My computer communications research background is rooted in my arts background, studying the ways human beings interact with each other. Fundamentally, I seek the most expedient and efficient means for allowing people to communicate with one another. Initially, this question was based on what signals could be placed on a pair of twisted wires formatted in a variety of wireline protocols. More recently, a complete understanding of the ways in which communication takes place has become more important. Recognizing that web browser-based communication was asynchronous led to the development of the consumer-prevalent technologies delivered by xDSL and cable modems. As broadband communication expands, synchronous communication becomes key when video and audio conferencing or remote monitoring and control are desired means of communication. Through my varied research topics of the past, I expect that my current and future research will lead to advances in areas and disciplines that have only begun to consider what computing technology and broadband communication can do. All of this work is only possible with good colleagues, partners and a supportive community willing to tackle the problems that need to be addressed.

Previous Research Work

My early applied research evolved within the UNH InterOperability Laboratory (UNH-IOL), where I started developing standards-based conformance tests associated with the **Token Ring** draft standard in the Institute of Electrical and Electronics Engineers (IEEE) LAN-MAN Standards Committee (LMSC) [7]. In the early 1990s, IBM succumbed to market pressure and began an effort in the IEEE LMSC as project IEEE 802.5 to develop a standards-based Token Ring solution. I participated in the drafting and final revision version of the standard as Corrigenda to 802.5:1998 and Amendment 1:1998 that were approved by the Standards Board in 2001, as well as the **Dedicated Token Ring** standard (802.5t) [2] that was approved in 1999 and **Gigabit Token Ring** (802.5v) [8] approved in 2001. With all of the detailed supported work completed, I was one of the eight voting members of the IEEE 802.5 Working Group that voted for hibernation of the Token Ring Working Group on May 3, 2000.

In parallel, I had begun studying a new technology protocol called Demand Priority (more commonly called 100VG-AnyLAN). Originally spearheaded by Hewlett-Packard, it was introduced into the LMSC as IEEE 802.12 and was standardized in 1998 [1]. I focused my Masters-level research on the implementation of Demand Priority framing within the TCP/IP protocol. My thesis discusses the changes necessary within TCP/IPv4 code to provide for priority framing used in the **Demand Priority Protocol** above the Media Access Control (MAC) layer. Internet Protocol version 4 does not take into account the real-time transmission benefits of Demand Priority. The addition of priority frame recognition at the network, transport, and application layers of the OSI Reference Model results in an increased performance benefit for multimedia applications running TCP/IP over the Demand Priority Protocol [9]. This increase in transfer for real-time applications does not significantly hinder the transfer of data at normal priority rates. By the time I had completed this research, 100VG-AnyLAN had lost the market battle of product sales and nearly every manufacturer had abandoned the technology. However, I remain convinced that the priority framing offered in the protocol is more favorable to low-latency crippled data streams (such as video) than the present-day packet-based protocols.

With the study of video streaming over networks such as **Fast Ethernet**, **100VG-AnyLAN**, **Asynchronous Transfer Mode (ATM)** and Token Ring, I concurred with the observations that the **Hypertext Transfer Protocol (HTTP)** encouraged an asynchronous traffic pattern across networks, especially broadband networks [3]. This pattern, along with federal legislation in 1996, encouraged the development and deployment of the digital subscriber line, or DSL for short. A variety of DSL flavors emerged, with the most predominant being **asymmetric digital subscriber line (ADSL)**, a deployable solution that offers higher downstream bandwidth over the upstream bandwidth level across a single twisted pair loop from a central office (CO) to the customer premises [10]. We also studied the operation of other related DSL technologies, such as **High-Speed Digital Subscriber Line Version 2 (HDSL2)** [11] and **Very-High-Bit-Rate Digital Subscriber Line (VDSL)** [12], but the most universally deployed DSL in the late 1990s and early 2000s was ADSL.

ADSL uses the ITU-standardized discrete multi-tone modulation (DMT) as a frequency-division multiplexing scheme to communicate the digital bit patterns from the transmitter to the receiver. Customer premises equipment (CPE) communicate with the aggregation device in the CO called the digital subscriber line access multiplexer (DSLAM) across the twisted pair wiring using a DMT carrier. The initial communication is a training process that determines which frequencies have interference and, once determined, may exclude interference-laden frequencies to ensure the clearest communication between CPE and CO devices. DSL has a maximum distance limitation of the local loop to 18k feet, and the strength of the training signal is proportional to the distance between the CO and CPE. Since our initial study of ADSL, there have been nearly ten additions or revisions of the ADSL standard to offer features such as signal interleaving, multi-pair DSL, and pair bonding of DSL. Most current worldwide DSL studies note that in the US, cable modems are deployed over DSL in a 2-to-1 ratio, while the opposite exists in the rest of the world.

