .....	31
Startup Costs .....	31
10. Videoteleconferencing Futures .....	32
Price/Performance .....	32
Multimedia- desktop systems .....	32
Packet Video .....	33
HDTV .....	33
11. Summary (revised 11 September 1992) .....	34
12. Conclusions (revised 11 September 1992) .....	36
Totals .....	36
Appendix A - Codec technology report .....	37
Comparison Conditions .....	37
Vendor Handouts .....	38
Technical Comparison Results .....	41
Product Review .....	45
Summary .....	51
Addendum to Appendix A (11 September 1992) .....	52
Purpose .....	52
Design of the Follow-up Comparison .....	53
Follow-up Comparison Results .....	54
Support Issues .....	57
Recommendation .....	59

Appendix B - Network engineering analysis .....	60
Appendix C - Common Carrier cost analysis.....	66





## **1. Introduction**

The Science and Technology Center for Computer Graphics and Scientific Visualization (or Gang of 5) is rare among STCs in its widely distributed nature and its policy for equal partner collaboration. These attributes also provide serious obstacles; the trans-continental distribution is constantly at odds with the tight collaborative goals of the STC. What is needed is a means to improve collaboration and the sense of community among the five sites.

It should be recognized, that while a distributed STC has reduced requirements for physical plant infrastructure, it has alternate needs for communications and other distributed infrastructure. This proposed communications system should be considered an integral cost of supporting a distributed research center; this teleconferencing facility may be construed as support in lieu of a central building. Moreover, the STC for Computer Graphics and Scientific Visualization is a pilot for future distributed STCs. What we accomplish and the methods we explore will serve as a foundation for the future development of tightly knit, long term, widely distributed research programs.

The principal investigators for the STC recognized the obstacles presented by the absence of a central site long before the proposal was submitted, and subsequently, funding was allocated to acquire a televideo conferencing system. After some consideration, some requirements for that system become apparent.

- **Easy to Maintain** - all equipment should not require separate maintenance staff and should be user serviceable. No booth engineer should be required for normal operation.
- **Easy to Use** - all connections should be easily made; no connection should be more difficult than a conference phone call. No special technical staff should be required for normal use.
- **High Quality** - since this system will service a center for computer graphics, the quality of the reproduced video should degrade as little as possible. Furthermore, since we are also interested in interactive applications, some effort should be made to attain real time video conferencing.
- **Flexible Scheduling** - The system should be available with flexible scheduling to meet the needs of our departments. Different time zones make common time schedules problematic. Informal discussions as

well as formal classroom presentations should be supported by the system. Provisions should also be provided for private conversations involving subsets of the member sites.

- **Current Technology** - it is not the charter of the Gang of 5 to develop this technology. Therefore, we will most probably purchase the equipment that we require, rather than build it ourselves.
- **Graphics/Overheads** - alternate and supplemental video inputs should be available to send visual information in addition to the conference camera feeds.
- **Evolving Technology** - we hope to continually upgrade our systems to maintain the state of the art in teleconferencing technology. Any systems purchased should be able to take advantage of the growing availability of high bandwidth communications.

Future developments should be incorporated into the growth of the televideo system. If permanent video networking links are established between the five participating institutions, data networks should be configured to utilize the same links as a permanent wide area data network. If packet video technology becomes available, the video network should be reconsidered in favor of a data network with sufficient bandwidth to support a video application.

The major expense of videoconferencing is as follows. The initial hardware to furnish each facility could be purchased under budget with additional items to be purchased over a number of years. This would allow resource for possibly new technology upgrades, or additional cameras, monitors, and the like, or it possibly could be rolled over into the purchase of more air time. The largest of all expenses will be the recurring expenses of bandwidth used, local connect charges, and monthly line charges with recur whether bandwidth is used or not.

The available budget for this project is targeted for the neighborhood of \$320,000 per year for the entire STC, with approximately half the amount anticipated for equipment and half for services.

The largest equipment cost is the codec unit. The number of units required depends on the configuration that is finally selected. One possibility is to lease some of this equipment, like the codecs, until the prices drop due to technical advances or alternatives become more attractive.

The ideal scenario in some respects would allow for full connectivity from site to site, a complete graph that has every possible link represented. This strategy would be extremely expensive in its recurring costs. A more limited configuration would allow for multiple sites to simultaneously dialogue, allow each site to have two three-way conversations, and also support full five-way dialogues. It should be noted however that the different telephone vendors have varying rates on whether the conversation is two, three, or four plus sites.

We have performed a preliminary evaluation of video technology available today, as well as a short term projection of upcoming technology. An analysis of different network topologies is presented with the technical strengths and weaknesses of each network structure. Moreover, we have begun a preliminary assessment of the cost of supporting the video link described above (a formal request for quotes to common carriers is recommended). We present some recommendations for video equipment acquisitions. Finally we will present the structure and plan for a field test of the equipment selected during the technical evaluation to investigate the limits of collaboration across this unfamiliar (at least to us) medium.

### **Anticipated Modes of Use**

We are viewing this facility as supporting an experiment in collaboration through the use of telecommunications. It is hard to know *a priori* just in what ways the system will be used most productively and most frequently. We can, however, itemize a number of fundamentally distinct styles of use which are likely to occur so that we can be certain that the adopted configuration will, in fact, address those requirements adequately.

A major purpose of the center is to forge a closer research collaboration among the researchers and PIs in the STC. Certainly it would advance this goal to have our weekly meetings in the videoconferencing environment where we are able to communicate more fully and to share visual exchanges as well as verbal ones. These meetings presently occupy about two hours per week. A clear extension of this notion of mutually benefiting from each site's distinct specialties is to offer collaborative seminars, and classes. From this, the next step would be to have outsiders, like vendors, feed this system so that we can all be addressed for disclosures, presentations, or explanations of the latest products, for example.

Clearly this can become an educational vehicle for us. It might also be a method of absorbing vendor short courses on maintenance or other topics without having to fly individuals to a vendor's home or educational site. This approach could be quite cost effective to both parties, when compared with alternative air fares associated with relocation. Finally, we might be able to include NSF or DARPA to participate in a closer, more involved style of sponsorship if a program leader in Washington could participate from a local teleconferencing studio. It is also a possibility that we might involve some of our illustrious advisory board members more readily via teleconferencing which minimizes the impact on their already heavily committed schedules.

We are hopeful that this medium will profoundly affect our remote research interactions. All the principals of this center already carry large burdens at home, so any technology that improves communications and eliminates travel, and minimizes time lost to overhead functions is likely to have a very positive overall effect on the success and productivity of the Center. It will allow individuals to participate in research committees remotely, to interact with students remotely as they observe new results, and to be effective at a distance when they otherwise might feel reluctant to become involved at that level of interaction.

Another form of this communication would be as a method of supporting bilateral research relationships for which telepresence is an important or critical aspect of understanding the dialogue. Each of the STC member sites has individual access to resources rare within our community. Different implementations of highly parallel processing resources are available at the distributed sites. One of our goals is to allow the real-time access to these facilities via the televideo network.

For example, while input transmission to UNC's Pixel-Planes 5 rendering engine is possible via existing data networks, the interactive video output cannot be sent back to the user in more than single frames. The inability to view image generated in near real time is a serious impediment to interactive graphics research and makes this resource unavailable to other STC member sites. Through the use of a scan converter, Pixel-Planes 5 output can be channeled through the conferencing system, making possible remote operation of interactive systems.

This is a largely uncharted course at the present time, but we are hopeful that new and productive relationships will emerge and be enabled by this technology. Another variant

of this scenario is simply sharing new research results by telepresent involvement. This is new ground which we anticipate exploring.

Finally, as our STC matures, we may enter into some experiences that we will want to share with a larger audience by using the national carrier's uplink facilities to broadcast to a larger national audience. This may apply for colloquia, general presentations, topical discussions or announcements, or other transactions of broad and general interest.

### **Design Philosophy**

The evaluation criteria for all aspects of this televideo system are based on the requirements (both stated and unstated) of the executive committee members of the STC. The overall philosophy was to first meet the high standards of the executive committee members for quality, flexibility, stability, and simplicity. Only after a prioritized list of needs and products and services to fit those needs was generated were costs introduced into the recommendation process.

Due to the importance of faithful image replication in our research, image quality (color fidelity, spatial resolution and temporal resolution) at real time rates (30 frames per second) was the foremost selection criteria for the codecs. The secondary criteria was the quality of the audio system. Effective audio is critical in conferencing applications. A wide range of applications are expected for the televideo system including teleoperation of remote equipment, still graphics transmission, and live transmission of a variety of inputs, including classroom and seminar sessions. The flexibility criterion manifested itself in the ability of each product to support these collaboration goals of the televideo network. Finally, within the parameters of budget constraints and user requirements, cost issues were considered last.

The issues of flexibility and stability apply in greatest part to the topology of the network. Due to the frequent scheduling conflicts of the individuals involved in our collaborative venture, scheduling becomes an area of great concern. Furthermore, the varied nature of the input scenarios (conference, classroom, interactive research, etc.) indicates that simple, quick and easily formed connections should be allowed in the network. Due to the large investment required to implement the network and the anticipated demand for televideo communication time, stability and robustness of the system become crucial areas of concern. Flexibility was the leading evaluation criterion and robustness the secondary design element in the selection of network topology.

Design issues surrounding national carrier selection, site local configuration and modification, and field test planning are all outgrowths of the same evaluation criteria. The priority of these elements was determined to be lower than the selection of the communications products and the planning of the network topology. Therefore the design effort has focussed most of its attention on the first two elements; recent information regarding the field test, national carrier pricing information and conference facility planning is published here.

## **2. Videoconferencing Technology**

The heart of the technology that we are investigating is in the compression algorithms, switching capabilities, multiplexing, robustness and fidelity of the transmitted video. The two elements that we addressed were the codecs and the multipoint control systems. Figure 1 shows a schematic of an example videoconferencing system. The boxed section includes the communication elements required at each site. Figure 2 shows an example configuration with a central MCU switch as the center of a spoke and hub network.

### **Codecs**

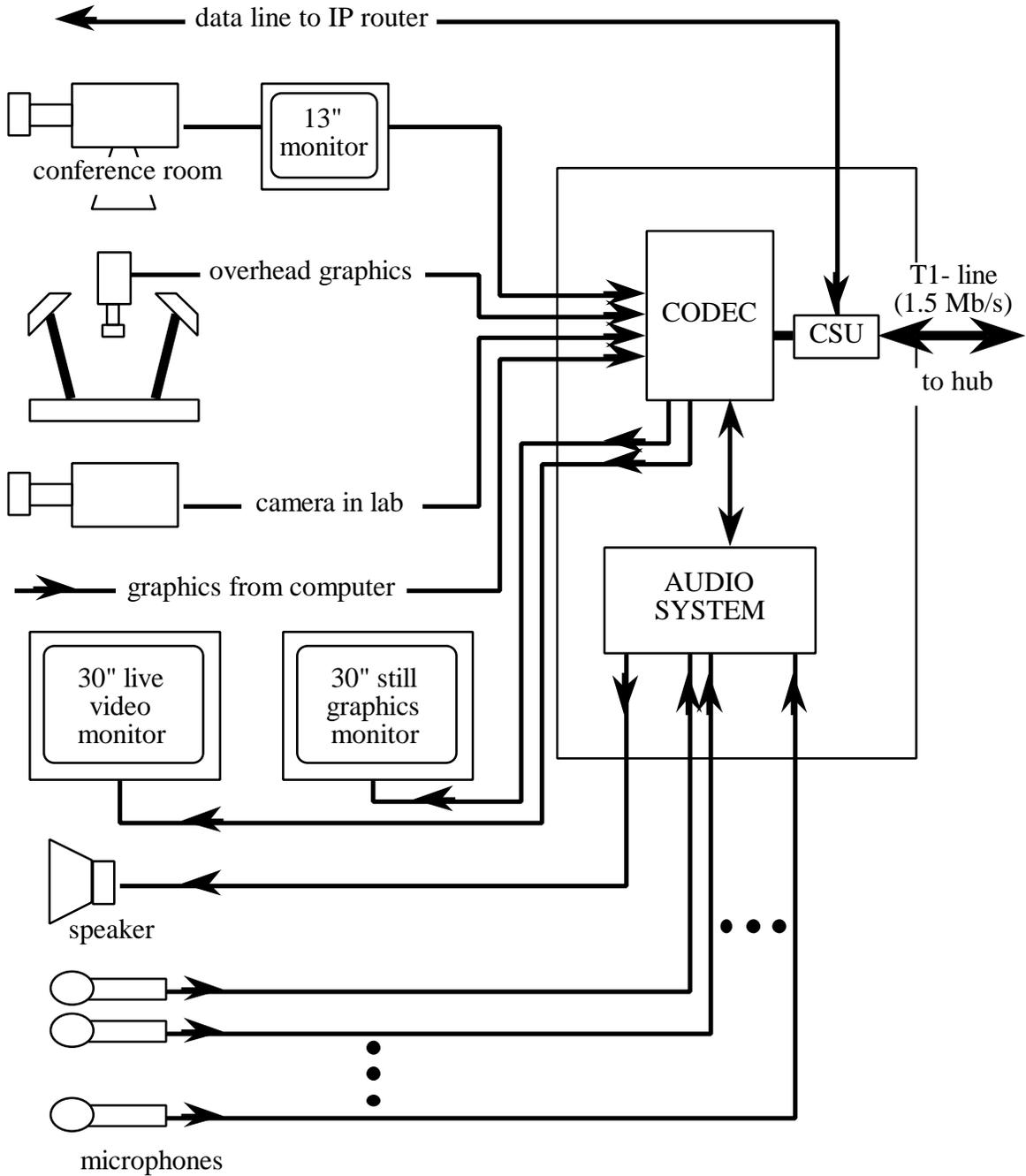
Few organizations require full time two way broadcast quality video networking systems. Most commercial televideo conferencing systems on the market today are therefore targeted toward common services available through telephone companies. Some vendors provide video compression units that are compatible with ISDN 56 KBaud telephone communication services, while others scale up toward speeds as high as 1.5 MBaud. The high end broadcast quality systems provide transmission rates that include 45 Mbaud. Uncompressed video requires dedicated bandwidth in excess of 12 Mbits/second; though suitable for commercial broadcast systems are not widely supported by current products on the televideo conferencing market.

Image quality varies with the quality of compression. A good compression algorithm together with sufficient processing power to support it are expensive features in a teleconferencing system. Speed is mostly the tradeoff between sacrificing good compression algorithms for time and investing more in the processing power of the system. A coder/decoder unit (or codec) typically can support many speeds, will perform many of the industry standard compression algorithms, as well as perform some company specific compression scheme that is usually more effective than standard compression schemes.

During this evaluation, only "high-end" T1 systems were considered. The systems we reviewed support DSP1 speeds (T1 or 1.5 Mbit/second) and/or significant fractions of that speed. In the original STC site visit, some codec systems were demonstrated, and images were viewed at different transmission rates. The members of the executive committee decided at the time that images generated at transmission rates slower than 384 KBaud were unacceptable. In this evaluation, codec systems were evaluated on their image

quality, their response to real-time video, and the expected cost of intersite communications.

The products of four vendors were reviewed by the technical committee: Compressions Labs, Inc., GPT (a subsidiary of Siemens), NEC, and PictureTel. Products were reviewed running at their best speed, at 768 Kb, and at 384 Kb. The NEC Visualink



**Figure 1 - A videoteleconferencing schematic**

5000/20 was selected as the best compromise among the systems being reviewed. GPT had poor sound quality, but an equivalent picture. PictureTel and CLI both had good sound, but PictureTel had poor spatial resolution. CLI had good spatial resolution, but poor color fidelity.

