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# SUNYIT VISITING FACULTY RESEARCH

STATE UNIVERSITY OF NEW YORK (SUNY)
INSTITUTE OF TECHNOLOGY

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FINAL TECHNICAL REPORT

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**AIR FORCE RESEARCH LABORATORY**
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FOR THE DIRECTOR:

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Work Unit Manager

/s/

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**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
The Research Foundation, for and on behalf of SUNY Institute of Technology, has contributed significant research capability and capacity to the in-house program at AFRL through the placement of highly motivated and accomplished faculty members and Graduate students pursuing advanced degrees in engineering, computer science, mathematics, and other recognized technical disciplines critical to the advancement of information technologies. The program supported and enhanced the existing AFRL Information Institute Summer Faculty Research Program and the AFOSR Summer Faculty Fellowship Program. SUNY-IT worked closely with AFRL to help build, foster, and nurture in-house research teams. Under this effort, SUNY-IT recruited, placed, and supported administrative requirements of 25 faculty undergraduate research assistants, and coordinated on 25 additional faculty extension efforts.

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**1.** The Research Foundation, for and on behalf of SUNY Institute of Technology (SUNYIT), has contributed significant research capability and capacity to the in-house program at AFRL through the placement of highly motivated and accomplished faculty members and undergrad/graduate students pursuing advanced degrees in Engineering, Computer Science, Mathematics and other recognized technical disciplines critical to the advancement of Information Technologies. The program supported and enhanced the existing AFRL/Information Institute Summer Faculty Research Program and the AFOSR Summer Faculty Fellowship Program.

SUNYIT worked closely with AFRL to help build, foster and nurture in-house research teams. Under this effort SUNYIT recruited, placed and supported administrative requirements of 25 faculty members and 21 undergrad/graduate research analysts and coordinated 25 additional faculty extension efforts.

## 2. Faculty

The faculty and their research areas included:

### 2.1 2009 Summer Professors

**Adam Bojanczyk –On Designing Angle-of-Arrival Estimators Through the Exploitation of Time-Difference-of-Arrival Information: General Principles and Algorithms/ School of Electrical and Computer Engineering Cornell University**

The Time Difference of Arrival (TDOA) technique for calculating the unknown position of a transmitter breaks down due to noisy measurements when receivers are located far from the transmitter. However, when the positions of receivers are properly chosen, the information in the TDOA data can be exploited to estimate the Angle of Arrival (AOA) of the transmitted signal. Receivers can then be moved towards the transmitter and collect less noisy TDOA data so its location can be reliably determined by the TDOA technique. In order to combat the influence of possible non Gaussian measurement errors, error weighting functions are applied in the minimization of TDOA objective functions. The scheme can be implemented with relatively inexpensive hardware.

**Yuan Xue –A Model-Based Integration of Network Emulation with HLA-based Heterogeneous Simulation Environments, ISIS, EECS/ Vanderbilt University**

Evaluation of Command and Control (C2) concepts requires a sophisticated modeling, simulation and experiment infrastructure. This requires the integration of existing simulation tools, system prototypes and experiment platforms that can interact in a coordinated way. The "Command and Control Wind Tunnel (C2W)" tool suite addresses this urgent need and enables rapid synthesis of heterogeneous simulation environments using a model-based approach, where an overarching C2 modeling environment is developed based on GME (Generic Modeling Environment) to integrated different platform specific simulation models. Network components and policies (such as security configurations) are essential aspects of C2 systems. Their impact on the performance and

the behavior of C2 systems need to be accurately characterized when evaluating C2 systems. However, the current network simulators, which lack the implementation details of network protocols and algorithms, are insufficient in providing the level of accuracy required by the evaluation of C2 systems.

This report presents our work on introducing the network emulation into the C2 Wind Tunnel environment as a solution to this problem. Network emulation environments allow the use of real network devices, components and systems, thus providing greater realism in the network experiment. Integrating network emulation into the C2W system, however, is a challenging issue. (1) Being a simulation environment, the C2W system runs under the discrete event-driven time model and uses the RTI time management; on the other hand, the network emulation platform runs in continuous real time. The time synchronization issue between the simulation and emulation environment is a non-trivial issue. (2) There is potentially large volume of data communicated between the simulation and emulation environment. Controlling the communication overhead while still ensuring the accuracy of the experiment is also a challenging issue. This report presents our approaches to these two issues and shows our models and algorithms developed for such system integration.

