

# Integrating CASA ERC Wireless Networking Research into Education

Byron Wallace<sup>1</sup>, Wayne Burleson<sup>2</sup>, Brian Donovan<sup>3</sup>, Jim Kurose<sup>4</sup>, Irene Ros<sup>5</sup>, and Michael Zink<sup>6</sup>

**Abstract** - A key CASA innovation, **Distributed Collaborative Adaptive Sensing (DCAS)**, relies on the networking of adaptive sensors to achieve observations not possible with traditional sensors. Innovative wireless networks, in particular, are needed to support off-the-grid radars such as those being developed in Puerto Rico as part of the CASA IP5 test-bed. In fall 2005, CASA faculty and students explored recent research in wireless networking through a novel, hands-on undergraduate course. Prof. James Kurose and CASA Research Scientist Mike Zink led a team of 9 undergraduate and graduate students and researchers to develop, deploy and measure novel outdoor networks based on the 802.11 standard. The course, UMASS Computer Science 496A, was archived in a novel multimedia format called jMANIC that was developed by CASA student Byron Wallace in collaboration with the UMASS RIPPLES group as part of the CASA Education and Outreach thrust. jMANIC provides a browser-based viewer of synchronized video, audio and graphics with search and logging capabilities. Using the materials developed in the course, Prof. Kurose and three students (Brian Donovan, Tim Ireland and Adam Nyzio) offered a 2-day version of the course at CASA partner University of Puerto Rico Mayaguez (UPRM), which consisted of lectures as well as outdoor installation and experimentation with wireless networks. This course was also archived and is available on CD and on the Internet for further dissemination.

*Index Terms* - Hands-on, Outdoor, Experimental content, Novel archival multimedia applications, Student research

## INTRODUCTION AND MOTIVATION

Wireless networks of adaptive sensor nodes are vital to CASA's DCAS paradigm, which uses a dense coordinated network of radars capable of high spatial and temporal resolution. DCAS is a critical aspect of CASA because modern single-beam antenna observing radars often provide insufficient coverage at low altitudes located far away from the radars due to the curvature of the Earth and terrain-induced blocking [1]. DCAS employs collaborative, distributed sensing to achieve greater sensitivity, precision and resolution [1]. DCAS radar nodes require a high degree of

communication to achieve collaborative real-time sensing of the atmosphere, and 802.11 is an efficient, low-cost means of providing such a communication channel in "off-the-grid" settings where there is no existing network or power infrastructure, such as the IP5 test-bed in Puerto Rico.

802.11 is currently the most popular Wi-Fi standard. As a result of mass production, 802.11 equipment is relatively inexpensive. However, the 802.11 standard was not originally designed for long distance communication. Moreover, 802.11 is typically used for point-to-multipoint communication rather than point-to-point communication. While some research has been done on using 802.11 in non-traditional ways [2], including deploying long-distance hops, this work was focused primarily on providing access to end users (i.e., on point-to-multipoint applications).

Computer Science 496a was a novel undergraduate course created to allow CASA researchers as well as graduate and undergraduate students to conduct research in using 802.11 for long distance point-to-point networking. The research was inherently cross-disciplinary, bringing together elements of engineering, meteorology and Computer Science. This was another important aspect of the course, because it was demonstrative of the increasingly diverse applications of the principles of Computer Science. Furthermore, it introduced students to the nature of cross-disciplinary research in an academic environment.

In this paper we explore the research that was conducted and how it is applicable to CASA. We then consider the pedagogical aspects of integrating applicable research into undergraduate curricula. Next, we investigate the use of a novel archival tool used to document the process, called jMANIC. Finally, we evaluate the shortened version of Computer Science 496a offered at UPRM and present data gathered from student evaluations of the version offered at UMass, Amherst.

