

NUTARNIQ: UNITING THE ARCTIC COMMUNITY WITH A WIRELESS ARCTIC NETWORK FOR CIRCUMPOLAR COMMUNICATIONS¹

Richard A. Beck

*International Center for Water Resources Management,
Central State University, 111 C. J. McLin Hall, Wilberforce, Ohio, 45384-1400*

Wendy Eisner and Kenneth Hinkel

*Department of Geography, University of Cincinnati, 401i Braunstein Hall,
Cincinnati, Ohio, 45221-0131*

Hillary Pesanti, Ben Ellis, Elizabeth Beiswenger,
Walter Parker, and Mead Treadwell
*Institute of the North, Alaska Pacific University,
P.O. Box 101700 Anchorage, Alaska, 99510*

Steve Smith

*University of Alaska at Fairbanks, Information Technology Services,
P.O. Box 755320 Yukon Drive, Suite 103D, Fairbanks, Alaska, 99775-5320*

Lars Krogh

Finnmark University College, Follums vei 31, 9509, Alta, Norway

Klaus Georg Hansen

*Sisimiut Museum, Jukkorsuup, aqq. 9, PostBox 308, DK-3911,
Sisimiut, Greenland*

Vladislav Peskov

*Russian Association of Indigenous Peoples of the North (RAIPON),
P.O. Box 110, Moscow, 119415, Russia*

Abstract: This paper provides a summary of the current state of telecommunications for eight Arctic nations and a common vision for a Wireless Arctic Network to unite the Arctic Circumpolar Community. It presents detailed requirements based on the North

¹This work was supported by grants from the National Aeronautics and Space Administration (NASA) to RAB and the National Science Foundation under grants OPP-9911122 and 0240174 to WRE and OPP-9732051 and 0094769 to KMH. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily represent the views of NASA or the National Science Foundation. We are grateful for the logistical support of the Barrow Arctic Science Consortium (BASC), the Ukpeagvik Inupiat Corporation (UIC), the Institute of the North (ION) at Alaska Pacific University, and two anonymous reviewers whose comments improved this manuscript significantly.

Slope of Alaska model, an overview of Arctic user communities, a summary of the current demand for Internet access in the Arctic, and general systems specifications for an improved Circumpolar communications system. We discuss several possible technical solutions based on input from NASA and several commercial telecommunications providers. We also propose a circumpolar telecommunications test bed to identify technologies that can make high latitude broadband communications accessible and commercially sustainable at a cost that is ultimately less than existing technology. We conclude with a possible technical and economic solution to the currently limited state of telecommunications in the Arctic.

INTRODUCTION

Nutarniq is an Inupiaq word meaning “new ice formed in a crack in old ice” (Webster et al., 1970) that welds fragments together. We propose the technological equivalent of nutarniq to unite the Circumpolar Community through high quality wireless telecommunications. Our project began with Alaskan Natives on the North Slope of Alaska. They represent one of the most isolated and underserved groups of citizens in the United States of America (Barnhardt, 1994; Kemp and Brooks, 1995; Carter, 1999; Pesanti, 2003; Denali Commission, 2004). Alaska Natives are a representative user community for the telecommunications needs of the Arctic in general. Communities on the North Slope of Alaska lack significant road access to the rest of Alaska and the conterminous United States. The area is also characterized by severe weather and oceanic conditions that frequently prohibit air or sea travel, resulting in complete isolation during times when access is most crucial such as medical emergencies (Beck et al., 2004).

Declining government spending and decreases in fossil fuel production are resulting in decreased economic opportunities for Alaskan Natives. This situation indicates the need for new and diverse economic opportunities for Alaskan Natives. These declines are only partially offset by traditional knowledge of subsistence hunting and fishing. These problems are nearly universal in the Arctic. Education is one potential method of securing the economic future of isolated Alaskan Natives and circumpolar peoples in general. Increasing scientific research and support opportunities in these areas is another method. Unfortunately, both educational and scientific research support opportunities are severely limited by poor wireless telecommunications (16–26.4 kb/s in many cases) and a rapidly decaying scientific research support infrastructure in these areas.

The plan outlined in this study addresses the first problem; isolation and the need to develop a robust, secure, and redundant high-bandwidth Wireless Arctic Network to support circumpolar education; research; telemedicine; municipal, federal, and public access to the Internet via hybrid terrestrial wireless and wired and space- and atmospherically based wireless network technologies. The cost of the network will be offset by increased economic opportunities and tax revenues as economic opportunities in these areas increase over time. Meetings with representatives from six arctic nations have resulted in a plan to develop a wireless arctic network to unite the circumpolar community.

BACKGROUND

This study began in 2001 at the request of Senator Ted Stevens of Alaska. He asked scientists at the University of Cincinnati (UC) for improved solutions for telemedicine and distance education for the North Slope of Alaska. UC and Central State University partnered with the University of Alaska–Fairbanks (UAF), Alaska Pacific University (APU), and NASA to address this question. This effort eventually merged with a parallel effort by the Circumpolar Infrastructure Task Force (CITF) when it became clear that the sparse telecommunications infrastructure of northern Alaska was characteristic of most of the Arctic and that economies of scale might help to solve mutual circumpolar telecommunications challenges. The CITF was created September 2000, to identify opportunities of international cooperation to advance circumpolar infrastructure including aviation, maritime, land, and telecommunication linkages. CITF is a program of the Northern Forum and the Arctic Council, with a secretariat at the Institute of the North and Alaska Pacific University (APU). CITF is financed by the United States Department of Transportation (USDOT), the Northern Forum, and the United States Arctic Research Commission (USARC).

Accordingly, the CITF held a workshop in Anchorage, Alaska, September 3–5, 2003, to evaluate the state of telecommunications infrastructure and service availability throughout all eight Arctic nations. Participants from the United States, Denmark (Greenland), Russia, and Norway discussed options for international cooperation to expand Arctic telecom capability and to focus on technical and “human” infrastructure. The group identified barriers within their own countries and collectively proposed solutions to bridge the common digital divide (Hudson, 2003; Pesanti, 2003; Beck et al., 2004).

Data collected during the workshop indicated that most rural Arctic communities in the circumpolar region are underserved (Table 1). The lack of basic services does not allow these regions to remain active and competitive in the global market. Service is often only available to rural areas if government subsidies are available. The resulting vision of a “connected Arctic” would build sustainable communities capable of affording high bandwidth data, secure voice communication, mobile communication, and mass media, which may be able to reduce these subsidies and lower service costs. Assets are needed to support distance learning, improved health care, and sustainable economic development. Higher capability at lower costs is feasible with cooperation across national borders.

Populations range from 56,000 to over 2,000,000 people in each of the eight Arctic nations. With the exception of the Nordic countries (Norway, Finland, and Sweden), approximately 1,500 communities are located off road and rail systems in the United States, Canada, Russia, Greenland, and Iceland (Table 1). The Russian Far East, northern Russia, and Siberia experience poor phone service. Russia lacks appropriate federal policy for infrastructure in local communities despite Universal Access legislation passed in 2003 to guarantee one telephone line and one web access line in each community in Russia.

Broadband data access is not available in many parts of northern Russia, the Russian Far East, or Siberia, and is rare in northern Canada, Alaska, and Greenland.²

²In December 2003, Tele Greenland started to offer broadband in one town.

