CENTER FOR MOBILE COMPUTING
http://www.cs.dartmouth.edu/CMC/
DARTMOUTH COLLEGE
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CMC

This issue's highlights

Campus-wide Wireless Network

We are thrilled to announce that Dartmouth College will deploy a campus-wide wireless computing network by April 2001, with generous support from Dartmouth alumni, Cisco Systems, Dell Computer and Apple Computer. The network will feature more than 400 Aironet 350 access points, the latest generation of 802.11b-compliant networking gear from Cisco Systems. The goal is to allow students, faculty, and staff a seamless network experience from any part of the campus.

"Dartmouth has long had a reputation as a leader in computing, as well as in research and teaching, and will be the first among the Ivy League institutions to implement a campus-wide wireless network," said Dartmouth Director of Computing Larry Levine. "Wireless network coverage will make it possible for students, faculty, and staff to access information anytime, anywhere," said Professor of Computer Science David Kotz. In addition to the academic functions described above, "people will initially use the network for applications like e-mail and web surfing. No doubt faculty and students will develop applications we haven't yet imagined." Several groups of faculty and students, including a development team called The Basement and several others associated with the Dartmouth Department of Computer Science, are already working on wireless applications.

Dartmouth alumni have been key to the development of the new wireless network. Several dozen Dartmouth alumni who work for Cisco Systems are donating funds that will be used to purchase many of the access points. "Alumni participation in this project is a sign of Dartmouth's long history of the use of computing in education," said Levine. "Dartmouth alumni graduate with a working knowledge of the power of computing. Many of those graduates, especially those now working in the computing industry, have a particular interest in advancing the computing environment at their alma mater."

In planning the deployment of this network, Dartmouth is working with Cisco, Dell, and Apple, using hardware and software under development, to create compatibility between components. Here in the CMC we are expanding our research into wireless networking issues, and supporting the development of applications that can be used on a campus-wide basis.

NEW PARTNERS

Cisco donates wireless access points

Cisco's University Research Program has generously donated a set of Aironet 802.11 access points and PC cards for use in CMC research. We are excited by this opportunity and look forward to working with them. One of our first planned projects is to instrument the campus wireless network to gather information about how our population uses the network: what protocols do they use? what sorts of applications do they use? how often do they roam between base stations? between buildings? and so forth. Other projects involved voice-over IP, location-sensitive content, and context-aware applications.

Mitsubishi Electric Research Lab

MERL is the US research laboratory for Mitsubishi Electric. Their charter is to conduct problem-driven basic research in computers and their uses, exploring entirely new categories of possibility rather than merely making incremental improvements to what is now possible. We look forward to working with them on fundamental challenges in mobile computing.

Nuance donates speech-recognition software

Nuance is a leading developer of speech-recognition software. Indeed, their technology is used in GM's OnStar network. In many mobile applications we believe that speech will be a more effective interface than keyboard or pen input, particularly in environments where the hands are busy elsewhere, such as when driving a car! Nuance has generously donated a license to their software for use in our teaching and research.

New Research Papers

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

Jonathan Bredin, David Kotz, Daniela Rus, Rajiv T. Maheswaran, Cagri Imer and Tamer Basar. **Computational Markets to Regulate Mobile-Agent Systems.** Submitted to *Autonomous Agents and Multi-Agent Systems*, November, 2000.

Abstract: Mobile-agent systems allow applications to distribute their resource consumption across the network, but naive shared-resource consumption is not efficient and often results in over utilization of resources. By prioritizing applications and publishing the cost of actions, it is possible for applications to achieve faster performance than in an environment where resources are evenly shared. We enforce the costs of actions through markets where user applications bid for computation from host machines.