**Enrique Galvez –Setup and Diagnosis of Entangled-light Sources for Quantum Computing/ Department of Physics and Astronomy/ Colgate University**

The activities of this research centered about producing and diagnosing photon pairs in polarization-entangled states for the purpose of performing quantum processing and computing. An imaging technique was developed to align optical components for generating beams of polarization-entangled light in predetermined directions. A quantum tomography technique was implemented and used for diagnosing the entangled-state output of several types of sources using the process of spontaneous parametric down conversion. A third activity involved setting up a Hong-Ou-Mandel interferometer for obtaining additional diagnosis and characterization of the light sources.

**Gregory Vert – "Global Contextual Based Processing Models, Similarity Analysis, Storage Management, Advanced Security Models by Temporal Spatial Relations and the Relationship to the JBI Paradigm"/ Louisiana State University**

The summer research explored the following:

1) Examined where contextual processing and JBI i) integrate, ii) conflict iii) synergize

2) Produce an integrated model of contextual modeling populated with JBI meta tagging data. The model will look at meta tags and their integration into the newly developed *set contextual repository model* that in theory can manage sets of any type of information type invented in the future and relate the information by spatial, temporal and thematic concepts for storage and retrieval

3) Evaluate and develop the concepts of *Brane* applied *spatial-temporal relationship based security* with traditional authentication methods to produce an understanding of how the existing contextually based Brane, *pretty good security* model may be developed to reduce computational security processing on streaming global contextual data.

4) Develop a notion of *adaptive relationship among meta-data classes* that strengthens or weakens based on statistical accesses in a database. This model may be nicknamed the $M_2D$ model (meta-meta data model) and can have application to the area of retrieval of similar information and aggregation for the purposes of ambiguity resolution.
5) The CBP model has the notion of hyper distribution of data among consumers and producers. However, the contextual model proposes that i) consumers are unaware of information that they may be interested in ii) that methods of information flowing to unknown consumer need to exist in a flat model, similar to that of how an amoeba finds food, iii) that sources of information come into existence, conflict with each other in information, can be ambiguous in content and have characteristic temporal behaviors and personalities (sporadic, continuous, cyclic, elderly, not interesting,…) Methods for resolving these conflicts need to be developed. The goal of this phase will be to examine how resolution of conflict may extend the JBI paradigm and consider how bio-inspired algorithms and complex behavior may be utilized.

**Shuvra Bhattacharyya – Development of a new taxonomy and associated class of dataflow processing models, called window processing patterns (WPPs)/ University of Maryland at College Park**

We have been working on integrating these models with the emerging methodologies of windowed dataflow representations and the dataflow interchange format (DIF) to provide an efficient, high level, retargetable framework for analysis and transformation of embedded signal processing applications. We expect that significant improvements in parallel processing efficiency and memory management can be achieved from direct support for window processing patterns in the specification of signal processing tasks and in the software synthesis process. We have started investigating precise methods for integrating window processing patterns into the formal framework of dataflow, and designing experiments to help validate and refine these methods.

**Aniruddha Gokhale – Real-Time and Fault-Tolerance Solutions for Cyber Physical Systems/ VanderbiltUniversity**

The software and hardware that comprise current and planned missions of the United States Air Force (USAF) often fall into a category of systems called Cyber Physical Systems (CPS). CPS is a form of distributed, real-time and embedded (DRE) systems that tightly integrate the computation and communication artifacts of the mission with that of the physical traits and constraints of the system. CPS often involves multiple smaller subsystems that form the larger systems-of-systems perspective prevalent in typical USAF missions. Timely and reliable dissemination of information is a key requirement of the mission despite the high degree of mobility of fighter aircrafts, the fluctuating wireless communication capabilities, constraints on available resources, and often the hostile terrain. Assuring the quality of service (QoS) properties (e.g., end-to-end latencies, reliability, security) and Quality of Information (QoI) in general, and possessing the ability to fight through software failures in particular, is a key requirement for USAF missions.