TABLE 1
 Tabular summary of Arctic Telecommunications Capabilities, Fall 2003

	United States (Alaska only)	Canada	Russia (North/Far East) and Siberia	Denmark (Greenland)	Denmark (Faeroe)	Iceland	Norway (Arctic only)	Finland (Arctic only)	Sweden (Arctic only)
Population	70,000	70,000	1-3 Million	56,000	48,000	283,000	464,000	194,000	253,000
Estimated no. of communities off road/rail system	200	100	1,150	60 (100%)	Almost none	Few	Few	None	None
Levels of regulation	Deregulated	Deregulation	Deregulated	Regulated	Regulated	Regulated	Regulated	Regulated	Regulated
Voice	Universal	Universal	Poor	Universal	Universal	Universal	Universal	Universal	Universal
Broadband data	Clinics/ Schools	Spotty	None	Spotty	Extensive	Extensive, 35%	Extensive	Extensive	Extensive
Land mobile	Poor	Poor	Poor	Extensive	Universal	Universal	Extensive	Extensive	Extensive
Radio and TV	Universal	Universal	Poor	Universal	Universal	Universal	Universal	Universal	Universal
Video-based telemedicine	Universal	Spotty	None	Spotty	Spotty	Universal	Universal	Universal	Universal
Wired schools	Extensive	Extensive	Poor	Poor	Extensive	Extensive	Extensive	42%	Extensive
Public access	Poor	Poor	Poor	Extensive	Extensive	Universal	Extensive	30%-40%	Extensive
Competition in voice, data, and wireless	Vigorous		Poor	None	Extensive	Yes			
National/regional "local" calling plans			Poor	Three levels	One level	One tariff zone/area for all Iceland			

Source: After Pesanti, 2003.

One percent of northern Finnish schools are connected with modems, but have limited use. Thirty to forty percent of Finnish homes are connected to the Internet, but most are through slow modem lines. Northern Russia's radio and television access is limited. One Russian indigenous participant in the workshop reported that, in some nomadic Northern communities, in order to run video TV for movie demonstrations they must use special power sources such as gasoline-powered generators and solar cells.

Video-based telemedicine is used frequently and successfully throughout the Nordic countries as well as in other countries such as the United States. It is spotty throughout Canada and is virtually non-existent in northern Russia outside larger communities such as Yakutsk. Public access to simple, reliable Internet is not available to most of Arctic Russia. They have no means of utilizing E-commerce or connecting with the outside world that relies heavily on Internet to run their businesses and manage their daily lives. Public access is insufficient in small communities in the arctic parts of the United States and Canada. Greenland has a monopoly over telecommunication components, which causes prices to remain high and affords no opportunity for other companies to enter the market.

Basic infrastructure could serve as a platform for telemedicine, distance education, science and environmental monitoring, resource development, aviation safety, and protection of cultural heritage. The integration of Arctic communities in the global economy can be obtained with the right information and communication technology. Three telephone lines and three television channels have been extended to 50 small villages in the autonomous okrug of Chukotka in the last two years. Dial-up net access is available in the capital city (Anadyr) and the eight regional centers: Anadyr, Beringovskiy, Bilibino, Evgekinov, Providenya, Cape Schmidt, Pevek, and Lavrentia. Mobile telephone service is available in Anadyr. Service is provided via two satellites of the Satellite Communications Corporation of Russia. There is not enough capacity on these two satellites to provide more service than identified above.

American Telephone and Telegraph (AT&T) Alaska Communications (Alascom) provides service to Anadyr for the Air Traffic Control network via one of their satellites, which is a useful model of international communication sharing. There are three telephone companies in Sakhalin to serve a population of 600,000 people. Out of 200 communities, 51 do not have telephone service. The present oil boom will generate more satellite capacity and extension of fiber optic cable networks to serve the industry and present a larger international network-sharing opportunity.

Some parts of the existing telecommunications infrastructure serve as models of international cooperation. They include: Anadyr/ATT; Globalstar Pilot Project; bilateral links at international gateways; U.S./Canada microwave; and the Pacific Transit Agreement. Aggregate demand throughout the eight Arctic nations reflects a strong need for a low-latency satellite network. We briefly describe a general solution to this problem that was formulated by the CITF information and communications technology (ICT) working group at the September 2003 workshop.

The September 2003 CITF ICT workshop was held to inventory and to identify ways to improve circum-arctic telecommunications. Participants identified many opportunities to close the digital divide in the Arctic. International joint planning of fiber networks and joint investment is necessary for deployment of CITF's vision. Installing more fiber creates less stress on satellite systems, yielding a low-latency

system. Satellites would cover those areas for which fiber connections are not technically or economically feasible. A proposal has been advanced by the University of Cincinnati and the University of Alaska to implement the first node of an international Information Communication Technology (ICT) test bed. This test bed would be appropriate for testing new Arctic technologies. Companies such as @CONTACT are in the final stages of approval for permission to use Ka band and Middle Earth Orbit (MEO) satellite networks. This constellation is capable of providing 45 megabits per second of bandwidth anywhere in the world and serve as the backbone for long-line, data and mobile service throughout the rural Arctic.

Participation from the Arctic Council, Northern Forum, federal regulatory representatives, international space agencies including the United States National Aeronautics and Space Administration (NASA), the Russian Space Agency (RSA), the European Space Agency (ESA), the National Space Development Agency of Japan (NASDA), and the aerospace industry (TRW, Raytheon, Boeing, Lockheed Martin, @CONTACT, BAE Systems, the German Aerospace Center [DLR]) would create a strong foundation for serving the eight Arctic nations. The vision needs to be defined and distributed to ensure proponents reach national leaders and commercial interests with one voice.

Possible funding sources for the CITF WAN include international financing institutions (IFI), European Bank for Reconstruction and Development (EBRD), World Bank, Global Environmental Fund (GEF), International Monetary Fund (IMF), European Inter-regional Fund (EIF), Barents Cooperation Fund (BCF), and donor countries. We believe the CITF Wireless Arctic Network (WAN) to be a viable concept because new infrastructure creates its own demand. The aggregate demand includes important anchor tenants such as the government, military, extractive industries, education, and medical facilities. Broadband will increase current customer usage and stimulate a new customer base. International participation will reduce fixed costs and allow new businesses to enter the open market. There are multiple physical, human, and governmental infrastructure opportunities available to aid the Arctic in bridging digital communications gaps. Economic benefits to carriers are plentiful and risk could be mitigated through international cooperation and multiple government subsidies (Estabrook, 1986; Boardman et al., 1986; DeLone and McLean, 1993).

Potential barriers to the WAN include the cost of bringing quality service into low population density areas. It is important for political leadership to understand the Arctic's situation and its need to be connected to the rest of the world to improve quality of life and build sustainable communities. The deficiency of uniform standards, lack of competition, possibility of providers arguing over areas of responsibility, regulatory barriers and international political leadership issues need to be resolved. After identification of common goals, the CITF workshop recommended convening Arctic telecom companies and regulatory authorities to discuss means to implement the CITF WAN vision. The establishment of a test bed would be beneficial during a trial period while a specific plan is agreed to in order to implement the operational system. Planning for joint infrastructure will require consultation between providers and authorities as new infrastructure is permitted and constructed with potential to advance a common circumpolar telecommunications vision.

A possible starting point for the CITF WAN vision was put forth by U.S. Secretary of Commerce, William M. Daley in a report on “The Emerging Digital Economy” (1999):

With the emerging digital economy becoming a major driving force of our nation’s economic well-being, we must ensure that all Americans [and the rest of the world] have the information and tools and skills that are critical to their participation. Access to such tools is an important step to ensure that our economy grows strongly and that in the future no one is left behind—Secretary William M. Daley, Department of Commerce

The CITF WAN is the set of information tools necessary to keep the Arctic part of the world community. It is for the CITF WAN members to decide on just how to build and operate those information tools. The following section describes the rationale and implementation plan for the first node of a technical and political WAN test bed.

ALASKA PROTOTYPE PROJECT DESCRIPTION

Background

The Arctic Research Commission (ARC), U.S. National Aeronautics and Space Administration (NASA), U.S. National Science Foundation (NSF), and commercial telecommunications providers sponsored a two-year systems and requirements analysis by the University of Cincinnati for educational and scientific networking in the Arctic from January 2001 through November 2003. The study was conducted in response to congressional frustration regarding the increasing “digital divide” between Alaskan Natives and other Native Americans relative to urban areas of the United States (Beck et al., 2004; Denali Commission, 2004). The study included four site visits to the North Slope of Alaska, meetings with telecommunications users and providers from all over Alaska, and in-depth discussions with distance education researchers at UC and the Alaska Tele-conference Network (ATN) at the University of Alaska-Fairbanks (UAF). UC also met with local leaders in Barrow. This study, and independent telecommunications inventories (Denali Commission, 2004), have confirmed the severity of this digital divide. The Denali Commission’s telecommunications inventory found that the digital divide is greatest for private citizens. Although Internet access to schools and health centers is subsidized, federal and state regulations prohibit extending these connections to private citizens. They also found a need for increased coordination between state agencies and federal regulators.

