This report was submitted to the UC Information Technology Guidance Committee in December 2006 for its consideration. The proposals contained herein are not necessarily endorsed by the ITGC.

The Advanced Network Services Landscape At the University of California – An Overview

Advanced Network Services Work Group
December, 2006

Introduction

Advanced computer networking services are indispensable tools for leading universities and research organizations. Currently, the networking facilities provided by the University of California (UC) to its faculty, students and staff are adequate for the vast majority of their needs. However, in the next decade UC is in serious danger of falling behind both the requirements of its leading researchers and the services provided by competitive universities in this country and abroad. UC must take immediate steps to plan for, and to implement, upgrades to its networking infrastructure and the advanced services provided by it to our research, education, and administrative communities.

Nationally and internationally, research networks are implementing higher bandwidth capacities that surpass UC's current capabilities. In addition, these networks are deploying application-driven services that can reconfigure world-wide research networks based on the needs of specific research projects, such as the Large Hadron Collider at CERN. In addition, the networking requirements of UC's research communities continue to grow rapidly.

Today there are approximately 350,000 connections to the campus networks at the 10 UC campuses. The majority of these are 100 megabits per second (Mbps); many remain at 10 Mbps, while a growing number of research connections are at 1 gigabit per second (Gbps). All UC campuses have at least 2 Gbps connections to CENIC, the statewide regional networking organization that provides UC with intercampus facilities, connections to the commodity Internet, and connections to national and international networks serving the higher education and research communities. A recent UC survey provides an overview of the status of each of our campus networks.[1]

The United States no longer leads the world in advanced computer networking deployment. For example, the International Telecommunications Union reports that the United States is 16th in world in broadband penetration, and studies show that Japanese consumers pay about the same price for 100 Mbps connections as American consumers pay for 1 Mbps.[2] To help the country regain a world leadership role, the National Science Foundation recently formed the Office of Cyberinfrastructure with the following overall vision:

> "NSF will play a leadership role in the development and support of a comprehensive cyberinfrastructure essential to 21st century advances in science and engineering research and education."

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1 *Current State of Networking at the University of California* http://www.ucop.edu:8080/display/WGAN/Current+State+of+Networking+at+the+University+of+California

2 Turner, S.D., *Broadband Reality Check II,* Consumers Union, the Consumers Federation of America, and Free Press, August 2006 http://www.freepress.net/docs/bbrc2-final.pdf

NSF defines cyberinfrastructure as “the comprehensive infrastructure needed to capitalize on dramatic advances in information technology. Cyberinfrastructure integrates hardware for computing, data and networks, digitally-enabled sensors, observatories and experimental facilities, and an interoperable suite of software and middleware services and tools. Investments in interdisciplinary teams and cyberinfrastructure professionals with expertise in algorithm development, system operations, and applications development are also essential to exploit the full power of cyberinfrastructure to create, disseminate, and preserve scientific data, information, and knowledge.”[3]

The Advanced Network Services Work Group was chartered by UC’s IT Guidance Committee (ITGC). Its mission is to focus on the advanced physical network and related service requirements of the University of California as part of the ITGC’s overall charge to lead a systemwide planning process to identify and recommend strategic directions to guide investments in information technology (IT) and UC’s academic information environment. Using NSF’s terminology, the ITGC and its work groups are evaluating and planning for the evolutionary path of the cyberinfrastructure for the University of California. More specifically, our work group was charged with evaluating the current state of UC’s networking infrastructure, identifying the best in global networking activities, and positioning UC for competitive advantage on a global basis by developing the recommended architecture for the next generation UC network architecture. The ongoing results of the work group’s efforts are available at the following URL:

http://www.ucop.edu:8080/display/WGAN/Home

The results of the first several months of deliberation by the work group include a ten campus survey, and seven short white papers describing important areas that UC must consider as it takes the next steps in implementing its systemwide networking services and infrastructure. In addition, the work group developed several specific recommendations. These white papers and related recommendations are summarized in the following sections.