**Annamalai, Annamalai Jr – Ergodic Capacity of Cooperative Airborne Networks with Adaptive Source Transmission/ Department of Electrical and Computer Engineering Prairie View A&M University**

Upper bounds on the link spectral efficiency of amplify-and-forward cooperative diversity networks with independent but non-identically distributed wireless fading statistics are studied by deriving the ergodic capacity of three distinct adaptive source transmission techniques: (i) constant power with optimal rate adaptation (ORA); (ii) optimal joint power and rate adaptation (OPRA); and (iii) fixed rate with truncated channel inversion (TCIFR). Asymptotic capacity bound is also derived which shows that optimal rate adaptation with constant power policy provides roughly the same ergodic capacity as the optimal joint power and rate adaptation policy at high mean signal-to-noise ratios (SNRs). Different from previous related studies, we advocate a simple numerical procedure for unified analysis of ergodic channel capacity in a myriad of fading environments. This framework allows us to gain insights as to how fade distributions and dissimilar fading statistics across the diversity paths affect the maximum transmission rates, without imposing any restrictions on the fading parameters.

**Lixin Shen –Bounds of Eigengaps for Hub and Hub-Dominant Matrices and Their Applications to Wireless Communications/ Department of Mathematics Syracuse University**

This report consists of three main parts. The first part of the report considers the lower and upper bounds of eigenvalues of arrow-head matrices. We propose a parameterized decomposition of an arrowhead matrix which is a sum of a diagonal matrix and a special kind of arrowhead matrix whose eigenvalues can be computed explicitly. The eigenvalues of the arrowhead matrix are then estimated in terms of eigenvalues of the diagonal matrix and the special arrowhead matrix by using the Weyl's theorem. Improved bounds of the eigenvalues are obtained by choosing a decomposition of the arrowhead matrix which can provide best bounds. Some applications of these results to hub matrices and wireless communications are discussed. The second part of the report studies lower and upper bounds of the Gram matrix associated with a hub-dominant matrix. To develop these bounds, we mainly use the results from the first part, the Poincare separation theorem, and the Gershgorin disc theorem. A class of hub-dominant matrices are then constructed by using equiangular tight frames. The third part of the report deals with conclusions and future research directions.

**Vijay Kumar – Adaptive and Proactive Security Schemes Synchronizing Moving Objects/University of Missouri-Kansas City Kansas City, MO**

A number of security schemes are deployed today to protect systems for various types of attacks. They do a good job; however, in some cases they fail to protect the systems and cope with new security threats because their approach is (a) static and (b) defensive. This project develops a new security model with the following properties.
Adaptive: Our schemes will adapt to new situation to successfully protect the system from any type of attack.

Proactive: Our schemes will continuously analyze the current attacks and be ready for any future new type of attack. The current attack is likely to provide enough information for a possible future attack. A current malicious attack on one account is likely to reach other accounts in future and the scheme proactively place protection on all other accounts of the user.
Efficient use of context for building new scheme on-the-fly: Our schemes will continuously monitor the context, execution profile of the activity and user profile to build effective protection scheme. The building of protection scheme will be similar to the action of human mind that generates necessary anti-bodies to protect the body from the current and related future attacks.

**Bharat Bhargava – Context based Adaptable Defense Against Collaborative Attacks in Service Oriented Architecture/Purdue University**

We developed a report that details the security issues in Service oriented Architecture (SoA). We considered collaborative attacks in variety of scenarios. We identified the various aspects of collaboration and context in which attacks can collaborate. The experiments on showing collaboration in port scanning are in a separate attached document. Providing secure and efficient access to large scale outsourced data is an important component of cloud computing. In this paper we propose a mechanism to solve this problem in owner-write-users-read applications. We propose to encrypt every data block with a different key so that flexible cryptography-based access control can be achieved. Through the adoption of key derivation method, the owner needs to maintain only a few secrets. Analysis shows that the key derivation procedure using hash functions will introduce very limited computation overhead. We propose to use over-encryption and/or lazy revocation to prevent revoked users from getting access to updated data blocks. We design mechanisms to handle both updates to outsourced data and changes in user access rights. We investigate the computation overhead and safety of the proposed approach, and study mechanisms to improve data access efficiency.