## APPLICATION OF RESEARCH TO THE CASA PROJECT

The primary research aim of the class was to measure link throughput over long distances using 802.11 together with directional antennas. Another important goal was to archive the process of setting up both the necessary hardware and software components, so that experiments could be replicated in Puerto Rico. Further, it was important that the class was

<sup>1</sup> Byron Wallace, University of Massachusetts Amherst, Department of Computer Science, byron@cs.umass.edu

<sup>2</sup> Wayne Burleson, University of Massachusetts Amherst, Department of Electrical and Computer Engineering, burleson@ece.umass.edu

<sup>3</sup> Brian Donovan, University of Massachusetts Amherst, Department of Electrical and Computer Engineering, donovan@mirsl.ecs.umass.edu

<sup>4</sup> James Kurose, University of Massachusetts Amherst, Department of Computer Science, kurose@cs.umass.edu

<sup>5</sup> Irene Ros, University of Massachusetts Amherst, Department of Computer Science, iros@us.ibm.com

<sup>6</sup> Michael Zink, University of Massachusetts Amherst, Department of Computer Science, zink@cs.umass.edu

archived digitally for further dissemination. Table I lists all equipment used in experiments. The total cost of the hardware used to conduct experiments totaled about \$2,800.

TABLE I  
EQUIPMENT LIST

Description	Part Number
VIA EPIA MII6000 Motherboard	MII6000
Compact Flash to IDE Adapter	CFDISK.5G
PC2100 / DDR 266 Memory	DDR266-512
Morex 60W Power Kit	PowerKit60
1 GB Compact Flash Card	PE188993
Morex Venus 668S Case - Silver	Venus 668S
Proxim Orinoco 11b/g PC Card	8470-FC
MC - N PigTail	CA-MCNFCN19
cable N-Male to N-Male, 50 ft	CA-6NMNM050
cable N-Male to N-Male, 100 ft	CA-6NMNM100
Antenna - Yagi 14 dBi	HG2415Y
Antenna - Parabolic Disk 24 dBi	HG2424G
Antenna - Parabolic Dish 30 dBi	HG2430G

Experiments were conducted using nodes that the class assembled, which were bare bones Wi-Fi enabled Linux boxes. The nodes consumed very little power and could be powered by a car's cigarette lighter using an adapter. Antennas were attached to the Wi-Fi cards in order to amplify signal strength. Various tools were used to monitor throughput rates (bytes received per second) including iperf, wavemon, tcpdump and wu-ftpd.

The experiments consisted of collecting throughput measurements of point-to-point traffic between nodes separated by distances ranging from hundreds of yards to roughly eleven miles. Data was saved onto the nodes' flash memory to be later analyzed. In order to demonstrate the type of data being collected in experimentation, we include Figure 1, a graph of data collected in an experiment where one node was atop the UMass Computer Science building on campus in Amherst while the other was on Hubbard Hill Road in Leverett, Massachusetts, a distance of about six miles. The graph plots TCP throughput versus time, and maintains running averages of instantaneous throughput.

This type of data is important to the DCAS approach because it is vital that the weather sensors are able to communicate effectively with one another, and in off-the-grid settings 802.11 provides the means for communication. It is also important in such a setting to know the average data throughput rate one is able to achieve at a given distance because of the real-time collaborative properties of DCAS. The research conducted in 496a provided important information on both of these fronts.

