>>> *FINAL REPORT* <<<

Advances in Networked Video to Improve Safety, Effectiveness, and Security of Florida Spaceport Operations

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Reference: FSREGP Spring 2001 cycle grant (Christensen, "Advances in Networked Video to Improve Safety, Effectiveness, and Security of Florida Spaceport Operations")

Project website: *http://www.csee.usf.edu/~christen/space/main.html*

Date of report: August 30, 2002

Period of performance: 1 year (September 1, 2001 to August 31, 2002)

Total Funding: $30,000

Name of organization: University of South Florida, Department of Computer Science and Engineering

Summary of Project

This project had two goals. The first goal was to explore the feasibility of adding video cameras to the clothing of spaceport technicians, or video-enabled technicians. Wearable video cameras can enable real-time consultation with off-site experts and allow for archiving of procedures for later safety audits or for use as training instruments. The second goal was to investigate new protocols for low-cost video transport to support deployment of thousands of video cameras in a local area (e.g., within a hanger or other facility). Such video infrastructures based on wired sensor networks have great promise for improving safety and security of spaceport operations.

For the video-enabled technician, our focus was on evaluating COTS hardware and software products. We completed an evaluation of existing products. We prototyped and evaluated a proof-of-concept video-enabled technician. For the wired sensor network, we focused on the emerging IEEE 1394b FireWire technology as a means of building large-scale and high-bandwidth wired sensor networks. We developed simulation models of FireWire networks and showed the feasibility of using FireWire for video transport. We also investigated location and attribute routing as needed for video surveillance. This effort resulted in an NSF proposal (submitted on July 29, 2002) for $449,705.

Project Accomplishments

This section describes project accomplishments. Referenced video clips, simulation models, and so on are all available at the project website at *http://www.csee.usf.edu/~christen/space/main.html* (Appendix A).

Funding of students and faculty

This grant supported (20 hours per week) two students for one year and faculty release time for one course. The students supported were:

- Christine Bexley (*http://www.eng.usf.edu/~bexley*) – Undergraduate honors student
- Vijay Chandramohan (*http://www.csee.usf.edu/~vchandr2*) – Graduate student
- John Shahbazian (*http://www.csee.usf.edu/~jshahbaz*) – Graduate student

Christine was supported for Fall 2001 and Spring 2002 semesters, John for Fall 2001 semester, and Vijay for Spring and Summer 2002 semesters. Christine is graduating in Fall 2002 and will be pursuing a PhD at the University of Notre Dame on a four-year graduate fellowship. John is a direct PhD student at the University of South Florida. Vijay is finishing his MS in Fall 2002 and will then decide whether to pursue a PhD.

Accomplishments for the video-enabled technician

The idea of a video-enabled technician was prototyped and evaluated. A video-enabled technician has a head-mounted bullet camera and a wireless transmitter. The concept is somewhat similar to that of the NFL "UmpCam". Figure 1 shows Christine as a prototype video-enabled technician.

Notes:

- The prototype consisted of a wireless transmitter and receiver, a bullet camera with RCA output, an RCA to USF converter, and a microphone.
- The procedure used to evaluate this proof-of-concept was to remove and replace a hard-drive in a PC using a formally described procedure. Video clips of the procedure for both a head-mounted and fixed-mounted camera can be found on the project website.

Figure 1. Prototype video enabled technician

Accomplishments for this portion of the project were:

- Evaluation of COTS software and hardware suitable for implementing a video-enabled technician.
- Development of a prototype video enabled technician using off the shelf video and wireless equipment.
- Demonstration of a mock procedure done by a video enabled technician. This demonstration was done in the Information Systems Laboratory at the University of South Florida.
- An evaluation report for the above.
- An honors thesis (Christine Bexley) submitted to the University of South Florida Honors College

We failed to find a satisfactory way to archive video locally (i.e., on a wearable on the human) when the wireless link was degraded. The video clips, evaluation, and Christine's honors thesis are posted on the project website.

Summary: We found that inexpensive cameras with relatively low bandwidth (several hundred kilobits per second) can achieve very high quality video. We found that installing cameras on people may be less practical than having stationary cameras focused on work areas. Wearable cameras are not always pointing at the workspace and require wireless links that sometimes degrade video quality (for which no satisfactory solution was found).