Commercial providers are making concerted efforts to provide dial-up Internet access to the remaining communities with upgrades to broadband cable or DSL access (GCI, 2001). Digital touch-tone telephone service is available in most Alaska communities with populations greater than 25 and wireless service is expanding throughout rural Alaska. One hundred and three communities have monthly priced local dial-up Internet access. However, as of spring 2004, 164 Alaskan communities (61%) are still without local dial-up access (Denali Commission, 2004).

These studies also revealed three significant causes for the digital divide. The first is a lack of coordination between state telecommunications efforts and federal regulators that leads to legal barriers that inhibit economies of scale. The second is the need for an affordable (commercially sustainable) advanced communications infrastructure consisting of a mix of Transmission Control Protocol/Internet Protocol (TCP/IP)-based network technologies (Allmann et al., 1999) possibly including Geostationary Earth Orbit (GEO), Mid Earth Orbit (MEO), Low Earth Orbit (LEO) and/or Molniya-orbit satellites, conventional aircraft, Uninhabited Aerial Vehicles (UAV)s and/or tethered blimps, as well as more conventional technologies such as microwave towers and cables under the sea or ground in order to support science education, research, telemedicine, local government, and industry in the Arctic. The third cause of the divide is a lack of fundamental information technology in the form of refined network protocols to support high-bandwidth, mixed-latency hybrid (wireless and wired) networks (Allmann et al., 1999; Alena et al., 2004). This lack of basic information technology (refined network protocols) inhibits the establishment of the sustainable, modern infrastructure necessary to bridge the digital divide between Arctic rural and urban areas.

The CITF WAN test bed seeks to establish a working prototype that intentionally explores a mix of high- and low-bandwidth, high- and low-latency, wired and wireless, mobile and stationary network information technologies to determine which are the most appropriate for regional deployment in the Arctic for a variety of applications. We explicitly intend to provide near-term connectivity for science and education in polar regions as part of this test bed for the development of advanced network infrastructure and protocols for the Arctic. Our goal is to conduct a synergistic blend of basic and applied research to develop appropriate and sustainable advanced infrastructures and network technologies to support polar science and education (Johnston, 2002; Johnson et al., 2004). This approach leverages existing NSF, NASA, U.S. National Oceanographic and Atmospheric Administration (NOAA), Department of Energy (DOE) and commercial investments in telecommunications, research, education and support infrastructure to reduce the total cost of the first phase of the project.

Preliminary Needs Assessment

A preliminary needs assessment has already been completed. The initial needs assessment focused on scientific research and educational outreach activities supported by NSF's Barrow Arctic Science Consortium (BASC) facility in Barrow, Alaska. Conversations by UC scientists with Senator Stevens in Barrow revealed the need for an expanded and significantly upgraded system to support science research and education, telemedicine, and local and federal government across the entire North Slope of Alaska. The Senator expressed particular frustration with the quality and extent of tele-education in rural Alaska given the limitations and extraordinary cost of current network technology (Jaeger et al., 1998; Mayer et al., 1999; Mayer, 2002). Given UC's success with establishing high-bandwidth hybrid networks for research and UA's success with distance education and computer network research, we have partnered to leverage our respective locations and capabilities as the first step towards the CITF WAN test bed.

The needs assessment was initially focused on the North Slope of Alaska. While Alaskan Natives of the Aleutian Islands are similarly underserved, this project is focused on establishing a limited but meaningful test bed for advanced network infrastructure and protocol research by linking NSF's Arctic and Antarctic research and education facilities and the NSF/United States Coast Guard (USCG) research vessel *Healy* to the conterminous United States with an experimental communications and scientific monitoring network (Schlosser and Tucker, 2003). Our reasoning is simple. If we can serve Barrow, Toolik Lake, and the *Healy* with advanced information technology and infrastructure, the equipment and protocols will probably be suitable for most polar regions and perhaps other rural areas as well.

Both UAF and UC have several years of experience in the architecture of advanced, high-bandwidth networks for scientific research and education (Beck and Mayer, 1998; Bailey et al., 2001; Beck, 2002, 2003; Beck et al., 2003; Beck, 2004; Johnson et al., 2004), much of it in partnership with rural Native Americans. At UC's request, NASA provided a new remote sensing and Geographic Information Systems (GIS) laboratory to Barrow High School that will be the distance education focus of this first step toward a circumpolar WAN test bed. We hope to extend the lessons learned from the experiment to the remainder of the ATN as part of subsequent operational versions of the WAN once appropriate technologies and protocols have been identified or developed.

UA's Alaska Tele-conference Network (ATN) has a wealth of specific experience with Alaskan Natives and maintains a large satellite distance education network (Barnhardt, 1994). UC, in cooperation with NASA's Satellite Architectures and Network group, has been experimenting with Ka-band geosynchronous high-bandwidth two-way Internet satellite communications to simultaneously serve multiple Native American educational institutions in Minnesota and Wisconsin as part of its Native American Remote Sensing Distance Education Prototype (NARSDEP, Bailey et al., 2001). We have also recently completed an end-to-end prototype geographic information network for emergency response (Beck, 2004) based on our lunar and planetary exploration systems (Beck et al., 2003; Alena et al., 2004). Together we seek to increase the extent of Arctic telecommunications as one result of this research.

A Working Prototype for a CITF WAN Test Bed—Alaska, USA

We propose a user-driven prototype based on an extensive educational and scientific needs and technology assessment. We used a UC-NASA funded Lockheed-Martin technology study and UC systems analysis in combination with discussions with Inupiat leaders and NSF's Barrow Arctic Science Consortium (BASC) in Barrow, the Barrow science community, and the ATN at UAF in mid-August 2002 to form the core of the following needs assessment for a prototype Wireless Arctic Network (WAN). Preliminary results include a detailed feasibility study for the use of Ka-band satellites for educational and scientific uses as well as the potential user communities and general types of applications that are needed.

The University of Alaska at Fairbanks has conducted extensive tests with Ka-band satellites in the Arctic and we believe that with some protocol enhancement this technology would help bring broadband communications into many rural areas and perhaps even to mobile users (Mayer et al., 1988, 1991, 1994, 1997; Vogel et al.,

1994; Mayer and Jaeger, 2000a, 2000b; Mayer, 2002). This needs assessment and previous arctic wireless network research experiments imply several potential wireless technologies that might be used in the long-term Wireless Arctic Network architecture to link the arctic user community. Elements of the potential user community and general applications are identified below. Given the extreme need, environment, and demanding specifications identified in the preliminary needs assessment, Senator Stevens has asked UC to identify the needs and NASA to help develop the CITF WAN test bed in cooperation with a network of appropriate commercial providers. We are seeking NSF support for the Alaska portion of the WAN test bed to conduct basic and applied information technology research necessary to construct the prototype and to develop the protocols for its Arctic operational follow-on. NASA has provided considerable technical input to the proposed test bed plan and has committed significant in-kind support in the form of its Tracking and Data Relay Satellite System (TDRSS) satellites at Senator Stevens's request.

OVERVIEW OF ARCTIC USER COMMUNITIES

Arctic user communities identified in the preliminary needs assessment include telemedicine, education, public access, scientific research, local government, federal government, and hydrocarbon exploration.

