Final Report for Period: 09/2008 - 08/2009   **Submitted on:** 10/05/2009

Principal Investigator: Ramachandran, Umakishore .   **Award ID:** 0121638

Organization: GA Tech Res Corp - GIT

Submitted By:

Ramachandran, Umakishore - Principal Investigator

Title:

ITR/SY: A Distributed Programming Infrastructure for Integrating Smart Sensors

Project Participants

Senior Personnel

> **Name:** Ramachandran, Umakishore
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**

> **Name:** DeWeerth, Stephen
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**

> **Name:** Mackenzie, Kenneth
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**

> **Name:** Starner, Thad
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**

> **Name:** Hutto, Phil
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> Research scientist overseeing resource acquisition, undergraduate
> student guidance.

> **Name:** Wolenetz, Matt
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> Research scientist, carrying out research on STAGES, DFUSE/MSSN, MediaBroker, Family Intercom and Event Web. Matt is
> actively involved in most aspects of the project and is focusing on DFUSE/MSSN related work for his dissertation.

> **Name:** Rehg, James
>
> **Worked for more than 160 Hours:**   No
>
> **Contribution to Project:**
>
> Prof. Rehg is one of the co-authors of the orginal Stampede system (while at Compaq CRL) and continues to work with us on
> semantically rich processing of visual sensor data. He also works on sensor fusion issues.

> **Name:** Abowd, Gregory
>
> **Worked for more than 160 Hours:**   Yes
>
> **Contribution to Project:**
>
> Prof. Abowd collaborates on higher-level interface issues, is the primary research contact in the Aware Home, and collaborates on
> architectural issues for pervasive computing middleware.

> **Name:** Jain, Ramesh
>
> **Worked for more than 160 Hours:**   Yes

Contribution to Project:

Prof. Jain leads the Event Web project that is one of the driving applications for our MediaBroker work. He has considerable expertise in media processing and automated 'event' detection. Professor Jain holds joint appointments in CoC and ECE and holds the Rhesa S. Farmer, Jr. Distinguished Chair in Embedded Experiential Systems within the College of Computing.

Name: Yu, HeonChung

Worked for more than 160 Hours: No

Contribution to Project:

Prof. Yu is on the faculty at Korea University in Seoul, S. Korea. He is on sabbatical for a year starting January 2004 and is spending this time in residence at the College of Computing at Georgia Tech. His research fault-tolerance and resource scheduling in grid systems. He is working with us on our efforts to dynamically support offloading of computationally intensive sensor processing on a computation grid.

Post-doc

Name: Kumar, Rajnish

Worked for more than 160 Hours: Yes

Contribution to Project:

Rajnish graduated in Fall 2006. I have hired him as a research scientist to work on aspects of the project particularly with respect to deployment of the technologies developed in real application scenarios.

Name: Singh, Rahul

Worked for more than 160 Hours: Yes

Contribution to Project:

Dr. Singh is a post-doc working with Ramesh Jain. He has been coordinating the Event Web project from Prof. Jain's side.

Name: Nakazawa, Jin

Worked for more than 160 Hours: Yes

Contribution to Project:

Jin joined the project in Fall 2004 and is working to help define and implement the next generation of MediaBroker infrastructure, with a focus on supporting distributed consumer applications in smart homes.

Graduate Student

Name: Agarwalla, Bikash

Worked for more than 160 Hours: Yes

Contribution to Project:

Bikash is one of the primary developers and maintainers of Stampede and D-Stampede. He is involved in a variety of aspects of the project, including work on leveraging grid resources for compute intensive sensor processing. He spent 9 months working at HP Labs in Palo Alto. His proposal based on his recent Streamline research received 2nd prize in the 2005 IBM North America Grid Scholars Challenge.

Name: Huneycutt, Chad

Worked for more than 160 Hours: Yes

Contribution to Project:

Chad works with Josh Fryman on the SoftCache infrastructure for supporting ubiquitous embedded network systems.

Name: Fryman, Josh

Worked for more than 160 Hours: Yes

Contribution to Project:

Josh works primarily with researching solutions for ubiquitous embedded network systems that can benefit from network-level cache architectures to reduce resource requirements on client devices.

Name: Wilson, Chuck

Worked for more than 160 Hours: Yes

Contribution to Project:

Chuck Wilson has graduated from Georgia Tech with a PhD.

Name: Harel, Nissim

Worked for more than 160 Hours: Yes

Contribution to Project:

During the scope of this project, Nissim has worked with Hasnain Mandviwala to research adaptive rate control mechanisms for streaming applications.

Name: Mandviwala, Hasnain

Worked for more than 160 Hours: Yes

Contribution to Project:

Name: Angelov, Yavor

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked on compute-instensive processing, parallelization.
Graduated from Masters program and now works at Microsoft.

Name: Hilley, David

Worked for more than 160 Hours: Yes

Contribution to Project:

On-line Television Channel Recommender project.
Funding from PURA award from Georgia Tech as ugrad.
Is now in the Masters program and continues extensive work on the project, video feature extraction algorithms.
Working with Prof. Irfan Essa. He is also working with Bikash Agarwalla and Nova Ahmed on integrating his application-level algorithms with grid infrastructures.

Name: Shin, Junsuk

Worked for more than 160 Hours: Yes

Contribution to Project:

Abstraction migration in Stampede
Funding from this project

Name: Lee, Jeannie

Worked for more than 160 Hours: Yes

Contribution to Project:

Audio-based location system on top of Stampede.
Funding from this project.
Student graduated with a Masters at the end of Spring 2003.

Name: Jeong, Namgeun

Worked for more than 160 Hours: Yes

Contribution to Project:

Stampede.NET project.
Partial funding from this project.
Namgeun is soon to complete his PhD and has been working at the Federal Reserve Bank in Atlanta.

Name: Song, Xiang

Worked for more than 160 Hours: Yes

Contribution to Project:

Stampede.NET project.
Partial funding from this project.
Xiang Song worked with Raj Kumar at HP labs summer 2004. His contributions have led to project growth, attracting undergraduate student involvement.

Name: Sharma, Rajat

Worked for more than 160 Hours: Yes

Contribution to Project:

Stampede.NET project
Partial funding from this project.
Student has graduated with a Masters at end of Spring 2003.

Name: Pack, Derick

Worked for more than 160 Hours: Yes

Contribution to Project:

Derick just completed his Master's thesis on an architecture for Event Web. He has done a large amount of implementation and integration of the current system.

Name: Liu, Bin

Worked for more than 160 Hours: Yes

Contribution to Project:

Bin is a PhD student working with Prof. Jain's group. He is exploring streaming database issues such as synchronization and query optimization. Working with James Kim and Matt Wolenetz, Bin assisted in the study of using MediaBroker to support EventWeb queries that has resulted in a journal publication.

Name: Ahmed, Nova

Worked for more than 160 Hours: Yes

Contribution to Project:

She is the student managing the group working on the middleware system. She worked on developing the key ideas of the system such as virtual readers, virtual paths and a simulation based study prior to the actual system implementation using C and MPI based communication among system components. Later she worked on the load management ideas to enhance the system and evaluated the real experimental testbed using RFID readers and tags.

Name: Edwards, Ken

Worked for more than 160 Hours: Yes

Contribution to Project:

Ken worked with us as an undergraduate on the TvWatcher project and is in the Master's program in the College of Computing at Georgia Tech. He has worked on resource monitoring and the information subsystem of the grid infrastructure in service of our grid scheduling research.