Accomplishments for video surveillance wired sensor networks

The largest cost component in an existing surveillance system is the cabling and underlying network infrastructure. Camera costs are rapidly decreasing; this is not the case of network costs based on dedicated cabling for each camera. To support economical growth in the size of video surveillance systems, shared-medium, "daisy-chained" protocols are needed. We found that IEEE 1394b FireWire is a very promising protocol for this application. Its delay and throughput performance for video streams was shown to be excellent. Improvements to allow for spatial reuse of bandwidth and for prioritizing video streams were identified and are being investigated. Figure 2 shows a large-scale video surveillance system with a shared-medium subsystem.

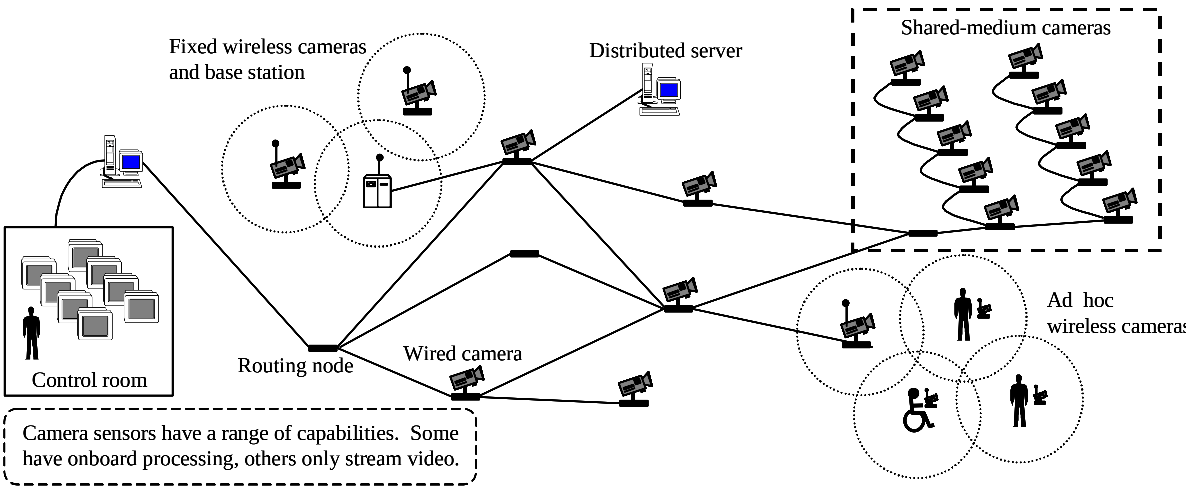


Figure 2. Future video surveillance system including a shared-medium subsystem

Accomplishments for this portion of the project were:

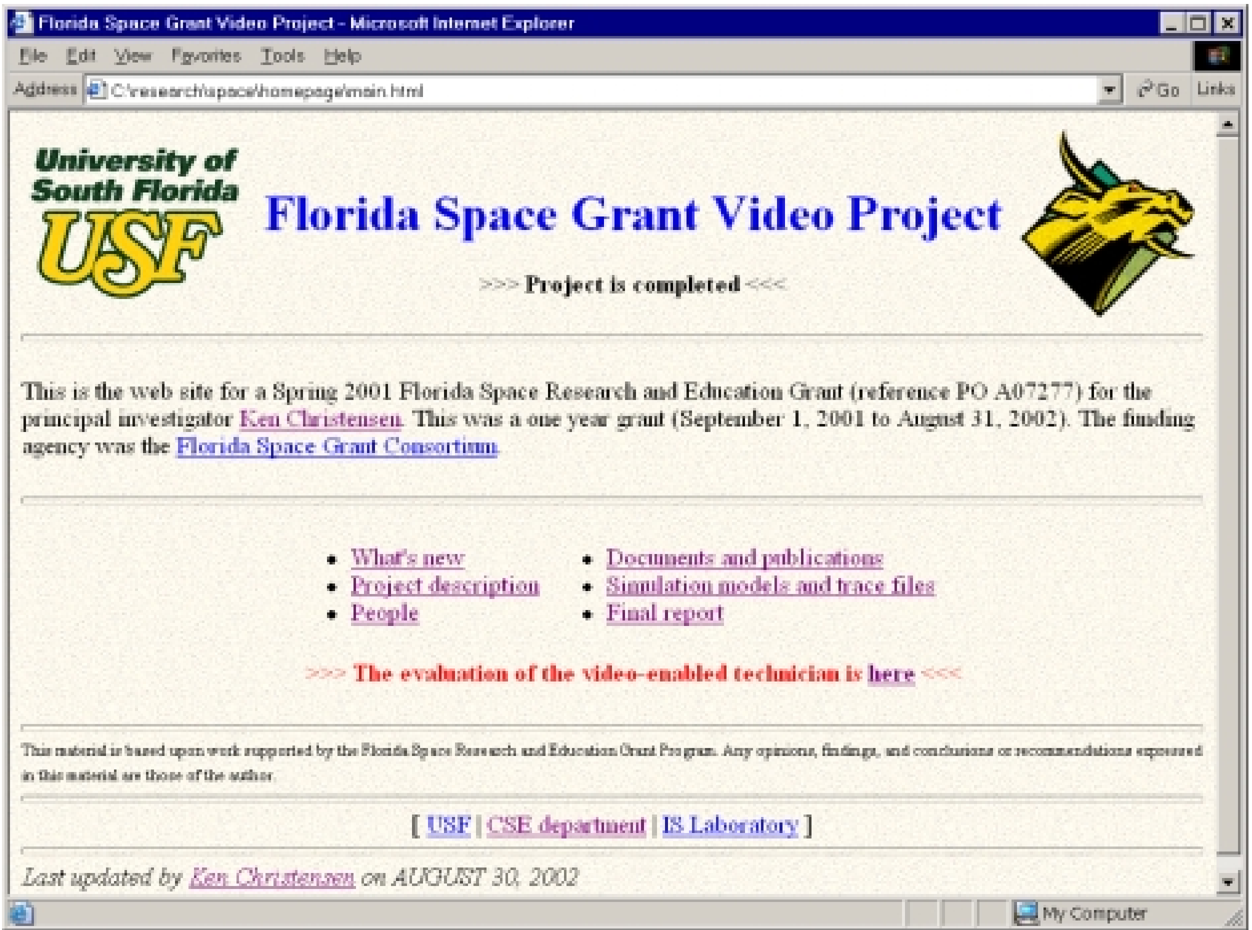
- Completion of simulation models for FireWire with MPEG video sources.
- Completion of simulation evaluation of suitability of FireWire for video surveillance networks.
- Submission and acceptance of a paper to the High Speed Local Network (HSLN) workshop (Appendix B).
- Submission of an NSF proposal for $449,705 (Appendix C).

All simulation models are available on the project website.

Summary: We showed that IEEE 1394b FireWire can be used as the underlying shared medium network infrastructure for video surveillance systems. This is a new direction (or application) for FireWire and needs to be further promoted and evaluated within the extended bus and networking research and development communities.

Appendix A – The Project Website

The project website is at *http://www.csee.usf.edu/~christen/space/main.html*. All video clips, simulation models, and so on are posted at this website.



Appendix B – HSLN Workshop Poster Paper

This appendix contains the poster paper that has been accepted by, and will be presented at, the High Speed Local Networks (HSLN) workshop as part of the IEEE Local Computer Networks (LCN) conference. The workshop will take place on November 6, 2002 in Tampa, Florida. The IEEE LCN conference at its workshops can be found at *http://www.ieeelcn.org*.

*** To appear at the *Workshop on High Speed Local Computer Networks* in November 2002 (at IEEE LCN) ***

A First Look at Wired Sensor Networks for Video Surveillance Systems

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Abstract

High-bandwidth sensor applications such as video surveillance give rise to the need for a wired sensor network (WSN). We show IEEE 1394b FireWire to be a suitable candidate for a shared-medium WSN. We also propose a hybrid location-centric routing protocol for future WSNs with store and forward nodes.

1. Introduction

In many applications sensor networks are wireless [1]. For sensor applications with fixed locations and high bandwidth and power demands such as video surveillance, a wired sensor network (WSN) is needed. Existing dedicated-medium Ethernet and ATM based video surveillance networks [7] will soon become the cost and performance bottleneck to further deployment of large-scale video surveillance systems with highly intelligent cameras [3]. In this short paper, IEEE 1394b FireWire is investigated as a shared medium protocol for ad hoc, economical installation of video cameras in near future WSNs.

In video surveillance there is a need to be able to query cameras by specific location or attribute [2]. A hybrid routing protocol for future arbitrary topology WSNs is presented that uses distributed location servers which maintain the route-attribute-location knowledge for routing in WSNs.

2. Overview of IEEE 1394b FireWire

FireWire is an extended serial bus technology with each node inserted in the repeat path. FireWire supports isochronous slotted and asynchronous packet transmissions. A FireWire cable supports full-duplex communication and power distribution. FireWire IEEE 1394b [4] offers better performance than IEEE 1394a [5] and is capable of 100-meter reach between nodes, 63 nodes, and up to 1.6 Gbps data rate on fiber.