No systems were evaluated at less than 384 Kb. This provided for a somewhat incomplete evaluation, because PictureTel was expected to have superior relative performance at lower bandwidth. CLI, while appearing "washed-out," performed well with synthetic images with smooth shading. NEC and PictureTel both contributed artifacts when drawing vector images at 384 Kb.

Overall, there were strengths and weaknesses to all of the codecs that were reviewed. All members present, including Fred Brooks, Henry Fuchs and Nate Huang agreed by consensus that the NEC Visualink 5000/20 was the best compromise for the STC. For a full description of the comparison and a complete presentation of the findings, see Appendix A.

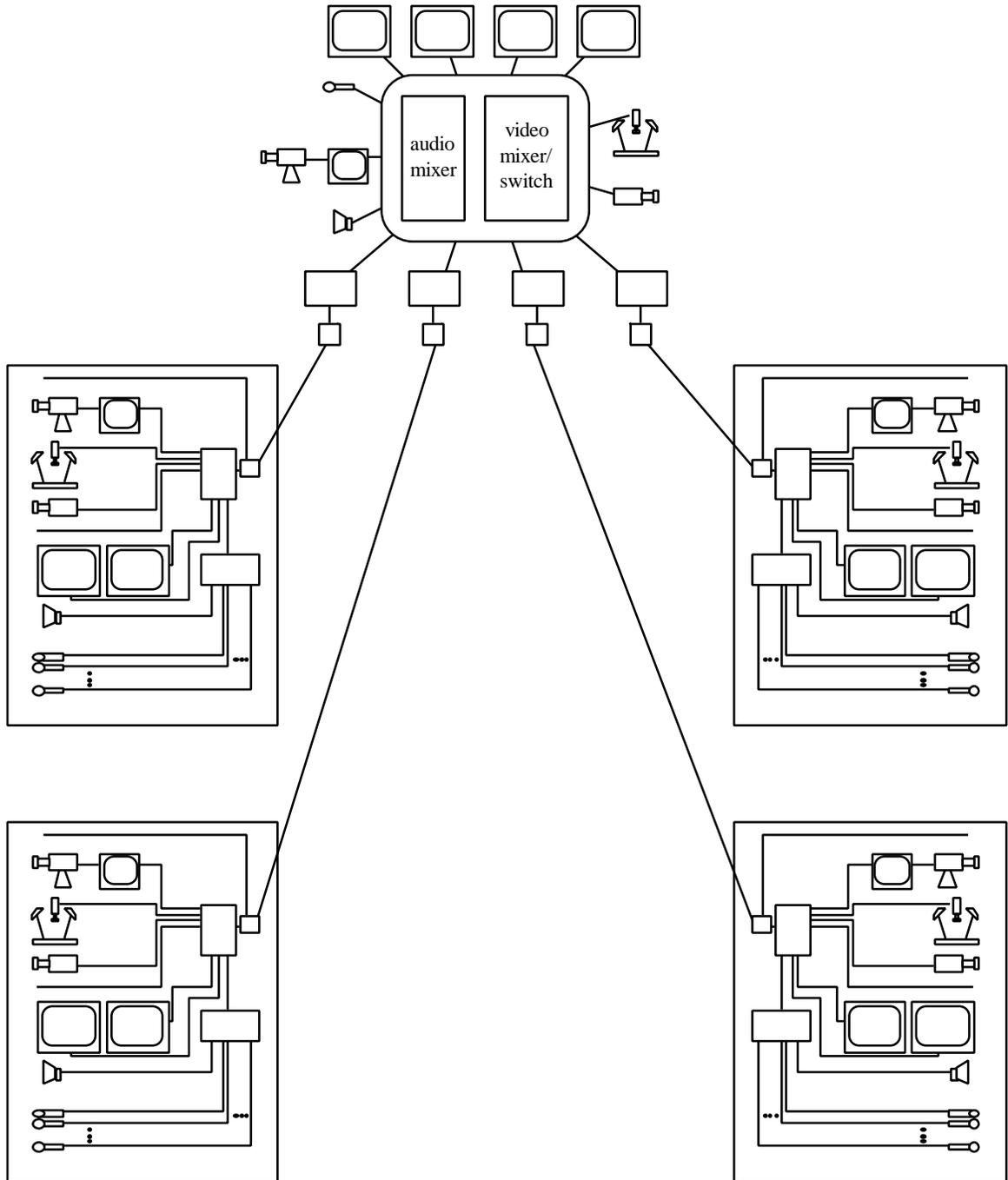
One advantage of the NEC system is that features considered options on other systems are standard on the Visualink 5000/20. The NEC system includes a data port multiplexer for transferring data. It also comes standard with picture-in-picture or dual monitor display. NEC also runs compression/transmission protocols that are industry standard Px64. NEC provides a two year warranty on their equipment. This is unusual in the industry; most vendors provide only a one year warranty.

#### **Codec Addendum (11 September 1992)**

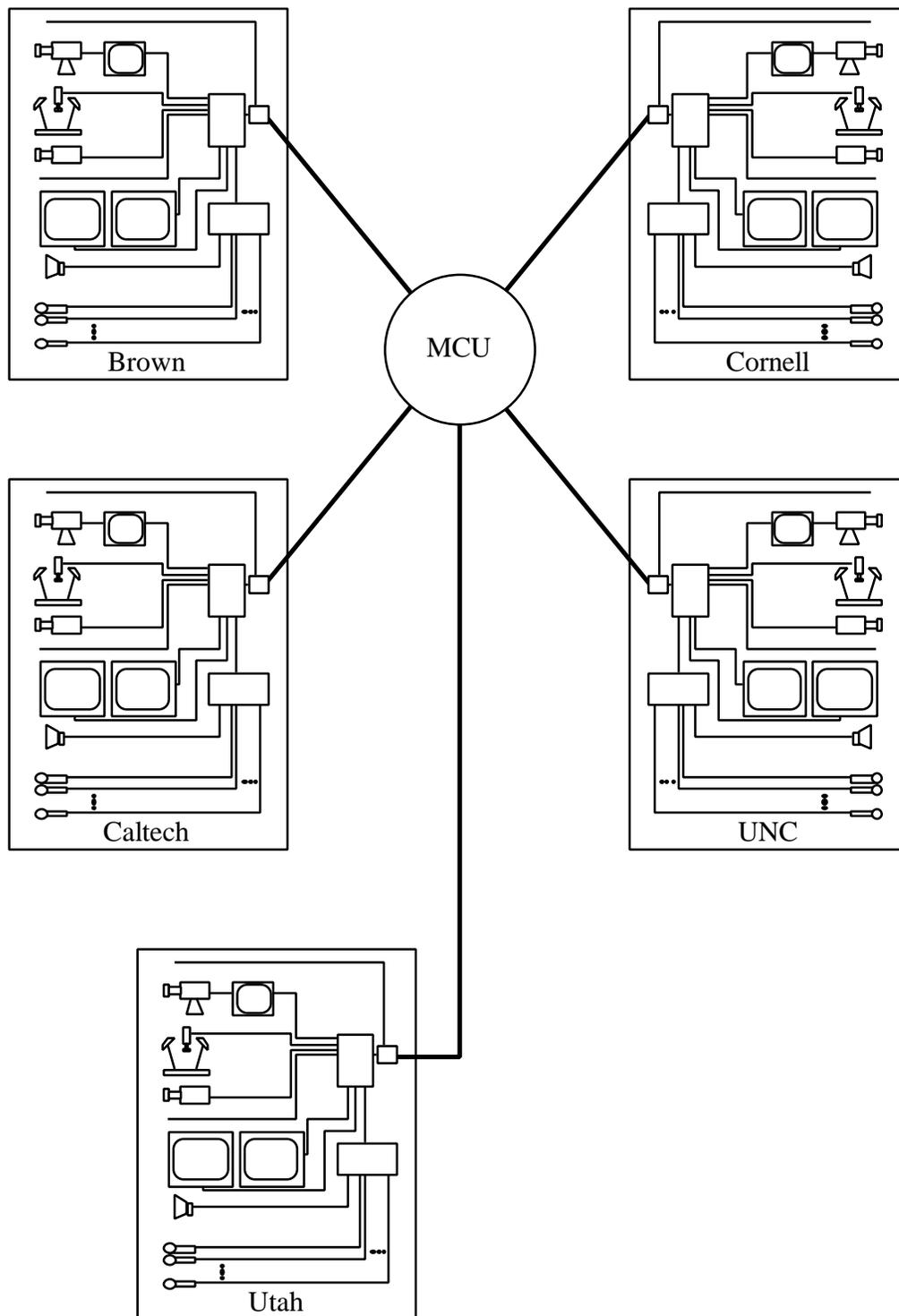
A follow up comparison of the NEC Visualink 5000/20 and the CLI Rembrandt II/VP running CTX+ was performed on 22 July 1992. The additional material gained from this separate evaluation alters the committee recommendation in support of the CLI codec. (See addendum to Appendix A)

#### **MCUs**

A further requirement that the Gang of 5 places on its videoconferencing facility is the need to have multiple sites on line simultaneously. Complete interconnect between all five sites would require a network system whose cost is currently prohibitive. Two other approaches, one utilizing digital technology and the other using analog video switches are being considered. The analog video switching system allows us the greatest flexibility in



**Figure 2. A spoke and hub system with an analog switch**



**Figure 3 - A five site network spoke and hub network with a central MCU**

the video that we mix and transmit. The digital system is an integrated solution that has lower cost, slightly lower flexibility, but higher expected stability.

A strictly analog system (see Figure 2) involving codec pairs arranged in a spoke and hub configuration with analog video switching at the hub is a flexible solution to the multisite problem. Essentially, four codecs would be distributed to the gang sites, with four codecs located in some central location (if the hub were co-located with one of the generating sites, only 8 codecs are required, 4 remote, 4 central). The video outputs of the central codecs would then be connected to an analog video switch (and perhaps special effects generator) and sent as the outgoing signal back to the originating sites. Products for switching and editing video signal are available from many different vendors. Different images could be sent to each of the five sites. Voice activated systems could be installed. A wide array of services could be provided with such a system; however, software to control the switching system remotely may have to be developed by STC personnel.

Digital multipoint conferencing units are available. An implementation using this technology would also appear as a spoke and hub system; however, this system only requires the use of five codecs (see Figure 3). The flexibility of the video presentation of this type of system is limited to the multipoint control software that is provided by the vendor. A digital switched system will provide lower signal loss due to the reduced number of digital to analog conversion steps. Control of this type of system does not require any implementation; turn-key control systems are provided by the vendors.

All four of the vendors involved in the comparison test can provide the STC with multipoint control units. Three of the vendors claim dial-up capability, while NEC expects to make that feature available in the second quarter of 92. All support voice activated as well as user controlled conferencing; all products support segmentable networking, allowing private conversation among subsets of the sites.

### **Recommendation**

The committee has reviewed all of the options and concluded that a digitally based spoke and hub system using an MCU is the best solution for the STC. NEC equipment has been identified as the most promising technology available on the current market. **(revised, see below)**

### Recommendation Addendum (11 September 1992)

After reviewing the results of a follow-up comparison of the CLI Rembrandt II/VP codec running the CTX+ software versus the NEC Visualink 5000/20, the recommendation of the committee has changed. The new software elevates the CLI product technically above the NEC system by a narrow but significant margin.

#### Estimated Costs

Provisionally, costs have been assessed at just under \$343,000. NEC has provided a 15% educational discount on all of their equipment. Channel Service Units are required for line signal restoration and liability isolation. For flexible communication, both data and video, dual port CSUs are necessary.

We have received complete quotes from two vendors. Prices, while still preliminary, are not expected to vary significantly in the near future. For a complete cost analysis and comparison, see Appendix A.

#	each	quantity	description
5	44,000	220,000	Visualink 5000/20 Codec
5	7,100	35,500	NTSC still graphics option
1	105,000	105,000	Multipoint Control Unit (8 ports)
.		360,500	subtotal
.		54,075	15% educational discount
.		306,425	subtotal
8	4,500	36,000	Datalink 2 port channel service unit
		342,425	Total

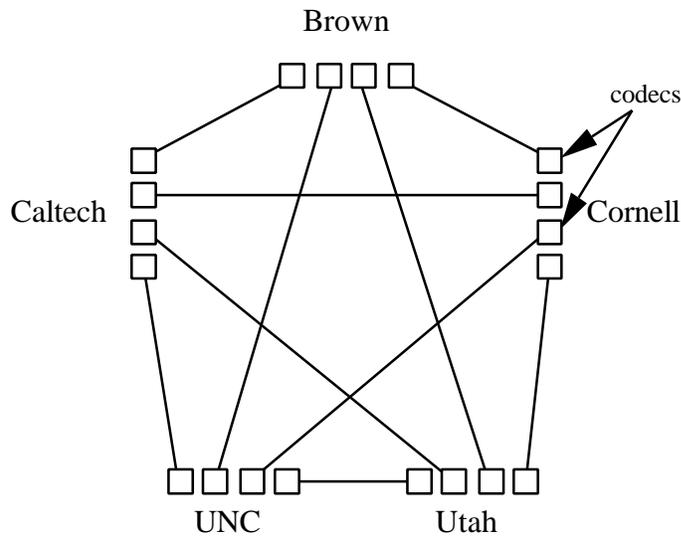
#### Revised Estimated Costs (11 September 1992)

Prices remain preliminary. However, the following confidential prices have been provided for the CLI equipment. Prices for both NEC and CLI equipment have been solicited. The following table has been assembled based on the revised recommendation of the technical committee of the CLI Rembrandt II/VP codec.

#	each	quantity	description
5	19,801	99,005	Rembrandt II/VP Codec
5	9,140	45,700	Compression Application Pkg.
5	1,142	5,710	T-1/RS449 Interface
5	3,808	19,040	Dual Display Graphics
5	1,904	9,520	Dual RS449 User Data Port
1	50,400	50,400	Multipoint Control Unit (3 ports)
1	3,360	3,360	remote control unit
1	26,400	26,400	additional 5 ports (T-1 Interface)
.		259,135	subtotal
8	4,500	36,000	Datalink 2 port channel service unit
		295,135	Total

### 3. Network Topologies

Several configurations for the conferencing network have been carefully considered. Different technologies (terrestrial networks, satellite implementations, microwave, etc.) were originally considered; terrestrial based 1.5 Mbit/second networks were selected as the solution that met the needs of the STC within reasonable costs.



**Figure 4. Example of a complete interconnect network.**

Beyond the selection of the technology, a topology for the network has been explored. In this section, we present the ideal configuration, followed by the topology that the technical committee has recommended. Alternative configurations that were previously rejected are described to exhibit the range of solutions that were considered.

#### **Ideal**

The scenario described here is the ideal configuration that realistically is unaffordable but should be discussed. It provides each site with the ability to control what it sees locally from any of the sites. This scenario is not a star system in that there is not a single point in which the images are switched together, rather each site is its own hub that can display and process the images as they see fit. This scenario offers full connectivity to all sites, however it requires that each site either purchase its own multipoint control unit (MCU) or purchase four codecs to handle the switching needs for each site. The major expense of this system is not actually the initial start-up capital investment needed to equip each site,

but rather the recurring service charges. Because of tariff structures, monthly local loops charges are (perhaps disproportionately) significant.

The delays in a MCU system of this type are technically large enough in themselves to merit consideration. If the network were only partially and not fully connected then the delays become a serious concern. Moving to a codec only system has prohibitive startup costs, retains the recurring service charges, but reduces delays and removes the MCU complexity. Reduced bandwidth might make this structure possible from the recurring monthly charges, but only if the STC were willing to reduce service to 384 Kbaud video and abandon hopes of using additional bandwidth for data. Any scenario involving this topology still retains significant startup costs.

