III B.1 INTER-CAMPUS INFRASTRUCTURE

This section summarizes the recommendations of the Network Infrastructure Team[1], which was established by the Systemwide Internal Partnership.

SCOPE AND GOALS

One goal of the ITS-TII is to provide the CSU with a telecommunications network infrastructure that will enable the university to carry out its mission in the information age. Advances in information technology have changed fundamentally the way individuals and organizations access, process and communicate information. The same changes are taking place in higher education, and, for that reason, it is imperative that all CSU campuses be adequately connected with each other and with information resources worldwide. Doing so will permit students to perform their academic, administrative and community functions effectively and efficiently and will prepare them to enter the work world and function in a networked environment. The ITS-TII Network Design Plan outlines how this need will be met.

The CSU network infrastructure begins at the desktop and extends within the system of 23 campuses, across an extended community of public educational institutions in the state and to information and communications resources worldwide. Increasingly, it enables the student, faculty or staff individual to do his/her work without regard for distance or time. To realize this potential, both the technology and the cooperation of the campuses will be necessary. The target environment will dramatically increase access to, and the speed and capacity of, network resources to the point where multimedia and real-time collaboration can be routinely supported. The broadband networked environment of the future will promote greater sharing of information, more interactivity in the learning and teaching process, and the seamless integration of voice, video and data resources using both wireline and wireless transports.

The sections of the ITS-TII Plan dealing with infrastructure provide a common point of departure to guide the preparation of specific campus build-out plans. Current needs and the potential for future network growth will be major factors in the selection of all hardware and software. Compliance with the standards and design criteria set forth in this plan will achieve a seamless network from the workstation to the larger universe.

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CURRENT ENVIRONMENT

The CSU has designed, implemented and operated regional broadcast networks for over 25 years, and statewide networks since the late 1970's, including CSUnet, founded in 1985. Tables 1 and 2 summarize the growth of CSU's wide area network.

Beginning in 1985, a fully interactive WAN, based on the CCITT[2] X.25 standard, was installed among all 19 CSU campuses. Each campus had a 9.6Kbps packet switch connection to a 56Kbps backbone between San Francisco, Sacramento and Los Angeles.

In 1990, CSU campus usage of the network expanded to T-1[3] circuits and the support of additional protocols such as DECNET, AppleTalk and two-way compressed video. StrataCom IPX switches were also installed at each campus to support these requirements, thereby making CSUnet the first research and education network to widely use fast-packet technology — both 24-byte "cell relay" and frame relay.

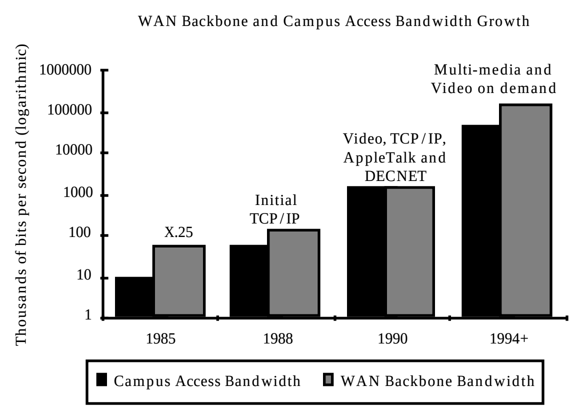

Table 1

Also during the 1990's, other California educational institutions approached the CSU for connection to CSUnet. Non-CSU members pay their share of the operating costs while avoiding the challenges associated with network backbone development, management and operation. By 1993, over 100 universities, community colleges, K–12 institutions and governmental agencies were paying their share to receive Internet connectivity through 4CNet[4], a collaborative effort between the CSU and the California Community Colleges. Currently, all 125 sites of the California Community Colleges system, 23 campuses and 4 other sites of the CSU, and over 50 K-12 sites are jointly connected to a common, private ATM backbone network over leased circuits.