Telemedicine

Of the potential user communities, telemedicine is by far the most mission critical in terms of quality of service. Telemedicine requires 100% reliability under the worst weather conditions (when it is most needed), high bandwidth for full-motion, high-resolution video, large image file transfer, and integration with all regional and national emergency wireless and wired communications systems. Given that it is an inherently episodic need it is also unlikely to be commercially viable without government subsidies although its costs can be offset somewhat on a shared communications system served by the commercial sector. The Wireless Arctic Network must be a redundant system that seamlessly integrates at least two separate (using different technologies) wireless links to the Internet. One of our collaborators, the NASA Glenn Research Center (GRC), is NASA's lead center for hybrid terrestrial and satellite wireless networks and includes telemedicine applications as one of its specialties.

NASA has offered the use of the unused Ka-band capability of its TDRSS satellite network to provide part of the test bed necessary to test refined network protocols in the real world. We plan to leave this Ka-band TDRSS capability in place after the experiment for emergency use only by NSF. Ka-band TDRSS is not a viable alternative to commercial services but is an excellent near-term research platform. TDRSS will provide one high-latency link and, more importantly, high-bandwidth satellite-to-satellite links that are an important first step towards MEO or LEO high-bandwidth constellations despite their orbital differences. NASA has also offered the use of a transponder to use on a UAV/Flying Aircraft Network (FAN) proxy (a single-engine aircraft) for bent-pipe, star, mesh, and hand-off experiments between ground nodes. We realize that this proxy does not simulate all aspects of UAV or FAN but it does allow us to test and optimize network protocols, architectures, and applications at

reasonable cost. The use of NASA's Ka-band TDRSS system reduces the cost of the experiment considerably and provides a back-up telemedicine capability for NSF staff and scientists in the future.

Education

Education is the second-most demanding user community in terms of quality of service (QoS) (Ambler, 1999; Barnhardt, 1994; Carter, 1999). Students have a very low tolerance for waiting and systems that do not work. This means that the system must be reliable. Moreover, the system must support voice-over-Internet Protocol (VOIP), full-motion video at high-resolution, and in many cases large file transfer and remote control of computer systems as well as multiple users of media-rich educational web sites and email. We will use Internet Protocol version 6 (IPv6) in our experiments to build in QoS accordingly.

Barrow was dropped from UAF's Alaska Tele-education Network (ATN) due to lack of (available) bandwidth. UC tests from NASA GRC's new remote sensing and geographic information systems computer laboratory at Barrow High School (one of the "best connected" schools on the North Slope) indicated a maximum usable bandwidth of 16–24kb/s. This is simply inadequate for educational purposes.

We believe that Ka-band satellite links will be part of the proposed CITF WAN. UC-NASA GRC experiments with distance education in Minnesota and Wisconsin via Ka-band, two-way IP-over-satellite to Native American communities produced consistently good results with a Ka-band NASA-Lockheed-Martin T-1 very small aperture terminal (VSAT) system (Bailey et al., 2000) and consistently poor to miserable results with an inappropriate commercial 256k system with a proprietary packet-binning algorithm that rarely carried more than video with poor reliability. The non-Lockheed-Martin commercial system was so bad that we spent most of the time on the telephone with understandable disappointment and low morale for all concerned. Large amounts of class time were wasted trying to reconnect to the non-NASA system. As a result, we suspended the Minnesota program for a semester in search of new technologies. We finally resorted to T-1 (1.544 megabits per second) landlines for the Minnesota test. Unfortunately, congestion and related lack of QoS frequently ruins even these connections, forcing us back to the telephone and eliminating most of the functionality of our original interactive system. This negative experience highlighted the importance of testing technologies in an end-to-end fashion in the real world to determine network performance and interoperability.

The Wireless Arctic Network will require a quality communications infrastructure with a minimum of dedicated T-1 connectivity to each active distance education *class*. A successful quality distance education and research network will require a minimum of 2 Mb/s of total capacity at each *village*. This amount of bandwidth would allow for distance education and collaboration as well as support services such as File Transfer Protocol (FTP), Hyper-text Transfer Protocol (HTTP), and VOIP. Each new system element must be tested with each new protocol and architecture as part of an end-to-end system to make certain all elements are interoperable and work as advertised.

The largest settlements such as Barrow may have up to four computer labs operating simultaneously with an additional 100 individual educational users. Tele-education reinforces rather than replaces traditional classroom education. Furthermore,

tele-education helps teachers as much as students by providing both with access to a rapidly expanding variety of scientific resources and colleagues. The need for improved tele-education and teachers who understand how to use it is acute in Alaska and presumably in the Arctic in general. The smallest settlements in Alaska are currently “graduating” up to six high school juniors at a time due to a lack of teachers for senior classes. The Wireless Arctic Network is a key element for providing Alaskan Natives with the complete primary and secondary educations they deserve.

This lack of effective bandwidth between Barrow and the rest of the Internet is due to congestion on available geo-synchronous satellite circuits with limited affordable capacity. Higher capacity circuits are available but not affordable. To support this experiment and to provide a near-term science support and distance education link for the NSF-funded Barrow Arctic Science Consortium (BASC) facility we requested NSF’s Office of Polar Programs (NSF OPP) to provide a C-band, T-1 geo-synchronous satellite link to support this research. NSF OPP agreed to do so. We expect the link to be used most heavily for science support in the summers and most heavily for education during the winters in addition to the experimental network tests.

Public

Public use of the Internet is very limited on the North Slope of Alaska due to lack of significant broadband connectivity. This lack of connectivity is grave due to the rarity of newspapers and limited telephone network. Dial-up access does exist in Barrow but is limited severely by extremely expensive external connectivity between Barrow and the Internet. With the exception of Anchorage, Fairbanks, and Juneau, most of Alaska also lacks broadband access to the Internet. The fundamental reasons for the digital divide in Alaska are: (1) government regulatory barriers; (2) a lack of affordability; and (3) a lack of “last-mile” broadband Internet infrastructure (due to the technology barriers discussed above). NSF’s BASC facility has proposed a local 802.11b wireless local area network (WLAN) with access controlled by domains that this experiment hopes to leverage. This network may also provide some public access depending on load and other factors. Some public access would be desirable because it would allow us to establish some anonymous public usage patterns, but we will leave these decisions up to NSF-BASC and NSF-OPP.

Barriers to Public Internet Access. Alaska currently spends approximately \$250–300 million per year on rural telecommunications. Despite this expenditure, broadband Internet access is extremely rare in a region that could make the best use of it, primarily due to the lack of affordability (transponders are shared between many communities) and the classic “last-mile” technology problem. While it is technologically feasible to bring broadband Internet access into most towns and villages in Alaska with current technology, there is still a major disconnect between the end user and the local satellite gateway.

Major telecommunications providers have assured us that adequate geo-synchronous transponder assets are available for stationary users or those within (rare) mobile LANs linked to stationary earth stations but very expensive for the providers as well as current and potential users. The construction of each communications satellite costs approximately \$200 million and is followed by a risky launch process. This cost and risk is reflected in the user fees necessary to cover them. For example, a full DS-3

transponder (45 Megabits per second) on a geosynchronous satellite costs approximately \$180,000 per month. It is obvious that most of Alaska will never be able to afford Internet-1 speeds of 10 Mb/s much less the current scientific computing standard of Fast Ethernet (100 Mb/s) connectivity using current geosynchronous satellite technology.

We need to develop an affordable, probably hybrid (wired and wireless), TCP/IP-based circumpolar telecommunications system, including voice, for Alaska and the Arctic in general. The WAN seeks to build a phased, operational, long-term CITF WAN test bed node in Barrow, Alaska for several new Internet technologies in an effort to solve the Arctic digital divide in an interoperable and extensible manner with phased expansion to all Arctic nations. NSF's BASC has developed a detailed plan for a Wireless Metropolitan Access Network for science and education support in Barrow that includes public access for the 5,000 inhabitants of Barrow, the largest community on the North Slope. Similar needs exist in the Aleutian Islands for both daily life as well as informal science education and regional sharing of traditional knowledge. The first phase of the CITF WAN prototype connects the BASC network to the rest of Alaska and the conterminous 48 United States. We seek to expand the CITF WAN test bed both in Alaska and around the Arctic.

