CENTER FOR MOBILE COMPUTING

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DARTMOUTH COLLEGE

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CMC

This issue's highlights

Springtime in the CMC

Wow, it's been a busy spring in the research labs of the Center for Mobile Computing! Dartmouth rolled out its new campus-wide wireless network, now 88% complete, covering nearly every academic, administrative, and residential building by an 11Mbps 802.11b network, using the latest access points from Cisco Systems. As Spring slowly arrived to melt the snow off the Hanover plain, we saw students lounging outside on the grass, surfing with their wireless laptop computers. Dartmouth is the first in the Ivy league with campus-wide wireless coverage, and doubtless recorded one of the fastest deployments (about 350 access points in two months).

Here at the CMC we immediately took advantage of this new network to enable several undergraduate research projects. Pablo Stern and Kobby Essien tracked the activity of every access point on campus, to capture a detailed picture of how the wireless network is used, who uses it, what they do with the network, and how they roam around campus. We'll repeat the study in the summer and fall when the network is more complete and more wireless devices are in place.

Dartmouth deployed its wireless access points in the existing building subnets, so a mobile user will switch subnets when roaming from building to building. Senior Ayorkor Mills-Tettey developed an extension to the H.323 telephony protocol that allows a voice-over-IP conversation to continue even when the mobile computer changes its IP address several times during the conversation. Senior Ammar Khalid developed a secure directory service to allow callers to initiate calls with mobile users, knowing only their name.

With wireless networking, computing devices become much more mobile. The CMC's "SOLAR" project aims to provide mobile applications information about their current context, such as location, so that they can adapt to the changing situation of their user. Ph.D. candidate Guanling Chen is developing the SOLAR infrastructure, and Senior Arun Mathias developed the first SOLAR application, a location-aware reminder program called SmartReminder.

The course on Computer Networks was excited to be a part of the action this Spring. In addition to the regular material, they were treated to a weekly seminar series on wireless networks and mobile computing. As a result several of their final projects were developed on Palm computers, and several took good advantage of IP multicast.

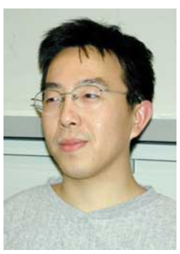
These are just a few of the exciting things that happened here this spring. You can find further details about the above projects in CMC papers, described within.

STUDENTS

Several students graduated, or passed their Ph.D thesis proposal, this spring. We describe each briefly below, but see New Research Papers for details.

Jon Bredin, Ph.D
Colorado College.

Jon used ideas from economics to develop a market-based approach to the allocation of resources in a distributed system. In his approach, computations are mobile agents that need to jump from host to host to reach the resources they need. They must pay for the computation time they use at each host. The resulting market is an efficient mechanism for fair, distributed allocation of computational resources. In the fall Jon will be a professor in the Mathematics and Computer Science department at Colorado College.



Guanling Chen, Ph.D candidate

Guanling defended his thesis proposal in which he outlined his plans to develop the SOLAR system, an infrastructure that will provide context information to mobile context-aware applications. His innovative approach uses a network of "operator" objects to filter and transform data collected from sensors and distribute it to subscribing applications. He plans to complete his Ph.D. in 2003.

Michael Corr, M.S.
SRI International.
Michael designed and built a collection of small sensor modules, each with a small processor and RF network link. When turned on, his modules quickly identify their neighbors in the ad-hoc wireless network and use a novel GPS-based routing algorithm to communicate their sensor readings to a central collection point.

Ammar Khalid, A.B.
Morgan-Stanley.

Ammar developed a secure, scalable directory service for mobile users, and applied it to the mobile voice-over-IP application developed by Ayorkor. Chief among its goals was protecting the privacy of mobile users, so that a stalker cannot track the IP address (and thus the location) of a moving user. For his work, Ammar was awarded High Honors and shared the Kemeny Prize for Computing.

Ayorkor Mills-Tettey, A.B.
Thayer M.E. program.

Ayorkor extended the H.323 telephony protocols so that a voice-over-IP conversation can continue even as the mobile user's computer roams from access point to access point, and from IP subnet to IP subnet, changing IP addresses. For her work, Ayorkor was awarded High Honors and shared the Kemeny Prize for Computing.

Arun Mathias, A.B.
Handspring, Inc.

Arun implemented the first application for Guanling's SOLAR system. His SmartReminder application reminds its user of upcoming appointments depending on the current location and the location of the next appointment. For his work, Arun was awarded High Honors and shared the Kemeny Prize for Computing.