These "ideal" configurations however shed some insight in what is desirable in a total system and what is not. What was learned from these configurations is:

1. We want to come as close to total connectivity as possible.
2. Delay for signals should be minimized in the design of the system.
3. Full connectivity is cheaper than satellite....but not much.

### **Spoke and Hub**

The Hub scenario is the most likely candidate to fit within the budgetary considerations of the STC. This hub, or star type system, is the most realistic, but poses some important problems that should be addressed. For configurations of this topology, see Figures 2 and 3 in the previous section. The issues can be broken down as follows:

- A. Location of the hub? Do we purchase hub services from a national carrier? Or do we acquire our own MCU and maintain it at a remote location? Or do we located the hub at one of the STC schools?
- B. Full time vs Scheduled? Full time connectivity favors an STC school as the hub. Scheduled favors purchasing switching services as needed.

For minimizing transmission delays, it would be best for the hub to be co-located with a switching center for the national carrier, preferably geographically located in the center of the United States. One site will always either have an additional, second delay introduced by the distance to the local loop, (e.g. Cornell faces 46 air miles between the site and the point of presence with the possibility of repeaters in that area), or it will potentially have

an additional delay for send/receive transmission. The delays that we can control and minimize by co-locating the hub with a national carrier switching center are local loop delays and the cross country delays. The delays that each site will retain in common are the 200 ms compression delays of the codecs on both ends, and the 10-20 ms T1 packet buffer delay at the CSU/DSU units that sit between the codecs themselves and the T1 local loop line.

Another reason to not have the hub at any of our sites is that one of the sites would be hit with four local loop installation and recurring monthly charges on those loops. Sprint, MCI, and WilTel all have hubs currently operating in the central region of the country.

However, placing the hub on non-STC property will relinquish our direct control over the network and/or switching system. Reconfiguration will be made considerably more difficult. A strong advantage to making one of the STC sites a hub is direct access and control of the network. A drawback to making an STC site the hub is increased technical burden that will be placed on the host site for support and maintenance.

### **Hubless**

The title of this section is a misnomer, since this type of system still requires a hub; we simply mean to suggest that a hub not be in use at all times and that the switching hardware need not be purchased by the STC. Switching services can be acquired from the national carriers.

An important consideration is how the system is to be used. As indicated above, full time connectivity favors an STC school as the hub. Switching services purchased from the national carrier for full time access rapidly become prohibitively expensive, without any adequate benefit. Limited connectivity favors purchasing switching services as needed, since multi-site conferencing may not represent the largest portion of the traffic.

### **Codeless**

It is actually possible to test the televideo needs of the STC without purchasing codecs and other encoding/decoding equipment by getting the signal to a national carrier in *analog* form. WilTel, for example, would do the analog to digital conversion and then pass off the signal to Vyvx, WilTel's broadcast division, who would do the multipoint control switch for us. Vyvx would perform a quad split of the incoming images and then send the newly converted multiplexed signals back to WilTel for transmission back to us.

WilTel expressed considerable flexibility in entertaining any needs beyond the standard offering in this approach.

This scenario has many advantages in that we can thoroughly test the requirements of the STC teleconferencing ideas without committing a large initial capital expenditure for unknown or unestablished needs. When it is determined over time what the actual needs of the STC are based upon empirically gathered information not assumed usage considerations, it should be straightforward to determine what codecs to purchase. It is recommended that this option be considered for the immediate needs of the STC. The video can be sent to WilTel, via common carrier, in a variety of analog formats from RF modulated signals to microwave, however the former is not recommended due to the FCC licensing requirements that accompany this type of transmission.

This scenarios main disadvantage is that we are tied to Vyvx's multi-point switch capabilities. This means that we are tied to a quad screen at all sites without the ability to switch to a full picture of a particular site that is of primary importance, in realtime. This however may be a minor inconvenience when compared to the possibility of the costly mistake of purchasing an inadequate system due to a limited study of the needs. We currently do not know what the real uses and needs will be.

The cost of codecs is not incurred but we have a short term increase in service costs as Vyvx is performing the switching instead of us. The local site logistics of camera operation, video switching for output, and local loop problems should be figured out in this time period, before the problems of having a codec on-site are added to the larger picture.

### **Recommendation**

After careful consideration and extensive deliberation, the technical committee agreed that direct control of the network is a preferable asset, and is worth the expected degradation due to longer distances in transmission. We suggest that the hub be co-located with one of the STC member schools. This determination is made with the expectation that near full time switching is desirable either for reasons of continuous use or scheduling flexibility.

We include the recommendation of the previous section that a digitally based MCU system be used at the hub site.

#### **4. Network Suppliers (Common Carriers)**

The breakup of the Bell System has led to the proliferation of companies offering long distance telecom services. Presumably this has led to greater competition and better service telecommunications landscape which creates added complications for the telecom systems designer. Anywhere from three to five organizations are now involved in providing telecom services from university site A to site B. First there are the long-distance carriers (AT&T, MCI, Sprint among others) who sell the trunk lines that provide *inter-office connections* (IOCs) from one carrier's *point-of-presence* (POP) to another. Next there are the *regional bell operating companies* (RBOCs, Baby Bells) who provide the *local loops* from the POPs to a university's telecom switch. Finally, at either end are the university netcom and telecom departments who provide the final link from the switch to the user's lab or office. While the long distance carriers typically subcontract with the RBOC's to provide seemingly transparent *premise-to-premise* connections, the fixed and variable costs of the services still reveal the underlying corporate boundaries.

Based on the design criteria outlined in an earlier section of this document, four long-distance carriers (AT&T, MCI, Sprint, and Wiltel) were asked to submit pricing information on a spoke-and-hub telecom network connecting the five sites of the STC. Information on full-time dedicated T1 (1.5 Mb/s); demand switched T1; and demand switched fractional T1 (768Kb/s, 384Kb/s) service was requested. Information about installation costs, and long-term, volume, and governmental/educational discount programs was also requested. The figures provided by the carriers are included in Appendix C. The issues and recommendations that came out of these inquiries are given below.

#### **Hub Placement**

The first step in pricing a spoke-and-hub network is deciding where to place the hub (see previous section on Network Topologies). Both local loop, and long-distance costs must be taken into account. Three of the four carriers (AT&T, MCI, and Sprint) indicated that placing the hub at UNC would minimize the total recurring charges for the network. There were minor differences between these carriers as to whether the split between local loop and long-distance charges favored Utah or UNC, but all three indicated that a UNC hubbed network would be least expensive overall. The figures from the fourth carrier (Wiltel) were not directly comparable to the others because pricing information was only

requested for a UNC based network, but the fact that Wiltel's pricing is so similar to the others implies that the final result would still favor UNC as the hub site. Fortunately this jibes well with the independent recommendation that UNC serve as the hub site because of its ability to best support the hub on a technical basis.

### **Dedicated vs. Switched Service**

Deciding on dedicated vs. switched service is the next issue. Full-time dedicated T1 service for the five sites of the STC costs approximately \$30,000/month. This cost is based on an annual term plan and includes a 36% discount on both local loop and long-distance charges. If a demand switched T1 network is preferred, local loop charges are a fixed cost of approximately \$6500/month leaving \$23,500/month for switched service charges. At an average connect cost of \$5.75/min./site, a five-way T1 conference would cost \$1380.00/hour (four remote sites, UNC directly connected to the hub). This would allow 17 hours of conferencing per month (or 4.25 hours/week) before a break-even point favoring dedicated service would be reached. Conferencing at the lowest visually-acceptable data rate (quarter T1, 384Kb/s) would double the available conferencing time to 34.5 hours/month (8.6 hours/week), with half T1 service (768Kb/s) falling somewhere between. Further economies could be realized if fewer sites participated in the conferences or if conferences were held at night. Another factor to be considered in a demand switched system are the upper and lower bounds on usage charges. One carrier (MCI) guarantees that the monthly usage charges for switched service will not exceed 120% of the full-time charge, the others currently have no upper cap. At the lower end of the usage spectrum, all carriers have a minimum usage charge for switched services which would be approximately \$2400/month for the STC network. Adding in the fixed local loop costs brings the minimum charge for a demand switched network with T1 capability to \$8900/month.

### **Additional Costs**

In addition to the recurring costs associated with the local loops, and long-distance usage, all carriers list a one-time installation charge to defray the cost of setting up the network. For the carriers queried, installation charges range from approximately \$9000 (Wiltel) to more than \$18,000 (AT&T). The range is curious considering that the same work is involved in each case. Fortunately it isn't necessary to ponder this further because all the carriers have indicated that they are willing to waive installation charges.

### **Additional Discounts**

All carriers offer discounts on term plans with deeper cuts for longer terms. One year term discounts are approximately 36%, increasing to 40% for a five-year term. In addition, carriers indicated that further volume discounts might be available based on aggregate-bandwidth usage by the universities, or by NSF projects like the STCs. None of the carriers currently offer educational discounts.

### **Choosing a Carrier**

The carriers are far more similar than they are different. Price packages for dedicated or switched services from the four carriers queried all fall within a few percentage points of each other though some carriers offer lower pricing on local loop service and others have the advantage in long distance rates. In this situation, distinguishing between the carriers is difficult, and impressions come into play.

Overall MCI and Wiltel seem to be the most technically competent and progressive companies. The contacts at these organizations immediately understood the unique needs and demands of this project and offered appropriate information. Additionally these carriers appear to be working to distinguish themselves in other areas of interest to the STC. MCI has just introduced demand switched T3 services which may be attractive for long-distance hi-speed data networking, and Wiltel is expanding its own support for videoconferencing which may become important for conferencing beyond the five-site network outlined in this document. In contrast, AT&T and Sprint did not seem to positively distinguish themselves in any particular aspect of this inquiry. Because of its Bell System lineage, AT&T did not seem to be as flexible as the others in its discount structure or its ability to shift costs between the local loop and the long distance domains to achieve competitive pricing.

Finally, Sprint did not seem to be oriented toward customers like the STC with our need for high-bandwidth, dedicated digital service. On the other hand, their orientation toward selling T1 service as aggregated px64Kb service would allow a greater degree of flexibility in a switched system than the other carriers currently offer. A final decision on which carrier to use should not be made until after the field test when other technical and usage issues will become clear.

## Recommendation

No national carrier has come forward as a clear candidate with better or significantly less expensive service than any of the rest. No clear recommendation can be made at this time.

## Estimated Costs

This is a cost estimate for a spoke and hub interconnect with UNC as the hub. The following cost summary is taken from a quote provided by WilTel. There is some concern that regarding the term discount, that commits the STC to extended service. This does not limit the STC from increasing the bandwidth in the network. Upgrading service at a later date remains an option throughout the lifetime of the conferencing system.

#	monthly	install	description
1	495	760	Brown to T1 center (Providence)
1	615	685	CalTech to T1 center (LA)
1	2,095	725	Cornell to T1 center (Syracuse)
4	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
1	500	745	Utah to T1 center (Salt Lake)
1	3,650	400	DS-1 Durham to Syracuse
1	9,950	400	DS-1 Durham to Salt Lake City
1	10,695	400	DS-1 Durham to Pasadena
1	4,625	400	DS-1 Durham to Providence
	36,425	9115	subtotal
	-8,195		less 4yr term discount
	28,232		subtotal
	-3,529		less dollar volume discount
	24,703		expected monthly total
	X 12		months / year
	296,436		expected annual total
		9,115	(WAIVED) installation charge

For a comparison of service prices from four national carriers, see Appendix C. Unlike the estimate listed above, the term discounts listed in Appendix C are only for 1yr term discounts.

## **5. Data Networking**

The possibility of using the additional bandwidth on the T1 lines for data traffic is a compelling reason to acquire full T1 lines. Fractional T1 tariffs are not substantially reduced over full 1.544 Mb service.

Part of the costs indicated in the price of initial equipment includes dual port Channel Service Units (CSUs). These units can be used as T1 multiplexers and can split fractions of the bandwidth off for both videoconferencing and data.

Datalink CSUs are also equipped with RS232 serial ports for soft reconfiguration. It would be possible to reconfigure the network on the fly to meet rising bandwidth needs for data, when video demands are low. Conversely, reconfiguration for site visits to present the best possible video signal would not require significant hardware intervention, but would rather become a problem of software and perhaps be performed remotely.

There remains a problem of integrating the data from the T1 serial network with our existing environments at each STC site. Most of our sites use either Wellfleet or Cisco IP routers (this is confirmed at UNC and Utah). The cost of connecting our LANS using the bandwidth from the T1 lines involves adding T1 or fractional T1 interfaces to existing routers.

### **Estimated Costs**

If UNC were the hub, UNC would need to acquire 4 additional T1 ports on its Wellfleet system. There are two ports per card-set, and sufficient open card slots in our existing racks. Each site would have to acquire a single T1 interface for their router, and connect to one of the ports of the CSU. The cost for the STC to provide data networking is currently estimated at just under **\$10,000 for the hub** site, and under **\$5,000 for each remote site**. Speaking conservatively, data networking could be achieved for **under \$35,000**.

## **6. Site Specific Issues - Unenumerated Costs**

This section was written in collaboration with video engineers. Specifications listed here are only approximations. Individual systems can vary from high quality camera and audio systems to office level desktop conferencing systems. Some sites will implement fancy conference room systems with multiple camera inputs for flexible presentation.

Each site will need to assess its need in regard to the equipment listed here. This list should not be considered complete, nor a list of requirements enforced by the STC; it should be used as a framework to begin a dialog at each local site as to what equipment should be acquired or considered.

**Cameras:** Each site needs 3-15 (possibly more) cameras to feed to the system. Each site should have two different types of cameras, fixed remote and ENG style. Fixed remotes are preset inside of a room for 3-4 positions of various groups of people in a room both seated and for the lecturer/presenter. A *ENG*, short for Electronic News Gathering, camera is a hand held camera that would be mounted on a tripod or on the shoulder for remote location shoots. A remote location is classified as a room outside of the general video conference room, such as a force-feedback room, or milling room, or just being inside of the lab itself. Decent cameras range in cost from \$1,000 (good consumer level) to about \$5000 (minimal professional level) and up. Automatic pan/tilt cameras are available.

**Monitors:** Most sites already have NTSC monitors available. Good 25" monitors run about \$1000 apiece. We intend to also use a projection television system costing \$20,000.

**Microphones:** Small lavallier microphones cost in the neighborhood of \$500. Table microphones cost around \$700-\$1000. Stereo is not expected to be necessary.

**Loudspeakers:** Stereo loudspeakers will be necessary and cost around \$500-\$1000/set. Cheaper models are available; even the television speakers can be used for most cases. More expensive ones are possible, too, though only likely to be useful for rare cases.

**Scan Converters:** Format converters are also available to convert 1024 resolution (actually, these deal in horizontal scanning rates--ours can handle up to 72kHz) to NTSC. Only one of these per site is necessary; they cost between \$12,000 and \$25,000.

**Additional video equipment:** The rack gear needed for all of this will consist of a system sync and test signal generator to time the different types of signals that coming into the local site switcher for output to the codec. Time base correctors (tbc) will also be needed for the video tape machines as well as digital disk recorders such as the Abekas A60, and the scan converters. This may potentially mean having to acquire three or four tbc's per site, or several duals. Waveform monitors and vector scopes will also be helpful in making sure that the outgoing signals are at the proper levels as to be NTSC legal and are NOT chopped off by the codecs. A NTSC illegal signal manifests itself as black lines that look very similar to video tape dropout, but only occur in areas where there is oversaturation (generally reds and greens).