Science

The science user community requires a variety of low- to very high-bandwidth two-way wireless communications. Several low-bandwidth radio, cellular, and satellite technologies are currently in use in rural Alaska. Most of these technologies suffer from a lack of interoperability. The Wireless Arctic Network must be TCP/IP based to increase long-term usability and decrease long-term costs. Many scientific applications, such as remote sensing calibration and validation, require very high-bandwidth (100 Mb/s or greater). Given the lack of wireless bandwidth on most of the North Slope of Alaska and in the Aleutians, many cutting-edge scientific research programs are simply impossible at this time.

Many science uses (floating buoys, roving sensors mounted on aircraft, near-real-time remote sensing studies) require mobility as well as high bandwidth over great distances. Neither microwave nor cellular communications are suitable for the entire area because of low population density. Therefore at least one of the technologies used in the Wireless Arctic Network will almost certainly need to be satellite- and/or aircraft-based and the overall network will need to be a hybrid of multiple two-way, mixed-latency IP-based technologies. Candidate technologies are listed in the section following the Needs Assessment and User Communities.

As part of the Alaska experiment we will work with NASA and AT&T to establish an ad hoc (e.g., Shah et al., 2004) network test bed that spans the Barrow Environmental Observatory with a network of five wireless temperature sensors that are linked wirelessly to provide real-time science data as well as an Information Technology Research (ITR) test bed. These units will also provide higher bandwidth users with connectivity on the Barrow Environmental Observatory (BEO) in order to ground truth satellite imagery with video cameras, spectroradiometers, pyrometers, etc.

We have also requested an experimental, web-controlled LEO (Iridium-based) communications unit to attach to remote scientific instrumentation such as buoys deployed in lagoons in summer. This provides us with a mobile dynamic moderate latency component for the test bed and allows us to evaluate a variety of “thin-client” applications such as near-real-time temperature data streams that are retrieved episodically from a data cache. Once we have gained experience with this system we will consider bonding multiple units together for higher data rates for high-value remote sites. We plan to establish Ka-band TDRSS links at Barrow and Toolik Lake, Alaska, and on the NSF/USCG *Healy*. We expect that they will be of immense benefit to field researchers for the life of the project and provide us with an important beginning for a circumpolar testbed. They will continue to be of safety value to researchers after the project when they are available for emergency use. We will use the new NSF T-1 science and education link at BASC to support the remote sensing and GIS laboratory that came on line in the fall of 2002.

Local Government

Most local government uses of the Wireless Arctic Network will be relatively low-bandwidth. Nonetheless, saturation of the current outbound Internet links from Barrow has required the North Slope Borough to cut emergency services from its intranet to conserve bandwidth. The implications of this with regard to law enforcement and EMT telemedicine are obvious. The negative impact of limited Arctic telecommunications on public safety will only increase as other areas begin to make use of geospatial emergency response information systems that require high-bandwidth imaging capabilities integrated with global positioning system (GPS) technology (Beck, 2003). A mobile TCP/IP-based communications system for homeland security simply does not exist in most of rural Alaska (Beck, 2004). The Wireless Arctic Network would eliminate these public safety and local governance communications bottlenecks.

Federal Government

Federal Government science facilities (NSF, DOE and NOAA) in Barrow and elsewhere in the Arctic have been subject to endless hacker attacks resulting in high maintenance costs and the loss of irreplaceable scientific data. The Wireless Arctic Network will provide these facilities with encrypted virtual private networks (VPNs) separate from those carrying all other civilian traffic. This will make it extremely difficult to interfere with the federal networks from within the Wireless Arctic Network. These facilities will need to provide their own security against hacker attacks from the Internet outside of the Wireless Arctic Network. We suggest several VPNs within the circumpolar WAN for secure intra- and international communications at the options of its members.

The U.S. National Oceanic and Atmospheric Administration (NOAA) plans to begin a near-real-time satellite image downlink from its Polar Orbiting Satellites at Barrow similar to UC's AmericaView near-real-time Landsat system (now run by the USGS and NASA). This satellite feed will consume a minimum of $2 \times$ DS-3 links. The U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM)

facility had T1 connectivity until a year or so ago when the Federal Telecommunications System contract was renegotiated, and the cost of a T1 line to Barrow more than tripled. Since then, ARM has been making do with 256 kb/s bandwidth, which has posed many problems. This node of the medium-term Wireless Arctic Network must include a dual 2 x DS-3 link for ARM users. Additional research in satellite networks and architectures will be required to provide security for international science facilities in any LEO or MEO/GEO satellite or aircraft mesh architecture as well as telemedicine, education, local government, public safety, etc.

Hydrocarbon Exploration

Income from the hydrocarbon industry has made modern infrastructure available to the inhabitants of the North Slope Borough of Alaska. Unfortunately, this income is decreasing rapidly along with decreasing production from Prudhoe Bay. A continued high standard of living for North Slope inhabitants depends on continued hydrocarbon exploration. Hydrocarbon exploration requires secure, reliable and symmetric, mobile, high-bandwidth two-way IP connectivity on land and sea to transfer satellite imagery to plan seismic lines, evaluate sea-ice conditions in real-time and to transfer seismic data from the field to interpreters during the exploration campaigns.

Exploration crews and support personnel will require a minimum of T-1 connectivity between the field and office for efficient use of expensive resources. Some of the bandwidth from this experimental system will be made available to the hydrocarbon industry on a trial basis in order to determine the most appropriate technologies and protocols for each industrial and scientific application. Good telecommunications will decrease the amount of physical travel necessary to communicate data, and transport personnel and materials. This should help minimize environmental damage to the tundra.

SUMMARY OF CURRENT DEMAND FOR INTERNET ACCESS IN RURAL ALASKA

The CITF WAN must be at least partly commercially viable in order to be sustainable. Our study indicates that the Arctic is already a significant telecommunications market for commercial vendors. Current demand for rural Internet access in Alaska is summarized in Table 2 to show total aggregate demand. These estimates are based on figures provided by major telecommunications providers in Alaska. Potential demand is simply unknown due to the affordability and technology barriers discussed above. Current Alaskan rural telecommunications expenditures are approximately \$250–\$300 million per year. In contrast, we expect the cost of the CITF WAN test bed to run between \$5 and \$50 million per year depending on the scope and speed of the program as decided by the circumpolar community.

General System Specifications

The Wireless Arctic Network must meet the following general specifications if it is to be able to meet the demands of the user communities identified above: (1) directionality—two-way, symmetric; (2) quality of service—24/7/365, fully redundant

TABLE 2

Aggregate Annual Telecommunications Demand in Rural Alaska

User community	Current (\$/year)
Telemedicine	\$140–180 Million
Education	\$60 Million
Public/Govt. Internet	\$8–12 Million
Public voice	\$30 Million
Hydrocarbon exploration	\$2–3 Million
Hydrocarbon development	\$10–14 Million
Aggregate usage	\$250–300 Million

over two separate technologies; (3) interoperability—TCP/IP; (4) security—encrypted VPNs for each user community and a separate satellite link for federal systems; (5) separate domains on the ground; (6) logistics—all ground systems must be heavy-lift helicopter and cargo aircraft portable; (7) temperature range—+100° to -55°F; (8) bandwidth—T-1 to DS-3 for each Earth station; (9) support for stationary and mobile educational and science users at T-1 minimum bandwidth (11 Mb/s for public access). Most user sites will require a minimum of DS-3 connectivity or more within a decade.

WAN Candidate Technologies—Summary

The following candidate technologies have been considered for the WAN in light of the needs assessments and resulting general system specifications listed above. New CITF WAN members may have better suggestions. Their relative strengths and weaknesses are tabulated in Table 3. These are perceived strengths and weaknesses relative to remote and mobile, symmetric broadband Internet access in the rural Arctic. The purpose of the CITF WAN test bed is to actually measure the performance and cost of these architectures, or at least close approximations thereof in the Arctic to make genuinely informed decisions regarding appropriate technologies. The goal is to determine which information infrastructures and networks are most likely to work for the circumpolar user communities and to develop the protocols necessary for efficient TCP/IP transmission in heterogeneous advanced networks via the CITF WAN test bed. We will then use the CITF WAN test bed to evaluate the most promising technologies and to develop protocols that will operate across that entire subset of technologies with acceptable performance for the circumpolar community. A summary of acronyms is available in Table 4.