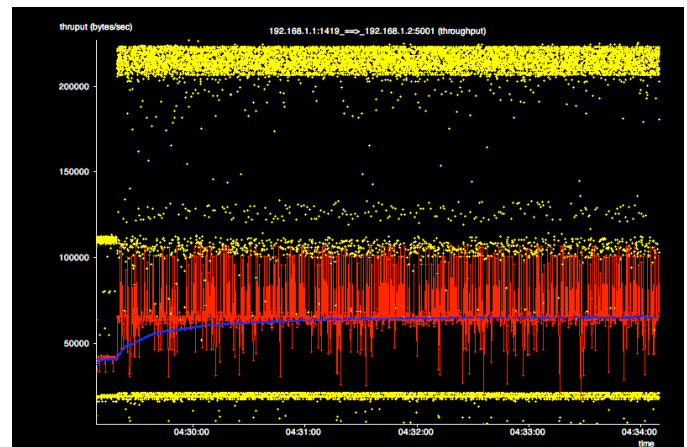


FIGURE 1  
TCP TRAFFIC THROUGHPUT GRAPH

### PEDAGOGY

The class had two primary components: outdoor experimentation and weekly meetings. This is a departure from the more traditional undergraduate lecture-only course model, and also differs from a typical 'independent study' wherein students usually work individually under a supervising faculty member. The meetings were used to analyze data that had been collected in previous experimentation, to plan upcoming experiments and to review relevant topics in networking (e.g., specific routing protocols). This type of class structure allowed participating students and researchers to share their opinions regarding the experiments conducted the previous week(s) and to collectively design and plan upcoming experiments. Moreover, the field experimentation component provided the opportunity for students to apply the knowledge acquired in the classroom directly.

Undergraduate research has traditionally been a didactic method for teaching science and engineering students how to conduct research properly. In other words, it is often the case that rather than conducting useful and novel research, undergraduates carry out experiments strictly for pedagogical purposes, in order to develop research skills. Indeed, including undergraduates in research can improve not only their research skills but also their communication and problem-solving skills [3]. Computer Science 496a was novel because the research conducted under the guidance of Professor Kurose and CASA Research Scientist Michael Zink was directly applicable the CASA project.

Students were divided into groups of three members, and each group was responsible for conducting their own experiments outside of the allotted class meeting times. This group dynamic resulted in students learning from their peers as well as from their instructor, especially with respect to the technical components of the experiments. Groups gave presentations regarding the experiments they conducted in order to share data, lessons learned and anything else that might be useful to the class. This presented the opportunity for

students to improve their communication skills by conveying knowledge to their peers.

Each student was required to maintain a ‘journal’ with responses to papers that the class had read and notes on experiments conducted. Students were also occasionally asked to independently research a topic (for example, a specific multi-hop routing protocol) and then communicate what they had learned

**JMANIC: A NOVEL ARCHIVAL APPLICATION**

One of the key aspects of the CASA project is its education and outreach component. It is a strategic goal of CASA to explore the development and use of innovative multimedia to support all aspects of the Center. To this end, CASA has compiled a multimedia archive at <http://www.casa.umass.edu/educationandoutreach/multimedia.html> in collaboration with the (Research In Production and Presentation for Learning Electronically) RIPPLES project.

In the past, the RIPPLES group has used the CD-MANIC format supplemented with papers, images and other materials along with custom-built interfaces in order to archive CASA multimedia [4]. CD-MANIC is an implementation of the general MANIC engine, which is a framework for viewing and navigating slides that are synchronized with audio and video. The primary advantages of CD-MANIC are ease of use and accessibility, allowing users to playback locally stored multimedia anywhere. However, there are drawbacks to CD-MANIC. Specifically, it is platform specific (limited to 32-bit Windows platforms) and is capable of playing back only local content (e.g., slides and video cannot be stored remotely via the internet).

Computer Science 496a was the first course to be archived with the newest implementation of the MANIC engine: jMANIC, a pure-java, cross-platform application. jMANIC maintains the usability of CD-MANIC while allowing for playback of both local and remote content stored on the web. Moreover, jMANIC can be launched via Java Web Start with an Internet browser, or it can be launched locally. Because jMANIC content can be web-based, lectures (also referred to as ‘sessions’) can be posted in real-time as the course progresses. This is an advantage over physical media, where one has to create new CDs or DVDs in order to disseminate new content. Figure 2 shows the jMANIC interface.

While similar course content delivery mediums exist, such as the MIT Physics Interactive Video Tutor project (PIVOT) [5], eClass from Georgetown Tech University [6], the CMU Just-In-Time-Learning (JITL) system [7], the Cornell Lecture Browser [8] and Authoring on the Fly (AOF) [9], jMANIC is unique in a number of ways. For instance, jMANIC is cross-platform, open-source, capable of playing back both locally and remotely stored content, can be launched via the Web or locally, features an extendable plug-in architecture and requires only the Java Virtual Machine (version 1.3+) because it is a pure-JAVA application. As far as we are aware, jMANIC is the only courseware system with all of the aforementioned attributes.