[2] An international standards body (Comité Consultatif International Téléphonique et Télégraphique)
[3] 1.544 Megabits per second
[4] California State University and California Community Colleges Inter-campus Network

Table 2
CSU Wide Area Network Growth

Period	Applications	Campus Bandwidth	Backbone Bandwidth	Network Protocols
1985-1987	Terminal to host and limited host-to-host file transfer.	9.6K	56K	X.25, X.3
1988-1989	Terminal to host (TELNET); full file transfer capability (i.e., FTP); Internet e-mail (i.e., SMTP); access to the Internet.	56K	56K	TCP/IP, X.25, X.3
1990-1993	Two-way video conferencing; terminal to host (TELNET); full file transfer capability (i.e., FTP); Internet e-mail (i.e., SMTP); multiple connections to the Internet.	T-1 (1,544K)	T-1 (1,544K)	TCP/IP, AppleTalk, DECNET, X.25, X.3, SNA/SDLC, ARA, SLIP, frame relay and early cell-relay technology from Stratacom.
1994-1995	World-Wide-Web, Complex graphical images, multi-point two-way video instruction	T-1	Multiple T-1	TCP/IP, AppleTalk, DECNET, X.25, X.3, SNA/SDLC, ARA, SLIP, PPP, frame relay
1996-	Desktop video conferencing, Group collaboration, Video on demand, MPEG video delivery	T-3 45Mb	T-3 45Mb	TCP/IP, AppleTalk, DECNET, SNA/SDLC, ARA, SLIP, PPP, ISDN, frame relay, ATM

4CNet has used advanced frame relay technology within its backbone since 1990. With services from Pacific Bell and GTE, 4CNet is expanding its use of frame relay to provide Internet connectivity virtually anywhere in the state for the same low price. Access speeds of 56K, 128K, 384K and T-1 are available.

Table 3 shows the current wide-area network bandwidth available to each CSU campus. Figure 1 depicts the current configuration of 4CNet.

Table 3
Campus Wide Area Bandwidth

Campus	Bandwidth
Bakersfield	2x45Mb ATM
Chico (5/98)	2x45Mb ATM
Fresno	2x45Mb ATM
Hayward	3x45Mb ATM
Long Beach	45Mb ATM
Maritime Academy	1.5Mb
Northridge	45Mb ATM
Sacramento	2x45Mb ATM
San Bernardino	45Mb ATM
San Francisco	45Mb ATM
San Luis Obispo	2x45Mb ATM
Sonoma	155Mb ATM

Campus	Bandwidth
Channel Islands	56Kb FR
Dominguez Hills	45Mb ATM
Fullerton	2x45Mb ATM
Humboldt (9/98)	45Mb ATM
Los Angeles	45Mb ATM
Monterey Bay	2x45Mb ATM
Pomona	45Mb ATM
Stanislaus	3x45Mb ATM
San Diego	45Mb ATM
San José	45Mb ATM
San Marcos	45Mb ATM

In addition to 4CNet, the current CSU telecommunications network infrastructure includes both analog and digital facilities, satellite transmission and reception systems, connections to local distribution systems and linkages to worldwide networks. Specific components include: voice, data and video services; microwave and satellite transmission and reception facilities; switched, dedicated and virtual inter-campus facilities and services; and all network hardware required for these services and capabilities.

Further, campuses have an installed base of "C" and "Ku" band downlinks; many (14) have Instructional Fixed Television Service (ITFS) omni-directional and directional microwave stations, some with multiple channel capacity; and, four northern campuses (Chico, Sacramento, Stanislaus and Fresno) are connected on a private microwave system known as the Central Valley Microwave Network. A number of campuses are also linked by point-to-point microwave, ITFS or coaxial cable to local or regional cable television companies, wireless cable operators; several campuses are connected by temporary or dedicated microwave systems or fiber to commercial uplinks. Chico has two dedicated earth stations supporting "C" and "Ku" (analog and digital) transmission, respectively, while Sacramento has provided transportable "Ku" uplink services as the custodian for the CSU Mobile Satellite Unit. Added to these services and systems are the more common mass media outlets such as broadcast radio and television. CSU campuses operate more than ten FM public radio licenses, one UHF public television station.