3. Simulation Evaluation of IEEE 1394b

A discrete-event queuing simulation model of IEEE 1394b FireWire was built using the CSIM18 simulation toolkit. Standard FireWire delay constants were included in the model. A daisy chained topology of 20 nodes, each node an independent traffic source, was modeled. Each node was assumed to have an infinite buffer for packets being sent on the link. All packets were destined to a head end (modeling a sensor fusion node).

We used two traffic models to evaluate performance. The first traffic model was twenty 5-Mbps MPEG-2 video sources based on frame traces. The MPEG-2 frame traces were converted into packets with a mean packet size of 1460 bytes and 52 bytes of overhead (representing headers). The second traffic model was Poisson arrivals of 1460-byte fixed-length packets.

Figure 1 shows results for MPEG-2 and Poisson traffic for increasing load. The offered load on the network is increased from 10% to 95%. IEEE 1394b queuing delay increases with load, but remains below a mean of 10 milliseconds and a 99% of 50 milliseconds even for 90% load. The Poisson source results in delays about one magnitude less than the MPEG-2 source.

Figure 2 shows the node distance experiment results for MPEG-2 source and 20 node network. The internode distance is increased from 10 to 100 meters at offered loads of 70% and 90%. It can be seen that with IEEE 1394b, queuing delay is not very sensitive to distance.

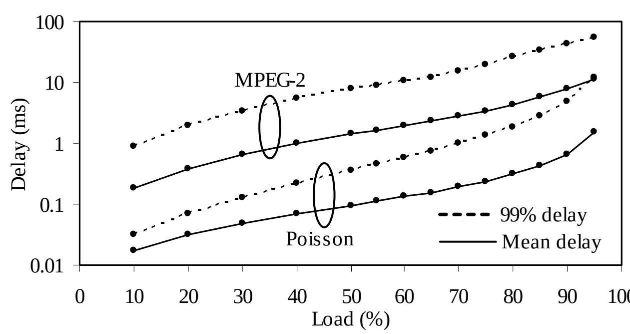

Figure 1. Load results (MPEG-2 and Poisson sources)

This work is funded by a Spring 2001 Florida Space Research and Education Grant.

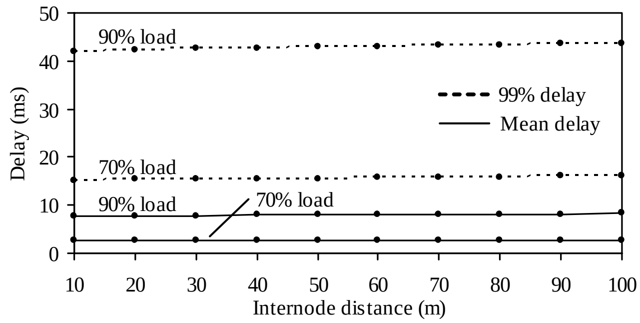

Figure 2. Node distance results (MPEG-2 sources)

5. Routing in a Store-and-Forward WSN

In the future, WSNs will be store-and-forward with each node acting as a sensor, router, and/or cache (see Figure 3). Thus, future WSNs can have arbitrary topologies for improved performance and robustness.

Existing link-state and distance-vector routing protocols are processor and bandwidth intensive. We propose to use a hybrid link state and source routing approach with distributed location servers. This approach minimizes node processor load, reduces routing-related broadcast traffic, reduces routing information at each node, and is a solution to geographical routing.

Hybrid routing – the distributed location server: The location servers maintain associations of node address and location and contain a network map used to determine best routes. Location servers receive and handle discovery, link state update, and route query packets. Each location server maintains and shares network map information with other location servers in the WSN. The distributed location servers return source routes to nodes in response to location queries.

Hybrid routing – the sensor node: Each node in a WSN has a unique id and an associated geographic location string (e.g., a human identified locations such as "terminal A – utility room 1 – west view"). Each sensor node acts as a source routing switch as described in [6]. A node initially searches for the nearest location server by route discovery with limited scope and caches the source route to the server by address or location. If a location server is known to exist, each node sends link state updates to the location server when major link status changes occur. Each node receives packets and forwards them by source routing or broadcast. Nodes forward "new" broadcast packets out all ports except the port on which the packet was received. A stored signature of each received packet can be used to identify packets recently seen which do not be broadcast in multiple copies. If the cache does not contain a route for a packet queued for transmission and if a location server exists, then the location server is queried. If there is no location server, routes are found via a broadcast discovery packet.