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[3] *NSF’s Cyberinfrastructure Vision for 21st Century Discovery*, NSF Cyberinfrasture Panel, National Sciencve Foundation, July 2006, pg. 6
http://www.nsf.gov/od/oci/ci-v7.pdf

Recommendations

(1) Expand UC's Collaboration Services

Objective

UC should develop a comprehensive set of tools and services that enhances collaboration within the University, as well as between members of its community and the people they work with around the world.

Background

Collaboration among students and faculty across geography is an increasing reality in the University. Research projects are increasingly interdisciplinary (spanning academic buildings), inter-campus, and inter-university (including across international borders). Students are increasingly participating in collaborative activities in the same class (group projects, homework) and across classes. Interactions among instructors and students are increasingly taking place online. All these activities should be encouraged and made more effective through use of a growing suite of networked and online collaboration applications and tools.

The need for an enhanced set of collaboration tools is a common theme of many of the ITGC's activities:

- Researchers need access to real-time collaboration tools, such as video conferencing, as well as tools for asynchronous collaboration, such as wikis, blogs, and shared repositories. These tools must be interoperable not only within UC but also with those used by researchers around the world.
- Teaching faculty need better tools for communicating with their students and coordinating class activities.
- Students are already using many of these tools through services such as FaceBook and instant messaging.

- Administrators bemoan the among of time they spend on airplanes, because of the limited availability of video conferencing capabilities.

UC currently provides two collaboration tools to all staff and faculty, telephones and electronic mail. In addition, all students are provided with electronic mail. While many other collaboration tools are available within UC, they are not ubiquitous, require local expertise, and, in many cases, do not interoperate with each other.

Action Items

- Implement an integrated set of asynchronous collaboration tools and services by the end of FY 2007/2008. While this work should address needs of all segments of the University, drawing broadly on the community for input, emphasis should be on the academic mission. This work should also identify a set of standards and guidelines for similar tools to maximize interoperability with like tools and services within UC and the rest of the world. A support model must also be identified that makes provision of collaboration services viable for the long term, evolving to meet future needs.
- Implement a desktop video conferencing infrastructure for UC by the end of FY 2007/2008, as a more available, lower cost alternative to high-quality video conferencing studios. As part of this work, identify standards and guidelines for all video conferencing within UC to maximize interoperability. As with asynchronous collaboration, this work

should address needs of all segments of the University, drawing broadly on the community for input, but emphasis should be on the academic mission.
    - Over the next five years, implement strategies to ensure that video conferencing becomes as ubiquitous as telephones. This includes:
        - Appropriate preparation of conference rooms for video conferencing.
        - Redirection of resources spent on campus telephone systems to enable video communication at every desktop, as well as voice.

(2) Improve End-User Support for Information Technology

Objective

Establish a multi-tier, coordinated infrastructure of information technology support professionals that provides first-class assistance in the use of information technology resources to the University community.

Background

We have done a much better job at getting IT tools and services to the University community than we have in helping the members of the community make effective use of those tools. The departmental computing support professionals who are best situated to provide direct support are often so occupied with keeping their technology functioning that they have little time to help their colleagues in the use of that technology, let alone the IT services offered by other departments within their campus and the rest of the University.

This is true despite the fact that the University currently devotes a significant segment of its staff resources to end-user support for information technology, primarily desktop computing. For example, in 2002 it was determined that approximately 2.5% of UCOP's total FTE was devoted to desktop computing support. We must leverage that resource to provide support for significant growth in IT services that are and will be offered from outside the department. Accommodating to that growth will require a support infrastructure for those local personnel, as well as a significant reduction in the effort expended on desktop computing support in order to avoid very large staff increases.

We risk failure of many ITGC initiatives if we do not deal with this issue.