As detailed above, the technology used by the CSU campuses has changed substantially over the last eight years in concert with the changing needs and requirements of the CSU faculty and students. This continual "reinventing" of the technology and services under the "service mark" of 4CNet, the Central Valley Microwave Network and others, is a continuing process as the CSU campuses evolve their inter-campus information needs.

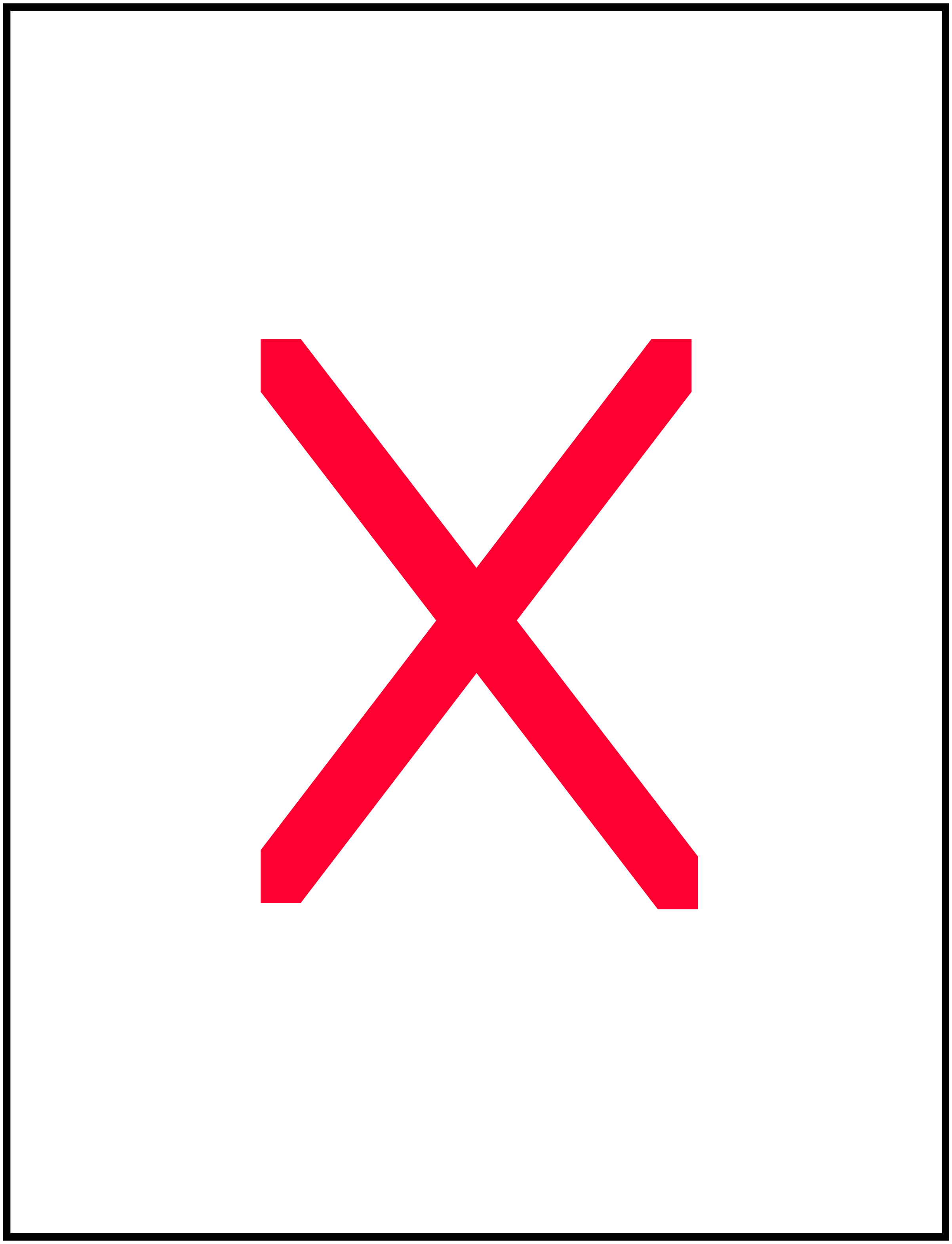

Figure 1 – Current 4CNet Topology

TARGET ENVIRONMENT

There are at least two ways of thinking about the target network environment. One describes the functions or applications that will be served beyond the current environment. The second describes the technical design and physical hardware required to support those applications.