**Routers:** Each site will want to switch computer-generated video to the system. Caltech has in place a Sierra Video Systems NTSC switcher, which costs about \$15,000. Audio will also need to be switched from either videotape or from microphones. Caltech's SVS audio switcher is also about \$15,000.

**Other:** camera stands, mike stands, and other suitable furniture and environmental stuff (e.g: lights, sound baffles or a big heavy curtain) are necessary and will generate some additional costs.

## **7. Field Test - a status report**

To justify the investment in this medium as a conduit for collaborative research, a demonstration of the capabilities of a televideo conferencing system is required. A trial period of thirty (30) days has been set forward as sufficient time to evaluate the contribution a conferencing system can make to our center.

Proponents of this testing process from Cornell indicated that any test not involving multiple sites would be deficient in its breadth of testing. Much of the value of such a system is the multi-way collaborative effort that we intend for the STC.;

The executive committee decided that a field test of the equipment would ensue, following the technology comparison that happened at Chapel Hill. The initial budget for the field test was slated for \$10,000, a number that has not yet been exceeded.

Briefly, the test plan is to deploy a teleconferencing system to a subset of the STC sites. Those sites have been identified as Cornell, UNC, and the university of Utah. Preparations have been made to begin conferencing by the week of March 16th. An agreement with WilTel, VSI and NEC has made possible a 30 day field test of a conferencing system using UNC, Utah and Cornell as the originating sites. WilTel has agreed to provide free switching services both for point-to-point connections as well as MCU services out their offices in Tulsa, Oklahoma.

WilTel is providing inter-office connect free of charge. They are coordinating the installation of local loops from individual STC sites and the WilTel points-of-presence in those areas. The STC is assuming the cost of installation of those lines and the monthly charges of operating the local loops.

NEC offered to support the field test on a thirty (30) day basis if the STC was willing to make the commitment of a conditional P.O. The principals were not amenable to this solution, so a rental agreement was drafted, where \$3500 was committed to the rental of per codec for a one month period. 75% of the rental price is applicable to the purchase price of these systems, upon purchase. Shipping of the third codec is being provided by NEC to Chapel Hill.

VSI is providing two roll-about conference ready video systems, free of charge. These systems will be equipped with a camera, a video switch, a single monitor with picture in

picture display, a NEC Visualink 5000/20 codec and a NEC provided AEC7000 audio system. Installation of these systems at Cornell and Utah is being provided gratis. STC assumes shipping costs of these cabinets from Atlanta to and from Ithaca and Salt Lake City.

Local loop installation is expected to be complete at the end of next week with the conferencing system operational by next weekend. The videoconferencing systems are shipping out of Atlanta on Monday and the UNC codec should be enroute from Maryland at this time. Local loop installation is the chief concern. They are pushing for a 13 Mar. installation date, since we will have video engineers waiting for the local connections to be completed.

#	each	quantity	description
1	917	917	local loop install (cornell)
1	723	723	local loop install (unc)
1	743	743	local loop install (utah)
1	2,092	2,092	local loop charge/mo (cornell)
1	960	960	local loop charge/mo (unc)
1	437	437	local loop charge/mo (utah)
		5,873	subtotal (network)
1	1,389	1,389	videosystem shipping
		7,262	subtotal (less codecs)
1	3,500	10,500	NEC codec rental/mo
		17,762	total (test)
		7,875	less 75% codec rental
		9,887	total (if purchased)

**Update (15 March 1992)** - Local loops have been installed at Utah and at Cornell. Installation at UNC is expected to be completed soon. Most installation setbacks have now been overcome; however, signal strength on the T1 lines is insufficient to support video traffic without line amplification. Channel Service Units (CSUs) are being acquired on a no cost basis for the duration of the test.

Utah and Cornell have completed the first test of a point-to-point conference. Roy Hall from Cornell made a brief presentation to audiences at both Cornell and at Utah. Enthusiasm for new research opportunities possible through this system has accelerated among personnel at the sites involved in the test.

**Update (1 May 1992)** - The test has been completed and a successful evaluation of this technology has been performed. More importantly, a great deal of enthusiasm for this

technology has been generated among faculty, students, and staff at the sites which participated in the field test.

Some examples of collaborative events that occurred during the field test are:

- Roy Hall and Jim Arvo from Cornell conducted a seminar on global illumination models.
- Dr. Gershon Elber of the U of Utah presented his (successful) public dissertation defense, with attendees from both Cornell and from UNC.
- Dr. Mark Surlis of UNC Chapel Hill also presented his (successful) public dissertation defense, with attendees at the other remote sites.
- Dr. David Baraff of Cornell held a two part seminar on physically based modeling techniques across the network to participating sites.
- UNC held its informal weekly graphics lunch, a “brown-bag seminar,” for the first time with Cornell.
- The STC Executive Committee held one of its weekly conferences using this system (as opposed to conventional telephone based conferencing) with Al Barr attending at a WilTel facility in LA and committee members from Brown participating via a audio-only phone bridge.
- Remote execution of real time particle system simulations were demonstrated using UNC’s Pixel-Planes system. Real-time control was provided to Cornell, and near real-time visual feedback was supplied using the videoconferencing system. A live video tour of UNC’s graphics lab was also conducted for the benefit of students, staff, and faculty at Cornell who are not familiar with UNC’s research environment.

The experiment was successful. Some aspects of this medium remain un-explored, such as the concurrent use of the network as a data channel simultaneously with bidirectional video communication. We also learned that audio echo cancelling is a more significant issue than originally supposed. Technical personnel now have some experience with scheduling concerns and have developed some expectations for the day-to-day maintenance and support that this system will require. The field test has increased our knowledge both from a technical viewpoint, as well as provided us with a working model for the uses of this technology and its limits.

## **8. Normal Operation**

This section describes the expected configuration of the network and the anticipated daily use and operation of each node. Each Site will be equipped with a NEC codec and have a T1 connection to the hub. A control panel will be available at each site to control the interaction with the conference. Any site can generate a conference. The MCU is partitionable into multiple private conversations; these segments can be specified remotely from the panel. Typical operation will not require a video booth engineer at any location.

Normal operation of the MCU is to shunt video from any single site to another site. During voice activated mode, the person speaking will be broadcast to the remaining participants. The speaker's monitor will show live video from the last speaker's location. It is also possible to control the video feed to your site. If you wish to watch someone other than the speaker for reactions to what is being said, the remote command console allows you to select the view.

A careful distinction must be made between selecting the video feed and selecting the video input. The system described does not control which input is supplied to the originating codec. Each site selects what it wishes to send (usually a live camera, but possible videotape, or live computer graphics). Selection at the MCU is from among whatever video feeds are being provided from the remote sites.

Audio in this system is decompressed at the MCU and merged into a conference call. Latency is introduced by transmission and compression delays. The images are lip-synced to the audio; however, latency will be nearly one-quarter of a second. Interrupt driven arguments/altercations will be difficult or perhaps exacerbated for this reason.

It is not possible with this system to provide a "quad-plexed" view of the conference. It is expensive in time, money, and image quality to uncompress the video, resample the image to a smaller size, and the recompress and transmit. This form of presentation was considered and rejected in the analog video switched hub system described above.

The equipment specified will not require constant preventative maintenance. It should be emphasized that this equipment as well as similar systems from other vendors are in production use among the national carriers, various government agencies, corporate management, and some educational institutions. This technology, while not as mature as cable television, is expected to meet the expectations of the Gang for stability.

The single point of failure in our system will be located at the hub. UNC has a staff engineer who is "video-literate" and who can have maintenance of the MCU added to his responsibilities. Since we anticipate this to be a low maintenance system, once constructed, we do not see this as an encumbrance for the hub site. The leading advantages for going with purchased switching services from a national carrier included 24 hour service and maintenance. We have foregone that level of service in favor of flexibility; however, during site visits and other critical periods, extended engineering support can be scheduled from UNC.

Mean time between failure on the NEC codec is advertised at 18,000 hours. The NEC two year warranty is unique among its competitors which provide only one year of coverage. The only PM is a user serviceable monthly loopback check. NEC and its service provider, VSI, have a policy of 24 hour delivery of replacement parts. The codec is a card cage with multiple circuit boards. As computer people, we all have a working familiarity with this kind of system, and maintenance is not expected to be an overwhelming issue.

For site visits and critical demonstrations, it might be reasonable to acquire spare boards and/or an entire spare unit. The initial cost of the spare equipment would be made up for in immediate service and peace of mind.

### **Operating Costs - Site Support Personnel / Overhead**

Initially, significant amounts of personnel resources will have to be dedicated to the deployment of this system. The field test revealed that the telecommunications connects must be individually debugged, and that local internal wiring and configuration does require expert personnel and lots of time. Startup is expected to consume two to three man-weeks of video literate engineer time in order to become operational.

If the bandwidth is acquired on-demand, some amount of scheduling and connection assurance will be required of some engineer/video administrator at each site. Over time, this procedure should become streamlined, and required less and less attention. If 24hr connections are established, no scheduling time is necessary, and maintenance on the communications equipment will be reduced; however, the duty cycle on the cameras, monitors and other such video equipment is limited, and subsequently, replacements will be needed earlier.

In order to support the system with a lower chance of failure, the STC will eventually need to acquire dedicated personnel to monitor and maintain the network. This is even more important if the network is to also carry data traffic. Overhead should be eventually supplied to cover a site video engineer for the hub location. In the early deployment stages, however, the STC is devoting outside resources to this function.

## **9. System Startup**

The cost of the equipment required to erect this support infrastructure is a serious threshold. Once begun, the recurring costs can be predicted and subsequently controlled. Each site has a different level of on-site expertise in this area, varying amounts of already available support equipment, and may or may not have a suitable environment to conduct video conferences. The section on site local issues reveals many of the "hidden" costs that vary wildly, depending on whether a site has microphone stands, video switching capabilities, an existing video cabling plant, etc.

### **Startup Costs**

The startup cost in terms of personnel will vary depending on the existence of video facilities at each site, and the learning curve required of available personnel. Caltech has an extensive video cabling system already installed, as does UNC. Video engineers exist at all sites, with much of the experience located at Utah and UNC. Information can be made available throughout the STC. Trained hands will most probably be the limiting factor.

The cost of the startup equipment required at each site does vary. UNC has an existing videoconferencing facility. No additional equipment will be necessary there to begin this work, but additional switches will eventually be required to facilitate the selection of the STC network vs the state-wide microwave channel. One means of supplying the remaining sites with sufficient equipment to begin conferencing would be to acquire turn-key conferencing systems. Speaking conservatively, these units can be acquired for under \$25,000 each, and come supplied with microphone, camera, 27 inch monitor, pan&tilt unit, audio system, and infrared remote. In addition, some of the echo problems experienced in the field test can be avoided by hanging a heavy cloth curtain in each conference room. The cost of this simple architectural modification must be determined on a site-local basis.

## **10. Videoteleconferencing Futures**

It is important to consider the evolving technology and the customer/market base that supports its development whenever making a design of this nature. The issues listed here have been identified to be pertinent, but not achievable within a 24 month time frame. The committee elected to relegate these issues to "futures" since it was determined that the STC will require more immediate motion than what these possibilities represent.

### **Price/Performance**

The codec on-site system is the most realistic in the immediate term planning for the STC. However, it should be noted that PC codecs are expected shortly on the horizon for substantially less money, according to experts we consulted. It should also be recognized that 384 Kilobits/sec. algorithms of today looks substantially better than T1 of two years ago. Moving video picture algorithms of today are undergoing substantial and rapid changes in both speed and quality. This rapid growth is likely to render the codecs of today obsolete very soon. Although much of what a codec processes is in software, they still rely to a large extent on hardware based algorithms.

With the algorithms becoming faster and more robust, it would be prudent to focus more seriously on 384 KBPS speeds, as it is likely that the T1 of today will look 384KBPS in 24 months. With the T1 of today able to adequately deal with moving computer graphics images, we expect that 384KBPS will be sufficient for the needs of the STC for synthetic images, and high ISDN for talking heads material. In our calculations, this would I believe be the only realistic scenario to stay within budget and still maintain a picture system.

### **Multimedia- desktop systems**

Desktop systems for videoconferencing are on the horizon. At least one codec vendor has already announced such a product and making it available to existing customers; however, the transmission speed is limited to 384 Kbaud. Some vendors have announced current collaborations with major computer manufacturers and integrated circuit design firms to provide conferencing systems as a part of multi-media products. The current projects employ limited bandwidth, but as mentioned above, tomorrow's limited bandwidth may prove more than adequate for normal use.

Videoconferencing for workstations is expected within 24 months, but with limited temporal and spatial resolution.

## **Packet Video**

Two of the members of the committee attended the packet video workshop held at MCNC in the Fall of 1991. The workshop concluded that packet video (video passed along traditional data networks) is not expected to be a product within a 2 to 10 year time frame. The reasons for this were not necessarily technical limitations, but seemed to be tied to a limited demand.

Packet video is currently limited by the restrictive bandwidth available on the internet. Most internet sites can only receive 1.544 Mbaud through their regional networks, even though the backbone is moving rapidly toward T3 - 45 Mbits/sec. Nonetheless, research in this area is proceeding quite rapidly and we will continue to monitor its development.

Two examples of progress in this area have been noted. A demonstration from the North Carolina Supercomputing Center to a conference in Washington DC was conducted using a CLI codec compressing at rates of 112 Kb and transmitted using the internet over TCP/IP. Another venture was demonstrated by Bolter, a subsidiary of Dynatech, in their 45Mb frame relay codec. They demonstrated this system both at the ComNET Trade show and at an invitation demo in Salt Lake City.

## **HDTV**

We are concerned not only with the quality of today's compressed images, but also with the possibilities of higher resolution. HDTV is one of the promising avenues for increased resolution, since it is endorsed by the entertainment industry. No standards are yet in existence for North America, so development is hampered. Products within the US are not expected soon.

Nonetheless, we continue to ask teleconferencing manufacturers about their intentions regarding this technology. The answers varied, but at least two vendors claimed active collaborations with video equipment manufacturers to build HDTV codecs.

The technical difficulties for compressing and transmitting the required data are immense. We expect that at least 45 MBit/sec transmission lines will be required to handle the data rates necessary to sustain full motion video.

### **11. Summary (revised 11 September 1992)**

A summary of the costs is assembled here for easy reference. All costs except the data connection expenses and site-local issues are presented from vendor prices officially quoted to the STC.

#	each	quantity	description
5	19,801	99,005	Rembrandt II/VP Codec
5	9,140	45,700	Compression Application Pkg.
5	1,142	5,710	T-1/RS449 Interface
5	3,808	19,040	Dual Display Graphics
5	1,904	9,520	Dual RS449 User Data Port
1	50,400	50,400	Multipoint Control Unit (3 ports)
1	3,360	3,360	remote control unit
1	26,400	26,400	additional 5 ports (T-1 Interface)
.		259,135	subtotal
8	4,500	36,000	Datalink 2 port channel service unit
		295,135	Total

#### **Cost summary of videoconferencing equipment (not including site local equipment - cameras, microphones, video gear)**

The costs of videoteleconferencing equipment necessary for real time image communication is shown in the following table. For information on this material, see the section titled **Videoconferencing Technology**.

#	monthly	install	description
1	495	760	Brown to T1 center (Providence)
1	615	685	CalTech to T1 center (LA)
1	2,095	725	Cornell to T1 center (Syracuse)
4	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
	950	1,150	UNC to T1 center (Durham)
1	500	745	Utah to T1 center (Salt Lake)
1	3,650	400	DS-1 Durham to Syracuse
1	9,950	400	DS-1 Durham to Salt Lake City
1	10,695	400	DS-1 Durham to Pasadena
1	4,625	400	DS-1 Durham to Providence
	36,425	9,115	subtotal
	-8,195		less 4yr term discount
	28,232		subtotal
	-3,529		less dollar volume discount
	24,703		expected monthly total

X 12	months / year
296,436	expected annual total
9,115	(WAIVED) installation charge

### Cost summary of annual communications recurring costs

The costs of the networking services recommended by the technical committee are summarized here. A justification for the selection of this topology is provided in the section titled **Network Topologies**. A complete description of the prices and services listed here can be found in **Network Suppliers**.