**Florentin Smarandache – A Class of DSm Conditioning Rules /Department of Mathematics University of New Mexico**

In this paper we introduce two new DSm fusion conditioning rules with example, and as a generalization of them a class of DSm fusion conditioning rules, and then extend them to a class of DSm conditioning rules.

**Zhiyuan Yan – Applying Network Coding in Wireless Computational Networks /Department of Electrical and Computer Engineering Lehigh University**

One of the most significant challenges to the DoD's network-centric information systems is the provision of on-demand computational infrastructure to applications at the tactical edges. Wireless computational networks (WCNs) are a promising solution to this problem due to their flexibility in deployment and convenience in broadcasting. A wireless computational network consists of a collection of computing nodes interconnected by a wireless network. As a parallel computing system, the performance

of a WCN is usually constrained by the bandwidth of its interconnect. Wireless networks have some unique characteristics, such as broadcast advantage and data redundancy, but also face serious issues in bandwidth and reliability, when used as computational backplanes. Thus it is critical to take advantage of these unique characteristics to help address the throughput and reliability issues. Network coding is a promising candidate for a new unifying design paradigm for WCNs, as it leads to significant improvements in throughput, reliability, mobility, and management of wireless networks. Aiming to develop a theoretical framework for the application of network coding in WCNs, we investigate two open research problems with significant impact on WCNs, unequal error protection and inter-session network coding, based on a combinatorial approach. This report consists of five main parts. The first part provides an overview of our work, providing the motivation and background and highlighting the key results of our work. The second part is a brief review of background in order to keep this report self-contained. The third part of the report investigates unequal error protection in network coding, and we propose a novel network coding scheme that provides different levels of protection to two classes of packets. The fourth part of the report studies inter-session network coding schemes that accommodate two simultaneous multicast sessions from the same source node. The final part of the report presents the conclusions of our work and points out future research directions.

### 2.2 2010 Summer Professors

**Yang Cai – Video Analysis for Smart Camera on UAV/Carnegie Mellon University**

In this summer, the CMU team has worked on three components for the onboard smart camera system: 1) the small form factor PC-based platform that receives frames from a USB high definition camera and encode flight metadata and object metadata (motion segmentation coordinates) with H.264 video stream; 2) spatial and temporal motion pattern recognition algorithms including off-line image-based formation pattern recognition and online video-based dynamic motion pattern recognition algorithms and tested with metadata from the UAV video; and 3) the analyst interface that displays UAV video, metadata, content annotations, and imagery registration. The preliminary system is developed based on Open Sources such as X264, GCC compiler and Linux Operation System so that it enables the unclassified development in a university environment. Furthermore, we have ordered over 2 TB unclassified UAV video data sets VIVID and VIRAT from WPAFB and DARPA. The data were delivered in July. Overall, we have built a common platform that both AFRL team and CMU team can collaborate for years to come.

**Qiang Zhao – Knowledge Representation and Reasoning for Impact/Threat Assessment in Cyber Situation Awareness Systems/ Mercer University**

The objective of this effort is to assist AFRL/RI personnel to explore strategies and techniques with regard to knowledge representation and reasoning that can be used in their prototype Situation Awareness reference system for the Cyber environment

(referred to as the Situation Identification and Threat Assessment (SITA) system). The insight gained from this system can also be used to develop similar systems for other Air Force domains (e.g., space, irregular warfare, chem/bio, etc).