Pablo Stern, A.B.
Microsoft.

Pablo used SNMP and an IP sniffer to trace the activity of the new campus wireless network, to characterize the way that people use the network. For his work, Pablo was awarded High Honors.

Ammar Khalid, Arun Mathias, Ayorkor Mills-Tettey, David Kotz, and Pablo Stern after the Honors Thesis defense.

New Research Papers

These papers are available on the web at
http://www.cs.dartmouth.edu/CMC/papers/

Jonathan L. Bredin. **Market-based Control of Mobile-agent Systems.** Ph.D Thesis, Dartmouth College, Technical Report TR2001-408, Dept. of Computer Science, Dartmouth College, June 2001.

Abstract: Modern distributed systems scatter sensors, storage, and computation throughout the environment. Ideally these devices communicate and share resources, but there is seldom motivation for a device's owner to yield control to another user. We establish markets for computational resources to motivate principals to share resources with arbitrary users, to enforce priority in distributed systems, to provide flexible and rational limitations on the potential of an application, and to provide a lightweight structure to balance the workload over time and between devices. As proof of concept, we implement a structure software agents can use to discover and negotiate access to networked resources.

Mobile agents represent informational and computational flow. In this dissertation we develop mechanisms that distributively allocate computation among mobile agents in two settings. The first models a situation where users collectively own networked computing resources and require priority enforcement. We extend the allocation mechanism to allow resource reservation to mitigate utility volatility. The second, more general model relaxes the ownership assumption. We apply our computational market to an open setting where a principal's chief concern is revenue maximization. Ultimately, the rationale for our mobile-agent performance optimizations may also be useful in many other distributed systems.

Guanling Chen and David Kotz. **Supporting Adaptive Ubiquitous Applications with the SOLAR System.** Technical Report TR2001-397, Dept. of Computer Science, Dartmouth College, May 2001.

Abstract: As we embed more computers into our daily environment, ubiquitous computing promises to make them less noticeable and help to prevent information overload. We see, however, few ubiquitous applications that are able to adapt to the dynamics of user, physical, and computational context. We believe that there are two challenges causing this lack of ubiquitous applications: there is no flexible and scalable way to support information collection and dissemination in a ubiquitous and mobile environment, and there is no general approach to building adaptive applications given heterogeneous contextual information. We propose a

system infrastructure, Solar, to meet these challenges. Solar uses a subscription-based operator graph abstraction and allows dynamic composition of stackable operators to manage ubiquitous information sources. After developing a set of diverse adaptive applications, we expect to identify fundamental techniques for context-aware adaptation. Our expectation is that Solar's end-to-end support for information collection, dissemination, and utilization will make it easy to build adaptive applications for a ubiquitous mobile environment with many users and devices.

Michael G. Corr. **Geographic Based Ad-Hoc Routing for Distributed Sensor Networks.** MS Thesis, Dartmouth College, June 2001.

Abstract: Recent advances in sensing devices and integrated circuit technology have allowed for the development of easily “reconfigurable smart sensor” products for the application of Distributed Sensor Networks. Primarily utilizing commercial off-the-shelf (COTS) components, I have developed Reconfigurable smart sensors, consisting of a microprocessor, GPS receiver, RF transceiver, and temperature sensor. The result is a flexible module capable of gathering sensor data and forwarding compressed information to a central location via other modules.

Robert S. Gray, David Kotz, Ronald A. Peterson, Jr., Peter Gerken, Martin Hofmann, Daria Chacón, Greg Hill, and Niranjan Suri. **Mobile-Agent versus Client/Server Performance: Scalability in an Information-Retrieval Task**. Technical Report TR2001-386, Dept. of Computer Science, Dartmouth College, January 2001.

Abstract: Mobile agents are programs that can jump from host to host in the network, at times and to places of their own choosing. Many groups have developed mobile-agent software platforms, and several mobile-agent applications. Experiments show that mobile agents can, among other things, lead to faster applications, reduced bandwidth demands, or less dependence on a reliable network connection. There are few if any studies of the scalability of mobile-agent servers, particularly as the number of clients grows. We present some recent performance and scalability experiments that compare three mobile-agent platforms with each other and with a traditional client/server approach. The experiments show that mobile agents often outperform client/server solutions, but also demonstrate the deep interaction between environmental and application parameters. The three mobile-agent platforms have similar behavior but their absolute performance varies with underlying implementation choices.

