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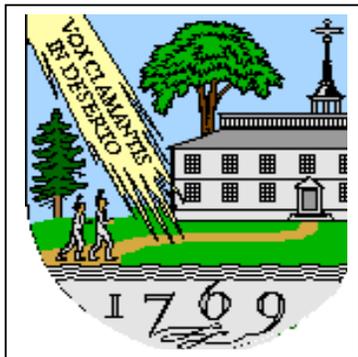
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What is the CMC?

The Center for Mobile Computing (CMC) at Dartmouth College is dedicated to advanced research in topics related to mobile computing and distributed information resources. Our current research projects involve information-retrieval technology, mobile software (in the form of transportable agents), mobile hardware (in the form of laptop and handheld computers), and wireless networks.

The CMC is comprised of researchers from the Department of Computer Science and from the Thayer School of Engineering, including faculty, post-doctoral researchers, M.E. and Ph.D students, and undergraduate students. Participating faculty members have extensive experience in mobile agents, parallel and distributed computing, operating systems, information retrieval, robotics, computer networks, signal processing, and advanced algorithm design.

The Center's projects receive federal funding from the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research, and a Department of Defense Multidisciplinary University Research Initiative (MURI) administered by the Air Force Office of Scientific Research.

Center research facilities include a variety of wired and wireless networks as well as a heterogeneous collection of computing systems. In addition, Dartmouth College offers a potential testbed environment with several thousand networked computers and active users.

What's New

Campus-wide wireless network

Professors Kotz and **Rus** have been working hard to bring Dartmouth's campus fully into the wireless age. With the aid of the Dartmouth's Computing Services department, we have deployed about 10 Lucent WaveLAN access points at key locations on campus: libraries, eateries, and the Computer Science and Engineering buildings. We are actively encouraging Dartmouth to take the plunge and deploy a network that will provide campus-wide wireless coverage, and we are actively seeking industrial partners for this process. Meanwhile, we have assembled a team of bright undergraduates to start deploying applications and services aimed at the wireless user. The great thing about working with Dartmouth undergraduates is that, given appropriate resources, they come up with incredible ideas! Dartmouth is an exciting environment to build a next-generation wireless testbed.

Large-scale wireless-networking lab

Research Engineer Bob Gray has assembled a large cluster of 50 Linux laptops, each with a WaveLAN Gold card (11 Mbps 802.11 wireless ethernet) and a GPS device. The cluster lives on several shelves in our lab, for development and testing, but will be taken out around campus for experiments involving wireless routing algorithms, mobile-agent applications, and so forth (see the article on the ActComm demo on page 4 of this issue).

Apple donates iBooks, joins CMC

Apple Computer recently donated 10 iBooks with Airport wireless cards, an iMac DV, and an Airport base station. They are also the newest partner in the CMC. We

are excited by the potential projects for these laptops and look forward to a fruitful partnership with Apple!

Microsoft Research donates Pocket PCs, joins CMC

Microsoft Research joined CMC recently, and also generously donated a dozen PocketPC and WindowsCE portables, several RangeLAN wireless devices, and books and software about Windows CE programming. We have been using the devices in several undergraduate projects.

Clayton Okino joins CMC

Clayton Okino is an assistant professor at the Thayer School of Engineering. His primary research interest is the performance of communication systems and wireless networks. Some of his current work focuses on statistical multiplexing schemes and smart sensor networks.

Recent Ph.D graduates

Jon Howell, Ph.D in Computer Science

Naming and sharing resources across administrative boundaries

Jon developed a new infrastructure for secure distributed authorization, in a system he calls Snowflake. As computers become more ubiquitous and mobile, it will be increasingly necessary for them to access remote resources, whether on servers or on other mobile devices. It is important for the system to ensure that only authorized access is permitted. The idea is to allow users to share resources in a secure way. Alice can delegate authority over some of her resources to Bob, but only regarding certain forms of access. Furthermore, Bob can delegate some of that authority to Charlie, perhaps placing

additional restrictions. This transitive restricted delegation is fully auditable, which means that the resource owner can later see who is trying to use the resource, and through what chain of people they obtained the authority. The system avoids any central authorization servers, and does not require all delegators to be present to verify each access, so the system fits well in the fluid networks so common in mobile computing.

Jon now works for a start-up in Seattle called Consystant Technologies.

Brian Brewington, Ph.D. in Engineering

Monitoring Information Sources under Low-Bandwidth Conditions

A person must often maintain current knowledge of some changing information source. For example, a saleswoman in the field must see all new orders and memos relating to her area of operation. If the information source does not provide change notifications, she must keep repeating the same queries. Unfortunately, since she is using a mobile computer and wireless network, she might have extremely limited computational resources with which to make these queries. Bandwidth, in particular, might prohibit her from making fixed-interval queries to all the information sources that she might like.