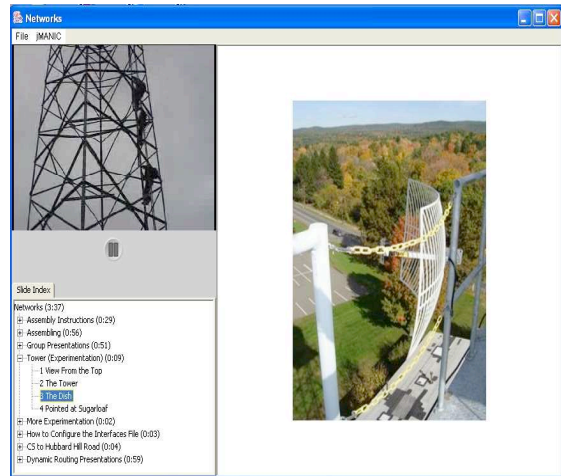


FIGURE 2  
SCREENSHOT OF JMANIC

For CS 496a, jMANIC was used as an archival tool rather than as a means for supplemental self-study. Both the lectures and the experiments were encoded into the jMANIC format and posted to the web for public access. The archived course could then be used both by those in academic settings as well as by the public for purposes of dissemination and outreach through multimedia.

A Macromedia Flash© front end was created for the jMANIC presentation and other data (including graphs, images and instructions). The course can be accessed here: <http://manic.cs.umass.edu/jMANIC/fall05/cs491/WirelessNetworksWeb.html>. Note that Flash is cross-platform (one need only have a Flash player installed) and so this does not compromise the platform independence of the presentation. The front-end, shown in Figure 3, provides access to a collection of content relevant to CS 496a, including research papers, data collected during experiments, pictures, the jMANIC presentations and PowerPoint© slides. The course was also distributed on CD in order to avoid network connectivity problems for users that may not have broadband Internet access.



FIGURE 3  
SCREENSHOT OF USER INTERFACEB

## OFFERING THE COURSE IN PUERTO-RICO

In preparation for the CASA IP5 test-bed in Puerto-Rico a shortened version of the course was offered to engineering students at the University of Puerto Rico, Mayagüez. Approximately fifteen students took part in the two-day course instructed by Professor Jim Kurose and graduate student Brian Donovan. Undergraduate students Adam Nyzio and Tim Ireland, who both participated in CS 496a at UMass, Amherst, also assisted with instructing the class.

The first day of the course focused on an overview by Professor Jim Kurose, students were given a whirlwind introduction to fundamental networking concepts, with special emphasis on wireless networks. The UPRM students were not assumed to have a background in networking, so this overview was a way of exposing them to the requisite concepts that CS 496a students had encountered in the required networking course (Computer Science 453) at UMass, Amherst.

On the second day, students took part in a demonstration conducted by Adam Nyzio, Tim Ireland and Brian Donovan. Initially a short distance experiment (a few hundred feet) was set up to illustrate the required hardware assembly process, and to demonstrate the basics of creating a connection between two points via the 802.11 wireless protocol. Several common pitfalls that were discovered throughout the semester-long CS 496a course were communicated to the UPRM students, and this prevented them from making the same mistakes.

The second experiment involved a longer distance between the two communication points (approximately 1.5 miles.) Although all equipment for experimentation in CS 496a had been transferred to Puerto Rico, several different computers were used for this experiment, resulting in complications. Consequently, students were exposed to the process of dealing with problems that arise ‘in the field’, and the troubleshooting processes inherent in experiment-based research.

After the two-day intensive introduction and training component, the UPRM students had acquired enough knowledge to setup and conduct their own experiments with point-to-point 802.11. This is demonstrative of the efficiency with which the knowledge acquired in CS 496a had been communicated to the UPRM students.