New Mixed Latency—Capable TCP/IP Protocols

The CITF WAN test bed will consist of a series of increasingly complex network architectures in order to develop the new mixed-latency TCP/IP protocols necessary to make the WAN operational. Several variants of the TCP/IP stack and routing

TABLE 3

Candidate Technologies Considered for the WAN with Their Perceived Relative Strengths and Weaknesses

Technology	Strengths	Weaknesses	Est. rank
Iridium	Existing technology, serves remote and mobile users	Very low bandwidth (10 kb/s), expensive per bit, expensive entry cost for end user	5
Iridium—bonded or mesh	Near-term technology, serves remote and mobile users, solves last mile problem	Low bandwidth (100 kb/s), very expensive per bit, very expensive entry cost for end user	4
LEO or MEO/GEO mesh	High bandwidth, global coverage, serves remote and mobile users, inexpensive per bit, solves last mile problem	Expensive to deploy for Arctic only usage, technology development required,	9
Terrestrial microwave link from Prudhoe to Barrow	Existing technology, good bandwidth, inexpensive per bit	Line-of-sight, expensive, difficult to maintain, covers Barrow only, does not serve mobile users, retains last-mile problem, possible aircraft hazard from high towers	6
Flying platform—tethered	Existing technology, serves mobile users in limited areas, inexpensive per bit, solves last-mile problem	Dangerous to other aircraft, especially in inclement weather	8
Flying platform—stratospheric UAV	Existing technology, good bandwidth, good for atmospheric and remote sensing research, safe for other aircraft, inexpensive per bit, solves last-mile problem	Moderately expensive construction and installation, relatively low risk deployment, flies above general and commercial aviation most of the time	1
Flying aircraft network	Good bandwidth, serves remote and mobile users, potentially inexpensive per bit, solves last-mile problem	Requires new technology, relies upon aircraft flying in inclement weather, subject to Sept. 12 scenarios, etc., depends upon cooperation of aircraft owners	7
Traditional geosynchronous satellite	Existing technology, low to high bandwidth available	Very expensive, moderately risky deployment, retains last-mile problem	3
Two-satellite Molniya orbit constellation for Arctic users	Existing technology, can use few satellites to cover Arctic and Antarctic, Ka band satellites available for launch, good bandwidth, inexpensive per bit, good for high-end users	Moderately expensive (\$200 mill. for two satellites), moderately risky deployment, requires tracking antennae, relatively expensive end-user entry cost	2

TABLE 4

List of Acronyms used in the Text and Their Explanations

Acronym	Explanation
Alascom	Alaska Communications—part of AT&T
APU	Alaska Pacific University
ARC	Arctic Research Commission
ARM	Atmospheric Radiation Monitoring—part of USDOE
AT&T	American Telephone and Telegraph
ATN	Alaska Telecommunications Network
AUV	Autonomous underwater vehicle
BASC	Barrow Arctic Science Consortium
BCF	Barrents Cooperation Fund
BEO	Barrow Environmental Observatory
BER	Bit error rate
CITF	Circumpolar Infrastructure Task Force
DLR	Deutsches Zentrum fur Luft- und Raumfahrt
DOE	Department of Energy (United States)
DOT	Department of Transportation (United States)
DS-3	45 Megabit per second signal carried by a T-3 carrier
EBRD	European Bank for Reconstruction Development
EIF	European Inter-regional Fund
ESA	European Space Agency
FAN	Flying aircraft network
FTP	File transfer protocol
GCI	General Communications Incorporated (Alaska)
GEF	Global Environmental Fund
GEO	Geostationary earth orbit
GIS	Geographic information system
GPS	Global positioning system
GRC	Glenn Research Center
H.323	ITU teleconferencing protocol
HEO	Highly elliptical orbit
HTTP	Hyper-text transfer protocol
ICT	Information and communication technology
IFI	International financing institutions
IMF	International Monetary Fund
IP	Internet protocol
IPV6	Internet protocol, version 6
ITR	Information technology research
ITU	International Telecommunication Union
LEO	Low Earth orbit

(table continues)

TABLE 4 (Continued)

Acronym	Explanation
MEO	Mid-Earth orbit
NARSDEP	Native American Remote Sensing Distance Education Project
NASA	National Aeronautics and Space Administration (U.S.)
NASDA	National Space Development Agency of Japan (now JAXA)
NEMIS	National Emergency Mapping Information System
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
OPP	Office of Polar Programs (part of NSF)
QoS	Quality of service
RSA	Russian Space Agency
RTT	Round-trip travel time
SIP	Session initiation protocol
T.120	ITU telecommunication and application sharing protocol
T-1	Carrier of 1.544 megabit per second signal
T-3	Carrier of 45 megabit per second signal
TCP	Transmission control protocol
TDRSS	Tracking and Data Relay Satellite System (part of NASA)
TRW	Thompson-Ramo-Wooldridge (an aerospace company)
UAF	University of Alaska at Fairbanks
UAV	Uninhabited aerial vehicle
UC	University of Cincinnati
US	United States
USCG	United States Coast Guard
VOIP	Voice over internet protocol
VPN	Virtual private network
VSAT	Very small aperture terminal (satellite link ground station)
WAN	Wireless Arctic Network
WLAN	Wireless local area network

protocols will be run on each architecture at saturation. The quality of service (QoS) will be measured by UAF, UC, APU, and NASA for each architecture and protocol combination in order to determine which protocols optimize performance for each architecture and traffic load for each scientific purpose. APU will develop user satisfaction studies and make suggestions to reduce the international regulatory barriers to a fully integrated WAN. Phase one results of the test bed will then be used to present a well-founded plan for a regional Wireless Arctic Network.

Quality of Service

The second element of the protocol research is the development of a careful application of QoS metrics for dynamic mixed-latency networks in order to assess the

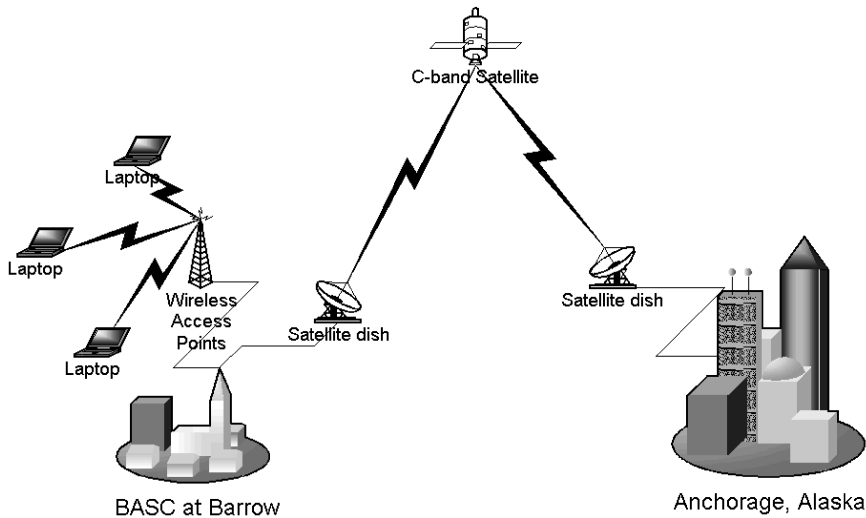


Fig. 1. WAN prototype (early)—dedicated C-band T-1 geosynchronous backhaul into BASC at Barrow.

relative performance of the various protocols on each combination of architecture and infrastructure. We will start with current metrics on conventional technology in conventional architecture similar to that one shown in Figure 1, and then change or add elements iteratively. We will develop QoS tests and develop a benchmark procedure that can be used to evaluate all transmission over all the proposed networks and the various protocol developments. Current protocols have difficulty over mixed latency networks, and the networks we propose have short, medium, and long latencies, making this an ideal test bed to evaluate protocol efficiencies.