Ammar Khalid. **A Directory Infrastructure to Support Mobile Services.** Technical Report TR2001-391, Dept. of Computer Science, Dartmouth College, June 2001. Senior Honors Thesis.

Abstract: Traditional Voice-over-IP applications such as Microsoft NetMeeting assume that the user is on a machine with a fixed IP address. If, however, the user connects to the Internet, via a wireless network, on a handheld device, his IP address frequently changes as he moves from one subnet to another. In such a situation, we need a service that can be queried for the most current IP address of a person whom we wish to contact. In this project, we design and implement such a directory service. The service authenticates all callers and callees, is robust against most host failure, and scales to several thousand registered users.

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Qun Li, Javed Aslam, and Daniela Rus. **Online Power-aware Routing in Wireless Ad-hoc Networks.** In Proceedings of the Seventh Annual International Conference on Mobile Computing and Networking, Rome, Italy, July 2001. ACM Press.

Abstract: This paper discusses online power-aware routing in large wireless ad-hoc networks for applications where the message sequence is not known. We seek to optimize the lifetime of the network. We show that online power-aware routing does not have a constant competitive ratio to the off-line optimal algorithm. We develop an approximation algorithm called *max-min* zP_{min} that has a good empirical competitive ratio. To ensure scalability, we introduce a second online algorithm for power-aware routing. This hierarchical algorithm is called zone-based routing. Our experiments show that its performance is quite good.

Arun Mathias. **SmartReminder: A Case Study on Context-Sensitive Applications.** Technical Report TR2001-392, Dept. of Computer Science, Dartmouth College, June 2001. Senior Honors Thesis.

Abstract: Designing context-sensitive applications is challenging. We design and implement SmartReminder to explore designing context-sensitive applications and to demonstrate how the SOLAR system can be used in developing such applications. SmartReminder is an application that reminds the user based on contextual information. Current appointment-reminder applications remind the user about their appointments at an arbitrarily specified time. For instance, they might remind the user ten minutes before each appointment. SmartReminder, on the other hand, uses contextual information, like location, to better estimate the appropriate reminder time for each appointment. It reminds the user based on where they are, where they need to be, and how long it will take them to get there. This paper presents SmartReminder as an illustration of how context-sensitive applications can be designed using the SOLAR system for dissemination of contextual information.

G. Ayorkor Mills-Tettey. **Mobile Voice Over IP (MVOIP): An Application-level Protocol.** Technical Report TR2001-390, Dept. of Computer Science, Dartmouth College, June 2001. Senior Honors Thesis.

Abstract: Current Voice over Internet Protocol (VOIP) protocols require participating hosts to have fixed IP addresses for the duration of a VOIP call. When using a wireless-enabled host, such as a tablet computer on an 802.11 wireless network, it is possible for a participant in a VOIP call to roam around the network, moving from one subnet to another and needing to change IP addresses. This address change creates the need for mobility support in VOIP applications.

We present the design of Mobile Voice over IP (MVOIP), an application-level protocol that enables such mobility in a VOIP application based on the ITU H.323 protocol stack. An MVOIP application uses hints from the surrounding network to determine that it has switched subnets. It then initiates a hand-off procedure that comprises pausing its current calls, obtaining a valid IP address for the current subnet, and reconnecting to the remote party with whom it was in a call. Testing the system shows that on a Windows 2000 platform there is a perceivable delay in the hand-off process, most of which is spent in the Windows API for obtaining DHCP addresses. Despite this bottleneck, MVOIP works well on a wireless network.

Daniela Rus, Clifford Stein, and Rong Xie. **Scheduling Multi-task Multi-agent Systems.** A poster at Autonomous Agents. May 2001.

Abstract: We present a centralized and a distributed algorithm for scheduling multi-task agents in a distributed system. Each agent consists of multiple tasks that can be executed on multiple machines which correspond to resources. The machines in the system have different speeds. There are different communication delays and data transfer delays. We optimize the overall completion time. Our centralized algorithm has an upper bound on the overall completion time and is used as a module in the distributed algorithm. We present extensive simulation results.

Pablo Stern. **Measuring early usage of Dartmouth's wireless network.** Technical Report TR2001-393, Dept. of Computer Science, Dartmouth College, June 2001. Senior Honors Thesis.