Name: Wei, JinPing

Worked for more than 160 Hours: Yes

Contribution to Project:

JinPing completed a 'mini-project' related the DFUSE work and was supervised by PhD students Rajnish Kumar and Matthew Wolenetz. This project was the primary outcome of special 'research orientation' course required of all incoming PhD students in the College of Computing at Georgia Tech.

Name: Urazov, Vladimir

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked on a java based implementation of the middleware system. It includes the major system components called virtual readers and their communication mechanism using virtual paths. He also contributed in the project in the simulation based evaluation of the system.

Name: Lillethun, David

Worked for more than 160 Hours: Yes

Contribution to Project:

Dave joined the project in Fall 2004 and has made good progress with the MediaBroker infrastructure to support the EventWeb continuous query application. Working with Bin Liu and Matt Wolenetz, he has successfully demonstrated the working combination and good performance of EventWeb and MediaBroker, resulting in a journal publication. He is currently working with the group to design and develop the next generation of MediaBroker infrastructure.

Name: Paul, Arnab

Worked for more than 160 Hours: Yes

Contribution to Project:

Arnab has worked closely with the project along with Rajnish Kumar to generate published research in the area of efficient code dissemination (FBcast) and remote authentication (LAWN). Arnab recently received his doctorate and is now pursuing a post-doc at Dartmouth.

Name: Mohapatra, Dushmanta

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted senior graduate student and research scientist to gather performance data for camera sensor network.

Name: Muthu, Chidambaram

Worked for more than 160 Hours: Yes

Contribution to Project:

Worked on service composition algorithm.

Name: Richardson, Jahmeilah

Worked for more than 160 Hours: Yes

Contribution to Project:

She worked on the project as an SAIC scholars program offered by COC. She was from an HCI background and thus contributed to the project by doing usability survey of our system as well as several other RFID based systems that are mentioned in commercial websites.

Name: Ryu, MungYung

Worked for more than 160 Hours: Yes

Contribution to Project:

machine learning techniques for anomaly detection

Name: Yusuf, Lateef

Worked for more than 160 Hours: Yes

Contribution to Project:

Opportunsitic networking

Name: Kim, Hyojun

Worked for more than 160 Hours: No

Contribution to Project:

Virtualization techniques for mobile devices

Name: Kumar, Jatin

Worked for more than 160 Hours: No

Contribution to Project:

Virtualization techniques for mobile devices, MS project

Name: Shim, Sang Min

Worked for more than 160 Hours: No

Contribution to Project:

Face detection algorithm implementation as an MS student

Name: Choi, Taeil

Worked for more than 160 Hours: No

Contribution to Project:

Network simulation assistance in the ASAP project

Undergraduate Student

Name: Talat, Zaib

Worked for more than 160 Hours: Yes

Contribution to Project:

Zaib Talat has graduated from the program with a BS in Spring 2003.

Name: King, Joseph

Worked for more than 160 Hours: No

Contribution to Project:

Name: Post, Ansley

Worked for more than 160 Hours: Yes

Contribution to Project:

Ansley has graduated and is now going to Grad School at Rice University.

Name: Bagrak, Ilya

Worked for more than 160 Hours: Yes

Contribution to Project:

Media broker project.
Funding from PURA award from Georgia Tech.
Ilya won CoC Outstanding Undergraduate Research Assistant
and was awarded Honorable Mention in the CRA nomination.
He now attends graduate school at Berkeley.

Name: Modahl, Martin

Worked for more than 160 Hours: Yes

Contribution to Project:

Media Broker Project
Funding from PURA award from Georgia Tech as a ugrad.
Has completed Masters program.
During his Masters, he worked on Event Web with federated Mediabroker as base. Since graduation, he has pursued embedded
systems application development in industry.

Name: El-Helw, Ahmed

Worked for more than 160 Hours: Yes

Contribution to Project:

On-line Television Channel Recommender project.
Funding from PURA award from Georgia Tech.
Ahmed implemented the text correlation engine, web browser pop-ups, and web service interfaces. He has entered the Masters
program and continues work on the project.

Name: Graciano, Ryan

Worked for more than 160 Hours: No

Contribution to Project:

Ryan was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004. He received one
hour of research credit and developed a Mediator and GUI for control of PTZ cameras.

Name: Kim, James

Worked for more than 160 Hours: Yes

Contribution to Project:

James was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004. He developed a
Mediator for the ER1 mobile robot. In addition, James continued implementation of the MediaBroker Federation architecture
begun by Martin Modahl for his Senior Design project in Fall 2004. He was heavily involved in developing a component
necessary to wrap the MedaBroker API to make it usable by the EventWeb application. This work has resulted in a journal
publication.

Name: Thomas, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Robert was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004 and will

continue into the Fall of 2004. Robert developed a Mediator for the Versus Tech RF/IR badge tracking system deployed within the College. In addition, Robert developed a Mediator for scrolling marquee signs and developed the Registry used for device discovery and for download of Mediator proxies (bytecodes).

Name: Whitehurst, Jason

Worked for more than 160 Hours: No

Contribution to Project:

Jason Whitehurst is working with Phillip Hutto and Xiang Song on the Stampede.NET project.

Name: Courtoy, James

Worked for more than 160 Hours: Yes

Contribution to Project:

JD Courtoy is working with Phillip Hutto and Xiang Song on the Stampede.NET project.

Name: Adkisson, Kevin

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working on developing a Stampede.NET demo.

Name: Horrigan, Seth

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working on the cyberforaging project (offloading computations from wireless to nearby wired surrogates).

Name: Mentonelli, Paolo

Worked for more than 160 Hours: Yes

Contribution to Project:

System support for RFID; worked for course credit.

Name: Pattillo, Ricky

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working on the cyberforaging project (offloading computations from wireless to nearby wired surrogates).

Name: Phillips, Bill

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working on the uMiddle project (pervasive computing interoperability framework), focusing on a UPnP Media Renderer for streaming a/v content.

Name: Rivard, Nate

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working closely with Jin Nakazawa, Bin Liu and Eric Sample on the next generation of MediaBroker (MB++). He is currently focusing on integrating Rendezvous/Bonjour capabilities into MB for advanced naming and lookup.

Name: Sample, Eric

Worked for more than 160 Hours: No

Contribution to Project:

Member of our Systems Summer Hackfest 2005 group. He is working us on the next generation of MediaBroker (MB++).

Name: Juang, Ryan

Worked for more than 160 Hours: Yes

Contribution to Project:

Implement the database backend for MediaBroker++. Worked for course credit.

Name: Heim, Gabriel

Worked for more than 160 Hours: Yes

Contribution to Project:

Hierarchical Wireless Sensor Networks; worked for course credit.

Name: Reiss, Charles

Worked for more than 160 Hours: Yes

Contribution to Project:

Hierarchical Wireless Sensor Networks; supported by NSF REU supplement.

Name: Lotfi, Puyan

Worked for more than 160 Hours: Yes

Contribution to Project:

Hierarchical Wireless Sensor Networks; worked for course credit.

Name: Gilliland, Scott

Worked for more than 160 Hours: Yes

Contribution to Project:

Hierarchical Wireless Sensor Networks; worked for course credit.

Name: Ukah, Echezona

Worked for more than 160 Hours: Yes

Contribution to Project:

System support for RFID; supported by REU supplement.

Name: Worsham, David

Worked for more than 160 Hours: No

Contribution to Project:

System support for RFID; supported by REU supplement.

Name: Young, Sam

Worked for more than 160 Hours: Yes

Contribution to Project:

Sam worked on MobiGO which is a system for supporting seamless mobility in a ubiquitous computing environment.