A field test was approved by the STC Executive Committee. \$10,000 was budgeted for the field test and \$3,500 for a technology comparison. An overview of planned field test activities can be found in **Field Test - a status report**.

#	each	quantity	description
1	917	917	local loop install (cornell)
1	723	723	local loop install (unc)
1	743	743	local loop install (utah)
1	2,092	2,092	local loop charge/mo (cornell)
1	960	960	local loop charge/mo (unc)
1	437	437	local loop charge/mo (utah)
		5,873	subtotal (network)
1	1,389	1,389	videosystem shipping
		7,262	subtotal (less codecs)
1	3,500	10,500	NEC codec rental/mo
		17,762	total (test)

### Cost summary of teleconferencing field test

**Additional costs** will include data port connections to local IP networks and sufficient equipment to conduct videoconferences (cameras, microphones, video routers, distribution amplifiers, etc.). Data connection costs are not expected to exceed \$10,000 per site; depending on the existing equipment at each site, data connections should cost considerably less (See **Data Networking**). Site local considerations will vary depending on the availability of audio/visual equipment already in place. No means of globally assessing this information has been identified (see **Site Specific Issues**), but startup systems can be rented (price unknown) or purchase for less than \$25,000 per site.

## **12. Conclusions (revised 11 September 1992)**

Careful scrutiny of contracts, agreements, and warranties will be discussed and included as available.

The recommendation of the committee is that we acquire 5 CLI Rembrandt II/VP codec systems, a CLI MCU, and construct a spoke and hub network with UNC as the hub using full-time T1 leased lines. National carriers are being approached for quotes for such a system, and firm information will be available soon.

The assessment to date however, is that annual connect cost of service that will be acceptable to the STC will be at best **\$300,000** and the cost of initial installation will be nearly **\$295,135**. The cost of the field test (assuming purchase of the test units) is approximately \$21,262 (\$17,762 for the field test, and \$3,500 for the technology comparison).

Data links are not expected to exceed **\$50,000** and are expected to be under **\$35,000**. Start up costs in video equipment are variable and will depend on individual sites.

### **Totals**

Initial investment costs that do not include site local equipment are expected to total: \$316,387. Site local startup costs **will vary** but are expected to run close to **\$25,000/site**.

Annual recurring costs will be not less than: **\$300,000**

## **Appendix A - Codec technology report**

A video teleconferencing technology comparison was performed on 25 February 1992 at the University of North Carolina at Chapel Hill by the Science and Technology Center for Computer Graphics and Scientific Visualization. This "codec shootout" was conducted to determine how well various products would meet the needs of the STC.

The STC is a center which explores new frontiers in computer graphics and information representation. It is distributed over five separate programs, located in widely scattered portions of the United States. The member sites are located within: Brown University - Providence, RI, Caltech - Pasadena, CA, Cornell - Ithaca, NY, UNC-Chapel Hill - Chapel Hill, NC, and the University of Utah - Salt Lake City, UT.

Unlike most STC which are centrally located often within a single building, the STC CGSV must function with a unified purpose, but from a distributed geographical base. The problems of creating a single center from distributed sites were recognized before the center was created, and plans for a videoconferencing system were provided in the original proposal to the funding agencies.

Fundamentally, the STC is a research organization. The purpose of the video network is to foster a research environment, and not solely to facilitate business. Transactions expected over this network include not only teleclassroom education, but also the transfer of full motion high resolution interactive graphics and computer animation sequences. An additional goal of the STC is to be able to interact with remote sites, including the manipulation of remote computers, with visual feedback being provided using the teleconferencing system.

Several manufacturers of videoconferencing equipment were invited to demonstrate their systems. Of the seven invitations that were sent, four vendors: CLI, GPT, NEC, and PictureTel attended the comparison.

### **Comparison Conditions**

We hoped to get an unbiased evaluation. A committee of technical personnel who have some experience with video equipment was assembled from member STC sites. A third party consultant was acquired to handle negotiations and ensure a double blind test.

During the evaluation, no evaluators were provided the source of the images on their monitors, except for the live feed which was labeled as control.

The codecs themselves were configured in send and receive mode, one to send and the other to receive, and the video signal from the receivers were distributed among four monitors of identical make and model. The monitors were adjusted prior to the test to attempt to achieve matching color response. During the test, the monitors were randomly reconfigured to ensure that no vendor had the advantage or disadvantage of an inferior monitor. The codecs were physically isolated from the evaluation team. Input signal to the codecs was distributed from the same video distribution amplifier in an attempt to generate identical signal for each of them.

A technical comparison was held during the morning of 25 February 1992, with an extended evaluation committee (including Henry Fuchs (Principal Investigator from UNC), Fred Brooks (Co-PI, UNC), Terry Yoo (UNC), Jim Ferwerda (Cornell), Jim Rose (Utah), Nate Huang (Brown)). The committee compared various inputs and different compression/transmission speeds.

After lunch, vendors were invited singly to present to the committee the issues not covered in the technical evaluation. Maintenance, software, product support, future products, collaboration potential, extended features, and other issues were discussed at length.

### **Vendor Handouts**

During the morning session, manufacturer representatives were not involved in the technical evaluation. They were instead invited to answer questions regarding their systems, and provided with information sheets about the design goals of the STC videoconferencing system. This was done to allow vendors to focus their afternoon presentations on the issues considered most important by the committee.

A copy of the information sheet is provided here both for completeness, and to impart a flavor of that day's activities:

## **Televideo Conferencing Technology Information Sheet and Questionnaire**

### **Comparison Criteria**

The comparison criteria for today's test will be based largely on the requirements for the intended applications for the televideo technology that we will deploy in our system. The purposes for this system are twofold: first is the matter of high quality televideo conferencing. We intend to carry on collaboration with members of our community with whom we require close contact but whom we seldom see face to face. Close interaction will only be possible through the application of teleconferencing systems that can support high resolution images with high fidelity audio. Furthermore, other types of interaction will include the multitude of classes, seminars and colloquia that are held frequently at each remote site. The clear ungarbled dissemination of this oral and visual material is vital to the success of the STC.

The second major purpose of the system is to conduct research in computer graphics remotely, sharing resources among widely distributed sites. The faithful compression and replication of synthetic images in near-real time is a significant component of this effort.

Our findings today will be based mostly on how well we believe each product and/or manufacturer/vendor can support the goals of this effort. For clarity, we will iterate some of the points for discussion.

### **Image Quality**

We will be interested in image resolution both in a spatial sense (does the image look blurry?) as well as the temporal sense (does the image blur over time? during motion?). Other issues include color shifting (is color preserved?), high frequency roundoff (are details preserved?), image size, temporal resolution (how many frames per second?), coding artifacts (errors introduced by the compression algorithm), and other noise introduced by the systems.

### **Audio**

High quality audio may be of secondary importance; however, it is still a requirement for a teleconferencing system for the STC. In both in the technical blind comparison as well in the information section that follows, we will be concerned about how each product handles audio. Issues reviewed will include: audio bandwidth (3.5K? 7K? Variable?), latency, echo cancelling or suppression, and whether room conditioning is required or recommended.

### **Options**

Since our collaboration will have a wide variety of uses for a teleconferencing system, we are interested in optional accessories that we believe will make joint research possible. Items such as dual display an/or picture-in-picture display are considered vital to successful collaborative conferencing. Remote operation of codecs may be required as well as the transmission of control information via an alternate data path.

**Multipoint Capability**

Since 5 way conferences are expected, some form of multi-point capability will be supported in the final configuration either in the form of a digital multi-point control unit or by the use of an analog video switching facility. During the information section of today's activities, we will be investigating the multipoint capabilities of the product lines that we are reviewing. If multi-point units are available, can multiple private conferences be conducted simultaneously (segmentable?)? How is video and audio handled in a multipoint conference? Who controls a multipoint conference? Can control of the multi-point unit be assigned to remote locations? Are setup and diagnostics available during remote operation? How are data channels supported during multi-point sessions? Does the unit have dial-up capability?

**Standards (Interoperability)**

Each of our centers may wish to communicate with sites other than their STC partners. If teleconferencing is involved in these transactions, our equipment may need to interface to other products. This raises questions of the interoperability of the products that we acquire. Does the current product support current industry standards? Does it comply with H.261? H.320? CCITT? Are there upgrades or modifications expected that will make it compliant?

How well can the product support or communicate using international standards? PAL? SECAM? Are there plans to support higher resolution video? HDTV? What about frame relay or packet video?

**Service**

A critical part of any operation is the maintenance of equipment. Questions regarding the reliability of the equipment will also be treated during the discussion. What warranties are available with the equipment? What service support is available and at what cost? What is the expected mean time between failure (MTBF) of the product?

## Technical Comparison Results

Evaluators made subjective evaluations of all products demonstrated at the comparison. Products were evaluated based on how well they would meet the needs of the STC to perform not only video replication of live subjects, but also of computer generated images. Issues discussed and critiqued included:

**Spatial Resolution:** the issues of spatial resolution were examined at length. The ability of the codec to reconstruct an image without blurring is vital to STC research.

**Temporal Resolution:** This was divided into two categories: blur induced by motion and frame skipping. Each codec degraded a bit differently when subjected to image where significant portions of the screen were in motion.

**Color Fidelity:** A common means of compressing images is to trade color depth for spatial resolution. Here we evaluated how well products restored images to their original color (another aspect vital to our research).

**Detail:** This was an overall assessment as to whether detail was preserved in transmission. All of the factors mentioned above contribute to image degradation, and some overall assessment as to whether certain tradeoffs can be considered acceptable was necessary.

**Encoding Artifacts:** Each of the codecs used some mechanism for encoding subscreen footprints, measuring coherency from frame to frame, and updating only screen regions that differed significantly. This encoding leads to artifacts and visible image distortions. We focussed some attention on how intrusive these artifacts were to teleconferencing and remote image research.

The products were ranked on a relative scale. Readers should be aware that no arbitrary grading scheme could be devised, so each grade should be considered relative to the other products in the comparison. A visual representation of the grading scheme is borrowed from a consumer magazine and used here (See Figure A1).



**Figure A1. Evaluation Scale**

The products compared side by side with a variety of inputs. First they were evaluated at their maximum speeds, with some products running at rates of 1.544 Mb/sec. They were successively stepped down in speed through the same inputs to evaluate their performance

at slower transfer rates. Those units running at slower transfer rates performed competitively later in the day.