**Jay Urbain/Upstream Development – Probabilistic Multirelational Models for Entity and Event Consolidation/Electrical Engineering and Computer Science Department Milwaukee School of Engineering**

Entity and event consolidation involves monitoring data streams or collections of text to automatically detect and consolidate events (topics) and related named entities. The ability to detect new events, aggregate multiple facets (aspects) of the same event, and identify related entities is an important problem in financial markets, news analysis, and intelligence gathering. Given the enormity of data coming from a variety of information sources, it is also a pragmatic problem as it is simply impossible for human analysts to process this information. Identifying the characteristics of an event from news stories is a difficult problem. New events do not follow any periodic cycle, can occur at any time, can contain any number and combination of named entities (people, places, organizations, things, etc), and can be reported in any language. Development of effective entity and event detection applications relies on our ability to accurately retrieve and extract relevant information from free text. This remains a difficult task due to the inherent ambiguity and complexity in natural language. Humans naturally apply multiple perspectives and sources of evidence when solving such complex problems. We are able to understand natural language by relating language to other sources of knowledge and by integrating semantic, syntactic, and contextual evidence.

**Madjid Tavana – Modeling Operational Robustness and Resiliency with High-level Petri Nets/ La Salle University**

Military operations are highly complex workflow systems that require careful planning and execution. The interactive complexity and tight coupling between people and technological systems has been increasing in military operations, which leads, on the one hand, to improved efficiency and on the other, a greater vulnerability to mission accomplishment due to attack or system failure. Although the ability to resist and recover from failure is important to many systems and processes, the robustness and resiliency of workflow management systems has received little attention in literature. In this study, we propose a novel workflow modeling framework using high-level Petri nets (PNs). The proposed framework is capable of both modeling structure and providing a wide range of qualitative and quantitative analysis. The concepts of self-protecting and self-healing systems are captured by the robustness and resiliency measures proposed in this study. The proposed measures are plotted in a Cartesian coordinate system; a classification scheme with four quadrants (i.e., possession, preservation, restoration, and devastation) is proposed to show the state of the system in terms of robustness and resiliency. We also introduce an overall sustainability index for the system based on the theory of displaced ideals. We demonstrate the application of our methodology in the evaluation of an air tasking order generation system at the United States Air Force.

**Yujian Fu –Safety Analysis of Reconfigurable Systems/School of Engineering and Technology Alabama A&M University**

Multi-million gate system-on-chip (SoC) designs easily fit into today's Field Programmable Gate Arrays (FPGAs). Combining the programmability of processors with the performance of custom hardware, FPGA technology has been widely adopted to speed up computationally intensive applications. As they become more common in safety-critical and mission-critical systems, it is desirable for new techniques to manage correctness, reliability and security in FPGA designs. How can designers effectively realize the potential of the latest FPGAs which can implement million-gate designs? How to ensure the correctness after synthesis of hardware design language? This summer research aims at verifying the functional equivalence of system and security properties during design transformation from Handel C to bit stream through three steps. First, extract a formal specification on Handel C description using Petri Nets. Secondly, define a translation rule from Petri Nets specification to maude programming language. Verify the formal specification against the system properties using model checking. Finally, validate this approach using a case study.

**Vijay Kumar – Object Discovery, Identification and Association/ University of Missouri-Kansas City Kansas City**

A tracking process captures the *state* of an object. The state of an object is defined in terms of its dynamic and static properties such as location, speed, color, temperature, size, etc. The set of dynamic and static properties for tracking very much depends on the agency who wants to track. For example, police need a different set of properties to track people than the Air Force to track a vehicle. The tracking scenario also affects the selection of parameters. Tracking is done by a system referred to in this paper as a "Tracker." It is a system that consists of a set of input devices such as sensors and a set of algorithms that process the data captured by these input devices. The process of tracking has three distinct steps (a) object discovery, (b) identification of discovered object, and (c) object introduction to the input devices. In this paper we focus mainly on the object discovery part with a brief discussion on introduction and identification parts. We develop a formal tracking framework (model) called "Discover, Identify, and Introduce Model (DIIM)" for building efficient tracking systems. Our approach is heuristic and uses reasoning leading to learning to develop a knowledge base for object discovery. We also develop a tracker for the Air Force Research Laboratory program NCET.