Name: Slaughter, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked on the project as an SAIC scholars program offered by COC. He is a first year undergraduate student and was new to research based work. He contributed to the project first by getting an idea of what is going on the system and then developing a simple graphical representation of the deployed graph in the system. He presented in the Undergraduate Research Symposium, 2007 on behalf of our group.

Name: McCauley, Michael

Worked for more than 160 Hours: No

Contribution to Project:

summer hackfest implementing camera sensor network code

Name: Woo, Joseph

Worked for more than 160 Hours: No

Contribution to Project:

summer hackfest implementing camera sensor network code

Name: Parker, Robert

Worked for more than 160 Hours: No

Contribution to Project:

summer hackfest implementing camera sensor network code

Name: McCawley, Matthew

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; scalable multiparty video conferencing system

Name: Stebar II, Brian

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; scalable multiparty video conferencing system

Name: Whitehead, Brandon

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; Scalable stream fusion

Name: DeRosa, Michael

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; Scalable stream fusion

Name: Rowswell, Brent

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; Active RFID system benchmarking

Name: Butler, Stewart

Worked for more than 160 Hours: Yes

Contribution to Project:

NSF REU support; GuardianAngel middleware for unobtrusive monitoring using passive RFID

Technician, Programmer

Name: Brennan, Sean

Worked for more than 160 Hours: Yes

Contribution to Project:

Sean is a staff member of the campus computing group (OIT) at Georgia Tech. He has been assigned part-time to work on a prototype of the Event Web system featuring campus seminars and other events at Georgia Tech. He has done extensive work provisioning and setting up specialized facilities on campus to accomodate the Event Web system.

Other Participant

Name: Essa, Irfan

Worked for more than 160 Hours: Yes

Contribution to Project:

He is a Co-PI on the award

Name: Yip, Man

Worked for more than 160 Hours: No

Contribution to Project:

implemented active RFID system with robots for navigation

Research Experience for Undergraduates

Name: Crowell, Zachary

Worked for more than 160 Hours: Yes

Contribution to Project:

Zach worked on the Event Web project for a semester and the TVWatcher project for another semester. He has graduated and is working at Microsoft.

>   **Years of schooling completed:**   Other
>   **Home Institution:**   Same as Research Site
>   **Home Institution if Other:**
>   **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>   **Fiscal year(s) REU Participant supported:**   2004 2003
>   **REU Funding:**   REU supplement

Name: Caudill, Harrison

Worked for more than 160 Hours: Yes

Contribution to Project:

Harrison worked for two semesters with other undergraduates developing a prototype sensor-based, pervasive computing application - the Future Library which involved tracking of library resources and associated interfaces for interacting with the system.

>   **Years of schooling completed:**   Junior
>   **Home Institution:**   Same as Research Site
>   **Home Institution if Other:**
>   **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>   **Fiscal year(s) REU Participant supported:**   2003
>   **REU Funding:**   REU supplement

Name: McCorkle, Eric

Worked for more than 160 Hours: Yes

Contribution to Project:

Eric worked for two semesters with other undergraduates developing a prototype sensor-based, pervasive computing application - the Future Library which involved tracking of library resources and associated interfaces for interacting with the system.

>   **Years of schooling completed:**   Junior
>   **Home Institution:**   Same as Research Site
>   **Home Institution if Other:**
>   **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>   **Fiscal year(s) REU Participant supported:**   2004
>   **REU Funding:**   REU supplement

Name: Chen, Simon

Worked for more than 160 Hours: Yes

Contribution to Project:

Simon was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004. Simon worked on a Mediator for the Berkeley Motes and the XML command channel.

>   **Years of schooling completed:**   Sophomore
>   **Home Institution:**   Same as Research Site
>   **Home Institution if Other:**
>   **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>   **Fiscal year(s) REU Participant supported:**   2004
>   **REU Funding:**   REU supplement

Name: Shanks, Thomas

Worked for more than 160 Hours: Yes

Contribution to Project:

Thomas was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004. Thomas implemented a Mediator for interfacing with tv-tuner video capture cards. This involved extending the source code for the Java Media Framework from Sun.

> **Years of schooling completed:**   Sophomore
>
> **Home Institution:**   Same as Research Site
>
> **Home Institution if Other:**
>
> **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>
> **Fiscal year(s) REU Participant supported:**   2004
>
> **REU Funding:**   REU supplement

Name: Sheridan, Rex

Worked for more than 160 Hours: Yes

Contribution to Project:

Rex was part of a group of students developing Java-based Sensor Lab infrastructure during the summer of 2004. He developed Mediators for wireless temperature sensors and developed a gui-based control panel demo application in Java using the SWT widget set and the Java Media Framework. Rex coordinated integration.

> **Years of schooling completed:**   Junior
>
> **Home Institution:**   Same as Research Site
>
> **Home Institution if Other:**
>
> **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>
> **Fiscal year(s) REU Participant supported:**   2004
>
> **REU Funding:**   REU supplement

Name: Boyer, Garrett

Worked for more than 160 Hours: Yes

Contribution to Project:

Garrett worked on some hardware issues and received a PURA Award in Spring 2004.

> **Years of schooling completed:**   Junior
>
> **Home Institution:**   Same as Research Site
>
> **Home Institution if Other:**
>
> **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>
> **Fiscal year(s) REU Participant supported:**   2004
>
> **REU Funding:**   REU supplement

Name: Snyder, Luke

Worked for more than 160 Hours: Yes

Contribution to Project:

Luke worked on hardware issues and received Third Place in the Undergraduate Research Symposium in Spring 2004.

> **Years of schooling completed:**   Sophomore
>
> **Home Institution:**   Same as Research Site
>
> **Home Institution if Other:**
>
> **Home Institution Highest Degree Granted(in fields supported by NSF):**   Doctoral Degree
>
> **Fiscal year(s) REU Participant supported:**   2004
>
> **REU Funding:**   REU supplement

Name: Caban, Jose

Worked for more than 160 Hours: Yes

Contribution to Project:

Jose has worked with initial reimplementation and debugging of the Family Intercom application that helps drive the development of MediaBroker infrastructure. He discovered, with Vladimir Urazov and Matt Wolenetz, several issues specific to the Family Intercom application that have previously prevented good performance.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2005

REU Funding: REU supplement

Name: Dalton, Steven

Worked for more than 160 Hours: Yes

Contribution to Project:

Steve worked on wireless sensor network project. His contribution was in the realm of using cameras with embedded processors.

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: No Info

Name: French, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

He worked on developing a java based emulation framework. It can deploy number of emulated RFID readers given a graph based layout of the deployment of the readers and provide the system with several tunable parameters that show similar behavior as real RFID readers. The major parameters are: number of readers, reader accuracy level, number of tags per time unit etc.

Years of schooling completed: Other

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: REU supplement

Organizational Partners

HEWLETT PACKARD

1) Stampede was developed jointly with DEC, which was bought by
   Compaq, and now merged with HP
2) Kath Knobe of HP Cambridge Research Lab is an active partner
   on the project
3) Ramachandran (PI) has had consultative arrangement with
   the Cambridge Research Lab
4) Grad students working with Ramachandran have done summer
   internships at HP Cambridge Research Lab, and HP Labs in
   Palo Alto, CA

Microsoft Corporation

Funding for Stampede.NET project.

Intel Corporation

Dr. Kath Knobe, Cambridge Research Lab and Santa Clara

Reservoir Labs., Inc.