## POST-COURSE STUDENT EVALUATIONS

After completion of the course at UMass, Amherst a questionnaire was distributed to the course participants. Table II shows tabulated response data where students were asked how much (on a scale from 1 to 5) they felt they had learned with respect to different components of the class.

Of particular interest is the fact that on average, students felt as though they had learned a substantial amount about conducting research and experimentation. This supports the hypothesis that undergraduate students in the engineering disciplines can benefit greatly from conducting hands-on research, especially since many colleges do not have a required research component for undergraduates.

TABLE 2  
AVERAGED RESPONSE DATA

How much do you feel you learned with respect to the following? (Scale: 1-5)	
Hardware	3.2
Unix	3.8
Group Work	4
Conduct research and experimentation	4
Design research and experimentation	3.4

Another noteworthy element of the response survey is that students were nearly unanimous in enjoying the group work component of the class. Indeed, traditional class work is not always conducive to group-oriented problem solving. CS 496a required group problem solving in order to overcome challenges in the field during experiments. Moreover, students were assigned to groups of three, and each group was responsible for carrying out an experiment independent of the weekly class meeting time.

The questionnaire also allowed for students to comment on the course qualitatively. One student noted: “I feel as though I learned more in this class than I have in most other Computer Science classes due to the technical ‘hands-on’ elements.”

## LESSONS LEARNED

In general, the response to this class from all participants, students as well as faculty, was uniformly positive. Furthermore, the experiments were replicated with success in UPRM and the information acquired through the research conducted in the course has been assimilated into the CASA knowledge base. The successes of the class include:

- **Research experience for undergraduates:** Students had a rare opportunity to “get their hands dirty” conducting experiments in the field. Feedback surveys filled out by the students suggest that most felt that they acquired some level of expertise in research. The surveys additionally indicated that the students generally enjoyed the format of the class and gained technical skills as well.
- **Real-world implementation of networking concepts:** Students benefited from having the opportunity to apply previously learned theoretical concepts to hands on experimentation thus providing them with skills of theory application.
- **Successful replication at UPRM:** The experiments and set up procedure were replicated at the test-bed in Puerto Rico, Mayagüez. The relevant knowledge was communicated efficiently to the UPRM students and mistakes made during the semester in CS 496a were avoided.
- **Content dissemination with a new multimedia archival format:** CS 496a has been posted on the CASA Multimedia Outreach and Education webpage for public

access. Interested parties, from researchers to the general public, can now view the experiments and associated data. Some things that might have been done differently:

- **Reduce costs by not purchasing equipment not likely to be used:** Students of CS496a were fortunate to have the ability to experiment with multiple hardware assemblies. However, due to time constraints and transport limitations some of the equipment was not used over the duration of the course. This includes the larger (and more expensive) parabolic dish, which was too cumbersome to be transported about for field experiments.
- **Winter weather not always conducive to outdoor activity:** Due to a large portion of the class involving outdoor activity, bad weather occasionally forced students to cancel outdoor activity limiting the amount of data gathered in the field.
- **Give A Crash-Course in Unix prior to experimentation:** It was noted on the questionnaire by several students that they would have benefited from a more thorough introduction to Unix prior to engaging in experiments. This is primarily because with the hardware and software configuration used in CS 496a, a detailed working knowledge of Unix commands was vital for participation. Indeed, some students noted that within their groups they were not able to participate to the degree they would have liked to due to their relative inexperience with Unix.
- **Increase outdoor activity:** Many of the students expressed interest in conducting more experimentation to further their understanding and knowledge of the course material. This was not always possible due to high reliance on group work and therefore personal conflicts limited the meeting schedule. One possible solution would be to clearly define weekly experiment times prior to the start of the class.
- **Increase personal research requirements:** Given the dynamic nature of the class much of the content came from additional work conducted by students in their spare time which allowed for newly discovered material and previous related research to be incorporated into the course. However, additional research outside the scope of the class was not mandatory and so the amount of discovery was fairly limited. A higher focus on individual research would benefit the progression of the course greatly. Potentially a list of related topics would have peaked students' curiosity and drove them to discover new information on a regular basis.
- **Decrease hardware setup times:** Frequently outdoor meetings were limited by individual schedules and did not allow for boundless experimentation. A considerable amount of time, especially at the beginning of the course was spent on setting up the required equipment for experimentation. Although a valuable lesson it was none the less a hurdle to overcome once understanding of the setup was gained. If possible, setup time should have been decreased by providing improved methods of

transportation that would allow for delivery of pre-assembled experimentation nodes to the field or optimization of the setup procedure should have been considered to speed up the process.