What is needed is an algorithm that will automatically schedule the queries according to some estimate of (1) the importance of each information source and (2) how fast each information source is changing. Brian developed several such algorithms. Although he considered the problem of a search engine trying to maintain an up-to-date index of the Web, his algorithms are generally applicable to any bandwidth-constrained information-monitoring application, and should work well in a mobile-computing domain. Brian devised a formal framework for what it means for an observer to be "up-to-date" with

respect to a particular information source, gathered empirical data about the speed with which the World Wide Web changes, and developed several algorithms for efficiently monitoring the Web. At Dartmouth, we hope to apply these same algorithms to the task of monitoring a distributed set of wireless sensors during a military operation.

Brian is now at a start-up company, Virtual Phonics.

Recent B.A. graduates:

Ned Holbrook's senior honors thesis project allows Palm users to see their Macintosh desktop file structure, over the network, and to cause files to be transferred to the Macintosh desktop of other Palm users. This application is really handy when you meet a friend downtown, and while chatting realize that you want to send her that new iMovie you just created. Zap! The file is transferred over the backbone network, under remote control of your Palm and with her authorization provided through her Palm. Apple's donated iBooks helped in this project. Ned is now working at Connectix in Silicon Valley.

Debbie Chyi's senior honors thesis project was on Windows CE, using equipment donated by Microsoft Research. Her goal was to create a personal mobile agent that would live on a wired computer and act as a proxy between a person using a wireless hand-held device, and the rest of the Internet. The agent would move from host to host in the wired network to remain close to the owner. It would act as an extended cache, retaining information too large to

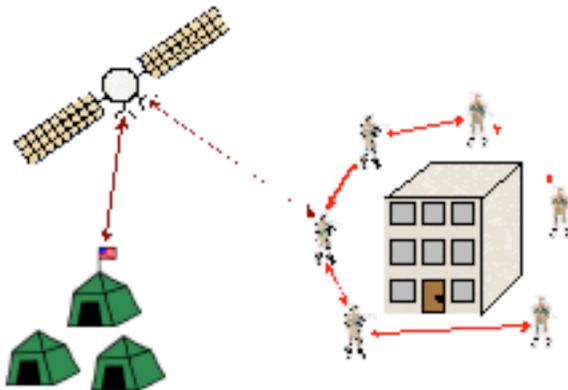
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The ActComm Project

Bob Gray

Overview

In current military operations, soldiers typically have voice communication only, which makes it difficult to access needed information and coordinate mission activities. Ideally, each soldier would have a portable computing device, through which they could query military databases, access maps of the surrounding terrain, view the positions of their fellow soldiers, and send complex observations to the mission planners at headquarters.



The ActComm (Active Communications) project, which is a Multi-University Research Initiative (MURI) now entering its fourth year, focuses on two parts of the overall problem: (1) routing and delivery systems that move data and requests from soldier to soldier (and between the soldiers and their headquarters), and (2) information-retrieval systems that allow the soldiers to efficiently access databases in the main military network. The underlying assumption is that each soldier has some portable computing device with short-range, high-bandwidth wireless hardware for communicating with other soldiers.

A few soldiers also have long-range, low-bandwidth wireless hardware and serve as gateways between the soldiers and the main network. Due to the short range of the soldier-to-soldier hardware, messages going from one soldier to another might need to be routed through several intermediate soldiers. Moreover, the soldiers are continually moving relative to each other, so the available routes change from one moment to the next. The soldiers might even move out of range of each other, requiring the routing and delivery systems to queue messages until the network disconnection goes away.

Under this assumption, the ActComm participants – Dartmouth College, Harvard University, Rensselaer Polytechnic Institute, the University of Illinois, Lockheed Martin and ALPHATECH – have developed several novel, robust and efficient routing, delivery and information-retrieval systems, which will play a significant role in providing effective computer access to soldiers in the field. The routing systems include APRL, which broadcasts beacons to explicitly identify network routes, and GPSR, which uses GPS position information to implicitly identify network routes. Current work aims to identify which combination of routing algorithms is most appropriate for soldiers in the field. The delivery system, which handles network disconnections, is based on active messages, messages that are tagged with their own routing strategy. In the ActComm project, these active messages move as far as possible towards the destination soldier, and then wait for the critical network disconnection to go away. The information-retrieval systems are based around mobile code. The code to perform query processing and other tasks is dynamically relocated to more attractive network locations. In particular, query-processing code is sent into the main network so that intermediate results are not (wastefully) sent through the wireless network. The

ActComm participants have constructed a testbed in which to exercise these systems.

In the current testbed, the soldiers can view a map of the local terrain, see the positions of all the other soldiers on the map, send observations of people and vehicles back to headquarters for analysis, and query any of three available databases: (1) news articles arriving over a military news feed, (2) transcripts of intercepted phone calls, and (3) descriptions of known terrorists and other personnel (black-gray-white). The soldiers in the field primarily search the black-gray-white database, while the mission planners at headquarters search all three.



Professor George Cybenko, fresh from a meeting with the Dean, participates in an ActComm test run.

Trial Runs and Next Steps

The testbed has been used in trial runs on the Dartmouth College campus with students playing the role of soldiers. Each run involved sixteen to twenty soldiers, observing either vehicular activity on particular streets or all activity at a particular building. Dartmouth College also recently purchased fifty additional laptops, which will be used to perform trial runs with fifty

to seventy soldiers. Although the past and future runs have been invaluable, the ActComm participants hope to participate in an actual military exercise, both to test the software in a more realistic environment and to receive feedback from military personnel. The participants are also continuing to develop the various systems. Current work aims to develop mechanisms to (1) efficiently allocate scarce network resources among competing applications and (2) monitor the network state and predict network disconnections shortly before they occur (so that applications can pro-actively take action).