Dr. Ken Mackenzie works with us on the project; provide rstream software

Samsung Electronics Corporation

Supported a device virtualization project under STAR center between Georgia Tech and Samsung Electronics Corp.

Other Collaborators or Contacts

Kath Knobe, Intel
Raj Kumar, HP Palo Alto Research
Ken Mackenzie, Reservoir Labs
Sang-bum Suh, Samsung
Ilpyung Park, Samsung
Junghyun Yoo, Samsung

Activities and Findings

Research and Education Activities:
See attached PDF file (Section Activities and Findings)

Findings:
See attached PDF file (Section Activities and Findings)

Training and Development:
See Attached PDF file (subsection Training and Development)

Outreach Activities:
See attached PDF file (subsection entitled Outreach)

Journal Publications

Books or Other One-time Publications

Web/Internet Site

URL(s):
http://www.cc.gatech.edu/~rama/ubiq-presence/
Description:
Research artifacts
Pointers to pubs

Other Specific Products

Contributions

Contributions within Discipline:
See attached PDF file (Section Contributions)

Contributions to Other Disciplines:

Contributions to Human Resource Development:

See attached PDF file (Section Contributions)
Contributions to Resources for Research and Education:
See attached PDF file (Section Contributions)
Contributions Beyond Science and Engineering:

Conference Proceedings

Categories for which nothing is reported:

Any Journal

Any Book

Any Product

Contributions: To Any Other Disciplines

Contributions: To Any Beyond Science and Engineering

Any Conference

ITR/SY: A Distributed Programming Infrastructure for Integrating Smart Sensors

PIs: Umakishore Ramachandran
Kenneth Mackenzie
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Final Report via Fastlane October 1, 2009

As we observed at the time of filing the annual report in August 2008, that that was really a final report on the project. The only unexpended funds at that time was the remaining in the category of REU for which NSF had given a one-year extension. Therefore, we present the work done with the undergraduates in the following section and then reproduce the contents of the annual report from August 2008 for the sake of completeness of this final report.

Work done with Undergraduates in 2008-09

ASAP System

This is a mature project that provides a middleware framework for situation awareness applications incorporating high bandwidth sensors such as cameras and low bandwidth sensors such as RFID. There is more description of this work in the body of the annual report, which follows this section. Several undergraduates were employed on this project during this NCE year and benefited tremendously from the exposure. It is worth noting that two of the students (Matthew McCawley and Brian Stebar II) who worked collaboratively on this project received **The 2009 College of Computing Outstanding Undergraduate Research Award** for their work in developing a scalable multi-party video conferencing system while receiving the REU funding from this research project. A third student (Steve Dalton) completed an undergraduate thesis on a research topic related to this NSF funded project. Steve was also the recipient of **The 2007 College of Computing Outstanding Undergraduate Research Award** for the research he did on this project.

1. **Steve Dalton (Aug 2008 to December 2008)**:
   Work Description: Distributed Feature Extraction Using Cloud Computing Resources: The goal of this project was to construct a cloud processing system that will be integrated into the distributed camera surveillance network (ASAP). The ASAP system uses a heterogeneous wireless sensor network

1

to collect and prioritize multiple video data streams. ASAP performs the stream processing using only the in-network computational resources. This limitation on the availability of computational resources has restricted the number of interesting applications that can be implemented. By using cloud resources to move computations out-of-network the project aimed to facilitate the construction of more computationally complex applications in the ASAP system.

Currently, Steve is a PhD student at UIUC.

Learning Outcome: Cloud computing framework, ASAP, distributed systems integration

Research Outcomes:

(a) UG thesis: **Distributed Feature Extraction Using Cloud Computing Resources**, May 2009

(b) **The 2007 College of Computing Outstanding UG Research Award**

(c) Code and documentation to be used in ongoing research

2. **Matthew McCawley (August 2008 to August 2009)**:

Work Description: Scalable video conferencing: The goal of this project was to build an efficient stream server for multi party video conferenencing. The project explored at designing prioritization and parallelization strategies for efficient bandwidth and computation management on the stream server. One example of bandwidth optimization is to control video quality based of participants based on their social network structure. Matthew looked at the web-based interface to the above system.

Learning Outcome: Actionscript and Flex programming framework, Web architecture, Distributed systems integration

Research Outcomes:

(a) **The 2009 College of Computing Outstanding UG Research Award**

(b) **Judges' First Place Award at 2009 College of Computing** *Undergraduates Research Opportunities in Computing (UROC)* **contest** for their entry entitled "Scalable Multiparty Video Conferencing."

3. **Brian Stebar II (August 2008 to May 2009)**:

Work Description: Scalable video conferencing: The goal of this project was to build an efficient stream server for multi party video conferenencing. The project explored at designing prioritization and parallelization strategies for efficient bandwidth and computation management on the stream server. One example of bandwidth optimization is to control video quality based of participants based on their social network structure. Brian looked at supporting multiple simultaneous room capability in the system.

Learning Outcome: Actionscript and Flex programming framework, Flash media server, Web architecture, Distributed systems integration

Research Outcomes:

(a) **The 2009 College of Computing Outstanding UG Research Award**

(b) **Judges' First Place Award at 2009 College of Computing** *Undergraduates Research Opportunities in Computing (UROC)* **contest** for their entry entitled "Scalable Multiparty Video Conferencing."

4. **Brandon J. Whitehead (May 2009 to August 2009)**:

Work Description: Scalable stream fusion: The goal of this project is to build a system for dynamic switching and stitching of multiple camera streams connected to a desktop.

Learning Outcome: Microsoft Directshow architecture and programming, Multimedia encoding and decoding process, Red5 open source flash media server architecture.

5. **Michael DeRosa (May 2009 to August 2009)**:

Work Description: Scalable stream fusion: The goal of this project is to build a system for dynamic switching and stitching of multiple camera streams connected to a desktop. Michael was responsible for exploring Xuggle system for its stream management capability and how it can be used for our project purpose.

Learning Outcome: Microsoft Directshow architecture and programming, Multimedia encoding and decoding process, Xuggle and Red5 system integration.

RFID Middleware

More details on this sub-project is also in the body of the annual report that follows this section. Several undergraduates have worked on this sub-project through the life of the NSF award. The following list

includes the 2 students who worked on the RFID middleware in 2008-09 during the NCE period of this award.

1. **Brent Rowswell (January 2008 to December 2008)**:
   Work Description: The student has done extensive evaluation of the active RFID system performance in an indoor environment. He has designed and evaluated set of experiments that considers an indoor environment using active RFID technology. He has also developed some theoretical searching procedures to aid the mobility in an active RFID enabled environment.
   Learning Outcome: The student learned and contributed to programming active RFID system and conducting early experiments in the use of this technology for object localization in an indoor environment.

2. **Stewart Butler (May 2009 to present)**:
   Work Description: The student worked on developing a prototype environment that mimics an assisted living center using passive RFID tags and readers. He specifically developed a python based prototype to evaluate a small scale performance of the system. He also helped in evaluation and writing of a scholarly paper on the system named GuardianAngel.
   Learning Outcome: The student learned how to design a localization system for an indoor environment using passive RFID, as well as how to calibrate the system for unobtrusive monitoring of objects in such an environment.
   Research Outcome: The student also participated as a co-author in the writing of a paper [6] to a prestigious conference venue (IEEE Percom 2010).