Action Items

- By the end of 2008, establish a framework within which IT service providers offer "tier 2" support to (tier 1) departmental computing support professionals. Require that the framework be utilized by multi-department IT services and all departmental computing support professionals by the end of 2010. There should be broad consultation to ensure that this framework meets the needs of the entire UC community and its service providers. At a minimum, this framework should include:
    - A federated knowledge base of documentation, FAQs, contact information, service commitments, hours of operation, etc.
    - A federated ticketing system for problems, suggestions, etc.
- By the end of 2007, identify services, tools, architectural changes, *etc*. that can be implemented through 2010 to reduce the effort required to keep desktop computing functioning by 50%.

(2a) Specific End-User Support Issues for Advanced Networking

Objective

UC should work with CENIC and other regional and national networks to implement end-to-end support services, including a network measurement infrastructure (NMI).

Background

Advanced Network Services bring new user support issues involving end-to-end connectivity. For example:

- Performance issues are difficult to diagnose. It is not always easy to tell if slow application performance is due to the network (or which part of the network), or the the software and hardware running the application at the network. The support infrastructure must be structured to address these issues, and measurement tools must be available to the support people.
- Current security measures and resource controls, such as firewalls and bandwidth managers, can have significant impact on application functionality and performance. The number 1 support issue for video conferencing is incompatible firewall settings on the campuses. Among its locations, UC must strike an appropriate balance between security and enabling services.
- Deployment of new network services, such as “lightpaths,” requires special support skills and coordination.

Recent discussions as to the role of high-speed networks in the realm of research computing have touched upon the topic of support for end-to-end connectivity and performance. This problem has turned out to be very difficult to solve, especially where the end-to-end path traverses multiple administrative domains. In addition to the very limited resource of troubleshooting expertise, the simple issue of visibility into different networks becomes an obstacle to supporting the research mission where performance is less than expected.

There are a number of potential causes of these problems:

- Network congestion somewhere along the path
- Actual network problems along the path (duplex mismatches, lossy links, etc.)
- Poorly-tuned TCP stacks on end hosts
- Poorly-optimized applications
- Other issues, such as security breaches and/or DoS attacks

No single solution exists to this set of problems. However, a number of reasonable steps may be undertaken to improve the current situation. Specifically, the first two bullet point issues, and to some extent the third, can be greatly ameliorated by the deployment of NMIs. Some campuses have already deployed tools for characterizing network performance and for providing consultation for the tuning of end-stations. Research networks such as Abilene and some gigapops have begun to deploy network measurement tools to allow users and campus network engineers to understand the performance characteristics of these networks and determine where bottlenecks might be occurring.

UC Campuses need to be able to accurately measure available bandwidth between campuses and across major research networks, in order to aid in troubleshooting of the above problems. Because of the difficulty in troubleshooting across domains, a *standard set of tools* should be deployed.

Such tools already exist, having been developed by the Internet2 End-to-End Performance Initiative (e2epi). Each of these tools provides unique information:

- BWCTL, a scheduler for automated and on-demand bandwidth tests between infrastructure nodes.
- NDT, a java-based tool for diagnosing network problems on user machines.
- OWAMP, a system for measuring one-way delay.

Action Items

- UC Campuses should deploy each of these standard tools in strategic locations on their campuses (border, core, and proximate to data centers and/or research locations on campus).
- We should work with CENIC and NLR to implement these tools in the CalREN and NLR networks. This involves determining proper locations within the various infrastructures. Given that some of these networks are moving toward switched layer-2 or layer-1 lambda provision, this presents an additional challenge that we will need to work through.
- In coordination with CENIC, UC should establish an intercampus support infrastructure for addressing end-to-end network issues that span multiple campuses.
- UC should establish common firewall standards among the campuses to facilitate network-based applications among the campuses.

(3) Enhance Network Connectivity

Objective

UC should implement high-bandwidth network connectivity among the campuses and to the national routed IP backbones, Internet2's Abilene and NLR's PacketNet, over the CalREN-HPR network. CalREN-HPR should be enhanced with capabilities for dedicated, private networks and "lightpaths" between campuses, as well as connecting to Internet2's NewNet and NLR's FrameNet and WaveNet.