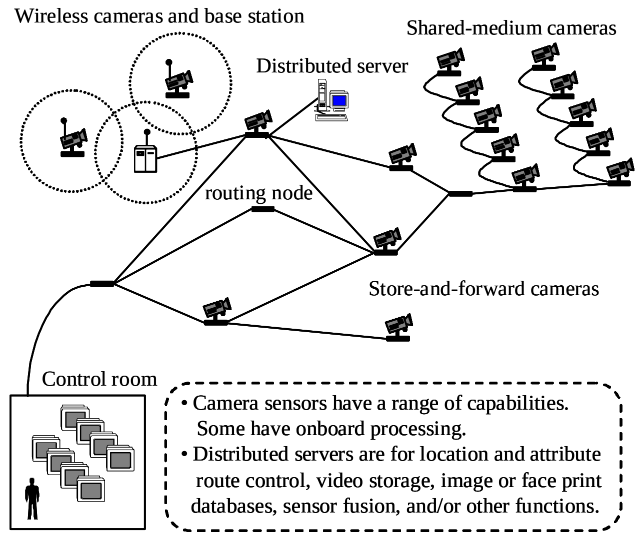

Figure 3. WSN with distributed location servers

6. Summary and Future Work

IEEE 1394b FireWire has significant potential for economical, packet-based video communications. More emphasis on FireWire as a candidate technology for WSNs is needed. Performance of hybrid routing has to be evaluated and more study is needed in the areas of distribution of location servers, scalability, and QoS support.

References

[1] A. Cerpa, J. Elson, D. Estrin, L. Girod, M. Hamilton, and J. Zhao, "Habitat Monitoring: Application Driver for Wireless Communications Technology," *Proceedings of the First ACM SIGCOMM Workshop on Data Communications in Latin America*, 2001.

[2] *Embedded, Everywhere: A Research Agenda for Networked Systems of Embedded Computers*. Committee on Networked Systems of Embedded Computers. National Academy Press, Washington, DC, 2001.

[3] W. Feng, J. Wadpole, W Feng, and C. Pu, "Moving Towards Massively Scalable Video-Based Sensor Networks," *Large Scale Networking Workshop*, 2001.

[4] IEEE P1394b, Draft Standard for a High Performance Serial Bus (High Speed Supplement), (*http://www.zayante.com/p1394b/drafts/p1394b1-33.pdf*), Draft 1.3.3, November 16, 2001.

[5] IEEE Std. 1394a, IEEE Standard for a High Performance Serial Bus Amendment 1, 2000.

[6] D. Johnson and D. Maltz, "Dynamic Source Routing in Ad Hoc Wireless Networks," in *Mobile Computing*, Kluwer Academic Publishers, 1996.

[7] "People-Mover Project Brings 21st Century Surveillance System to Dallas Airport," Telindus, 2002. URL: *http:// www.cellstack.com/news_info/case_dallas_airprt.pdf*.

Appendix C – NSF Proposal

This appendix contains the cover page and project summary of the submitted NSF proposal (submitted to the NSF Networking Research Program – nsf98164) The proposal was submitted on July 29, 2002 and is requesting $449,705.

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2	FOR NSF USE ONLY
NSF 02-123 08/01/02	NSF PROPOSAL NUMBER
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) ANI - NETWORKING RESEARCH	0240014

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
				069687242	

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN)	SHOW PREVIOUS AWARD NO. IF THIS IS	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY?
593102112	☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE
University of South Florida	University of South Florida 4202 Fowler Avenue Tampa, FL. 336209951
AWARDEE ORGANIZATION CODE (IF KNOWN) 0015370000	
NAME OF PERFORMING ORGANIZATION, IF DIFFERENT FROM ABOVE	ADDRESS OF PERFORMING ORGANIZATION, IF DIFFERENT, INCLUDING 9 DIGIT ZIP CODE
PERFORMING ORGANIZATION CODE (IF KNOWN)	

IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Sensor Networks for Video Surveillance: Medium Access, Location/Attribute Routing, and Server Selection**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 449,705	36 months	09/01/03	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