The target network environment is a prerequisite for achieving the overall vision of the ITS and for meeting the goals of excellence in learning and teaching, administrative productivity and quality, and the quality of the student experience both on and off campus. At its core, the target network will provide all students, faculty and staff with the following personal productivity tools for communication and information: 24 X 7 access to intra-campus and inter-campus network connections; full access to the Internet; and access to information resources from a variety of worldwide sources for instructional, scholarly and creative endeavors.

In addition to expanded access, the target network environment also promises greater speed and bandwidth capabilities. It will encourage multimedia applications through the integration of voice, data and video. It will permit both asynchronous and real-time, collaborative instruction and research from multiple remote locations. It will bring desktop conferencing and high resolution imaging to students and faculty. It will promote the sharing and use of massive data bases through multimedia repositories. Finally, it will use a variety of integrated, digital delivery systems to provide these capabilities. The target environment will make the CSU a full participant in the national, broadband, high-speed networks known as the Next Generation Internet and Internet2.

From a technical standpoint, the proposed Inter-Campus Infrastructure plan builds upon the existing ATM/SONET[5] 4CNet backbone network. The plan calls for expansion of the existing backbone with higher bandwidth circuits leased from commercial providers. The plan also calls for relocating the backbone nodes from the CSU campuses to "telco-quality" facilities leased from commercial providers.

In addition to applications and technical factors, a series of ongoing partnerships can be expected to influence the character and pace of the network build-out. These include:

1. <u>California Community Colleges (4CNet)</u>

   Currently 4CNet provides Internet access (TCP/IP protocols) to the Community Colleges at T-1 rates. Certain collaboration philosophies, such as the shared-cost model and full node redundancy, should continue to be met through a network implementation plan, which may involve industry participants. Other collaborative projects anticipated are compressed video

[5] Asynchronous Transfer Mode/Synchronous Optical Network

conferencing (such as room systems at 384K and other low-bandwidth video) and digital satellite delivery systems.

2. Corporation for Education Network Initiatives in California (CENIC)

   CENIC is a non-profit corporation formed by the CSU, the University of California (all campuses), Stanford University, the University of Southern California and the California Institute of Technology. The first project of CENIC is a network known as "CALREN-2." CALREN-2 offers opportunities for jointly building networks in the San Francisco and Los Angeles metropolitan areas and in selling (or jointly constructing) network bandwidth throughout California.

3. University Corporation for Advanced Internet Design (UCAID / Internet2)

   Internet2 is a strategic activity for the CSU. The Internet was originally created by the scientific, governmental and educational communities to meet their growing demands for collaborative research and inter-network connectivity. Once again, these entities are leading migration from the increasingly commercial Internet to the Next Generation Internet (NGI) of high bandwidth capabilities. Network planning within the CSU should be consistent with the policy and technical directions of Internet2.

   UCAID, in cooperation with Qwest, Cisco, and Northern Telecom, is building a high-bandwidth nationwide network for research and education known as Abilene. At least one connection to the Abilene network will be established.

4. Linkage to Other Projects

   The Inter-Campus Network build-out must be coordinated with these other projects to insure that a total integrated solution is implemented for the CSU. Two of the leading areas that may affect both the schedule and the connection speeds are implementation of the intra-campus build-out and the funding alternatives available to the CSU.

STANDARDS

CSU has always adhered to national and international standards in the deployment of technology throughout the campuses. CSU personnel have often provided leadership in the development of those standards.

The proposed networking standards for the Inter-Campus Network will use a scalable architecture to support enhanced voice, video and data applications. This architecture will provide the CSU with a stable "state-of-the-art" base from which to build and grow the network enterprise.

Future network growth capabilities will be a factor in the selection of all hardware and software.