**Kui Ren - Authentication In Tactical MANETs/ Department of Electrical and Computer Engineering Illinois Institute of Technology**

As a new paradigm of wireless communication for mobile nodes, mobile ad hoc networks (MANETs) are mainly utilized in the security-sensitive operations such as military tactical net-works, because of their quick setup, takedown, and mobility features. In the tactical MANETs, there are no infrastructure and network topology changes frequently, and therefore every military unit (e.g., plane) is equipped with wireless communication devices and functions as a router to keep the whole network connected. In this report, we first explore the security issues in the tactical MANETs with focus on authentication, and

further utilize two cryptographic primitives, zero- knowledge proof (ZKP) and direct anonymous attestation (DAA) to address the authentication problem. Secure and reliable communication between mobile nodes is highly demanded in the tactical and other security-sensitive MANETs. There are five main security attributes to achieve a secure tactical MANETs as authentication, availability, confidentiality, integrity and non-reputation. Authentication this attribute enables the mobile node to verify the identity of other mobile nodes before they exchange and share any valuable information. With the protection of authentication, the tactical MANETs could prevent adversary nodes from establishing connection with other nodes and accessing data in the network.

**James Hill – Service-oriented QoS Validation: Principles and Techniques for Realizing QoS Validation as a Service/ Indiana University-Purdue University Indianapolis**

We performed literature review of existing techniques that can be used as reference implementations for portions of the proposed research. We determined candidate technologies that will be used in proposed research including: capturing the genetic make-up of QoS tests as platform independent models; learning the structural model of components undergoing testing to determine how to test the component undergoing QoS validation; realizing of complete system QoS tests from models that capture its genetic make-up; automating the deployment and configuration of complete QoS test into a cloud-like environment, such as Emulab; automating the testing and QoS validation process in cloud-like environment, such as Emulab. We performed final testing, validation, and improvements to QUOTAS.

**Shangping Ren – Building Dependable Software Systems that Operate in Vulnerable Environment/ Computer Science Department Illinois Institute of Technology**

The proposed research is to develop a model and methodologies to build dependable systems that operate in a vulnerable environment. To achieve the objective, we performed the following:
We researched different types of attack models to understand how these different types of attacks affect the system services and dependability
We researched the mappings between complex distributed software systems and complex network systems and studied the feasibility of utilizing the research results from the complex network systems community in building dependable software systems.
One of the well-known research results from the complex network systems community is that by hiding small percentage of network topology information from potential attackers, we can make the network more attack-tolerant. We investigated if we can achieve the same effect for complex software systems through software architecture re-configuration and software-to-hardware deployment reconfiguration.
We developed a mathematical model that allows us to formally and quantitatively express and analyze the system survivability improvement achieved through dynamic reconfiguring of software to physical node deployment.

**Warner Miller – The Geometry of Networks: Discrete Ricci Flow/Department of Physics Florida Atlantic University**

The operational objective of this project is to understand the connection between the geometry of information networks and network congestion. The technical objective of this project is to develop the first network curvature analysis using Discrete Ricci Flow (DRF) techniques in dimensions greater than two. The approach will leverage our in-house experience indiscrete geometry -- Regge Calculus (RC) -- to define and numerically solve the RF problem for a network in 4-spatial dimensions.

**Henry Zmuda – Optical Interconnects in a Distributed Quantum Computer/ University of Florida Department of Electrical and Computer Engineering**

This project seeks to build upon past AFRL-sponsored theoretical work on distributed quantum computing and investigate the use of optical interconnects in a distributed quantum computing (**DQC**) approach to building a quantum computer in hardware. Techniques to launch and receive entangled photons with and without necessary ancillary bits were investigated. This involved setting up several small optical quantum optical interconnect circuits on an optical table using existing in-house methods of generating entangled photons to test the overall concept in hardware.

**Enrique Galvez – Diagnosis of Entangled Qubits of Light and Bell Inequalities/Department of Physics and Astronomy Colgate University**

The activities of this research centered about characterizing photon pairs in polarization entangled states for the purpose of establishing quantum bits that can be used for quantum computation. This involves making projective measurements leading to measurements of the violation of a Bell Inequality.