QoS is necessary for the CITF WAN because in the Arctic, geostationary satellites are low on the horizon, forcing a propagation path at a low elevation angle through the atmosphere. Low elevation angles require a long traverse through the lower atmosphere, which is often unstable. This instability in the propagation medium causes a time-varying index of refraction, which slightly refracts the propagating electromagnetic waves. The net result is known as scintillation, which is a relatively rapid increase and decrease of the received signal strength. Scintillations can impact communication links (Mayer et al., 1988, 1991, 1994, 1997; Vogel et al., 1994; Mayer and Jaeger, 2000a, 2000b; Mayer, 2002). If the signals become too strong, the amount of inter-modulation can increase in a multi-carrier environment, such as a satellite transponder. As the signals attenuate, the reduced signal-to-noise ratio can impact the quality of data transmission and create an unacceptable bit error rate (BER). Scintillations increase as the elevation angle of the link decreases and as the frequency of the link increases. Scintillations can limit the lowest usable elevation angle from any satellite, GEO, LEO, MEO, or HEO (Molniya orbits), which limits the span of a satellite network. We will measure the impact of scintillations on the CITF WAN test bed to assess coverage limits.

End-to-End Network Experiments

The third element of the network protocol research is a series of end-to-end network experiments that are summarized below. We will test a suite of scientific applications with each architecture/infrastructure/protocol combination. Those suites of scientific applications to be tested on the system include at a minimum: (1) satellite and aircraft image data transmission, visualization, and ground truth; (2) distance education/collaboration (including T.120, H.323, and SIP); (3) VOIP via LEO and GEO satellite, UAV/FAN, and various 802 technologies; (4) buoy/tundra sensor data relay; (5) high and low resolution video audio relay; (6) field worker geospatial database access; (7) UAV/autonomous underwater vehicle (AUV)/robot remote control; (8) web surfing and e-mail.

We will include satellite, aircraft, and terrestrial relays and wired, wireless, mobile, and ad hoc network tests to try to explore the largest possible suite of architectures, infrastructure, and protocols within the budget and time allowed. A systematic analysis will communicate those combinations that have been tested and their relative suitability for different Arctic applications.

Preliminary Results from the Early Barrow, Alaska Node of the CITF WAN Test Bed

Initial file transfer tests in August of 2003 of the early Alaska node of the WAN (Fig. 1) indicated the importance of appropriate TCP/IP protocols for mixed-latency networks. Relatively simple adjustments of the GlobalMaxTCPWindowSize, TcpWindowSize, and Tcp1323Opts windows on a client-server pair improved throughput by a factor of four at virtually no cost. In effect, the early NSF T-1 satellite link became the equivalent of a 4 x T-1 link with five minutes of work at each end of the satellite link. Other practices such as multi-threaded FTP for multiple files, in combination with appropriate TCP/IP tuning improved file transfer rates by a factor of nine.

Unfortunately, current default TCP/IP settings in Windows and LINUX operating systems are not set for mixed-latency/mixed-bandwidth networks. Ideally the TCP/IP client-server links would provide each other with enough information to automatically adjust for bandwidth and round-trip time (RTT). TCP/IP does some of this already but clearly not enough to get maximum performance from Arctic wireless telecommunications investments. More efficient Internet links will lower the overall cost of the WAN and in some cases make the difference between a viable technology or application or the lack thereof. We conclude that it is cost-effective to invest at least some effort into improved TCP/IP protocols for mixed-latency/mixed-bandwidth networks accordingly.

This simple T-1 C-band satellite link system (Fig. 1) provides more connectivity to scientists in Barrow than is available to most of the Arctic. It is, however, insufficient for many applications such as videoconferencing with applications sharing. Moreover, it does not provide a mixed-latency/mixed-bandwidth test bed in the sense of multiple possible paths from Barrow to the "outside" over, say, thin and thick pipe connections or over low-latency links such as microwave or fiber optic cable *and* high-latency geosynchronous satellite links.

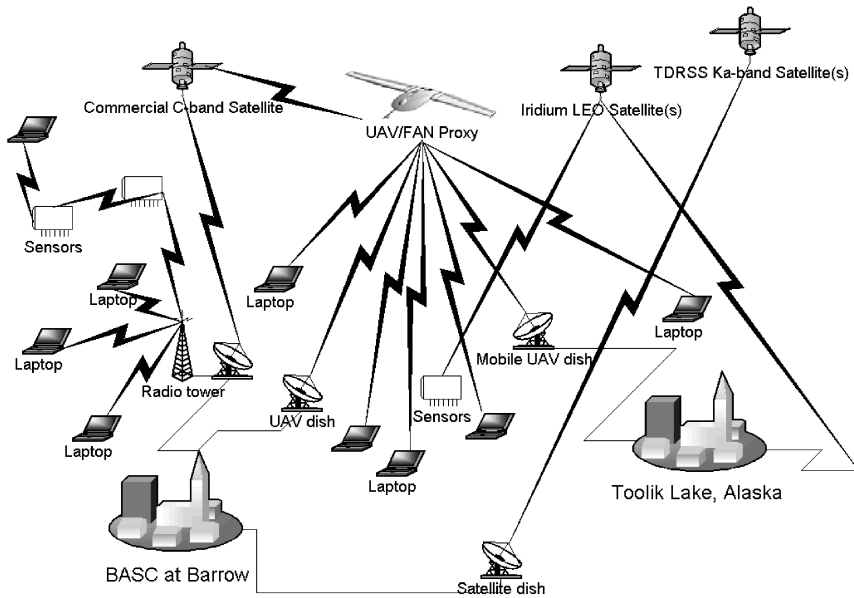


Fig. 2. CITF WAN Test Bed—Alaska Prototype (Year 4)—UAV/FAN (proxy) network with Ka-band TDRSS, iridium and fiber-optic backhaul with mobile and ad hoc networks.

We have formulated a plan for the next step of the Alaska node of the CITF WAN test bed that includes just such a variety of latency and bandwidth (Fig. 2). Figure 2 is a schematic diagram of the mixed-latency and mixed-bandwidth scientific test bed that we hope to construct in Alaska by 2006 with similar nodes in at least four other Arctic nations. We are well aware that technology may turn out to be the easiest aspect of the construction of a truly integrated, capable, ubiquitous, and transparent Arctic telecommunications infrastructure.

CONCLUSIONS

A two-year study by the authors and subsequent workshop sponsored by the University of the Arctic on the Information and Communications Technology (ICT) infrastructure of the Arctic held from September 3–6, 2003, in which representatives from four arctic nations (Denmark [Greenland], Norway, Russia, and the United States) participated, found similar ICT infrastructure problems throughout most of the Arctic. The workshop suggested the establishment of a mixed low- and high-bandwidth test bed consisting of bonded iridium and Ka-band satellite terminals linked to terrestrial telecommunications networks to work out the technical and legal issues involved in the establishment of the CITF WAN. This international collaboration expands and builds upon a local U.S. National Science Foundation wireless test bed in Barrow, Alaska, and aims to establish Arctic anchor tenancy for a commercial Mid-Earth Orbit (MEO) Ka-band wireless mesh constellation similar to that proposed by the @Contact corporation. Our goal is to construct a robust, secure, and redundant high-bandwidth Wireless Arctic Network to support circumpolar

science, telemedicine, education, public and government, and industry access to the Internet via hybrid terrestrial wireless and wired and space- and atmospherically-based wireless network technologies.