Peripheral to my studies of computer networks has been my involvement in the devices and methods that will use these networks. The Service Availability Forum has worked with me and seven students, both graduate and undergraduate, over a five year period to develop a testing mechanism for their standard hardware platform interface (HPI) for **highly-available systems** architectures. Working closely with IBM and Nokia, we wrote C code and built test platforms to examine devices for their conformance to the HPI standard, as well to test the OpenHPI open source software project supported by the Service Availability Forum.

Ongoing Research Work

My existing research is focused within the networking area of computer science. **Cyberinfrastructure (CI)** was a term presented by the National Science Foundation (NSF) as a strategic area of focus to advance next-generation science and research. The NSF Strategic Plan for FY11-16 notes that "The advent of widespread use of computational and communications capabilities across all S&E fields, and in STEM education, has made cyberinfrastructure, including its easy access and use, a vital element of tools and capabilities provided by NSF" [4]. CI, in particular, the establishment of large data paths across New Hampshire, is a key investment in the future success of NH citizens. With support and coordination for the NH Department of Resources and Economic Development (NH DRED), I wrote the two attempts at securing funding from the US Department of Commerce's National Telecommunications and Information Administration (NTIA) through the Broadband Technology Opportunities Program (BTOP). The Round 2 proposal [13] secured $44.5 million in federal funds (matched with $21.5 million in private funding) to construct 750 miles of dark fiber cable across all 10 counties in New Hampshire, a microwave network for public safety communications across 20 NH mountaintops, 20 miles of in-ground fiber for the NH Department of Transportation's (NH DOT) **Intelligent Transportation System (ITS)** upgrade along I-93, nearly 1200 homes and business receiving an initial installation of **fiber-to-the-home (FTTH)** connectivity in the western area of NH by NH FastRoads, and the connection of 35 community anchor institutions (including all of the USNH and CCSNH campuses) onto a single 10Gbps **dense wave-division multiplexing (DWDM)** network service. This unprecedented cyberinfrastructure uplift for NH from our research attempts to establish connectivity with non-existent pathways to allow for the participation of NH in cutting-edge, international research because we now have the resources to engage.

As a result of this CI investment, there are specific problems that I am researching solutions today. Beyond using the microwave network for public safety communications by the NH Army National Guard, NH DOT, NH State Police and NH DRED, NH Public Television (NHPTV) will use the network to deliver its digital television (DTV) broadcast signal to its transmitters across NH. Besides being the state-designated participant in the Digital Emergency Alert System (DEAS), NHPTV participates in delivering emergency digital data using datacasting. **Datacasting** uses the excess bandwidth in the DTV stream to deliver any digital signal in a one-way broadcast to receivers configured to accept the signal [14]. My earlier research in 2005-2007 pioneered the installation of datacasting receivers in NH State Police cruisers through a grant from the US Department of Justice [15]. We discovered that the solution was very effective in allowing the cruisers to receive digital images and video across the DTV stream. However, the datacasting technology did not allow for receivers to be in motion when receiving DTV signals. DTV appeared to address the need for getting large data to remote users, but not mobile remote users. Fast forward five years, and today, the two competing standards for mobile DTV have converged into one solution that allows for full mobile DTV while traveling 65 MPH as demonstrated using existing equipment. Exciters and transmitters that support mobile DTV are being installed in the NHPTV broadcast network in 2013 and the datacasting pilot test will be re-performed to demonstrate that public safety can achieve the benefits of large data broadcasts using mobile DTV. A new question to be studied is how datacasting can handle movement from one mobile DTV transmitter to another. We have examined the handoff mechanisms that the cellular network and mesh networks employ [16], and will be testing which of these solutions operates best as mobile DTV receivers transmit from the two primary southern NH towers in Keene and Deerfield.

Essentially, we see datacasting as a possible step in bringing broadband-like services to the broadband unserved in NH. Following the asynchronous web usage patterns of DSL, important digital service information can be broadcasted via datacasting to receivers across a region of the state. Users who need a particular piece of digital data can use a dial-up or other modem to request the data from a central repository, one managed by a state or municipal agency. Then, the data would be served through the datacasting channel to the requestor via the mobile DTV stream. With a coverage map of nearly the entire NH landscape, NHPTV's datacasting service already reaches areas where broadband services do not.