DESIGN CONSIDERATIONS

The deployment of an expanded Inter-Campus Network at CSU campuses will provide an opportunity for CSU and campus network planners and analysts to take a systemic look at networking. The uniqueness of each campus will generally require an extensive review of its data backbone, WAN and LAN activities and their relationship with the Inter-Campus Network.

Design Topology and Architecture

In the context of data networks, topology refers to the way that end points, or stations, are connected. Topology is determined by the layout of the communications links, switching elements, and path between any pair of stations. Thus, design choices are influenced by such factors are reliability, expandability and performance. Unconstrained topology is the most general type, characterized by stations that are connected in an arbitrary pattern. An unconstrained topology has no significant advantages and requires a high degree of complexity at each station. As a result, network designers use constrained topologies, which have to meet several requirements. They must:

- Ensure proper receipt of all message traffic;
- Route traffic across the network's least-cost path;
- Minimize the length of the channel;
- Support the least expensive transmission medium; and,
- Provide the best possible end-user response time and throughput.

FUNCTIONAL TARGET ENVIRONMENT

The topology and architecture used for the digital network is intended to be highly robust and flexible. Its ability to support voice, data and video, with bandwidth-on-demand and quality of service characteristics are just a few of the examples inherent in the design.

Satellite and short and long-haul microwave will be considered together with traditional terrestrial-based services for transporting voice, data and video applications across the network. Although satellite and microwave facilities require high initial investments, they are options for serving more mass audiences over large geographic regions. For the foreseeable future they are the most viable transport for delivering broadcast quality and high-definition video.

Inter-Campus Network

The base design calls for a backbone network consisting of two or three rings with one or more nodes (central connection points) located in ten of California's eleven LATAs[6]. Additional bandwidth will be added between the nodes of the rings, and between campuses and their nodes, as needs and projections justify. Cost and availability of fiber circuits are the primary limitations to growth of the network bandwidth. As needed capacity (or speed) increases, both the monthly cost and term of commitment increase dramatically. Lack of fiber, especially in Northern California, has also been an issue with respect to very high-speed circuits.

The design of each node specifies a redundant pair of appropriately sized ATM switches connected to the backbone OC-3c[7] network (and in the near future, OC-12c[8] network) and a redundant pair of routers connected to the ATM switches. Facilities to house the backbone equipment required for the Inter-Campus Network will be leased from commercial providers and will typically be located within the same POP[9] as the backbone circuit provider.

All campuses will initially connect to the nearest backbone node with a point-to-point OC-3c (or OC-12c) circuit, will be connected to a private SONET ring, or will be connected to a public ATM network which is in turn connected to a backbone node. Campus equipment will include an appropriately sized ATM switch directly connected to the off-campus circuit and an appropriately sized router connected to the ATM switch. The private SONET rings will be deployed in the three large metropolitan areas where the CSU has a significant presence; Los Angeles (connecting Los Angeles, Northridge, Dominguez Hills, Fullerton, 4CNet (Los Alamitos) and Qwest Anaheim), San Francisco (connecting Hayward, San Jose, San Francisco and Qwest Oakland), and San Diego (connecting San Marcos, San Diego and Qwest San Diego).

The bandwidth available to a given campus will be determined by:

a) educational requirements;
b) geography;
c) cost; and,
d) facilities availability.

The campus ATM backbone switches will be used to support quality of service (QoS) applications (voice, video, multi-media, etc.) that have specific delivery requirements. For applications which require guaranteed bandwidth (e.g., voice), the ATM switches could interconnect campus voice-switching systems to one another across the backbone. It is expected that, with the increasing growth and ubiquity of the Internet and Internet protocols, the technology to deliver QoS over

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[6] Local Access Transport Area (See Figure 3)
[7] 155 Megabits per second clear channel
[8] 622 Megabits per second clear channel
[9] Point of Presence

IP (without underlying ATM support) will become common. Because ATM imposes additional network overhead and complexity into the operation of the network, it is expected that, over time, the inter-campus backbone will be upgraded to make use of Packet Over Sonet (POS) and other non-ATM technologies.

The campus backbone routers will provide statewide network backbone access as well as an OC-3c or better ATM connection to the campus ATM backbone switches. The router's connection to the campus network will consist of multiple 10Mb, 100Mb, 155Mb, and 1Gb interfaces as needed.