Annual Report from August 2008 reproduced below

The research undertaken in this proposal is integrating sensing hardware, embedded processing and distributed system support to build a seamless programming infrastructure for ubiquitous presence applications. Fundamental invention and integration of techniques spanning programming idioms and runtime systems for distributed sensors, and building blocks for embedded processing are expected as the primary intellectual contributions of the proposed research. Interfacing these technologies to emerging applications on the one end and novel off-the-shelf sensors at the other end are secondary goals of the proposed research.

We have made the following contributions through this research:

- definition of an elaborate system architecture for prototyping sensor-based distributed applications covering distributed programming paradigm and data fusion
- issues that pertain wireless sensor networks including protocol stack, security issues, and code dissemination
- use of the technologies to construct prototype of complex cyber physical application for situation awareness

1   Activities and Findings (This Past Year 2007-08)

First we summarize the research accomplishments this past year followed by those in the previous years in Chronological order.

1.1   Research and Education

1.1.1   Systems Technologies to support Sensor Based Distributed Computing

1. e-SAFE: An Extensible, Secure and Fault Tolerant Storage System. In an ubiquitous setting it is important to ensure the integrity of remote access to information from mobile devices. This research resulted in using erasure codes to simultaneously assure the security of remote access to file systems as well as the fault tolerance when the requested data can be reconstructed even when there is partial communication in remote communication. The work [3] is part of the dissertation of Dr. Arnab Paul [38] who was supported by this award and appeared in the *First IEEE International Conference on Self-Adaptive and Self-Organizing Systems*, Boston, Mass., USA, July 9-11, 2007.

2. $Stampede^{RT}$**: Programming Abstractions for Live Streaming Applications.** Stampede is a programming system for distributed computing that is at the heart of this research. The principles behind this programming system is part of the dissertation of Dr. Sameer Adhikari [2], a student supported on this award. $Stampede^{RT}$ represents a new twist on this programming model to support live streaming applications. It was presented at the *27th International Conference on Distributed Computing Systems (ICDCS)*, 2007, and represents a part of the dissertation work of David Hilley, a student working on this project but supported by an IBM Fellowship.

3. On Improving the Reliability of Packet Delivery in Dense Wireless Sensor Networks. Reliable communication is essential in distributed sensing and this research work investigates techniques for improving the reliability for packet delivery and appeared in *16th International Conference on Computer Communications and Networks (ICCCN 2007)*, August 2007 [53]. It also represents a part of the dissertation work of Junsuk Shin, a student supported by this award.

4. Memory Optimizations for Distributed Streaming Applications. Sophisticated sensors such as cameras generate significant amounts of data. It is important to ensure that the resources are managed to contain the amount of memory resources used in streaming applications involving such high bandwidth sensors. This research uses the information in the application task graph to reduce the resource requirements in streaming applications [19, 18]. It is part of the dissertation work of Dr. Nissim Harel [17] who was supported by this award.

5. MobiGo and Chameleon: Supporting Seamless Mobility. Supporting user mobility seamlessly is important. This research devised techniques for application level (MobiGo) [58] and system level (Chameleon) [60] seamless mobility of a user in a distributed setting. This research represents part of the dissertation work of Dr. Xiang Song [55] who was supported by this award.

6. Streamline: Scheduling Streaming Applications in a Wide Area Environment. One of the premises for the project as a whole is that ambient computing infrastructure is ever available to support distributed sensing applications. This work [5] discusses a heuristic for efficiently scheduling streaming applications on a computational grid, and represents a part of the dissertation work of Bikash Agarwalla.

7. ASAP: A Camera Sensor Network for Situation Awareness. As a canonical example of sensor based distributed computing, we have built a camera sensor network for video based surveillance. The mockup uses typical security threats that may occur in an airport setting. This work was presented in the *11th International Conference On Principles Of Distributed Systems (OPODIS'07)*, Guadeloupe, French West Indies, December 17-20th, 2007. It also represents a part of the dissertation work of Junsuk Shin, a student supported by this award.

8. Mobile Virtual Sensors: A Scalable Programming and Execution Framework for Smart Surveillance. Building on the ASAP work, we are defining a platform (programming infrastructure) for the rapid prototyping of cyber-physical systems (Position Paper) . Hot EmNets 2008, The Fifth Workshop on Embedded Networked Sensors Charlottesville, Virginia, USA, June 2-3, 2008.

1.2 Training and Development

Needless to say, graduate students pursuing their doctorate are the primary focus of training and development. Please see Section 3.1 for a complete list of students at all levels who are alumni of this project.

Graduate students associated with the project have been benefiting from internships in leading research labs. In the spring of 2008, Dave Lillethun interned at Microsoft Research in Cambridge, England. In the summer of 2008, David Hilley was interning at IBM Almaden, Mung Yung Ryu was interning at Motorola Labs, and Lateef Yusuf was interning at QualComm. Dushmanta Mohapatra spent 2 semesters as an intern at AMI Corp., and Junsuk Shin is currently (in Fall 2008) interning at Microsoft Research, Redmond, Washington.

We continue to attract bright and interested graduates and undergraduates to research projects in our group. Undergraduate participation in research within the College is facilitated by the excellent UROC program (`www.cc.gatech.edu/program/uroc`), coordinated by Professor Amy Bruckman. A variety of institute-wide programs are also available (`www.undergraduateresearch.gatech.edu`) including a special fund sponsored by the president of Georgia Tech (PURA) and several NSF-sponsored projects. Since we associate these UGs to work with graduate students, it serves as a valuable tool for training our

graduate students in serving as mentors and student advisors.

In this past year, we have entertained a number of UG students as researchers in our lab. They include:

- Michael S. Slaughter (worked with Nova Ahmed on RF^2ID project in Fall 2007 and Spring 2008), Man Fung Yip (an exchange from Hongkong who worked with Nova Ahmed on RF^2ID project in Spring 2008).
- Matthew Wesley McCauley, Joseph Woo, and Robert Parker (worked with Junsuk Shin on ASAP project in Summer 2008).

1.3 Outreach

Professor Ramachandran has concluded negotiations with Samsung Electronics Corporation to establish a joint-center at Georgia Tech for carrying out collaborative research of mutual interest to Samsung and Georgia Tech. Under this agreement, Samsung will fund a number of research projects that had their roots in the ITR award. One such project is *MobiGo* that supports seamless mobility in a ubiquitous setting. A second one (to be carried out by PI Professor Irfan Essa) involves Non Photo-realistic Rendering.

The joint-center will have engineers from Samsung visiting on a year-round basis and working closely with the faculty and students in the College of Computing. So far, the agreement has resulted in funding 5 research projects at Georgia Tech. Please visit http://www.star.cc.gatech.edu.

We are in communication with the City of Baton Rouge and their department of Homeland Security. They are interested in serving as a beta-site for the camera sensor network technology we have developed for video-based surveillance.

We have similar ongoing dialogue with the IT department of the Hartsfield-Jackson International Airport in Atlanta to deploy our camera sensor network.

1.3.1 Research Commercialization

Georgia Tech has active interest in research commercialization. *Venture lab* is an entity that identifies research work in Georgia Tech that are worthy of consideration for commercialization. The *SensorStack* dissertation work performed by one of the students (Rajnish Kumar) funded by this ITR award has been chosen for research commercialization. We have developed an architecture for *priority aware situation awareness* with the SensorStack at its core. Potential application of this technology includes airport surveillance and critical infrastructure protection. Rajnish Kumar, research scientist, has been hired expressly to oversee the development of these technologies for application in such scenarios.