Abstract: In Spring 2001, Dartmouth College installed a campus-wide 802.11b wireless network. To understand how that network is used, we examined the usage characteristics of the network over a five-week period. We monitored access points to determine user behavior, and user and network traffic characteristics. Because our study coincided with the deployment of the access points, our analysis captures the growth of a wireless network. The results of this study help understand the behavior of mobile users and provide a reference to network engineers wishing to deploy and expand similar wireless networks.

These papers are available on the web at http://www.cs.dartmouth.edu/CMC/papers/

On-line Power-aware Routing in Wireless Ad-hoc Networks

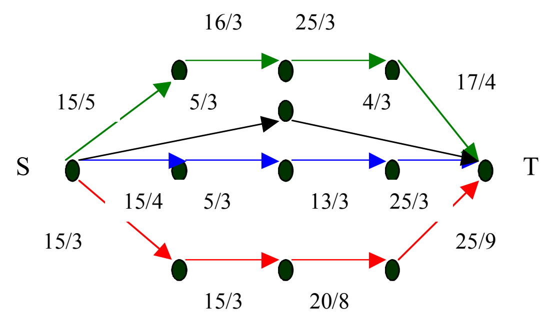
Qun Li, Javed Aslam, Daniela Rus

Imagine a large ad-hoc wireless network consisting of thousands of computers, such as a network of sensors distributed over a large geographical area. In such networks, energy consumption is a critical factor, and the wireless transceivers are the most significant energy consumer. Our goal is to develop a *power-aware* approach to routing messages that is fast, scalable, and on-line. An on-line algorithm *does not know ahead of time the sequence of messages* to be routed over the network, whereas an off-line algorithm knows the complete sequence of messages to be routed, in advance. Needless to say, on-line algorithms are more realistic.

In our current research, we focused only on issues related to minimizing power consumption during communication, that is, while the system is transmitting and receiving messages. We use a global metric: maximizing the lifetime of the network, defined to be the earliest time that a message cannot be sent.

Our proposed on-line algorithm, called the *max-min* zP_{min} algorithm, combines the benefits of selecting the path with the minimum power consumption and the path that maximizes the minimal residual power in the nodes of the network. Despite the discouraging theoretical result concerning the competitive ratio for on-line routing, we show that the *max-min* zP_{min} algorithm has a good competitive ratio in practice, approaching the performance of the optimal off-line routing algorithm under realistic conditions.

The algorithm limits the total power consumption to send a message up to zP_{min} where P_{min} is the minimal power needed to forward the message one hop and z is a small constant; at the same time, it chooses the path on which the nodes have the maximal minimal residual power after the message is sent, to avoid using the low-power nodes. Consider the accompanying figure (the first number after the node is the power level of that node before the message forwarding, and the second is the power consumption of sending the message along that edge). Suppose P_{min}, the minimal power consumption from S to T is 6 (along the black path) and we choose z to be 3. The total power consumption of the red path (23) is more than $z\ P_{min}$ (18), so it is not considered. The total power consumed on other paths (green 15, blue 13, and black 6) are within the limit, so we then identify the node on each path with the lowest remaining power if the message were to be sent along that path. After sending the message, the green path would have minimal residual power 10; the black path 1; and the blue path 2. Since the green path has the maximal minimal residual power level, we choose the green path to send the message.



This algorithm requires information about the power level of each computer in the network. Knowing this information accurately is not a problem in small networks. For large networks, however, it is difficult to aggregate and maintain this information, which makes it hard to implement the *max-min* zP_{min} algorithm for large networks. Instead, we propose another on-line algorithm called *zone-based routing* that relies on *max-min* zP_{min} and is scalable. Our experiments show that the performance of zone-base routing is very close to the performance of *max-min* zP_{min} with respect to optimizing the lifetime of the network. Zone-based routing is a hierarchical approach where the area covered by the (sensor) network is divided into a small number of zones. To send a message across the entire area we find a "global" path from zone to zone and give each zone control over how to route the message within itself. Thus, zone-based power-aware routing consists of (1) an algorithm for estimating the power level of each zone; (2) an algorithm computing a path for each message across zones; and (3) an algorithm for computing the best path for the message within each zone (with respect to the power lifetime of the zone.)

More details can be found in our upcoming paper at Mobicom 2001 (available now on the CMC web site).

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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 June 2001 the group also includes 9 staff, 6 undergraduate students, and 11 graduate students.

Contacts:

General information, partnership inquiries, and subscription changes:
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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 mobile 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 extensive 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.