We represent applications as collections of mobile agents and introduce a distributed mechanism for allocating general computational priority to mobile agents. We derive a bidding strategy for an agent that plans expenditures given a budget and a series of tasks to complete. We also show that a unique Nash equilibrium exists between the agents under our allocation policy. We present simulation results to show that the use of our resource-allocation mechanism and expenditure-planning algorithm results in shorter mean job completion times compared to traditional mobile-agent resource allocation. We also observe that our resource-allocation policy adapts favorably to allocate overloaded resources to higher priority agents, and that agents are able to effectively plan expenditures even when faced with network delay and job-size estimation error.

Jonathan Bredin, David Kotz and Daniela Rus. **Trading Risk in Mobile-Agent Computational Markets**. In *Proceedings of the Sixth International Conference on Computing in Economics and Finance,* Barcelona, Spain, July, 2000.

Abstract: Mobile-agent systems allow user programs to autonomously relocate from one host site to another. This autonomy provides a powerful, flexible architecture on which to build distributed applications. The asynchronous, decentralized nature of mobile-agent systems makes them flexible, but also hinders their deployment. We argue that a market-based approach, where agents buy computational resources from their hosts solves many problems faced by mobile-agent systems.

In our earlier work, we propose a policy for allocating general computational priority among agents posed as a competitive game for which we derive a unique computable Nash equilibrium. Here we improve on our earlier approach by implementing resource guarantees where mobile-agent hosts issue call options on computational resources. Call options allow an agent to reserve and guarantee the cost and time necessary to complete its itinerary before the agent begins execution.

We present an algorithm based upon the binomial options-pricing model that estimates future congestion to allow hosts to evaluate call options; methods for agents to measure the risk associated with their performance and compare their expected utility of competing in the computational spot market with utilizing resource options; and test our theory with simulations to show that option trade reduces variance in agent completion times.

Robert S. Gray, George Cybenko, David Kotz, Ronald A. Peterson and Daniela Rus. **D'Agents: Applications and Performance of a Mobile-Agent System**. Submitted to *Software Practice and Experience,* November, 2000.

Abstract: D'Agents is a mobile-agent system that is used primarily for information-retrieval applications. In this paper, we first examine two such applications, where mobile agents greatly simplify the task of providing efficient but application-specific access to remote information resources. Then we describe the D'Agents system, which supports multiple languages, Tcl, Java and Scheme, and strong mobility for Tcl and Java. After considering the D'Agents implementation, we present some recent performance and scalability experiments that compare D'Agent mobile agents with traditional client/server approaches. The experiments show that mobile agents often outperform client/server solutions, but also demonstrate the deep interaction between environmental and application parameters. The mobile-agent performance space as a whole is complex, and significant additional experiments are needed to characterize it. Finally, after discussing current and future experiments, we explore the differences between D'Agents and other mobile-agent systems.

George Cybenko and Guofei Jiang. **Developing a Distributed System for Infrastructure Protection.** *IT Pro,* 2(4):2-7, July/August, 2000.

Abstract: National-scale critical infrastructure protection depends on many processes: intelligence gathering, analysis, interdiction, detection, response and recovery, to name a few. These processes are typically carried out by different individuals, agencies and industry sectors. Many new threats to national infrastructure are arising from the complex couplings that exist between advanced information technologies (telecommunications and internet), physical components (utilities), human services (health, law enforcement, emergency management) and commerce (financial services, logistics). Those threats arise and evolve at a rate governed by human intelligence and innovation, on "internet time" so to speak. The processes for infrastructure protection must operate on the same time scale to be effective. To achieve this, a new approach to integrating, coordinating and managing infrastructure protection must be deployed. To this end, we have designed an underlying web-like architecture that will serve as a platform for the decentralized monitoring and management of national critical infrastructures.

David Kotz, George Cybenko, Robert S. Gray, Guofei Jiang, Ronald A. Peterson, Martin O. Hofmann, Daria A. Chacon, Kenneth R. Whitebread and Jim Hendler. **Performance Analysis of Mobile Agents for Filtering Data Streams on Wireless Networks**. October, 2000. To appear in *ACM MONET*.