1.4 Activities and Findings in previous Years

The research in previous years have resulted in the generation of a number of technologies for distributed sensing. Here are few highlights:

- Distributed Programming idioms including the Stampede [48] and D-Stampede [1] programming systems.
- Middleware for data fusion called DFuse [28, 45], and a sophisticated yellow pages for match-making of sensors and actuators to applications called MediaBroker [34, 47].
- Technologies for making our programming infrastructure available on a variety of platforms including .NET [56].
- Technologies for marrying ambient HPC infrastructure with distributed sensing [4].
- Middleware for increasing the reliability of RFID deployments [7].

We also initiated a number of activities including the formation of a sensor lab that allows undergraduates to come and experiment with sensing technologies, and outreach to industries and potential consumers once this kind of technology matures.

All of these activities are well documented in the annual reports of the previous years. Rather than itemize the activities and findings from previous years, we simply present the web pointers to the previous years

- Web URL for the project:
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/

- Year 2001-02 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2001-02.pdf
- Year 2002-03 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2002-03.pdf
- Year 2003-04 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2003-04.pdf
- Year 2004-05 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2004-05.pdf
- Year 2005-06 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2005-06.pdf
- Year 2006-07 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2006-07.pdf
- Year 2007-08 Annual report
  http://www.cc.gatech.edu/ rama/ITR-PROJECT/2007-08.pdf

2 Publications and Products

2.1 Publications

See the references at the end of this document for publications that appeared in the period that covers this project.

2.2 Web Site

Please visit the project web site at http://www.cc.gatech.edu/ rama/ITR-PROJECT/

3 Contributions

The activities we have undertaken in this project have resulted in a significant number of publications and software artifacts. These are listed in the references at the end of this report.

3.1 Human Resource Development and Student Placement

In the course of this project, every year roughly 10 graduate students worked on the project on an average. In addition, we hosted at least half a dozen undergraduates on the project, either as RAs supported by the REU program or for course credit. Students at all levels, who are alumni of this project, are sought after for summer internships by leading industries and get very good placements when they graduate.

As a direct result of this grant, we have graduated the following students who are well placed in industries and/or academia:

1. Zack Kurmas: Graduation Date: 8/2004
   Thesis title: "Generating and Analyzing Synthetic Workloads using Iterative Distillation"
   Position: Assistant Professor, Department of Computer Science & Information Systems, Grand Valley State University, Michigan.
2. Sameer Adhikari: Graduation Date: 12/2004
   Thesis title: "Programming Idioms and Runtime Mechanisms for Distributed Pervasive Computing"
   Position: Intel Corp., Portland
3. Arnab Paul: Graduation Date: 5/2005
   Thesis title: "Application of Error Correcting Codes to Distributed and Pervasive Computing"
   Position: Intel Corp., Portland
4. Josh Fryman: Graduation Date: 8/2005
   Thesis title: "Power management in embedded devices"
   Position: Intel Corp., Santa Clara
5. Matthew Wolenetz: Graduation Date: 8/2005
   Thesis title: "Characterizing Middleware Mechanisms for Future Sensor Networks"
   Position: Microsoft Corp.

6. Nissim Harel: Graduation Date: 12/2006
Thesis title: "Memory Optimizations for Distributed Stream-based Applications"
Position: Jambool - Startup
7. Hasnain Mandviwala: Graduation Date: 12/2008
Thesis title: Capsules: Expressing Composable Computations in a Parallel Programming Model
Position: Software Engineer Ask.com
8. Rajnish Kumar: Graduation Date: 12/2006
Thesis title: "Protocol Architecture for Future Sensor Network"
Position: Research Scientist II, Georgia Tech
9. Xiang Song: Graduation Date: 08/2008
Thesis title: "Seamless Mobility in Ubiquitous Computing Environments"
Position: Microsoft Corp.

There are several more students at advanced stages of their dissertation research who have been funded by this award including, and expected to finish in the next 9-12 months:

1. Bikash Agarwalla
2. Nova Ahmed
3. David Hilley

Alumni of this project at MS and BS level include:

1. Kirill Mechitov, BS 2001, Grad Student UIUC
2. Durga Devi Mannaru, MS 2001, IBM Research Triangle Park, NC.
3. Ansley Post, BS 2002, Grad Student Rice U.
4. Rajat Sharma, MS 2003, Verizon Wireless
5. Zaib Talat, BS 2003
6. Ilya Bagrak, BS 2004, Grad Student UC-Berkeley
7. Martin Modahl, MS 2004
8. Sam Young, BS 2007, Amazon
9. Steven French, BS 2007, Microsoft
10. Vladimir Urazov, MS December 2007, Citadel Investment Group

During the course of the award, we also entertained one post-doctoral visitor (Dr. Jin Nakazawa, Keio University, Japan, Oct 2004–October 2005; and one sabbatical visitor Professor HeonChang Yu, Associate Professor, Korea University, Seoul, S. Korea, Jan 2004–Jan 2005.

3.2 Software

Students working Dr. Ramachandran's group, developed a toolchain for Federal Reserve Bank, Atlanta, that allows scheduling applications on a cluster. The tool chain is built using the Stampede programming system, which was developed in this project. This tool-chain called *EcoSys* [49] is used by the economists at Federal Reserve Bank, who are domain experts in their area for utilizing cluster computing resources.

3.3 Impacting Education

The research artifacts from the project have found their way into graduate courses and we have had significant undergraduate participation in project-related research. We have funded a number of undergraduates through the REU supplement attached to this ITR grant, sponsored a number of independent undergraduate research projects for course credit (CS 4903), and have sponsored capstone senior design projects (CS 3901) that each result in a poster presentation at the annual Undergraduate Research Symposium.

The ITR project has reinforced the connectedness of hardware and software and the need to train students in system architecture quite early in their undergraduate preparation. With this in mind, Professor Ramachandran embarked on writing a set of course notes [46] for use in the sophomore level course on systems and networks. The course notes were well received by the students. In Spring 2006, he has signed a contract with Addison-Wesley to have the book published as a textbook. A custom edition is already in use at Georgia Tech [46], and a regular edition is expected in Spring 2009. A paper describing the pedagogical approach

underlying this textbook is appeared in WCAE 2007 [50].

4   Special Requirements

We have received permission from the Program Director (Dr. Helen Gill) for expending the remaining REU funds in the project by August 2009.

References

[1] S. Adhikari, A. Paul, and U. Ramachandran. D-stampede: Distributed programming system for ubiquitous computing. In *Proceedings of the 22nd International Conf. on Distributed Computing Systems*, July 2002.

[2] Sameer Adhikari. *Programming Idioms for Pervasive Computing*. PhD thesis, College of Computing, Georgia Institute of Technology, December 2004.

[3] Sandip Agarwala, Arnab Paul, Umakishore Ramachandran, and Karsten Schwan. e-safe: An extensible, secure and fault tolerant storage system. In *First IEEE International Conference on Self-Adaptive and Self-Organizing Systems*, July 2007.

[4] Bikash Agarwalla, Nova Ahmed, David Hilley, and Umakishore Ramachandran. Streamline: A scheduling heuristic for streaming applications on the grid. In *Thirteenth Annual MultiMedia Computing and Networking Conference (MMCN 2006)*, January 2006.

[5] Bikash Agarwalla, Nova Ahmed, David Hilley, and Umakishore Ramachandran. Streamline: scheduling streaming applications in a wide area environment. *Multimedia Systems*, May 2007. http://dx.doi.org/10.1007/s00530-007-0082-0.

[6] Nova Ahmed, Stewart Butler, and Umakishore Ramachandran. Guardianangel: An rfid-based indoor guidance and monitoring system. Submitted for consideration for publication in IEEE Pervasive Computing and Communications 2010. PerCom '10.