At campuses with projected high bandwidth needs, the campus backbone routers may connect directly to the inter-campus infrastructure with one or more OC-3 or OC-12 Internet Protocol Packet over SONET interfaces (IPoS). The individual OC-3 or OC-12 interfaces will connect over the inter-campus infrastructure to neighboring backbone routers connected in the same manner.

Internet and videoconferencing services for the California Community Colleges and other subscribers (libraries, county offices of education, etc.) will not be impacted by the funding provisions of the build-out. Further, serving 4CNet subscribers will not impact the network capacity of current 4CNet backbone node sites.

The Inter-Campus Network will support backhaul services (both voice and video) intended for re-broadcast via CSUSat, local/regional ITFS[10], MMDS[11], Cable TV, PSTN[12], etc., that are at least equal in quality (bandwidth or compression) to the delivery system they are connecting to.

Figure 2 depicts the target build-out of the inter-campus backbone with the CSU campuses indicated.

Remote access (i.e. 'dial-up' service) is not currently defined for the initial deployment. Further development of the requirements and functional specifications are required before a solution can be proposed for implementation. Some of the critical issues facing remote access services are: authentication, authorization and technology currency.

Inter-Campus Physical Infrastructure

The Inter-Campus Network will be based primarily on leased point-to-point circuits. Wherever possible these circuits will be based on SONET technologies and will employ SONET rings to allow automatic rerouting in the event of a fiber cut or failure of telecommunications electronics. Satellite and microwave services could be used in areas where wireline services are not available or economically feasible.

[10] Instructional Television Fixed Service
[11] Multi-Media Distribution Service
[12] Public Switched Telephone Network

For cost reasons, some connections may be made using public ATM services rather than point-to-point circuits. Where this is done to connect node sites, special care must be taken to ensure that adequate physical redundancy is available to meet CSU's needs.