Background

High performance computing today is generally considered to require 10 Gbps connectivity, for example:

- The 2005 NSF HPC grant solicitation strongly suggested (i.e. fell just short of requiring) 10 Gbps campus connections to **two** 10Gbps national backbones.
- Current planning for LHCnet - for storing and sharing Large Hadron Collider data - includes 10 Gbps connectivity between Tier 2 and Tier3 sites; a number of UC campuses will be Tier 3 sites.
- Advanced networking applications being demonstrated at the SC06 International Conference for High Performance Computing, Networking, Storage, and Analysis typically depend on one or more 10 Gbps connections to the conference network and to the outside world.

Several instances of UC research projects requesting dedicated, "private network" connectivity between two or more campuses occurred during the last 2-3 years:

- The DETER project, which operates out of UC Berkeley and USC, requires layer 2 (cannot be routed) IP connectivity between the two sites that is isolated from the other IP traffic. DETER studies Internet attack vectors (virus, worms, and other malware) and uses its own routers to study the dynamics of these vectors on a routed network. As such, this research traffic must be isolated from other IP traffic to prevent the "escape" of DETER's attack vectors into the Internet. DETER researchers requested a 1 Gbps "private network" connecting the two labs; however, the cost and setup time were daunting. At present, DETER uses IPsec encapsulation to achieve the required isolation, but this imposes performance limits. A better solution would be a 1 Gpbs Ethernet VLAN between the two research labs, dedicated to DETER usage for the duration of the project.
- A CITRIS project developing advanced audio/video capability requested a dedicated 1 Gbps connection between UCB and UCD for a demonstration. UCB and UCD and CENIC were not capable of satisfying the request in a timely and cost-acceptable manner. Networking staff at the two campuses were able to provide a temporary, "almost-dedicated" path through a single router (possible because both campuses happen to have connections to the same CENIC PoP) but the researchers felt the

performance characteristics of the routed path was detrimental. A short-lived, 1 Gpbs Ethernet VLAN between the two research labs would have better met the researchers' needs.

The examples listed above expose an important consideration in this kind of networking: timeliness. Researchers desire that the network be capable of providing dedicated, "private networks" in some cases for short-term use, in other cases for long-term use, with rapid setup and teardown times (on the order of minutes or hours rather than weeks or months). Procedures and protocols need to be developed for the scheduling and the network reconfiguration required for this.

NLR's FrameNet (layer 2) has the capability to provide 1 Gbps and 10Gbps dedicated Ethernet VLANs between connectors. Internet2's NewNet, when fully deployed, will have similar capabilities. In order for UC campuses to use these services, new infrastructure and services need to be built onto CalREN-HPR to extend these services to the campuses.

The third action item listed below, "Implement a 10 Gbps switched ethernet backbone...," proposes an initial, limited step toward an infrastructure capable of providing dedicated, "private networks" between research projects as needed. It allows for up to ten simultaneous 1 Gbps "private networks" each connecting two or more research labs on different HPR-connected campuses. It also allows these "private networks" to extend to sites outside the state via ethernet VLANs on Internet2's NewNet and/or NLR's FrameNet. It will give UC an opportunity to assess the level of need for this kind of connectivity, and to explore the challenges of providing of such a service.

"Lightpath networking" is an increasingly significant, leading-edge area of network research. The term is inclusive of two very similar types of connectivity between two research labs: (1) an end-to-end optical path connects the two labs and the researchers are presented with the specific wavelength of light (i.e. ITU grid "colored" light) used on the optical network; (2) an end-to-end optical path connects the two labs, the optical signal is converted at the ends to a conventional datalink type such as GE, 10GE, or SONET, and the researchers are presented with a conventional network interface. The significant similarity between these two types of connection is the end-to-end optical path, often across one or more wide-area optical networks, with all switching along this path being done at the optical layer. Examples of current lightpath networking projects are CANARIE's CA*net4 backbone, the Global Lambda Integrated Facility (GLIF), and Internet2's Hybrid Optical and Packet Infrastructure (HOPI) project.