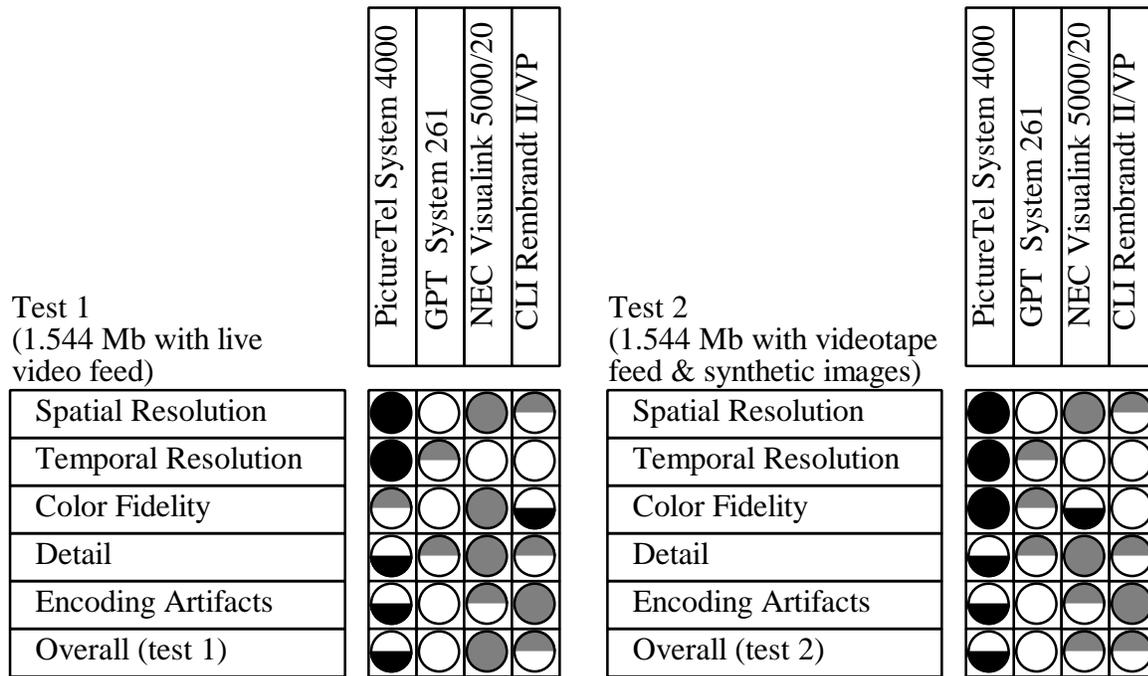


Figure A2. Results from Tests 1 & 2 running at maximum transfer rates

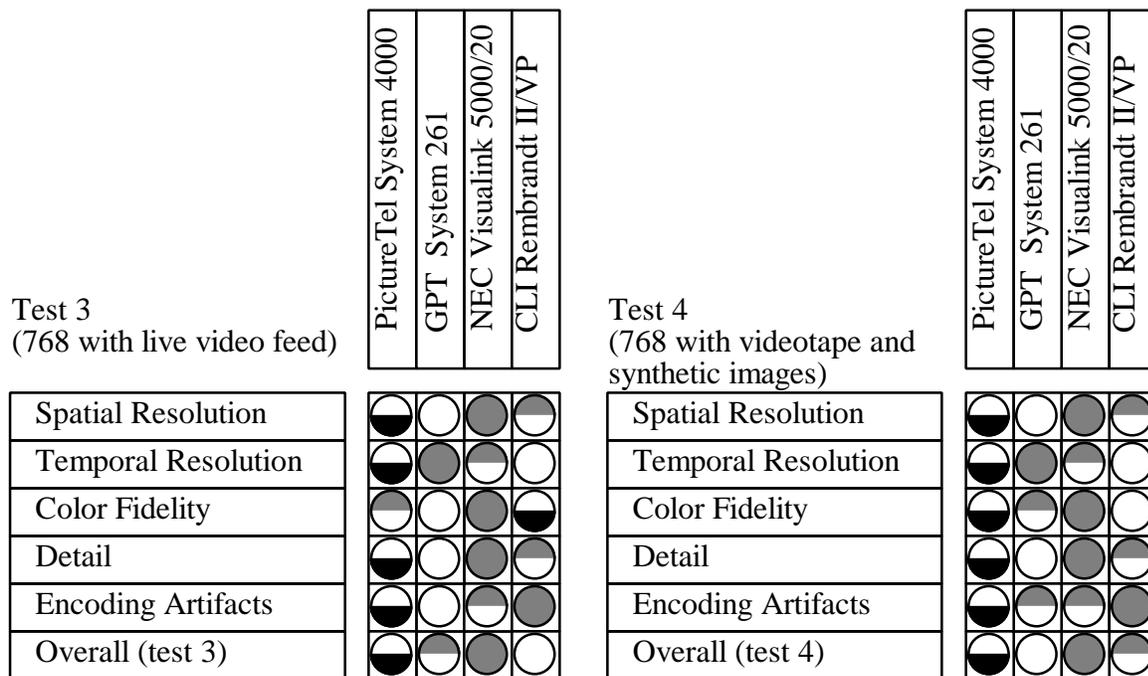
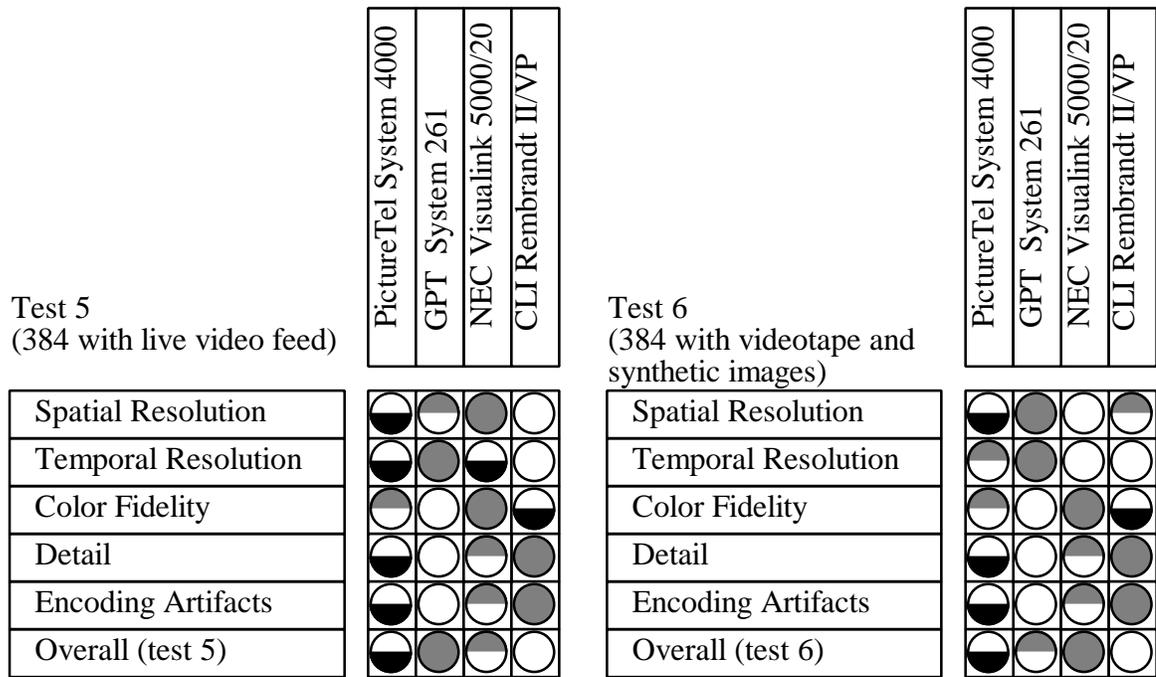


Figure A3. Results from Tests 3 & 4 running at 768 Kb/sec or maximum



**Figure A4. Results from Tests 5 & 6 running at 384 Kb/sec**

The trend in the tests was for the PictureTel and CLI products to perform relatively worse at the higher transfer rates. These two units had maximum transfer rates of 384 Kb and 768 Kb/sec respectively. As the communication speeds decreased, properties such as color fidelity and/or spatial resolution did not improve; the relative performance of particular units compared with others cause the evaluations to change.

One of the most striking things about these units was their dissimilarity. We had anticipated most of them to have similar performance and features, but we found this to be quite untrue. Many tradeoffs can be made in search of a better picture, and each product struck a different balance to achieve its goal.

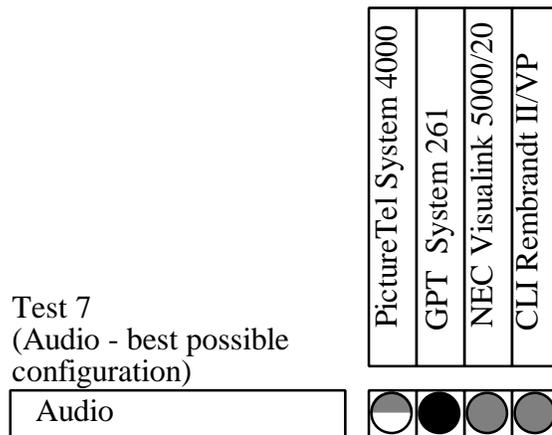
For example, the Compression Labs Rembrandt II/VP images appeared washed out. Clearly they trade color depth for accurate intensity reconstruction. During a color bar test, no image except that of the CLI system could replicate the grey bars; however, its colors bars did not closely correspond to the expected hues. By comparison, the GPT and PictureTel units tended to oversaturate the colors during image restoration, leading to a slight loss of spatial resolution and achieving a better color balance. This manifests itself differently for different inputs. Panelists often preferred the images on the PictureTel system for color fidelity to the CLI system when images of live subjects were displayed;

however, during the display of synthetic images, the PictureTel color distortions proved themselves unacceptable to graphics researchers.

Temporal resolution was similarly input dependent. Some units trade motion blur for loss of frame rate. While watching cars pass on the street on separate units, some images would appear as moving blurry streaks while others as a series of less blurry stills.

Some units elect to perform contrast enhancement filters to attempt to restore high frequency elements to the images that are lost in transmission. Edge enhancers were obvious both during test patterns, but also in the distortions they induced around large colored polygons often found in computer graphic images.

Although we were not originally configured for an audio evaluation, a cursory comparison was conducted with significant results. The GPT unit performed very poorly in comparison with the other units, which were effectively of the same caliber. No distinction could be discerned between the NEC and CLI codecs, and only a slightly poorer response was heard from the PictureTel codec. (See Figure A5.).



**Figure A5. results from the audio comparison**

It should be noted that since the time of this comparison, the STC has gained some experience with the use of this kind of system, and we recognize that a more thorough study of audio performance is merited. Echo cancelling, microphone equalization, and other issues play a greater role in trouble free teleconferencing than originally supposed.

The panelists were polled at the end of the evaluation, to determine a ranking for the four systems that were displayed. They were asked to consider fatigue from watching degraded images (a serious concern after three and a half hours of careful scrutinizing),

audio performance, the quality of the transmitted computer generated images, and the overall capability of the units to perform their normal function of teleconferencing. The conclusions of the panel are shown in Figure A6.

Overall Ranking

NEC Visualink 5000/20	
CLI Rembrandt II/VP	
GPT System 261	
PictureTel System 4000	

The NEC Visualink 5000 was considered the best compromise among the candidates. The CLI system was rated highly on the strength of its performance with synthetic images. GPT's System 261 was impressive, but suffered from a tinny audio system. PictureTel targets their product at lower bandwidth entry level customers, and their product was not considered suitable for this application; however, it should be noted that their system outperformed other units in color fidelity when displaying live images.

### **Product Review**

This is a brief overview of the committee regarding the various products. Information in this section includes material that was presented during the vendor presentations from the afternoon.

#### **CLI Rembrandt II/VP**

The CLI Rembrandt II/VP is one of the widely recommended products in the industry. It performed well during most tests. The chief complaint among the panelists was the lack of color depth in the reconstructed images. The intensity depth was well rewarded, however, during tests with synthetic images, where brightness is often more important than hue. Audio on this system was crisp and clean.

One of the most important considerations that was addressed during the session after the technical evaluation regarding the CLI Rembrandt II/VP was the software release that accompanied the demonstration units. CLI was unable to provide us with codecs for this demonstration, so an equipment loan had to be secured from MCNC Communications, a CLI customer and collaborator with UNC. The software provided was CLI's Application

Package 1, which is an older product and is currently being displaced by a new proprietary compression algorithm, CTX+.

The system under evaluation was a Rembrandt II/VP running CTX (Application package 1) It has only one third the resolution of CTX+, with a maximum frame rate of 15 frame/sec.

The newer CTX+ software has a wider range of capabilities than the system that was demonstrated to the STC. Essentially, CTX+ is capable of 30 fps with motion compensation at a resolution of 480x368 during normal operation, and transfer of still image of high resolution graphics (736x480). The software also allows for the full T1 (1.544 Mb/sec) bandwidth to be utilized; it also provides for fractional T1 use, in increments of 56 Kb/s. The amount of bandwidth dedicated to audio is selectable among 8, 16, 32, 48, and 64 Kb/s. This provides sufficient bandwidth to match commercial CD recording devices.

Our chief concern regarding this material is that CTX+ has been announced, but it is not yet in delivery to paying customers. CLI representative Steve Parrish confirmed shipping delays in excess of 110 days for this software system. CTX+ is also a proprietary algorithm, and does not conform to the international H.261 standard. H.261 video can be supported with some loss in image quality.

Additional options for the CLI codec include integrated PIP, split screen, remote access, self diagnostics, menu driven user interface, automatic NTSC/PAL conversion, DES encryption, and a graphics cursor.

A new direction for CLI is toward microcomputer based desktop teleconferencing. They recently announced a Macintosh add on videophone product. Products for IBM PS/2 microchannel and AT standard bus platforms will be announced in Fall 1992. The Macintosh product is a sidecar box requiring 2 ISDN lines and achieving 7-12 frames/sec. It uses 1 ISDN line for the video, 1 for the audio. Alternatively, it can employ standard phone line for the audio. Using digital delay systems they achieve synchronous audio and video.

Regarding the CLI MCU: It has 8 ports and is segmentable (up to 3 concurrent conferences), cascadable to up to two MCUs supporting a wider audience (in cascade: up to 5 concurrent conferences). It supports multiple speeds, load preset configuration, lowest common denominator determines the conference speed. Conferencing with parties

running at different speeds is controlled and automatically configured by the MCU. High resolution graphics can be sent from any location. NO master site, All codec functions supported by the MCU, voice switching hysteresis settable at differing time lag (anywhere from low to up to 500 ms.) Audio and video typically in band, but can be placed out of band, 3.5K to 7K audio.

## **GPT**

The GPT System 261 performed well in most tests; its greatest failing was inadequate audio fidelity. Most members of the panel saw this drawback as a fatal flaw in this product.

The video images on the Systems 261 were being transferred at 1.544 Mb/sec, full T1. The images had acceptable color balance and spatial resolution; however, this system tended to saturate colors, tending toward red. Furthermore, the System 261 uses an edge enhancing filter that became distracting when viewing some computer generated images. As its name implies, the System 261 does comply with the H.261 standard.

The GPT System 261 supports: encryption (DES and B-crypt), audio echo cancellation, split screen system, conference system controller, additional video I/O modules, alternative network interfaces, International standards (compatible and automatically configures itself for NTSC and PAL), PIP, graphics with full control of addendum video (35 mm slides, plain paper text). GPT can provide an internal data multiplexer card (RS449 port (multiples of 56k), and comes standard with 2 low speed RS232 dataports.

GPT is combined with Siemens, and they claim a wide international customer base. Customers include: ARCO, Digital, Glaxo, USC (with local high school), U Michigan (with association MICTA), AT&T, MCI, Sprint, Wiltel, and Bell laboratories. They retain a working relationship with WilTel.

Applications spectrum supported by Siemens companies includes everything all the way down to telephony and up to near broadcast quality. Video systems are focussed on video communications... from meeting rooms/studios down to the desktop. Their current focus are in desktop and roll-about units. They are very interested in interactive multimedia.

soon to announce PC based codec (2card slot system) first a generic chipset. Not as highly integrated system... later implementations will improve. (IBM Europe)

The GPT MCU has eight ports, supports two simultaneous conferences, uses 7K wideband audio, employs voice activated or chairman control, has encryption capability, fully digital switching, zero picture degradation, 56Kbps to T1 speeds, independent data routing, and is cascadable. (latency is single figure milliseconds) at differing speeds, data rate drops to lowest speed among conference viewers.

## NEC

The NEC unit outperformed the rest of the units on display in most categories. It proved to be the best compromise among the four units under evaluation. It had a good balance between color depth and spatial integrity. It balanced motion artifact and blurring cleanly. At higher transmission speeds, the NEC Visualink 5000 model 20 seemed well suited to the kinds of applications expected within the STC. The audio on this system was excellent.

However, the committee has reservations as to the performance of the NEC codec at slower rates. When switched into 384 Kb/s transmission, it went into field mode, transmitting only half the vertical scan lines. This caused diagonal lines to appear broken or dashed, and made the unit unacceptable for the transmission of vector images at less than 1/2 T1 rates. Such tradeoffs may continue if lower bandwidth is incurred.

NEC provided the STC with the latest version of its px64 software, capable of sustaining up to 30 frames/second, with a range of transmission speeds between 56Kb and 1.544 Mb. It supports forward error correction and is H.261 compatible.

When in high resolution mode, the Visualink 5000/20 transmits 480x352 images. It has user selectable audio bandwidth (.34 K or 16Kb/s (CCITT G.711) option or 7K (CCITT G.722)). It comes standard with three user data ports: Two low speed ports 1200-9600 baud and one high speed port 64-768 Kb/s (built-in multiplexer at no cost). Standard features include PIP, DES encryption, a 4x3 Video Switcher with Black Burst, local remote loopbacks, is compact Size 8"H 17"W 18"D 44 lbs., low power consumption 200 watts max. It also has an RS232 remote computer control port that can be operated via a UNIX system (control software is available from KAtetelech). Audio systems can be selected from a range of products; echo cancellation and echo suppression are both available.

Two of the optional features include “image plus,” (full-screen multicamera multiplexers) and a still frame graphics option (resolution: 480x352 using a proprietary compression scheme).

NEC supports a full line of video and teleconferencing products... up to 45 Mb T3 products and down to fractional T1. They carry two lines of codecs - designed for communication at 56Kb to 1.544 Mb OR 56Kb to 384 Kb. The Visualink model codec is built for the high end. The low end unit is not equipped with a good proprietary algorithm.

They are supporting ventures in multimedia and have an HDTV project operating in Japan. A network was recently installed for an educational application as an 8way distance learning system in Atlanta.

The NEC MCU support speeds from 112 Kb to 1.544 Mb, compatible with NEC's Visualink 5000 and can support either the T1 or RS449 interface. Maintenance is aided by extensive local diagnostics. It can operate both in voice activated mode or can be controlled via a conference chair. The standard unit is a 4 port MCU (add on card for 8 ports). Up to three MCUs can be cascaded for a possible configuration of 21 ports. These systems can sustain up to 3 segmentable conferences. Lowest common denominator of the speeds of the participating parties determines the conference speed; unlike other products, the MCU does not autoconfigure itself to adjust for differing speeds; a technician must configure the MCU for conferences.

### **PictureTel**

The PictureTel System 4000, while a fine product, was poorly matched for the needs of the STC. It is designed for lower bandwidth transmission rates, and has a maximum rate of 384 Kb/second. Its strength is in transmission at ISDN rates (56-384 Kb/s) with a best performance (relative to the performance of other products) at 112 Kb/second.

The images were transmitting only at 12 frames/sec, which made motion artifact a distracting issue during the evaluation. The images did not have good spatial resolution, but its performance relative to its competitors was improving as they were equalized in speed. Color fidelity was moderately good, though they were a bit over saturated. The color was good for live subjects but poor for synthetic images, suggesting that they have been paying careful attention to the tradeoffs targeting their product for its normal use in

teleconferencing. Audio for this system was clear and performed well. This unit is not H.261 compliant.

Some features of the PictureTel codec arise from its position in the market. These units are designed for customers who traditionally do not have professional video expertise available. The other codecs in the evaluation required time base correctors (TBC) to be used when transmitting input from videotape. The PictureTel System 4000 does not require an in-line TBC to handle videotape transmission.