LITERATURE

- Alena, R. L., J. Ossenfort, C. Lee, E. Walker, and T. Stone.** "Design of hybrid mobile communication networks for planetary exploration," *IEEE Aerospace Conference*, 2004.
- Allman, M., D. Glover, and L. Sanchez.** "Enhancing TCP over satellite channels using standard mechanisms" *RFC 2488, BCP 28*, January 1999.
- Ambler, M.** "The Native student at a distance," *Tribal College Journal of American Indian Higher Education*, Spring 1999.
- Bailey, K., R. A. Beck, R. Frohn, R. Krute, D. Pleva, D. Plumer, M. Price, C. Ramos, and R. South.** "Native American Remote Sensing Distance Education Prototype (NARSDEP)," *Photogrammetric Engineering and Remote Sensing*, Vol. 67, No. 2, 2001, pp. 193-198.
- Barnhardt, R.** "The domestication of the ivory tower: Institutional adaptation of cultural distance." Unpublished paper, University of Alaska–Fairbanks Center for Cross-Cultural Studies, 1994.
- Beck, R. A.** "Geographic information systems," in: J. R. Schement, ed., *Encyclopedia of Communication and Information*. London, UK: MacMillan, 2002, pp. 357-359.
- Beck, R. A.** "Remote sensing and GIS as counter-terrorism tools in the Afghanistan War: A case study of the Zhawar Kili Region," *Professional Geographer*, Vol. 55, No. 2, 2003, pp. 170-180.
- Beck, R. A.** National Emergency Mapping Information System (NEMIS). Unpublished Master's thesis, University of Illinois, Urbana-Champaign, 2004, 344 pp.
- Beck, R. A., W. Eisner, and K. Hinkel.** "NUTARNIQ: Uniting the Arctic community with a Wireless Arctic Network for circumpolar communications," *IASSA, 2004 Abstracts with Programs*. Fairbanks, AK: IASSA, May 2004, 2004, p. 1-1.
- Beck, R. A. and L. Mayer.** "Gateway2Earth: The OhioView Pilot for the distribution of satellite data to schools, industry, and the public," *EOS (Transactions of the American Geophysical Union)*, 1998, pp. 101-102 (American Geophysical Union Fall Annual Meeting, U42A-25).
- Beck, R. A., R. Vincent, D. Watts, M. Seibert, D. Pleva, M. Cauley, C. Ramos, T. Scott, D. Harter, A. J. Ross, J. Kosmo, K. Groneman, and J. Rojas.** "NASA Mobile Lunar and Planetary Science Module," in: 34th Annual Lunar and Planetary Science Conference, Houston, Texas, 2003, abstract [<ftp://www.lpi.usra.edu/pub/outgoing/lpsc2003/full96.pdf>].
- Boardman, A. E., D. H. Greenberg, A. R. Vining, and D. L. Weimer.** *Cost-Benefit Analysis: Concepts and Practice*. Upper Saddle River, NJ: Prentice-Hall, 1986 (specifically ch. 1-2: pp. 1-27).
- Carter, C. S.** "Education and development in poor and rural communities: An interdisciplinary research agenda," *ERIC Digest*, December, 1999 [<http://www.ael.org/eric/digest/edorc999.htm>].
- Daley, W. M.** "Falling through the net: Defining the digital divide [<http://www.ntia.doc.gov/ntiahome/fttn99/daley.html>], 1999.

- DeLone, W. H. and E. R. McLean.** "Assessing the business value of information systems" [<http://lattanze.loyola.edu/frames/research/wp0493.017.html>], 1993.
- Denali Commission,** "Commission focus: Telecommunications" [<http://www.denali.gov/web/content/Commission%20Focus/Other%20Infrastructure/Telecommunications/telecom.htm>], 2004.
- Derby, S. P.** "Eskimo words for snow," The AFU and Urban Legend Archive—Language [http://tafkac.org/language/eskimo_words_for_snow_derby.html], 2005.
- Estabrook, L. S.** "Valuing a document delivery system," *Research Quarterly, American Library Association*, Fall issue, 1986, pp. 58-62.
- GCI,** "GCI Announces rural internet strategy, high-speed internet services to roll-out in 152 Alaska communities" [http://www.gci.com/about/press/rural_high_sp.htm], 2001.
- Hudson, H. E.** "Bridging the broadband divide: Strategies for rural and developing regions" (white paper), p. 1-14 [http://www.gci.com/about/press/rural_high_sp.htm], 2003.
- Jaeger, B. E., D. Hopkins, D. Kim, and C. E. Mayer.** "Model comparison and verification for scintillation, fade duration, and cloud effects," in: N. Golshan, ed., *Proceedings of the Eleventh ACTS Propagation Studies Workshop (APSW XI)*. Oklahoma City, OK: JPL Publication 98-13, 1998, pp. 15-34.
- Johnson, M., K. Freeman, R. Gilstrap, and R. A. Beck.** "Networking technologies enable advances in Earth science," *Computer Networks*, 2004 (in press).
- Johnston, W. E.** "The computing and data grid approach: Infrastructure for distributed science applications," *Computing and Informatics*, Vol. 2, No. 4, 2002.
- Kemp, W. B., and L. F. Brooks.** "Towards information self-sufficiency: The Nanavik Inuit gather information on ecology and land use," *Cultural Survival Quarterly*, Winter 1995, 1995, pp. 25-28.
- Mayer, C. E.** "Evaluation of eight scintillation models," in: *URSI XXVth General Assembly Abstracts*. Maastricht, Netherlands, August 17–24, 2002 [FP0141-1 to FP0141-4].
- Mayer, C. E., J. H. Davis, and H. D. Foltz.** "Texas 5-m antenna aperture efficiency doubled from 230-300 GHz with error compensating subreflector," *IEEE Transactions on Antennas and Propagation*, Vol. AP-39, No. 3, March 1991, pp. 309-317.
- Mayer, C. E., J. H. Davis, W. L. Peters III, and W. H. Vogel.** "A holographic surface measurement of the Texas 4.9-m antenna at 86 GHz," in: P. F. Goldsmith, ed., *Instrumentation and Techniques for Radio Astronomy*. New York, NY: IEEE Press, 1988, pp. 207-214.
- Mayer, C. E., D. T. Emerson, and J. H. Davis.** "Design and implementation of an error compensating subreflector for the NRAO 12-m antenna," *IEEE Proceedings*, Vol. 82, No. 5, May 1994, pp. 756-762.
- Mayer, C. E. and B. E. Jaeger.** "Rain attenuation modeling," in: *Proceedings of the Sixth Ka-Band Utilization Conference*. Cleveland, OH, May 31–June 2, 2000a, pp. 53-68.
- Mayer, C. E. and B. E. Jaeger.** "Rain attenuation model comparison and validation," in: *Proceedings of the Advanced Communications Technology Satellite (ACTS) Conference 2000*. Cleveland, OH: NASA/CP-2000-210530, 2000b, pp. 215-221.

- Mayer, C. E., B. E. Jaeger, R. K. Crane, and X. Wang.** "Ka-band scintillations: Measurements and model predictions," *IEEE Proceedings*, Vol. 85, No. 6, June 1997, pp. 936-945.
- Mayer, C. E., B. E. Jaeger, and D. Kim.** "Five years of ACTS propagation studies in Alaska," in: N. Golshan, ed., *Proceedings of the Twenty-Third NASA Propagation Experimenters Meeting (NAPEX XXIII)*. Washington, DC: JPL Publication 99-16, June 2-4, 1999.
- Pesanti, H.** "Closing the digital abyss: Options for Arctic telecom workshop." Report to the Arctic Council Information and Communication Technology (ICT) Conference Akureyri, Iceland, Abstracts, October 2003, 5 pp., 1 table.
- Schlosser, P. and T. Tucker.** *Arctic Research Support and Logistics: Strategies for the 21st Century*. Fairbanks, AK: Arctic Research Consortium of the United States, 2003, 78 pp.
- Shah, S. H., K. Chen, and K. Nahrstedt.** "Dynamic bandwidth management for single-hop ad hoc wireless networks," *Mobile Networks and Applications (MONET) Journal*, v. 10, 2004, pp. 199-217.
- Vogel, W. J., J. H. Davis, and C. E. Mayer.** "Line-of-sight observations at 86 GHz with a very large and a small antenna," *IEEE Transactions on Antennas and Propagation*, AP-32, No. 2, 1984, pp. 113-118.