### CONCLUSIONS AND FUTURE WORK

CS 496a was a great success in terms of providing undergraduates with real, hands-on research experience and also with respect to gathering data vital to CASA's DCAS sensing approach. The experiments were replicated without any substantial problems at UPRM. The RIPPLES group developed jMANIC, a cross-platform web-ready courseware system that was used by CASA for information dissemination as part of their outreach and education thrust. The RIPPLES group will continue to collaborate with CASA for the purposes of creating multimedia modules and archives to assist CASA in it's goal of both providing the general public and researchers with convenient ways to access existing data.

Future experimentation might include 802.11 experiments where nodes are "installed" for long durations of time at fixed points and traffic is measured continuously over this time period. This might help CASA researchers gain insight into how fluctuations in weather might affect 802.11 traffic. Finally, faculty at involved with CASA research at UMass, Amherst will seek to continue including undergraduates in conducting research.

### ACKNOWLEDGEMENT

This work was primarily supported by the Engineering Research Centers Program of the National Science Foundation under NSF Award Number 0313747. Any Opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the National Science Foundation.

### REFERENCES

- [1] McLaughlin, David, Chandrasekar, V., Droegeimer, Kelvin, Frasier, Stephen, Kurose, Jim, et. al. "Distributed Collaborative Adaptive Sensing (DCAS) for Improved Detection, Understanding, and Predicting of Atmospheric Hazards." *2005 American Meteorological Society (85th AMS Annual Meeting), Ninth Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS)*, 2005.
- [2] Bhagwat, Pravin, Raman, Bhaskaran and Sanghi, Dheeraj "Turning 802.11 Inside-Out.", *Second Workshop on Hot Topics in Networks (HotNets-II)*. Nov 2003, Cambridge, MA, USA.
- [3] Gates, Ann, Patricia, Teller, Andrew, Bernat, Delgado and Della-Piana, Connie, 1998. "Meeting the Challenge of Expanding Participation in the Undergraduate Research Experience." *In Proceedings of the IEEE Nelly28th Annual Frontiers in Education Conference*, Nov. 4-7, Tempe, AZ.
- [4] Wallace, Byron, Adrion, Rick, Cooper, Wendy, Kurose, James, and Watts, Ken. "Using Multimedia to Support Research, Education and Outreach in an NSF Engineering Research Center." *35th ASEE/IEEE Frontiers in Education Conference*. Oct. 2005, Indianapolis, IN.
- [5] A. Lipson. "A Three-School Comparative Analysis of Student Usage Patterns and Attitudes Toward PIVoT"

<http://caes.mit.edu/research/pivot/index.html> (downloaded March 10, 2005).

- [6] G. Abowd, "Classroom 2000: An Experiment with the Instrumentation of a Living Educational Environment," *IBM Systems Journal*, Special issue on Pervasive Computing, Volume 38, No. 4, pp. 508-530. 1999.
- [7] Just-In-Time Lectures, <http://www.jitl.cs.cmu.edu/> (downloaded March 10, 2005).
- [8] S. Mukhopadhyay and B. Smith, "Passive Capture and Structuring of Lectures," *Proceedings of ACM Multimedia'99*. Orlando, FL pp.477-487. 1999.
- [9] C. Bacher, R. Muller, T. Ottmann, and M. Will, "Authoring on the Fly. A New Way of Integrating Telepresentation and Courseware Production," *Proceedings of International Conference on Computers in Education (ICCE'97)*. Kuching, Sarawak, Malaysia. 1997