Participation in this network research, as well as research in other disciplines relying on lightpath networking, requires lambdas on the optical network be extended (in the first case described above) all the way to the research lab, or (in the second case described above) to at least the edge of campus before the lambda is converted to GE, 10GE or SONET for transmission across campus to the research lab. The current CalREN Optical Network has only limited capability for this, and it is expensive to the campus and time-consuming to set up. Once again, researchers desire that the network be capable of providing lightpaths for either short-term or long-term use, with rapid setup and teardown times. Procedures and protocols need to be developed for the scheduling and the network reconfiguration required for this.

The fourth action item listed below, "Implement a 10 Gbps optical backbone...," proposes an initial, limited step toward an infrastructure capable of ubiquitous lightpath networking. It allows for a single 10 Gbps lightpath between any two HPR-connected campuses, or between a HPR-connected campus and a campus outside the state via a lightpath across Internet2's NewNet and/or NLRs' WaveNet. This resource would be shared among the CalREN-connected campuses, configured for specific projects at specific times as needed, similar to the way astronomers schedule specific times for viewing through large telescopes. It will give UC an opportunity to assess the level of need for this kind of connectivity, and to explore the challenges of providing such a service.

Delivering the above-mentioned services on CalREN-HPR is highly reliant on the underlying services of the CalREN Optical Network. At present all UC campuses except UCSC have at least one direct fiber connection between the campus and a CENIC PoP. It is imperative that such a connection be established to UCSC in order that UCSC participate fully in UC advanced networking initiatives. This need is addressed in the first action item listed below.

Action Items

- Establish a fiber connection between UCSC and a CENIC PoP. This is needed in order for UCSC to participate in the upgraded networking described in the subsequent action items. Schedule: completion by June 30, 2008.
- Upgrade every campus's primary connection to CalREN-HPR (layer 3, routed IP network) to 10Gigabit Ethernet.   UC and CENIC should work together to find ways to reduce the costs to individual campuses for these upgrades. Schedule: completion by June 30, 2008. In the special case of UCSC, completion of this action item is contingent upon completion of the first action item.
- Implement a 10 Gbps switched ethernet (layer 2) backbone connecting to every UC campus. A single lambda on the CalREN Optical Network would connect to a small number of 10GE switches in the core. At the edge, each campus would operate an ethernet switch connected by 10GE to the layer 2 backbone and providing multiple GE interfaces to campus research labs. VLANs defined across all switches would provide dedicated, private networks between research labs on two or more different campuses. UC and CENIC should work together to complete a fully-specified design and to find ways to reduce the costs to individual campuses. Schedule: completion by December 31, 2008. In the special case of UCSC, completion of this action item is contingent upon completion of the first action item.
- Implement a 10 Gbps optical (layer 1, "lightpath") backbone connecting to every UC campus. 10 Gbps lambdas on the CalREN Optical Network would connect to each campus and to a small number of optical switches (optical cross-connects) in the core of the network. Implement protocols and procedures such that CENIC can manage the optical switch(es) to quickly reconfigure the lightpath between different pairs of campuses. UC and CENIC should work together to complete a fully-specified design and to find ways to reduce the costs to individual campuses. Schedule: design should be completed by December 31, 2007; an implementation schedule should be completed by June 30, 2008, targetting full deployment in a 12-18 month timeframe (June 30 - December 31, 2009).

(4) Sustain UC Leadership in Advanced Network Services

Background

Other recommendations for Advanced Network Services will raise the University to the next level. This recommendation addresses the step after that. While there are some capabilities on the horizon that we can predict, such as 40 Gbps and 100 Gbps transmissions speeds and sensor nets, there will be others we cannot predict. There is no indication that we're nearing the end of line, either in terms of the University's need for network capacity, or in terms of networks' capabilities.

There are a few issues the University must address in order to sustain its competitiveness:

- Ongoing Funding. The University's efforts to build campus and intercampus network services over the past two to three decades have served it well. Much of that growth, however, has been opportunistic, relying on grants and other large influxes of money to fund significant upgrades. It is often the case that, when opportunistic funds are not available, network services languish.