While we are trying to bring broadband to areas where broadband isn't, we are also examining ways to make areas with existing broadband operate better. One key area of research is in **software-defined networks (SDN)**. Through a research partnership with New Hampshire Optical Systems (NHOS) of Nashua, I secured grant funding from the NH Innovation Research Center (NHIRC) to examine the benefits of SDN in a production-like environment, rather than in the research networks where SDN has been since its discovery as part of the **GENI Project** funded by the NSF [17]. SDN purports to offer data transfer speedup because of the specialized, standards-based tagging of data flow from transmitter to receiver across a centrally-controlled network. **OpenFlow**, the technology being deployed by some hardware switch vendors, is currently being empirically investigated by me and my students to determine how much of a benefit over traditional packet-based networks is achieved. If any benefit is apparent, NHOS is likely to invest in lighting some of their fiber optic cable plant with OpenFlow technology in a production environment, and will likely be able to claim to be the first commercial SDN provider in NH.

My most recent research activity has less to do with technology and more to do with people. Two research awards from the National Science Foundation are core towards the development of Research Computing Facilitators and Cyberinfrastructure (CI) Engineers. By working closely with research scientists in understanding their approach and needs, I am developing a new set of expert scientists and leaders who can participate in the computationally-heavy domain work of science while partnering with the technology-heavy support teams that make CI available to all researchers. Our next set of research scientists need this skill to advance everyone forward.

Future Research Work

With a large portfolio of over $75 million in externally-funded research, my future research plans might seem to be broad. Rather, I am laser aimed at some key questions that must be addressed: "*What do we do with such huge levels of broadband across the state?*" and "*What happens when computers are cheaper than LEGO blocks?*" [6]

With nearly $4.7 billion invested in broadband expansion by the NTIA across the US, there are many efforts taking place to ensure that the investment reaps the benefits intend with the ARRA Stimulus funding. Efforts, such as US Ignite, are challenging US individuals and organizations to consider the development of technology that will capitalize on the broadband capacity in the US. I am working with NH companies to start new efforts in building applications and devices that impact video conferencing and **telepresence** in common, everyday ways that we have never considered. The 2012 Horizon Report identifies, in the four-to-five year window, the expansion of the "Internet of Things." [5] The collection of sensors and devices on everything in the world will change our behaviors, such and reconsidering going to the mall due to overcrowding or buying groceries because our refrigerator can tell us exactly what we are short or missing for a good meal. Eldercare is a growing segment of the homecare market, and most homecare services are provided in NH either in person or with expensive, proprietary monitoring devices. In partnering with Lamprey Networks, Inc. (LNI), a Durham, NH-based open standards developer and homecare communications device entrepreneur, we are working with an open-standards healthcare program to create an ecosystem that relies upon broadband and can utilize **interoperable medical devices** to give homebound patients and their caregiver families the freedom to live comfortably and with the highest quality utilizing technology solutions. Through an active NHIRC grant, a new communications protocol between the home device and the control system is being developed along with a voice-activated authenticated system to make the patient engagement with the system easier to accept. These two area examples are part of the greater problem of finding applications and solutions that will utilize the deployed broadband in NH in a manner that will require the installation of more broadband.

As part of an initiative to encourage STEM graduates, I am intensely intrigued and have begun efforts to utilize small sensor networks using small devices, such as the Beagle Board, Arduino Kits, and Raspberry Pi [6]. The NH EPSCoR RII Track 1 project "Ecosystems & Society" is a project that has the expectation to develop and use sensor networks to measure what is taking place in the world as well as what is taking place with society. My present involvement is as a consultant to the CI required. However, I am following my research partners and discovering that they are in need of good, low power, low cost sensor networks as part of this research and other work.

Plan to Involve Students

I see the need for student involvement in all aspects of research as critical. I advocate for meshing research project activity as part of introductory coursework. I see the learning benefits of having small programmable devices be illustrative in the structures of introductory operating systems where memory management, communications bus transactions, swapping, paging, deadlocks and file management can be presented in ways where the question "why is this important" can be answered. I see the learning benefits of those same programmable devices working together in ways to demonstrate computer networks and to support students working with and developing mesh networks.

Early in my time in the UNH-IOL, I moved all of my students towards using laptops, which has been embraced strongly. I prefer to offer my students the ability and option to perform their research where-ever and when-ever, using the tools that the commercial world has been pioneering to increase productivity. Our philosophy in the UNH-IOL has always been to give students the experience of being in the commercial development world without having to be there during their academic studies. I continue to offer that same environment outside of the UNH-IOL for students who work with me, and would be looking to maintain that atmosphere with all organizations in which I come in contact.