PictureTel claims the industry's best picture quality at the lowest bandwidth (112kb), the industry's lowest cost system (\$19K including camera, monitor, and codec) with crystal clear audio, desktop dialing and operation, advanced system integration (board level CSUs, audio, and video codec in the same unit), keyboard operation, H.261 international standard compliant compression (Px64) is in beta-test and will ship in March (will interact with VTC and will announce compatibility with CLI). The H.261 product is expected to improve their frame rate to 15 frames/sec.

The implication is clear. PictureTel manufactures complete systems for customers interested in teleconferencing, but not interested in assembling the vast array of equipment necessary to support the high-tech wizardry involved in operating the system. Their integrated units come complete with CSUs, desktop cameras, keyboards with built in microphones, full screen menu operation, zoom, and adaptive/smooth pan and tilt units for the cameras. They support PIP display, but limit the inset picture to a small non-resizable area of the screen.

PictureTel no longer supports direct marketing, but instead chooses to deal with value added resellers. The vendor support team for UNC is Carolina Telephone, a 92 yr old company owned by the United Telephone System. Sales, service, and support would be provided by VAR companies local to each site.

The PictureTel MCU supports simultaneous segmented conferences. It has a maximum capacity of 16 ports (sold with 3, additional ports are add on options). This MCU has dial up operation. This unit can flexibly support switched, dedicated and hybrid network configurations. Voice activated, chairman control, distributed director control, far end control, telephone audio-only bridge, flash up display are all standard modes of operation provided with the MCU.

PictureTel is moving toward true desktop conferencing. Workstation compatible multimedia teleconferencing products are in development now and should provide 12 frame/second video on workstations in the near future.

### **Summary**

This analysis was performed with a specific set of requirements in mind. It was conducted not only to determine how well conferencing could be conducted via televideo systems, but also whether computer graphics research is possible using this medium.

Our conclusions were that such research is possible, but only if high end systems are employed and sufficient bandwidth is dedicated to the transmission of images. We evaluated four codec products in an attempt to determine which product best meets the needs of the STC today. Of those evaluated, the NEC Visualink 5000/20 was selected as having the balance of features and compromises that best suits our purposes.

### **Addendum to Appendix A (11 September 1992)**

A separate analysis was conducted to compare two of the previously evaluated products a second time. The purpose of this procedure was to determine whether the CTX+ compression software from Compression Labs Inc. elevated the technical strength of their codec system. Only the CLI Rembrandt II/VP running CTX+ was compared with the NEC Visualink 5000/20. The comparison was strictly an evaluation of the new software versus the previous evaluation.

#### **Purpose**

Primarily, this evaluation committee is chartered with identifying and recommending the best available video compression, transmission, and conferencing products. Beyond product / technology analysis, the technical committee is responsible for the design, execution and deployment of the proposed videoconferencing network. We are required to be flexible since the rapidly changing constraints placed upon us by our sponsors, the marketplace of video products, and the economics of telecommunications impede our ability to make accurate predictions.

The motivations for conducting the follow-up evaluation were twofold. New pressures from our funding agencies made possible avenues for increased connectivity, but at the cost of introducing higher requirements for interoperability. Also, our previous evaluation was unable to secure a comparison of the best compression algorithm for the CLI product. Because of this, the evaluation was considered somewhat incomplete.

NSF and DARPA have indicated an interest in connecting the national supercomputing centers together using a videoconferencing network. The design for this network is commencing at the same time as our equipment identification and procurement stage. Our funding agencies have indicated a desire that both systems (the STC network and the proposed network for the supercomputing network) be compatible and operate together. The technical constraints placed on the supercomputing centers are slightly different than those imposed on the STC; however, the strong overlap indicates that the acquisition of similar or identical equipment will ensure both compatibility and ease of maintenance. Some of the supercomputing centers are currently equipped with CLI CTX+ based

systems; their recommendation and the proposed affiliation among our organizations were a significant element in inducing us to perform a follow up evaluation.

Although the evaluation in February was able to identify the product that best met the needs of the STC among the codec units present, the CLI product was not equipped with CTX+, the latest and most effective compression algorithm then available from CLI. (CTX+ was an announced product at the time of the February shoot-out. Our demonstration units were not equipped with this algorithm). This resulted in a somewhat incomplete evaluation, biased against CLI, a fact that was recognized in the original technical report (**see Appendix A, Product Review**). In an effort to provide the STC with the most complete technical comparison of available products, it was determined that we review the improvements in image quality attributable to the new algorithm, and compile the results of that comparison with our original report.

We point out that no other vendors were considered for this follow-up evaluation. No presentations were solicited nor were any accepted, as we believe that at this point, the committee does not require information that cannot be observed from a direct product comparison. We reiterate that the purpose of this evaluation was to compare the two leading products, with units that demonstrate the best capabilities that the manufacturers can supply.

### **Design of the Follow-up Comparison**

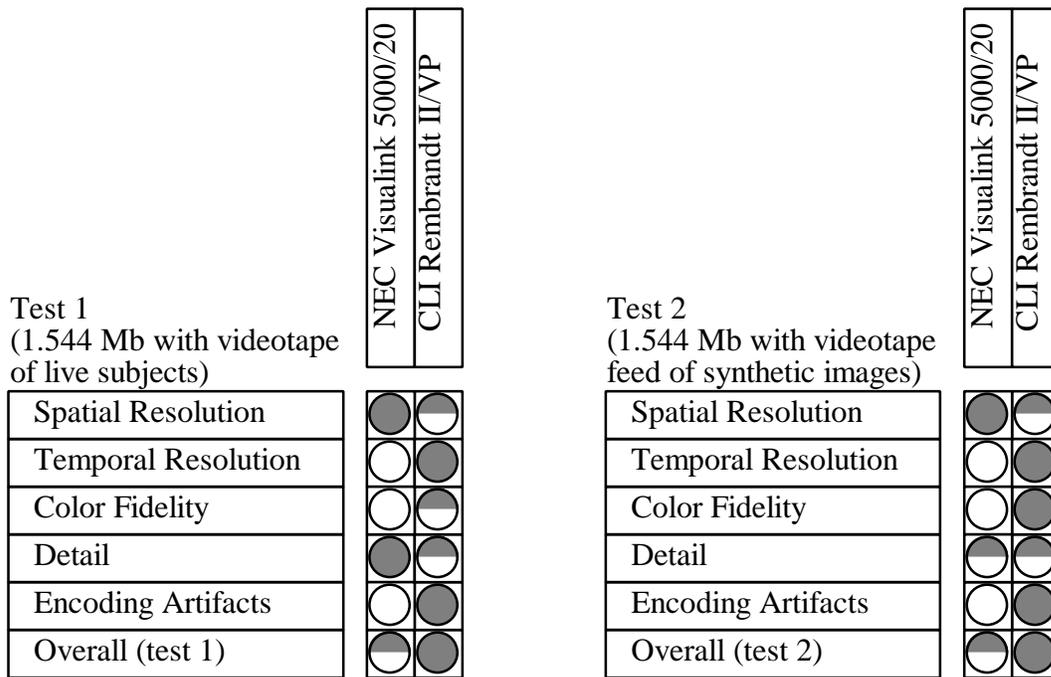
Two products were compared at great length side by side during the test at MCNC Communications. The NEC Visualink 5000/20 was reviewed using all four possible compression/display modes (CIF-motion, CIF-resolution, Proprietary-motion, Proprietary-resolution) and at 3 separate speeds (1.544 Mbs, 768 Kbs, and at 384 Kbs). The CLI Rembrandt II/VP codec was evaluated using both the proprietary CTX+ algorithm as well as its CIF standard algorithm. The best images were obtained using CTX+ on the CLI codec, and CIF/motion mode on the NEC.

Identically configured monitors were used for the side by side comparison. The monitors were switched during the comparison, to avoid introducing a bias due to the quality of the monitors. The STC Demonstration tape produced for the original site visit from Spring 1991 was used as input to both units. This tape (provided in Betacam format) was considered to be the best available collection of representative work from each of the STC member sites. The footage includes both synthetic and live images produced by computer

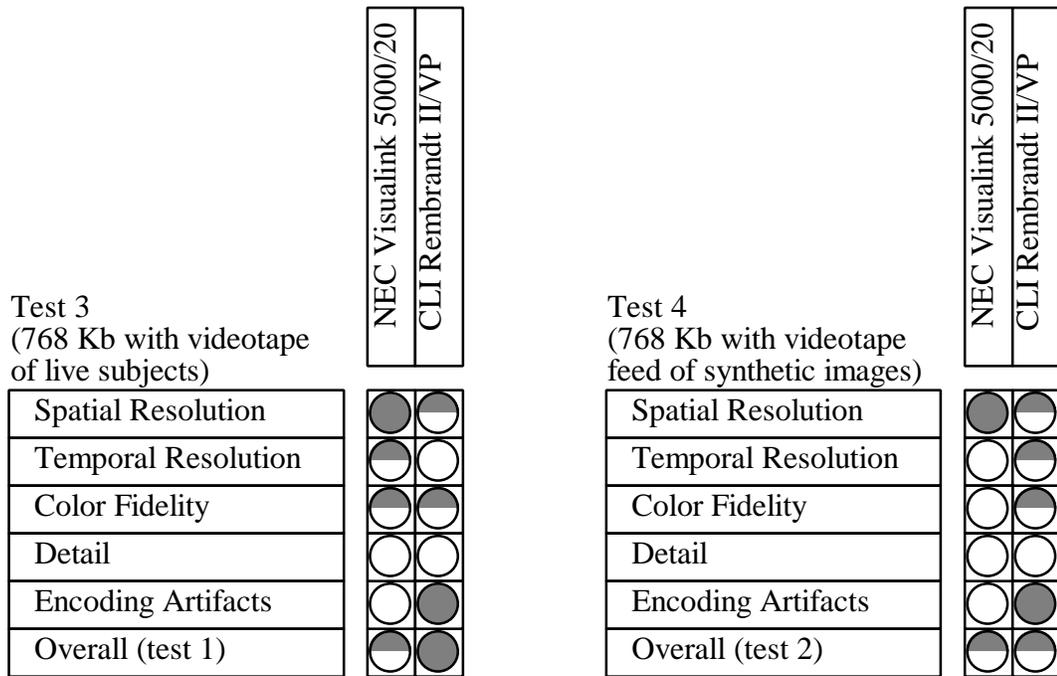
animation, interactive computer simulations, and video of live presentations. A distribution amplifier was employed so that a full bandwidth signal could be provided to each unit simultaneously. Only two codecs were used with each configured in an external loop-back mode (a T1 cable was attached from the output to the input ports).

**Follow-up Comparison Results**

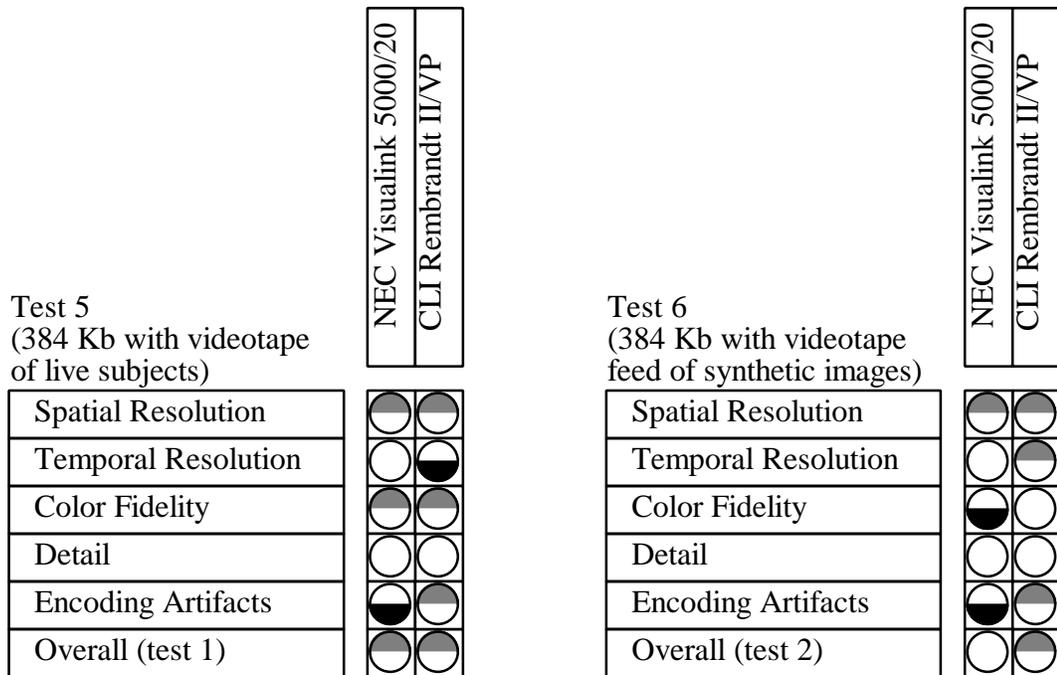
The criteria used in this evaluation were the same as those used in the original comparison (see **Appendix A, Technical Comparison Results**). Subjective responses regarding each of the issues were recorded and are summarized in the following tables:



**Figure A?. Results from Tests 1 & 2 running at 1.544 Mb/sec**



**Figure A?. Results from Tests 3 & 4 running at 768 Kb/sec**



**Figure A?. Results from Tests 5 & 6 running at 384 Kb/sec**

Overall, the comparison showed a marked improvement in the CLI product. The earlier algorithm was only capable of 15 frames per second. The new algorithm allows the same hardware to produce video images at 30 frames per second, with much higher picture quality. The previously evaluated CLI software indicated a tendency to “top-out” or not improve in quality when bandwidth higher than 512 Kbs was provided. The newer software clearly elevates the usable bandwidth for CLI to a full T1 (1.544 Mbs).

In side by side viewing, several distinct differences appeared. The philosophy of how to encode information and what elements of picture quality to compromise were quite evident.

The NEC unit tended toward sharper images, with detail clearly preserved; however, image detail was preserved at a cost of making the boundaries of the tiling procedure (used in image encoding) evident to the viewer. The CLI codec compensated for this by diffusing the image slightly, blurring the edges of the encoding tiles and removing those artifacts. Unfortunately, some fine detail is lost in this process. These distinctions became pronounced as transmission bandwidth was reduced.

An example of these effects is clear when viewing the building walkthrough prepared by Cornell. Features of texture mapping were well preserved in the NEC images, but the window frames showed pronounced aliasing or "jaggies." The CLI images were smooth, and more pleasing, but the impressionist paintings used in some of the views were no longer as crisp; detail had been compromised.

CLI has overcome their earlier tendency to create pictures that appear “washed-out.” Color in images during this comparison were of comparable quality and reproduced the original video signal quite well. When connected to a vector-scope, the CLI unit shows a tendency to overdrive color slightly; however, this did not appear as a noticeable problem when viewing images at 1.544 Mbs.

Spatial resolution was one element where CLI showed significantly better performance than the NEC unit. The CLI codec was able to resolve still regions of images from frame to frame, while the NEC codec seemed unable to take advantage of the coherency between frames. That is, in still images, or more importantly, in images where only part of the screen is moving, entire regions do not change (or change only slightly) over time. The NEC codec seemed unable to improve the image beyond its full motion capability, while the CLI codec corrected the image until a fairly crisp image was resolved.

Conversely, full motion images on the CLI system tended to be slightly worse than on the NEC. This was not apparent at full T-1 rates, but had appeared at lower bandwidth and had a tendency to become worse as available bandwidth decreased. At 384, temporal resolution, jerky-ness between frames, was unacceptable on the CLI system, while the NEC seemed to exhibit a more acceptable behavior.