  We see this both at campus and intercampus levels. While system-wide funding for intercampus network has sufficed in the past, it will soon no longer cover operating costs, and no money is available to implement new capabilities. The campus situation is similar; some have established sustainable funding models for their networks, and some have not.

- Ongoing Assessment of the University's Network Capability. Much of the University's network planning effort has been directed toward collaboration within CENIC over the past few years. This needs to continue, as well as collaboration within national and international network organizations. We also, however, need to ensure that we are appropriately tracking UC's internal needs.
- Ongoing Efforts to Increase Network Capacity. Because of the high dynamic nature of network demand, particularly for research, the University must continue to maintain a network capacity much larger than its need at any given time. This is particularly true of the intercampus network, requiring close collaboration with CENIC.

Action Items

- By the end of 2007, a new or existing organized group should be made responsible for tracking the network needs of the University's community, particularly research, as well as tracking developments in advanced network services both nationally and internationally. This group should maintain a a five-year plan for network services that is updated on an annual basis.
- By the end of FY 2007/2008, establish a financial plan for campus and intercampus network services that assures long-term funding for base level services, as well as growth of existing services and development of new services. The intercampus portion of this work will require collaboration with CENIC.
- In conjunction with the previous action item, work with CENIC to ensure, by the end of FY 2007/2008, that they have sustainable plans to increase their bandwidth capacity to meet the University's increased need for that capacity.

Seven Important Background Topics

(1) Collaboration technologies for the University of California

http://www.ucop.edu:8080/download/attachments/4166/Collaboration-white-paper-v2.pdf

Nothing is more fundamental to UC than collaboration, both in research and in education. In research, it is increasingly common for opportunistic and long-established research groups to collaborate based on shared expertise and interest, largely unconstrained by geography or political unit. Directly aligned with its mission to be the top research institution in the world, UC should seek to offer the most advanced environment in the world in support of collaboration. It is critical that the University enable collaboration across campuses, among campus, and with other research institutions worldwide.

In addition, UC should take a world leadership role in incorporating collaboration into its education, partly through the use of collaboration technologies. UC should assume a leadership role in interdisciplinary research to refine and improve collaboration environments and experiment with new uses in an academic environment.

(2) Advanced Network Services End-to-End Support

http://www.ucop.edu:8080/display/WGAN/Advanced+Network+Services+End-to-End+Support+Discussion

The increased complexity and variety of choices inherent in advanced networking activities place increasing demands on users (both active and potential) of services required by their disciplines.

Support for end-users that spans the various organizations that provide network services within and for UC is a crucial need. A support infrastructure is needed among departmental personnel to provide general support, as well as networking specialists at the campuses and CENIC, empowered by tools that provide visibility into relevant portions of the network to resolve performance and connectivity issues. This support infrastructure should include systemwide specialists in the full range of network-based services, such as high-performance computing and video conferencing.

(3) Access to Networking Facilities and Services

http://www.ucop.edu:8080/display/WGAN/Network+Access+Discussion+Outline

The fundamental network is physical. It involves both physical pathways and physical media. In the future, every lab and every classroom will have greater requirements than today. It is essential for the University to establish guidelines for the physical pathways that are every bit as detailed as ADA requirements. The stance of the University must be that these fundamental elements can no more be "value-engineered" out of a building than could be the restrooms. The evolving network must support a wide range of devices, protocols, and security features.