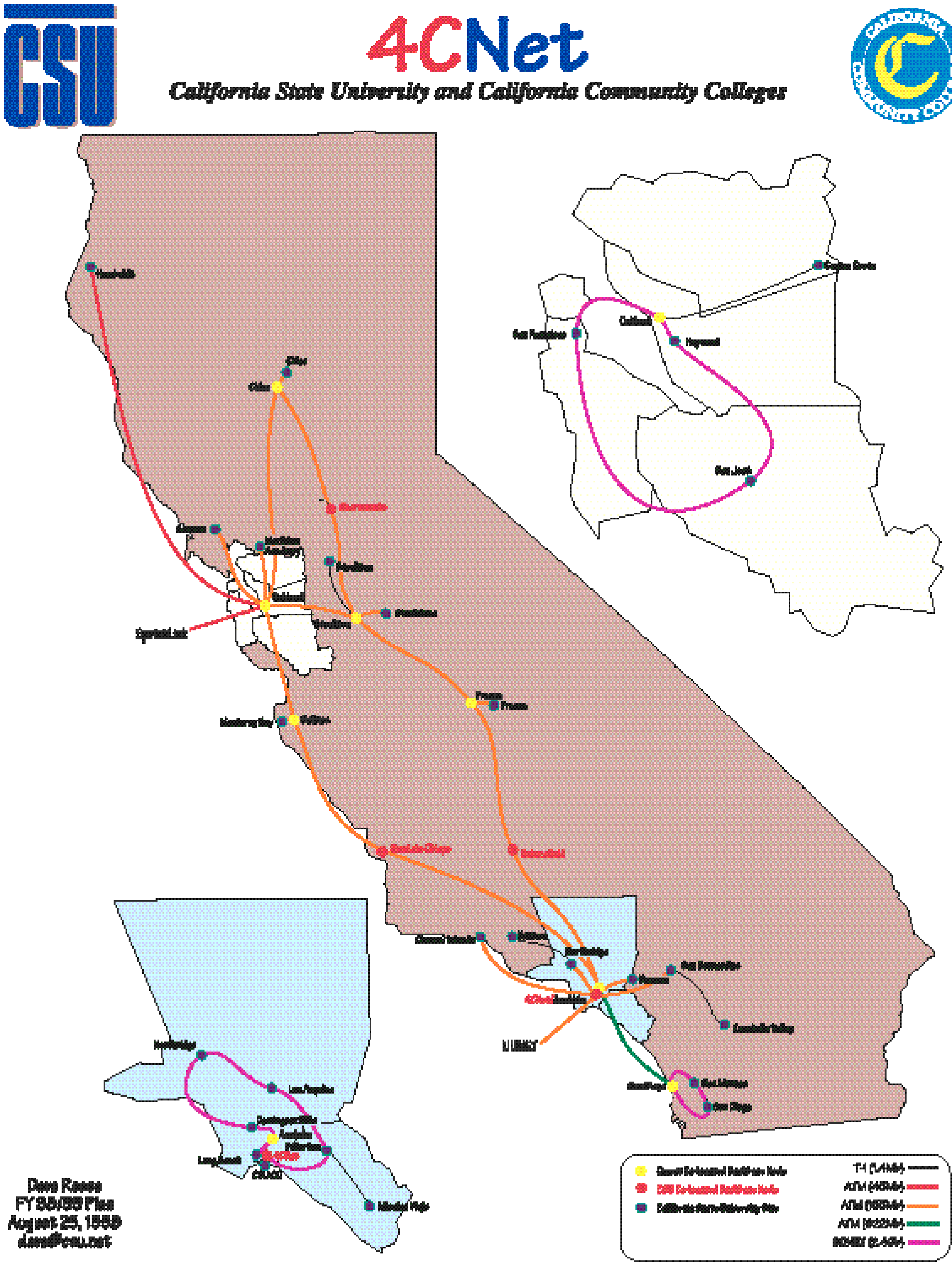

Figure 2 – Planned Inter-Campus Backbone

IMPLEMENTATION

The implementation schedule below was based on the most effective phasing of network upgrades. The plan builds the backbone between the serving areas (LATAs) in California (see Figure 3) and upgrades campuses in subsequent phases.

Dec 98 Begin building the OC-3c backbone between LATAs 5 (Los Angeles), 10 (San Luis Obispo), 8 (Monterey) and 1 (San Francisco). Upgrade the Southern Internet access to 66Mb service. Build OC-48 SONET ring between Los Angeles, 4CNet (Los Alamitos), Qwest Anaheim, Fullerton, Dominguez Hills and Northridge.

Jan 99 Begin building the southern ring of the backbone with circuits between LATAs 5 (Los Angeles) and 6 (San Diego). Build OC-48 SONET ring between San Marcos, San Diego and Qwest San Diego. Upgrade Cal Poly Pomona and San Bernardino to OC-3c.

Mar 99 Continue building the center ring of the backbone with circuits between LATAs 1 (San Francisco), 9 (Stockton), 4 (Fresno), 7 (Bakersfield) and 5 (Los Angeles). Connect Stanislaus, Fresno and Bakersfield to the backbone at OC-3c.

Jul 99 Begin building both the northern ring of the network between LATAs 5 (San Francisco), 3 (Sacramento), and 2 (Chico). Connect Sacramento and Chico to the backbone at OC-3c. Upgrade Dominguez Hills to OC-3.

Sep 99 Upgrade Long Beach to OC-3c.

Dec 99 Upgrade the Maritime Academy to OC-3.

Jan 00 Upgrade Channel Islands to OC-3.

Feb 00 Upgrade the Chancellor’s Office (Golden Shore) to OC-3c. Begin next phase of backbone by upgrading to OC-12c on the ring serving LATAs 5, 8, 10 and 1.

May 00 Complete upgrade of central ring to OC-12c serving LATAs 1, 4, 5, 7 and 9.

Jul 00 Complete northern and southern rings with OC-12c circuits between LATAs 1, 2, 3, and 9 and LATAs 5 and 6.

Future upgrades to both backbone and campus access speeds will be based upon a combination of predicted network growth and future applications needs of the campuses.