### **Support Issues**

Two issues not covered in the previous comparison were the subject of some concern; their exclusion from the earlier comparison criteria were perhaps of some significance, though certainly not the most important issues before the review committee. These issues were the video support interface and the user interface for operation and configuration.

When closely examined, it was noted that the NEC Visualink 5000/20 would not accept genlock from an external source. This was significant during the recording of the follow-up comparison, since all the equipment in the video editing suite at MCNC had to receive gen-lock from the NEC codec, a signal that failed to gen-lock the CLI at times. On the other hand, the CLI codec is not deficient in this area, and would accept gen-lock from any source, including the external sync generator available in the editing lab. This issue was significant enough in the minds of some of the technical video personnel we interviewed to warrant the elimination of the NEC codec from consideration.

The other issue not discussed in the earlier evaluation that was raised at the follow-up comparison was the issue of user-interface design and supportability. In the earlier tests, the technical committee did not have access to personnel with extensive videoconferencing experience. This test, however, was conducted at MCNC Communications which supports an extensive state-wide videoconferencing system. We include their observations regarding support issues, ease of use, set-up operations, and maintenance in this discussion.

### **Software User Interface**

Each of the Codecs has a push-button panel and lighted LCD display for configuring the units by hand. For remote configuration and maintenance, each is supplied with an RS-232 serial port and rudimentary user interface. The LCD panels and menu driven interfaces for directly manipulating the systems were quite comparable and easy to use. Evaluators unfamiliar with the operation of this equipment were easily trained to perform simple functions using the control panels.

The serial interfaces distinguished the two systems. The CLI system was fairly self explanatory with a command language that was easy to understand and clear. Help menus were available and commands were intuitive. The NEC interface depended on a series of command and interrogation codes that required the user to have manual in hand in order to operate efficiently. Although support software can be acquired that facilitates the operation of NEC codecs, from the viewpoint of a computer science organization, issues of useability and configuration management were clearly in favor of CLI.

### Overall

As with the original evaluation, an overall assessment of the two products being evaluated was formed. Criteria considered included fatigue from watching degraded images (a serious concern after two hours of careful scrutinizing), the quality of the transmitted computer generated images, and the overall capability of the units to perform their normal function of teleconferencing.

#### Overall Ranking

CLI Rembrandt II/VP	
NEC Visualink 5000/20	

The improvements provided by the CTX+ compression algorithm elevates the overall technical appraisal of the CLI Rembrandt II/VP to the most acceptable product reviewed by the committee. The CLI system previously rated highly on the strength of its performance with synthetic images, has improved its capabilities in its primary function as video teleconferencing system. Its ability to resolve still portions of images makes it superior for teleconferencing as well as the transmission of many computer animation sequences. NEC remains highly recommended. In many of the research efforts involving the transmission of synthetic computer generated images, the NEC has many advantages, but these tradeoffs only exist in certain types of operations (full screen motion, and other types of motion at lower transmission bandwidth). The inability of the NEC system to accept gen-lock from an external source was considered a notable handicap.

The principal activity for this system will remain conferencing and distance learning applications. The research portion involving synthetically produce computer graphics images are expected to seldom produce the kinds of full screen motion that create significant deterioration of the reproduced images using the CLI system.

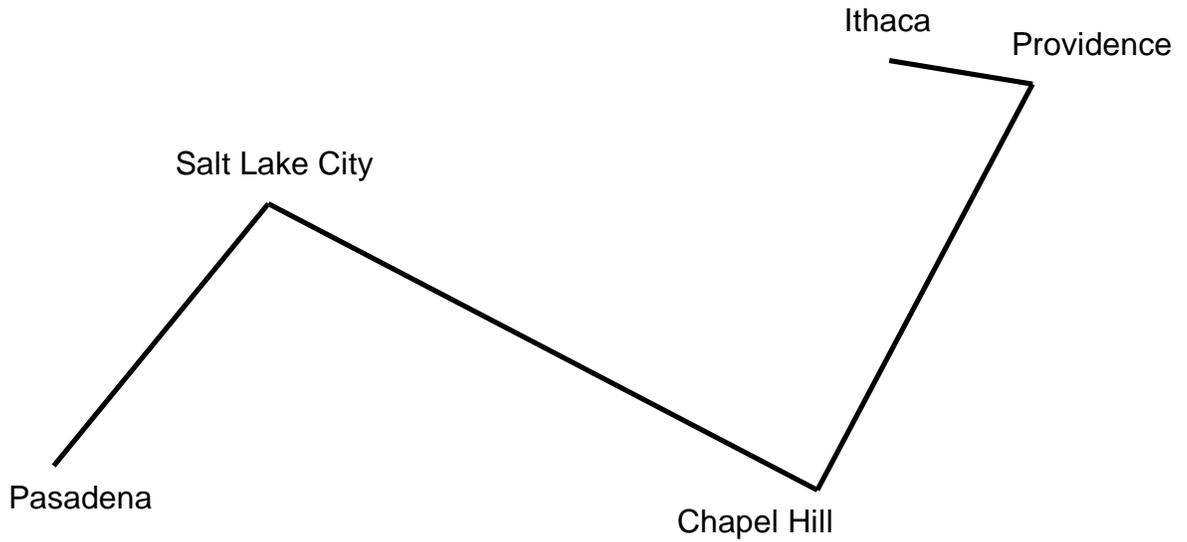
**Recommendation**

Our position, based upon the premise that the tradeoffs that were implemented in the CLI product were less objectionable than those expressed in the NEC codec (specifically that a loss of spatial and temporal resolution in the CLI images is preferable to the noise and encoding artifact visible in the NEC images) at the transmission rates expected to be available for our network (1.544 Mbs to 768 Kbs) is to recommend the CLI Rembrandt II/VP with CTX+.

**Appendix B - Network engineering analysis**

The following is a set of viewgraph “foils” that were presented to the STC as part of a videoconferencing network evaluation. This presentation was made at Caltech on 16 December 1991 to PIs Henry Fuchs and Alan Barr.

## Topology 1



Connections are T1 fibers

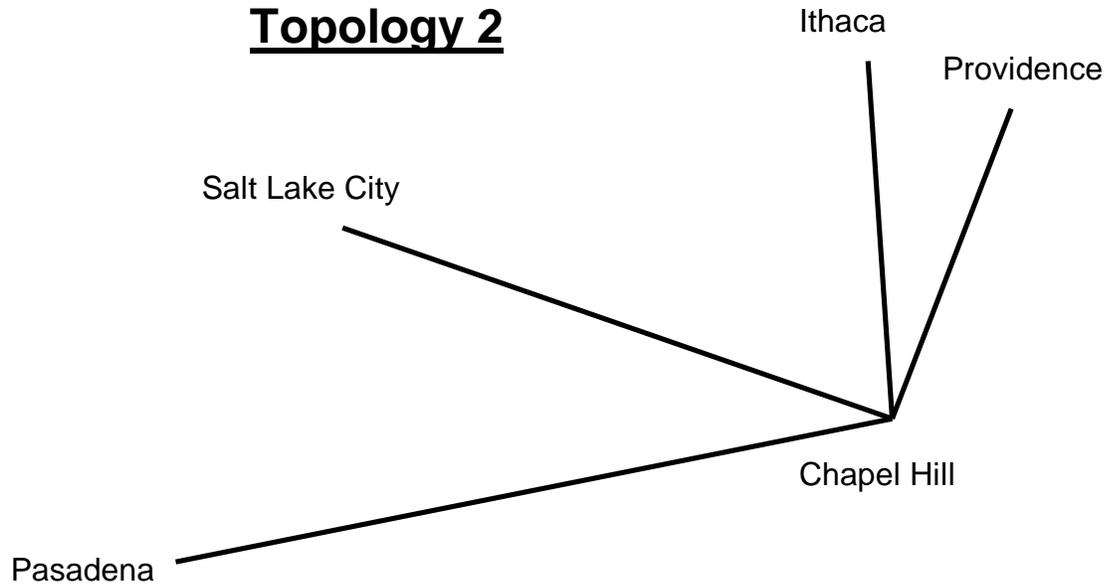
### Costs of fiber rental

Long Range Connections:	\$K/month
Pasadena to Salt Lake City:	6.2
Salt Lake City to Chapel Hill:	12.7
Chapel Hill to Providence:	6.2
Providence to Ithaca:	4.2
<b>Subtotal:</b>	<b>29.3</b>
<b>Less 40% Discount*:</b>	<b>17.6</b>

Local Connections from local companies (# of required local links):

- Pasadena (1):
- Salt Lake City (2):
- Chapel Hill (2):
- Providence (2):
- Ithaca (1):

<b>Subtotal:</b>	<b>6.6</b>
<b>Total:</b>	<b>24.2</b>
<b>Yearly Cost of fiber rental:</b>	<b>290.4</b>



Connections are T1 fibers

**Costs of fiber rental**

Long Range Connections:            \$K/month

Pasadena to Chapel Hill:	16.0
Salt Lake City to Chapel Hill:	12.7
Ithaca to Chapel Hill:	5.8
Providence to Chapel Hill:	6.2

<b>Subtotal:</b>	<b>40.7</b>
<b>Less 40% Discount:</b>	<b>24.4</b>

Local Connections from local companies (# of required local links):

Pasadena (1):	0.7
Salt Lake City (1):	0.5
Chapel Hill (4):	2.8
Ithaca (1):	2.3
Providence (1):	0.6

<b>Subtotal:</b>	<b>6.9</b>
<b>Total:</b>	<b>31.3</b>
<b>Yearly Cost of fiber rental:</b>	<b>375.6</b>

## **Advantages and Disadvantages**

### **Topology 1:**

#### **Advantages:**

- Low Cost

#### **Disadvantages:**

- Assumes Doubling up on two interior links, causing reduction to half bandwidth maximum
- Data connections on reduced bandwidth become narrower.

### **Topology 2:**

#### **Advantages:**

- Full Bandwidth available at all times
- Flexibility to add processing at center, if desired
- Flexibility to be full interconnect at 1/4 T1

#### **Disadvantages:**

- Cost

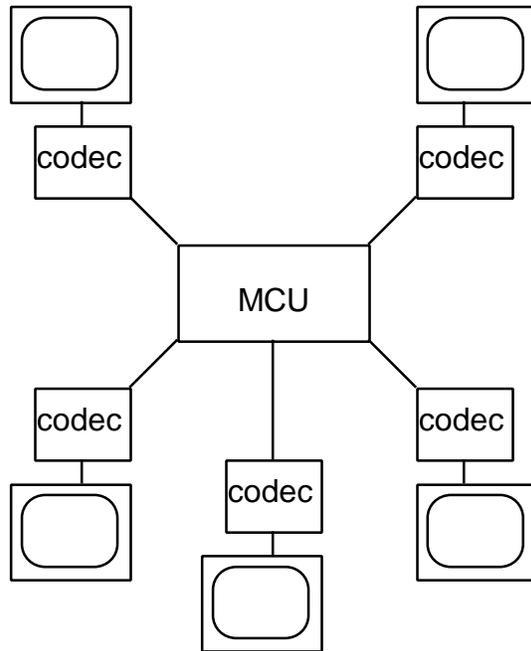
## **Notes on Costs:**

These dollar figures are quotes from AT&T. Other vendors have cheaper quotes, though only AT&T has supplied the full breakdown as yet. (For example, MCI quoted \$21,500/month for Topology 1 instead of AT&T quote of \$24.2K)

The 40% discount assumes a) \$25,000 expense per month, and b) 4-year commitment. Other vendors' discounts are based on other criteria. AT&T might be flexible about these terms and/or prices.

AT&T supplies long distance connections, but local companies supply local connections. Discounts are possibly available from the local companies.

Installation of fiber connections will cost about \$10-20,000, though we do not have an exact quote, yet. This is a one-time fee.



#### Advantages

- lower cost
- lower latency  
~250 ms
- less image degradation

#### Disadvantages

- single image at a time
- less flexibility video presentation

#### Costs

5 codecs + spare  
1 multipoint control Unit  
5 conference control panels

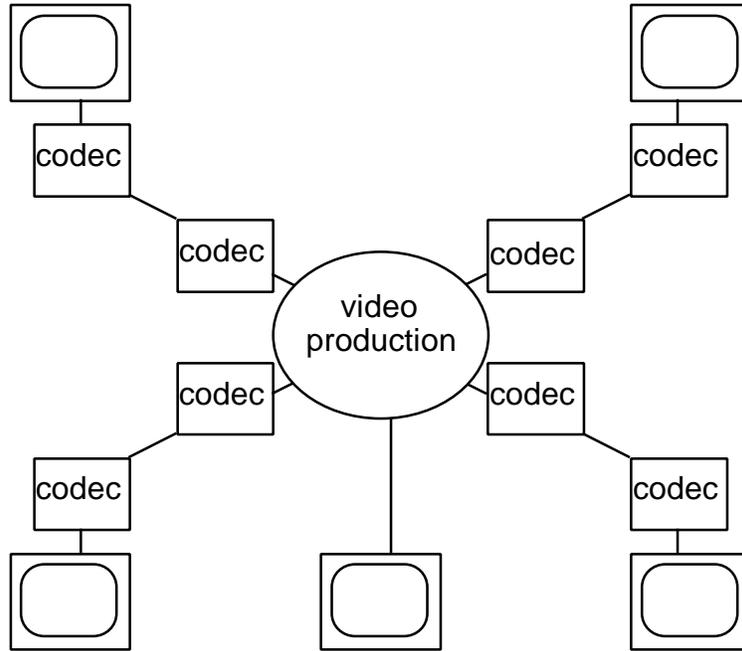
#### price/each

~\$35K/each  
~\$75K/each  
~\$1K/each

#### totals

\$210K  
\$ 75K  
\$ 5K

\$290K



Advantages

- Split-screen images possible
- video facility provides rich set of presentation capabilities

Disadvantages

- Higher cost
- longer latency ~500ms
- image degrades with additional A/D and D/A encoding

Costs

8 codecs + spare  
video production facility

price/each

~\$35K/each  
~\$50-150K

totals

\$315K  
**\$100K**  
\$415K

**Appendix C - Common Carrier cost analysis**

<b>Dedicated T1 Service (UNC hub)</b>						
Carrier	Installation (waived)	Local Loop Charges	Long Dist. Charges	Total/ Month	w/ 1 year Discount	Annual Charges
ATT	\$18,931	\$7,244	\$41,337	\$48,581	\$33,679	\$404,148
MCI	N/C	\$5,582	\$36,083	\$41,665	\$28,676	\$344,112
Sprint	\$14,240	\$8,075	\$33,821	\$41,896	\$30,806	\$369,672
WilTel	\$9,115	\$7,505	\$28,920	\$36,425	\$28,556	\$342,672

<b>Switched T1 Service (avg. cost, UNC Hub)</b>		
Site	Connect/min.	Connect/hr.
Cornell	\$5.00	\$300.00
Brown	\$5.50	\$330.00
Utah	\$5.95	\$357.00
Caltech	\$6.45	\$387.00

At T1 rates a five-way conference costs \$1374/hour. This rate allows 17 hours of conferencing per month before the break-even point favoring dedicated service is reached.

<b>Switched 384 Kb Service (avg. cost, UNC Hub)</b>		
Site	Connect/min.	Connect/hr.
Cornell	\$2.82	\$169.20
Brown	\$2.82	\$169.20
Utah	\$2.82	\$169.20
Caltech	\$2.86	\$171.60

At quarter T1 (384Kb) rates a five-way conference costs \$679/hour. This rate allows 34.5 hours of conferencing per month before the break-even point favoring dedicated full T1 service is reached.

The switched service figures do not include fixed recurring local loop charges, (approximately \$6500/month) and potential minimum usage charges (approximately \$600/site/month or \$2400/month for an unused network).