[7] Nova Ahmed, Rajnish Kumar, Robert Steven French, and Umakishore Ramachandran. Rf2id: A reliable middleware framework for rfid deployment. In *Proceedings of the 21st International Parallel and Distributed Processing Symposium*, 2007.

[8] Nova Ahmed, Vladimir Urazov, and Umakishore Ramachandran. Evaluating rf2id in a supply chain environment. Submitted for publication.

[9] Yavor Angelov, Umakishore Ramachandran, Kenneth Mackenzie, James Matthew Rehg, and Irfan Essa. Experiences with optimizing two stream-based applications for cluster execution. *Journal of Parallel and Distributed Systems*, June 2005.

[10] J.B. Fryman, C.M. Huneycutt, H.S. Lee, K.M. Mackenzie, and D.E. Schimmel. Energy efficient network memory for ubiquitous devices. Technical Report GIT-CERCS-03-05, CERCS, Georgia Institute of Technology, 2003.

[11] J.B. Fryman, H.S. Lee, C.M. Huneycutt, N.F. Farooqui, K.M. Mackenzie, and D.E. Schimmel. Softcache: A technique for power and area reduction in embedded systems. Technical Report GIT-CERCS-03-06, CERCS, Georgia Institute of Technology, 2003.

[12] Josh Fryman. *SoftCache Architecture*. PhD thesis, College of Computing, Georgia Institute of Technology, August 2005.

[13] Joshua Fryman, Chad Huneycutt, and Kenneth Mackenzie. Investigating a softcache via dynamic rewriting. In *Fourth Workshop on Feedback-Directed and Dynamic Optimization (FDDO)*, 2001.

[14] Joshua B. Fryman, Chad M. Huneycutt, Hsien-Hsin S. Lee, Kenneth M. Mackenzie, and David E. Schimmel. Energy efficient network memory for ubiquitous devices. In *IEEE MICRO*, Sept/Oct 2003.

[15] Joshua B. Fryman, Hsien-Hsin S. Lee, Luke A. Snyder, Chad M. Huneycutt, and Gabriel H. Loh. Intelligent cache management by exploiting dynamic UTI/MTI behavior. Technical Report GIT-CERCS-05-08, Georgia Institute of Technology, CERCS, 2005. Also submitted to IEEE MICRO 2005.

[16] N. Harel, H. Mandviwala, K. Knobe, and U. Ramachandran. Dead timestamp identification in Stampede. In *The 2002 International Conference on Parallel Processing (ICPP-02)*, August 2002.

[17] Nissim Harel. *Memory Optimizations for Distributed Stream-based Applications*. PhD dissertation, Georgia Institute of Technology, College of Computing, December 2006.

[18] Nissim Harel, Hasnain A. Mandviwala, Kath Knobe, and Umakishore Ramachandran. Methods of memory optimizations in streaming applications. In *The 2007 International Conference on Parallel Processing*, September 2007.

[19] Nissim Harel, Hasnain A. Mandviwala, Umakishore Ramachandran, and Kath Knobe. Use of dependency information for memory optimizations in distribute streaming applications. In *16th IEEE International Conference on Computer Communications and Networks (ICCCN)*, August 2007.

[20] David Hilley, Ahmed El-Helw, Matthew Wolenetz, Irfan Essa, Phillip Hutto, Thad Starner, and Umakishore Ramachandran. Tv watcher: Distributed media analysis and correlation. Technical Report GIT-CERCS-04-25, Center for Experimental Research in Computer Systems, Georgia Institute of Technology, 2004.

[21] Chad Huneycutt, Joshua B. Fryman, and Kenneth Mackenzie. Software caching using dynamic binary rewriting for embedded devices. In *International Conference on Parallel Processing 2002*, August 2002.

[22] Rajendra Kumar and Xiang Song. Gridlite: An infrastructure for provisioning and managing grid services in resource constrained devices. Abstract appeared in GlobusWorld 2005. http://www.globusconsortium.org/journal/20050907/gridlite.html; also available as technical report http://www.hpl.hp.com/techreports/2005/HPL-2005-146.html.

[23] Rajnish Kumar. *Adaptable Protocol Stack Architecture for Future Sensor Networks*. PhD thesis, College of Computing, Georgia Institute of Technology, August 2007.

[24] Rajnish Kumar, Santashil PalChaudhuri, and Umakishore Ramachandran. An adaptable protocol stack architecture for wireless sensor network, June 2006. Provisional patent application for GTRC ID No. 3710.

[25] Rajnish Kumar, Santashil PalChaudhuri, Charles Reiss, and Umakishore Ramachandran. System support for cross-layering in sensor network stack. In *The 2nd International Conference on Mobile Ad-hoc and Sensor Networks (MSN 2006)*, 2006.

[26] Rajnish Kumar, Arnab Paul, and Umakishore Ramachandran. Fountain broadcast for wireless sensor networks. In *Proceedings of the Second International Workshop on Networked Sensing Systems (INSS 2005)*, San Diego, CA, June 2005.

[27] Rajnish Kumar, Arnab Paul, Umakishore Ramachandran, and David Kotz. On improving wireless broadcast reliability of sensor networks using erasure codes. In *The 2nd International Conference on Mobile Ad-hoc and Sensor Networks (MSN 2006)*, 2006.

[28] Rajnish Kumar, Matthew Wolenetz, Bikash Agarwalla, JunSuk Shin, Phillip Hutto, Arnab Paul, and Umakishore Ramachandran. Dfuse: A framework for distributed data fusion. In *Proceedings of the First International Conference on Embedded Networked Sensor Systems (SenSys'03)*, pages 114–125, November 2003.

[29] Zachary Kurmas. *Generating and Analyzing Synthetic Workloads using Iterative Distillation*. PhD thesis, College of Computing, Georgia Institute of Technology, December 2004.

[30] H.S. Lee, J.B. Fryman, A.U. Diril, and Y.S. Dhillon. The elusive metric for low-power architecture research. In *Proceedings of the Workshop on Complexity-Effective Design*, 2003.

[31] Hasnain Mandviwala, Nissim Harel, Umakishore Ramachandran, and Kath Knobe. Adaptive resource utilization via feedback control for streaming applications. In *Proceedings of the 19th International Parallel and Distributed Processing Symposium*, Denver, CO, April 2005.

[32] Martin Modahl, Bikash Agarwalla, T. Scott Saponas, Gregory Abowd, and Umakishore Ramachandran. Ubiqstack: a taxonomy for a ubiquitous computing software stack. *Personal and Ubiquitous Computing*, 10(1):21–27, February 2006.

[33] Martin Modahl, Ilya Bagrak, Matthew Wolenetz, Ramesh Jain, and Umakishore Ramachandran. An architecture for eventweb. In *Proceedings of the 10th IEEE International Workshop on Future Trends in Distributed Computing Systems (FTDCS'04)*, pages 95–101, May 2004.

[34] Martin Modahl, Matthew Wolenetz, Phillip Hutto, and Umakishore Ramachandran. Mediabroker: An architecture for pervasive computing. In *Proceedings of the Second IEEE International Conference on Pervasive Computing and Communications (PerCom'04)*, pages 253–262, March 2004.

[35] Jin Nakazawa, W. Keith Edwards, Hideyuki Tokuda, and Umakishore Ramachandran. A bridging framework for universal interoperability in pervasive systems. In *26th International Conference on Distributed Computing Systems (ICDCS 2006)*, 2006.