(4) Legislative, Regulatory, and Policy Issues

http://www.ucop.edu:8080/display/WGAN/Legislative%2C+Regulatory%2C+and+Policy+Issues+Affecting+the+University+of+California+Networking+Environment

University, state, and federal regulations impact the ways in which our networks interconnect, what security features we must incorporate, when we must use encryption technologies, what acceptable use policies we can define, how we can monitor and manage the network, and a host of other important policy considerations. As examples, the work group identified several current laws and policies that we must consider as we move forward with the design, implementation, and operation of communications networks within the UC:

- Health Insurance Portability and Accountability Act (HIPAA)
- Family Educational Rights and Privacy Act of 1974 (FERPA)
- UC Electronic Information Security Guidelines (BFB IS-3)
- UC Electronic Communications Policy
- Payment Card Industry data security standard (PCI)
- Communications Assistance for Law Enforcement Act (CALEA)
- Deleting Online Predators Act of 2006 (DOPA)

In addition to these established laws and policies, the outcome of debates concerning Network Neutrality may have significant impact on the way in which UC networks and communicates with the broader world.

(5) The Statewide, National, and International Networking Environment

http://www.ucop.edu:8080/display/WGAN/The+Environment+at+Large

The UC campus networks are part of a complex and rapidly evolving set of regional, state, national and international networks. CENIC's CalREN Optical Network provides external connectivity to all of the UC campus networks.[4] Except for a small number of special-purpose applications, the entirety of each campus's external connectivity currently comes from the CalREN-DC and CalREN-HPR IP backbones that CENIC operates on the CalREN Optical Network.

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[4] http://www.cenic.org/

Internet2 and National LambdaRail (NLR) both operate national backbones for research and education. Internet2 operates the Abilene IP backbone, and has announced plans for its next-generation backbone "NewNet" which will offer IP ("packet switched") and circuit switched services[5]. NLR operates the NLR PacketNet IP backbone, as well as the NLR FrameNet circuit switched backbone.[6]

Through CENIC, Internet2, and NLR, the UC campuses have access to international networks connecting higher education and research organizations throughout the world. These networks are evolving rapidly and UC must continue to play a leadership role in their governance if the needs of our research and education communities are to be met in the future.

(6) Common or Coordinated Network Architecture for UC

http://www.ucop.edu:8080/display/WGAN/Common+or+coordinated+architecture+for+the+University+of+California

There is a strong tendency in a large, diverse, geographically distributed institution like UC toward local autonomy, resulting in a great diversity of installed technology, with higher maintenance and support costs. Especially in research, groups tend to look to the discipline-based community, increasingly on a global basis, for standards and support more so than the University. This situation will almost inevitably persist due to the great diversity of applications (especially legacies) and needs which probably cannot be shoehorned into a common infrastructure, but at the same time the University and its campuses should move aggressively toward more commonality in both infrastructure and applications.

Increasingly, applications incorporate and integrate communication, storage, and processing in mutually advantageous ways. Already the network and operating systems have approached homogeneity in the sense of a limited set of competitive options which display a great degree of interoperability among them. This has not yet occurred in distributed processing and distributed storage, either commercially or even less so in UC. UC should encourage this through well-planned architectural concepts that allow the seamless interoperability of distributed processing and storage across the University, through the provisioning of infrastructure following these architectural precepts, and through incentives (such as subsidies and attractive pricing) to encourage their adoption. Virtualization should be used to offer a menu of operating systems and applications.

(7) Sensor Networks

http://www.ucop.edu:8080/display/WGAN/Home

Sensor Network is an emerging networking technology increasingly used by researchers in various research areas. Sensor networks enable researchers to collect previously uncollectible data thus greatly aid their researches and discoveries. Because it is emerging technology and still evolving, deployment and utilization of a sensor network can be challenging. UC as a system should take action to better enable its researchers to utilize Sensor Networks. Proposed actions, include but are not limited to, encouraging and aiding the development of generic sensornet tools to save researchers resources and time for deploying and utilizing their sensornets, facilitating sensornets infrastructure sharing so the resource may be used by many researchers seeking the same type of field data, and building and/or extending network infrastructure in partnership with

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5 http://www.internet2.edu/

6 http://www.nlr.net/

network providers, such as CENIC and/or wireless providers, to overcome common obstacles of connecting sensor networks to the Internet.

In addition, UC schools are on the leading edge in terms of research and development of sensor network technology. UC should support these research efforts and leverage such efforts to benefit UC researchers as a whole.