Abstract: Wireless networks are an ideal environment for mobile agents, since their mobility allows them to move across an unreliable link to reside on a wired host, next to or closer to the resources that they need to use. Furthermore, client-specific data transformations can be moved across the wireless link and run on a wired gateway server, reducing bandwidth demands. In this paper we examine the tradeoffs faced when deciding whether to use mobile agents in a data-filtering application where numerous wireless clients filter information from a large data stream arriving across the wired network. We develop an analytical model and use parameters from filtering experiments conducted during a U.S. Navy fleet Battle Experiment (FBE) to explore the model's implications.

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Geographically Distributed Sensors

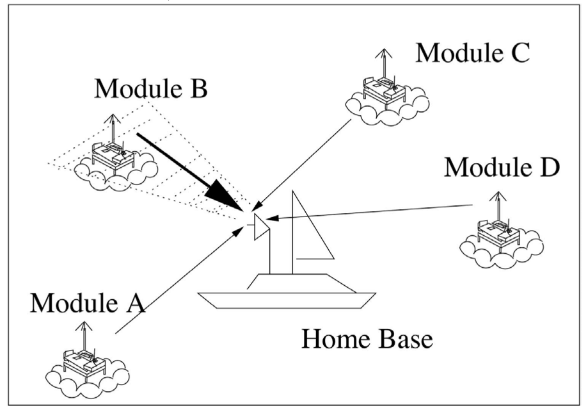
Michael G. Corr and C. M. Okino

The goal of this research project is to develop a sensor module and corresponding network routing scheme for the application of distributed data acquisition networks. Specifically, we consider a network of sensors capable of obtaining, processing, and forwarding data to a central and potentially distant location. Such a network can be used to monitor events such as brush fires, hazardous chemical spills, and violent storms. The concept of independent and distributed collection and processing of sensor data in a geographically distributed topology is defined as a *Distributed Smart Sensor Network* (DSSN).

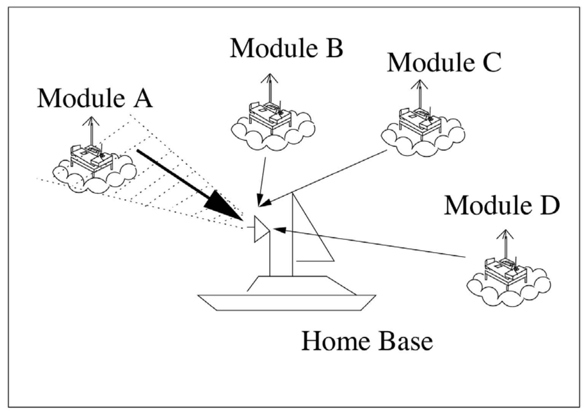
In this research, we introduce a novel approach of addressing each module purely by its acquired GPS position. Each sensor unit uses a GPS receiver to acquire its current position at a regular interval. The unit's position, within some threshold factor, is then used to identify the unit, analogous to an IP address. Sensor units use their newly acquired address as an identifier for routing and communicating among each other. This idea differs from IP addressing in that the address is not fixed, since it will change as the unit's location changes.

To demonstrate the value of this concept, consider the scenario where a number of sensors are scattered in the ocean, gathering localized temperature readings. Due to uncontrollable environmental affects, the sensor network topology is volatile.

Therefore, information gathered by the sensors should be location dependent, not identity dependent. As an example, Figure 1(a) depicts data being collected in the shaded region occupied originally by sensor ***B***. After some time, sensor ***A*** occupies sensor ***B***'s coordinates as depicted in Figure 1(b). This repositioning of the units is transparent to Home due to the geographical nature of the sensor identification.