[36] Jin Nakazawa, Hideyuki Tokuda, W. Keith Edwards, and Umakishore Ramachandran. g^2ui: A geographical user interface for multimedia exploration using diverse off-the-shelf devices, 2006. Unpublished manuscript, submitted for publication to a conference.

[37] Ripal Nathuji, Joshua B. Fryman, and Karsten Schwan. Dynamic voltage and frequency scaling in real-time pervasive computing environments: A systems-level perspective, 2005.

[38] Arnab Paul. *Application of Error Correcting Codes to Distributed Pervasive Computing*. PhD thesis, College of Computing, Georgia Institute of Technology, December 2004.

[39] Arnab Paul, Sameer Adhikari, and Umakishore Ramachandran. Design of a secure and fault tolerant environment for distributed storage. Technical Report GIT-CERCS-04-02, CERCS, Georgia Tech, January 2004.

[40] Arnab Paul, Nissim Harel, Sameer Adhikari, Bikash Agarwalla, Umakishore Ramachandran, and Ken Mackenzie. Interaction between stampede runtime and operating systems. In *2003 IEEE International Symposium on Performance Analysis of Systems and Software*, March 2003.

[41] Arnab Paul, Rajnish Kumar, and Umakishore Ramachandran. LAWN: A lightweight authentication protocol for wireless networks. In *Proceedings of the 4th IEEE International Conference on Network Computing Applications (NCA 05)*, July 2005.

[42] Arnab Paul and Umakishore Ramachandran. Computation-communication trade-off for power and bandwidth saving for remote authentication over wireless networks. Technical Report GIT-CERCS-04-01, CERCS, Georgia Tech, January 2004.

[43] Umakishore Ramachandran, Phillip Hutto, Bikash Agarwalla, and Matthew Wolenetz. A system architecture for distributed control loop applications. In *Proceedings of the 9th IEEE International Workshop on Future Trends in Distributed Computing Systems (FTDCS'03)*, May 2003.

[44] Umakishore Ramachandran, Kathleen Knobe, Hasnain A. Mandviwala, and Nissim Harel. Distributed garbage collection for timestamped data. *IEEE Transactions on Parallel and Distributed Systems*, 2006.

[45] Umakishore Ramachandran, Rajnish Kumar, Matthew Wolenetz, Brian Cooper, Bikash Agarwalla, JunSuk Shin, Phillip Hutto, and Arnab Paul. Dynamic data fusion for future sensor networks. *IEEE Transactions on Sensor Networks*, 2006.

[46] Umakishore Ramachandran and William D. Leahy, Jr. Computer systems: An integrated approach to architecture and operating systems, To appear in print in 2009. Preliminary edition for CS 2200: Introduction to Computer Systems and Networks, ISBN# 0536533105.

[47] Umakishore Ramachandran, Martin Modahl, Ilya Bagrak, Matthew Wolenetz, David Lillethun, Bin Liu, James Kim, Phillip Hutto, and Ramesh Jain. MediaBroker: a pervasive computing infrastructure for adaptive transformation and sharing of stream data. *Elsevier Journal on Pervasive and Mobile Computing, special issue*, 1(2):257–276, July 2005.

[48] Umakishore Ramachandran, Rishiyur Nikhil, James Matthew Rehg, Yavor Angelov, Arnab Paul, Sameer Adhikari, Kenneth Mackenzie, Nissim Harel, and Kathleen Knobe. Stampede: A cluster programming middleware for interactive stream-oriented applications. *IEEE Transactions on Parallel and Distributed Systems*, November 2003.

[49] Umakishore Ramachandran, Vladimir Urazov, Namgeun Jeong, Hasnain Mandviwala, David Hilley, Daniel F. Waggoner, and Tao Zha. Ecosystem: A set of grid computing tools for a class of economic applications. Technical Report GT-CS-07-09, School of Computer Science, Georgia Institute of Technology, 2007.

[50] Umakishore Ramachandran and Jr. William D. Leahy. An integrated approach to teaching computer systems architecture. In *Workshop on Computer Architecture Education*, June 2007. held in conjunction with 34th International Symposium on Computer Architecture.

[51] B. Rhodes and T. Starner. Remembrance agent: A continuously running automated information retreival system. In *Proc. of Pract. App. of Intelligent Agents and Multi-Agent Tech. (PAAM)s*, April 1996.

[52] Junsuk Shin, Rajnish Kumar, Dushmanta Mohapatra, Umakishore Ramachandran, and Mostafa Ammar. Asap: A camera sensor network for situation awareness. In *OPODIS'07: Proceedings of 11th International Conference On Principles Of Distributed Systems*, 2007.

[53] Junsuk Shin, Umakishore Ramachandran, and Mostafa Ammar. On improving the reliability of packet delivery in dense wireless sensor networks. In *16th IEEE International Conference on Computer Communications and Networks (ICCCN)*, August 2007.

[54] Luke Snyder, Joshua Fryman, Chad Huneycutt, and Umakishore Ramachandran. Poster presentation: Better cache design through memory reference behavior. In *Undergraduate Research Symposium, College of Computing, Georgia Tech*, 2004. Third Place Award.

[55] Xiang Song. *Seamless Mobility in Ubiquitous Computing Environments*. PhD thesis, College of Computing, Georgia Institute of Technology, August 2008.

[56] Xiang Song, Namgeun Jeong, Phillip Hutto, Umakishore Ramachandran, and James Rehg. State management in web services. In *Proceedings of the 10th IEEE International Workshop on Future Trends in Distributed Computing Systems (FTDCS'04)*, May 2004.

[57] Xiang Song and Rajendra Kumar. Gridlite: An infrastructure for provisioning and managing grid services in resource constrained devices. In *Proceedings of The 2006 International Conference on Grid Computing & Applications*, pages 127–133. CSREA Press, 2006.

[58] Xiang Song and Umakishore Ramachandran. Mobigo: A middleware for seamless mobility. In *The 13th IEEE International Conference on Embedded and Real-Time Computing Systems and Applications (RTCSA 2007)*, August 2007.

[59] S. Stillman and Essa I. Towards reliable multimodal sensing in aware environments. In *Perceptual User Interfaces (PUI 2001) Workshop (held in Conjunction with ACM UIST 2001 Conference)*, November 2001.

[60] Sang-bum Suh, Xiang Song, Jatin Kumar, Dushmanta Mohapatra, Umakishore Ramachandran, Jung-Hyun Yoo, and Ilpyung Park. Chameleon: A capability adaptation system for interface virtualization. In *MobiVirt 2008, The Workshop on Virtualization in Mobile Computing*, June 2008. Held in conjunction with MobiSys 2008, Breckenridge, Colorado, USA.

[61] Matthew Wolenetz. *Characterizing Middleware Mechanisms for Future Sensor Networks*. PhD thesis, College of Computing, Georgia Institute of Technology, August 2005.

[62] Matthew Wolenetz, Rajnish Kumar, Junsuk Shin, and Umakishore Ramachandran. Middleware guidelines for future sensor networks. In *Proceedings of the First Workshop on Broadband Advanced Sensor Networks*, 2004.

[63] Matthew Wolenetz, Rajnish Kumar, Junsuk Shin, and Umakishore Ramachandran. A simulation-based study of wireless sensor network middleware. *International Journal on Network Management, special issue on sensor networks*, 2005.

[64] Matthew David Wolenetz, Hasnain A. Mandviwala, Sameer Adhikari, Yavor Angelov, Umakishore Ramachandran, Kenneth Mackenzie, and James Matthew Rehg. Towards aspect-oriented programming support for cluster computing. Unpublished manuscript. April 2002.