Figure 3 - LATA Boundaries in California

COSTS

Costs will weigh heavily in how the details of the network plan are implemented. Following are some of the key considerations; each of these strategies will be part of the implementation plan.

1. Local Transport

   The "local loop" (or local transport between the campus and the provider's location) is a significant portion of the overall circuit cost. For this reason, co-location of networking hardware, where equipment is housed at the provider's location, is very attractive. The local loop cost is significantly reduced, if not entirely eliminated, with co-location. Where local loops are required, multiple providers should be surveyed to insure that the best price/value is obtained. This could result in using multiple providers at backbone locations where redundancy is a key factor in improving overall network reliability.

2. Using Existing 4CNet Facilities and Equipment

   Where possible, existing 4CNet facilities and equipment will be re-used and/or upgraded to provide the network infrastructure. The proposed design permits continued use of all CSU-owned Fore ATM switches and Cisco routers for both backbone and campus access.

3. Build-out to Current Need with Flexibility for Expansion

   In many instances, a campus may not have an immediate need for connections in the OC-3c range and above. However, it is prudent to design the network with future bandwidth needs in mind.

4. Existing Network Upgrade and Construction Phasing

   Significant savings can be obtained by treating the implementation as upgrades to the existing 4CNet backbone network rather than constructing and operating a separate network. In that sense, the proposed network will be a phased extension and expansion of 4CNet.

5. Circuit Contracts

   The network will be based on OC-3c and OC-12c network speeds. The existing network (4CNet) has several contracts for DS-3 circuits that must be maintained or bought out when the network migrates to the new infrastructure.

6. Industry Participation

   It is anticipated that funding for the infrastructure build-out will be accommodated through a variety of channels. The participation of private industry, whether through strategic alliances, vendor relationships or some other type of joint agreement, may eventually be an important part of network design, management, refresh and support, as well as funding.

10-Year Cost Projection

All costs directly associated with the building, management and maintenance of the shared infrastructure (i.e., the backbone) will be divided proportionately according to bandwidth allocation between the CSU and CCC starting in fiscal year 1998/99. Each institution would continue to be responsible for all costs associated with connecting their respective campuses to the shared backbone.

Based on this financial agreement, Table 4 divides the total budget for the Inter-Campus Network into components that can be allocated to their respective funding sources.

Table 4
Inter-Campus Network Costs

Fiscal Year	Shared Costs	CSU Circuits	CCC Circuits	Grand Total	CSU Allocation	CCC Allocation
1998 / 99	10,972,538	1,013,731	1,013,731	13,000,000	6,500,000	6,500,000
1999 / 00	12,800,358	4,299,821	1,115,104	18,215,283	10,700,000	7,515,283
2000 / 01	18,000,809	1,699,595	1,226,614	20,927,018	10,700,000	10,227,019
2001 / 02	17,884,364	1,757,818	6,418,260	26,060,442	10,700,000	15,360,442
2002 / 03	18,147,783	1,626,108	4,310,086	24,083,977	10,700,000	13,383,978
2003 / 04	18,424,373	1,487,813	4,741,095	24,653,281	10,700,000	13,953,282
2004 / 05	31,330,776	2,975,626	14,560,185	48,866,587	18,641,014	30,225,573
2005 / 06	31,635,716	2,975,626	13,266,203	47,877,545	18,793,484	29,084,061
2006 / 07	31,955,903	2,975,626	14,592,823	49,524,352	18,953,578	30,570,775
2007 / 08	32,292,100	2,975,626	16,052,105	51,319,831	19,121,676	32,198,155
TOTAL	**223,444,720**	**23,787,390**	**77,296,206**	**324,528,316**	**135,509,750**	**189,018,568**

The shared expenses represent both O&E (personnel, software and hardware maintenance agreements, equipment replacement, etc.) and the backbone expenses for both the local access and long distance circuits which comprise the backbone. The costs associated with the "buy-out" of existing long-term contracts, as well as costs for Internet access trunks, have been included in this section as well.

The costs associated with connecting CSU campuses to the inter-campus backbone at the OC-3c level, under the proposed timeline, are also based upon estimates received from local access providers.