(a) initial state of sensors



(b) after sensors have drifted

Figure 1: Geographical addressing of networked sensors - location oriented data acquisition

The Sensor Modules

The smart sensor modules are all identical, in terms of both hardware and software. The homogeneous design eliminates inherent hierarchical dependencies between sensor modules. These modules are composed of fundamental functional blocks that are primarily commercial-off-the-shelf (COTS) parts. Each unit as shown in Figure 2, is equipped with an off-the-shelf microprocessor, RF transceiver, GPS receiver, and sensor. The modular design reduces development cost and time (off-the-shelf parts are readily available and fairly inexpensive), and allows easy replacement or enhancement to meet specific mission goals (e.g. change type of sensor, or replace an RF FM modulation unit with a low power RF spread spectrum unit to minimize the effect of RF jamming and detection). This idea allows for reusability and "reconfigurability" of the same sensors for multiple missions.

The GAaRP algorithm

In this section, we briefly describe our routing protocol, GAaRP (*Geographical Addressing and Routing Protocol*). The routing protocol involves initial acquisition of a GPS position, followed by an RF signal message used to "ignite" communication with modules in RF range. Once a module negotiates

This research was partially supported by National Science Foundation grant CCR-98113744, Air Force Office of Scientific Research Multidisciplinary University Research Initiative Grant F49620-97-1-0382, and DARPA Contract F30602-98-2-0107.

and establishes a valid route, the module announces this new route to other modules within RF range. This procedure is repeated in a radial fashion until the entire network is configured relative to a Home position. A cost-function algorithm determines

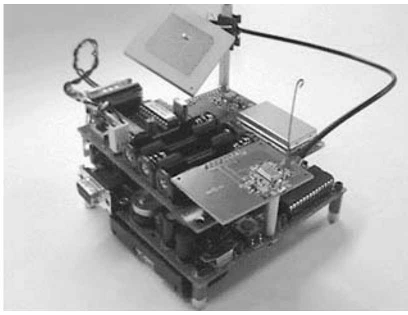


Figure 2: Smart Sensor Module

optimal routes based on radial distance, angular difference between multiple candidate routes, number of hops to a Home destination, and number of available slots through the routing node. Link routes are continuously updated on a fixed interval basis.

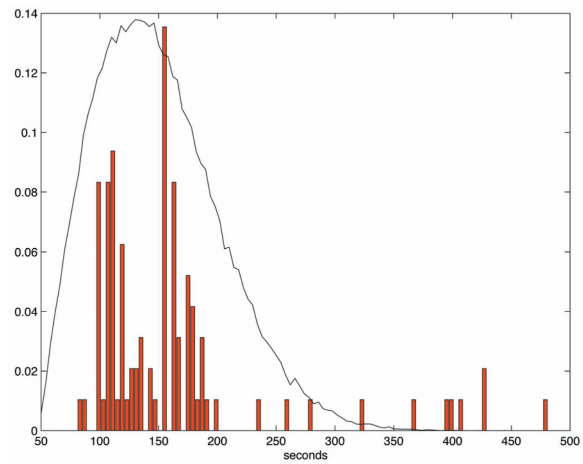
The development of the GAaRP algorithm takes into account the inherent characteristics of a typical sensor unit: the units have limited power since they run off batteries; the sensor units have limited memory (RAM) and program space (ROM); and transmission ranges are limited thus requiring the ability to forward information in a hop-by-hop manner through several units before reaching an intended destination.

The routing protocol also takes into account the unique characteristics of a typical network in which these sensor units will be deployed: the network is primarily used for data acquisition, *not* for communication; the network consists of many small sensor units with only *one* or *few* central Home terminals; when collecting data from the network, a user (Home) is concerned with geographically *where* the data comes from and not specifically *who* it comes from; all sensor data is localized; and the network is polarized (i.e. *data communication* is one way, from unit to Home while *control communication* flows the other way, from Home to unit).