References

[1] IEEE Standard 802.12-1998: Demand Priority Access Method, Physical Layer and Repeater Specification for 100Mb/s Operation, Institute of Electrical and Electronics Engineers, Inc., Piscataway, NJ, July, 1998.

[2] Supplement to ISO/IEC 8802-5:1998 [ANSI/IEEE Draft Standard 802.5t], Information Technology -- Telecommunications and Information Exchange Between Systems -- Local and Metropolitan Area Networks -- Part 5: Token Ring Access Method and Physical Layer Specifications -- High Data Rate Operation, Draft 2.6, Institute of Electrical and Electronics Engineers, Inc., Piscataway, NJ, February 1999.

[3] Fielding, R., Gettys, J., Mogul, J., Frystyk, H., Masinter, L., Leach, P., Berners-Lee, T., Hypertext Transfer Protocol – HTTP/1.1, RFC 2616, June 1999.

[4] *Empowering the Nation Through Discovery and Innovation: NSF Strategic Plan for Fiscal Years (FY) 2011-2016*, NSF 11-047, National Science Foundation, Arlington, VA, April 2011.

[5] *NMC Horizon Report: 2012 Higher Education Edition*, New Media Consortium and EDUCAUSE Learning Initiative (ELI), Stanford, CA, 2012.

[6] Petrone, Emile, "What happens when computers are cheaper than LEGO blocks?" Website http://gigaom.com/2012/10/12/what-happens-when-computers-are-cheaper-than-lego-blocks/, October 12, 2012.

[7] ISO/IEC 8802-5:1998 [ANSI/IEEE Standard 802.5, 1998 Edition], Information Technology -- Telecommunications and Information Exchange Between Systems -- Local and Metropolitan Area Networks -- Part 5: Token Ring Access Method and Physical Layer Specifications, Institute of Electrical and Electronics Engineers, Inc., Piscataway, NJ, July 1998.

[8] Supplement to ISO/IEC 8802-5:1998 [ANSI/IEEE Standard 802.5v], Information Technology -- Telecommunications and Information Exchange Between Systems -- Local and Metropolitan Area Networks -- Part 5: Token Ring Access Method and Physical Layer Specifications – Amendment 5: Gigabit Token Ring Operation, Institute of Electrical and Electronics Engineers, Inc., Piscataway, NJ, May 2001.

[9] Valcourt, Scott A. and Robert D. Russell, *A Method for the Incorporation of Demand Priority Framing of 100VG-AnyLAN in the TCP/IP Protocol*, TR 99-01, Computer Science Department, University of New Hampshire, Durham, NH, May 1999.

[10] [ANSI T1.413-1998] *Network and Customer Installation Interfaces—Asymmetric Digital Subscriber Line (ADSL) Metallic Interface*, American National Standards Institute, Washington, DC, 1998.

[11] [ITU-T G.991.2] High-Bit-Rate Digital Subscriber Line, Second Generation (HDSL2), International Telecommunications Union, Geneva, Switzerland, 1998.

[12] [ITU-T G.993.2] Very-High-Speed Digital Subscriber Line Version 2 (VDSL2), International Telecommunications Union, Geneva, Switzerland, 2005.

[13] Network New Hampshire Now, website http://www2.ntia.doc.gov/grantee/university-system-of-new-hampshire, retrieved December 11, 2012.

[14] Valcourt, Scott, Kent Chamberlin, Benjamin McMahon and Andrew Kun, "Systems Engineering of Datacasting for Public Safety Vehicles," in *Proceedings of the 2007 IEEE Conference on Technologies for Homeland Security: Enhancing Critical Infrastructure Dependability*, Woburn, MA, May 2007.

[15] Valcourt, Scott A., Pushpa Datla, Kent Chamberlin and Benjamin McMahon, "Using Two-Way Datacasting to Deliver Real-Time Public Safety Information," 2008 IEEE International Conference on Technologies for Homeland Security, Boston, MA, May 12-13, 2008.

[16] Tripathi, Nishith, Jeffrey Reed and Hugh F. VanLandingham, "Handoff in Cellular Systems," *IEEE Personal Communications*, Piscataway, NJ, December 1998.

[17] Mussman, Harry, "GENI—An Introduction," GENI Project Office at Raytheon BBN Technologies, Cambridge, MA, February 2011.