- ☐ BEGINNING INVESTIGATOR (GPG I.A)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
- ☐ HISTORIC PLACES (GPG II.C.9)
- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
- ☐ VERTEBRATE ANIMALS (GPG II.C.11) IACUC App. Date ________
- ☐ HUMAN SUBJECTS (GPG II.C.11) Exemption Subsection ______ or IRB App. Date ________
- ☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.9) ________
- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT	PI/PD POSTAL ADDRESS
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Electronic Signature

PROJECT SUMMARY

Video surveillance is an application of growing national importance. To enable large-scale video surveillance systems to be built, major improvements in the underlying computer network protocols are needed. The cost of a camera is already lower than that of the cabling used to connect the camera – one cable per camera – to monitoring locations. For near future networks, new ideas are needed in shared-medium protocols with built-in power distribution to enable cost-effective camera placement. The human “eyeball” is a bottleneck to scaling-up to thousands of cameras in one installation. Automated image processing within, and between, cameras for target recognition and tracking cannot be advanced with existing network protocols. Beyond the near future, sensor nodes will have sensing, processing, caching, and routing capabilities (and arbitrary network topologies will be possible with both wired and wireless nodes). New ideas are needed in location and attribute routing and in server selection schemes to make large-scale, heterogeneous wired and wireless sensor networks feasible.

The objective of this project is to investigate network protocols for implementing large-scale video surveillance networks in both the near (next five years) and far (beyond five years) future. In the near future, we believe that IEEE 1394b FireWire has significant potential for economical, packet-based video communications. However, very limited performance evaluation has been done for FireWire and industry directions are not advancing asynchronous packet-based usage. In the far future, we envision that sensor networks will become heterogeneous with wired and wireless nodes where individual nodes will be sensors, caches, and/or routers. In a network of such nodes, there exist many trade-offs and new problems in routing. For example, routing must move from a data centric to location and attribute centric focus. Trade-offs in power consumption, processor usage, link bandwidth usage, and QoS capability must be explored. When resources (e.g., image databases and location servers) are distributed and mirrored, selecting the least-loaded server is demonstrably a poor approach if state information is stale. New schemes are needed for server selection using stale load information. Our specific *objectives* are to:

1. Measure, model, and improve the performance of IEEE 1394b FireWire for video surveillance applications;
2. Investigate new location/attribute routing protocols using agent-based modeling to study resource tradeoffs;
3. In conjunction with routing, investigate server selection policies in the presence of stale load information.

For the second objective, we will specifically investigate hybrid routing protocols that are adaptable for heterogeneous sensor networks. Source routing will be explored as a mechanism for packet forwarding, route sharing between location servers and sensor nodes, and enabling a range of distributed to centralized routing implementations. The use of distributed servers requires automatic server selection. How to use stale load information to select the best server is an open problem. Over a three-year period, the two principal investigators and three graduate students will address the stated objectives. The *methods* to be employed are:

∉# We will build a prototype video surveillance system using FireWire. Performance will be measured and traffic characterized. Models will be built to investigate protocol changes to FireWire for spatial reuse and addition of multiple priority levels in order to better support video surveillance applications.

∉# Using simulation we will investigate existing and new routing protocols for location and attribute routing with clear measurements of trade-offs for power, processor, memory, link bandwidth, and other resources.

∉# We will adapt existing agent-based simulation environments to be useful for studying the macroscopic behaviors of routing. We will be able to evaluate performance measures and trade-offs in resource usage.

∉# We will apply control theory to server selection to gain a formal understanding of selection behaviors. This will yield new schemes to avoid the herd effect of popular, but unscalable, least-loaded selection.

Intellectual merit: The intellectual merit of this project is in three areas. First, we will improve experimental performance evaluation of emerging IEEE 1394b FireWire and gain a better understanding of the role that shared-medium, daisy-chained protocols need to play in near future networks for video surveillance. Second, we will look at routing from a macroscopic view and develop the tools and methods to do this. This will result in new and better geographic routing protocols for heterogeneous sensor networks. Third, we will gain a better theoretical and practical understanding of server selection in the presence of stale load information.

Broader impact: The broader impact of this project is in addressing and solving problems of national importance with both a short and long-term view. This project will pioneer the future development of networks for video surveillance for improving the safety and security of our communities. Without network protocols that can scale-up to meet the requirements of thousands of cameras and new paradigms of communications and distributed computing, video surveillance cannot progress beyond where it is today. Our work will open the door to new uses of distributed image processing. Through NSF REU and RET programs, we will outreach to both K-12 and under-represented populations. Participation of under-represented populations in this research will be a major focus.