Project Personnel and Funding

The ActComm personnel are leading researchers in the networking, information-retrieval and mobile-code fields: George Cybenko, Bob Gray, David Kotz, and Daniela Rus at Dartmouth College, H. T. Kung and Brad Karp at Harvard University, Ken Vastola and Major Lisa Shay at Rensselaer Polytechnic Institute, P. R. Kumar, Tamer Basar and Gul Agha at the University of Illinois, Ken Whitebread and Sue McGrath at Lockheed Martin, and Eileen Entin at ALPHATECH. The Department of Defense funds the ActComm project under AFOSR contract F49620-97-1-03821.

For more information, including contact information for all participants, see <http://actcomm.dartmouth.edu>

Recent Graduates, *continued from page 3*

fit in the hand-held device, and as a filter, discarding or delaying incoming messages that are not appropriate for the users' current situation (as determined by the time and their calendar). Debbie is now at Handspring in Silicon Valley.

Jay Artz's senior honors thesis aimed to create a personal radio. The goal was to develop a prototype of a next-generation digital radio, that receives audio content over a wireless digital network, caches it in the player device, and plays the content that the user wants, when she wants it. The user chooses when to listen to news, weather, or music, can skip stories or songs that are uninteresting, and can provide feedback that allows the system to learn the user's tastes. Jay is now at Vignette Corporation.

Flora Wan developed a low-cost bit-error-rate measurement device for commercial off-the-shelf (COTS) Amplitude Shift Keyed (ASK) transceivers. The pseudo-random-number generator, synchronization and bit-calculation routines written in assembly code reside in two 8-bit microprocessors, one for the transmitter and one for the receiver, respectively. The COTS processors cost about \$5 a piece.



Selected recent research papers:

Mobile agents: motivations and state of the art. Robert S. Gray, George Cybenko, David Kotz and Daniela Rus. In *Handbook of Agent Technology*, AAAI/MIT Press, 2000.

Mobile agents and the future of the Internet. David Kotz and Robert S. Gray. *ACM Operating Systems Review*, 33(3):7-13, August, 1999.

Performance analysis of mobile agents for filtering data streams on wireless networks. David Kotz, Guofei Jiang, Robert Gray, George Cybenko, and Ronald A. Peterson. In *Proceedings of the Workshop on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2000)*, August, 2000. ACM Press.

Mobile agents for mobile computing. David Kotz, Robert Gray, Saurab Nog, Daniela Rus, Sumit Chawla and George Cybenko. *Mobility: Processes, Computers, and Agents*, chapter 14.3, Addison Wesley and ACM Press, April, 1999.

Keeping up with the changing web. Brian Brewington and George Cybenko. *IEEE Computer*, 33(5):52-58, May, 2000.

Sending messages to mobile users in disconnected ad-hoc wireless networks. Qun Li and Daniela Rus. In *Proceedings of the Sixth Annual International Conference on Mobile Computing and Networking*, Boston, August, 2000. ACM Press.

Modeling and analysis of active messages in volatile networks. Clayton Okino and George Cybenko. In *Proceedings of the 37th Allerton Conference on Communications, Control and Computing*, Monticello, IL, 1999.

more....

End-to-end authorization. Jon Howell and David Kotz. *In Proceedings of the 2000 Symposium on Operating Systems Design and Implementation.* USENIX Association, October 2000.

A Formal Semantics for SPKI. Jon Howell and David Kotz. *In Proceedings of the Sixth European Symposium on Research in Computer Security (ESORICS 2000).* Springer-Verlag, October 2000.

Note: All papers can be found at <http://agent.cs.dartmouth.edu/papers/>

Partners



Inform*ix* SOFTWARE

Microsoft

Microsoft Research



CMC Partnership

Our goal is to conduct advanced research in topics that are relevant to future industrial, government, and commercial applications and products. We are interested in, and able to focus on, emerging technologies likely to become mainstream in a few years; we are currently focused on mobile computers, mobile agents, wireless communications, and information-retrieval applications. There are clear benefits for partnerships with Dartmouth's Center for Mobile Computing. Partners have early access to advanced research that can lead to next-generation products and services. At the same time, the CMC benefits from a better understanding of the needs and direction of industry, helping to keep research relevant and driven by application needs. Other benefits include:

- Subscription to quarterly newsletter;
- Access to CMC students, making connections that may lead to future employment and other relationships;
- Access to CMC faculty as consultants;
- Early access to prototype systems;
- Access to CMC labs and facilities, when appropriate.

Ultimately, each partnership leads to a host of benefits and to a relationship that can be customized to the needs and interests of the partner. Contact us if you are interested in being a partner (cmc@cs.dartmouth.edu).

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As of August 2000 the group also includes 4 staff, 7 undergraduate students, and 8 graduate students.

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