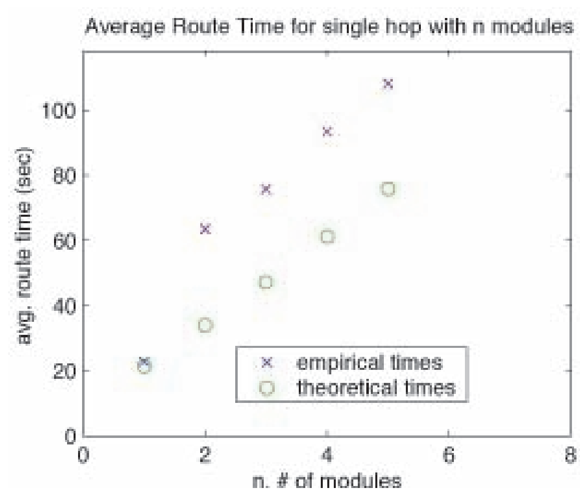
Current Results

Recent field-testing of the sensor modules and the GAaRP algorithm involved ***6*** modules with one used as a Home module. Acquisition times for GPS locations are shown in Figure 3(a). Routing times obtained for the single hop case by varying the number of competing modules are depicted in Figure 3(b).

Preliminary tests for the multiple-hop scenario indicate that incremental route times decrease as the network approaches a completed routing topology. Specifically, as more sensor units establish routes, the remaining units have a greater chance of establishing a link, thus reducing their individual setup times. In no case was a sensor unit left without a route.



(a) GPS acquisition times



(b) Single Hop, Multiple Nodes

Figure 3: Resulting "times"

Summary

The project involves extensive field-testing of off-the-shelf equipment, integrated with an innovative routing protocol. Currently, six prototype modules have been placed together with some level of self-routing connectivity tested. Initial results convey a good understanding of the characteristics of the protocol, although there is a need for further optimization and testing to prove the GAaRP protocol as a useful and effective ad-hoc routing scheme.

For further information on geographical information used as an addressing and routing methodology, visit:
http://actcomm.dartmouth.edu/~mgcorr/

New Research Papers, *continued from p. 3*

Michael G. Corr and C. Okino. **Networking Reconfigurable Smart Sensors**. *Proceedings of SPIE,* Vol 4232 Enabling Technologies for Law Enforcement and Security.

Abstract: The advances in sensing devices and integrated circuit technology have allowed for the development of easily "reconfigurable smart sensor" products. Primarily utilizing commercial off-the-shelf (COTS) components, we have developed reconfigurable smart sensor, consisting of a microprocessor, GPS receiver, RF transceiver, and sensor. The standard serial control interface allows for ease of interchangeability for upgrades in RF transmission schemes as well as customizing the sensing device (i.e. temperature, video images, IR, motion, Ethernet) per application. The result is a flexible module capable of gathering sensor data, local processing, and forwarding compressed information to a central location via other module.

In this paper, we present our system infrastructure design and a cost function based geographical self-routing algorithm for networking reconfigurable smart sensors. The algorithm allows for the sensors to automatically negotiate in a geographical radial topology relative to a central location, utilizing other sensors as routes or hops for forwarding information to this central location. A number of these sensors are deployed in the field and performance measurements for routing times are analyzed and presented.

Daniela Rus, Clifford Stein, Rong Xie. **Scheduling Multi-Task Multi-Agent Systems.** Submitted to *Autonomous Agents 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.

Guanling Chen and David Kotz**. A Survey of Context-Aware Mobile Computing Research.** *Dartmouth Technical Report TR2000-381*.

Abstract: Context-aware computing is a mobile computing paradigm in which applications can discover and take advantage of contextual information (such as user location, time of day, nearby people and devices, and user activity). Since it was proposed about a decade ago, many researchers have studied this topic and built several context-aware applications to demonstrate the usefulness of this new technology. Context-aware applications (or the system infrastructure to support them), however, have never been widely available to everyday users. In this survey of research on context-aware systems and applications, we looked in depth at the types of context used and models of context information, at systems that support collecting and disseminating context, and at applications that adapt to the changing context. Through this survey, it is clear that context-aware research is an old but rich area for research. The difficulties and possible solutions we outline serve as guidance for researchers hoping to make context-aware computing a reality.

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

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

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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.