**Garrett Rose – Design, Modeling and Simulation of Memristor Based Circuits and Systems/Polytechnic Institute of NYU**

In today's world there exists ever increasing demand for high performance computing machinery. However, conventional CMOS technologies are approaching real limits in terms of device scaling that may also limit potential performance gains. One approach to achieving performance goals is to leverage non-traditional computer architectures such as multicore and neuromorphic computing systems. In the case of neuromorphic computing, performance increases can be obtained but only with a high number of components that easily results in a large area footprint if using CMOS. Thus, novel nanoscale technologies must be considered that can be used to provide a desired increase in performance with only a small area penalty. It is expected that the final solution will consist of a combination of both novel technology (nanoelectronics) and novel architectures (neuromorphic). The objective of this research is to better understand how nanoscale memristors can be leveraged to help continue the trend of increasing performance with subsequent technology generations. More specifically, we aim to explore memristor based digital circuits from low-level circuit simulations that will provide real insight into

the speed and energy consumption expected from memristive circuits. In order to ensure circuit level simulations reflect what would be observed in real world systems memristor device models will be developed and updated based on experimental data. Furthermore, the combination of accurate device models and circuit-level simulation will be used to characterize and explore the expected performance of more complex digital systems. Benchmarking results for memristor based logic systems will be obtained for the ISCAS benchmarking suite. The end goal of this work is to obtain an accurate picture showing the expected performance of memristive logic circuits in terms of delay and energy.

## 3. Students

Students supported under this effort were enrolled in undergraduate and graduate education programs, demonstrating excellent academic accomplishment; they included:

### 3.1 2009 Students

Anthony Rahul - NYU Polytechnic Institute
Sean Cain - SUNYIT
Andrew Dickson - SUNY, Binghamton
Stephen Won - University of Maryland
Katherine Byrnes - SUNY, Buffalo
Scott Pudlewski - SUNY, Buffalo

### 3.2 2010 Students

Christopher Tison - Florida Atlantic University
Corey Peters - University at Albany
Vijit Bedi - SUNY, Binghamton
Hein Hatt - Carnegie Mellon University
Michelle Lin - Carnegie Mellon University
Wednel Cadeau - SUNY, Binghamton
Marissa Gomes - Utica College
Bradley Ashcroft - University of Rochester
Andrew Gorczyca - SUNY, Binghamton
Christopher Parich - Louisiana State
Charles LeDoux - Louisiana State
William Proia - Whorsher Poly Tech
Thomas Booth - Rochester Institute of Technology
Matthew Hodge - Rochester Institute of Technology
Timothy Yeskoo - Colgate University

## 4. Continuing Research Projects

This initiative was intended to allow AFRL scientists and engineers to identify and support the continuation of outstanding faculty research projects begun during the summer. Due to limited funding, the continuation efforts proved to be very competitive and sought after. Following the summer of 2009 and 2010 continuation projects were supported, they included efforts by:

### 4.1 2009 Extension Grants

**Bharat Bhargava – Context Based Adaptable Defense Against Collaborative Attacks in Service Oriented Architecture/ Purdue University**

Based on research discussions with my mentor and other researchers at AFRL in summer and Fall 2009, I have extended the research results and present them briefly in this report. Specifically, we developed a report that details the security issues in Service oriented Architecture (SoA). We considered collaborative attacks in variety of scenarios. We identified the various aspects of collaboration and context in which attacks can collaborate.

**Sanjay Madria – Performance Analysis of Memory Efficient Caching Model to Improve Data Accessibility in Mobile Ad hoc Networks / Missouri University of Science and Technology**

Improving data accessibility using caching and replication in mobile ad-hoc networks (MANET) is an extensive area of research. The topology changes play a vital role in determining the efficacy of any caching model including for MANET. Though, caching bears its own advantage such as saving bandwidths, reducing roundtrip time, and power, it too has to overcome its own challenges such as consistency issues, cache replacement, memory, mobility and load distribution. Moreover, caching can bring data closer to the source in multi-hop wireless networks thus help in conserving overall energy as wireless transmission consumes lot of battery power. Furthermore, shared memory in MANET is also limited and therefore, it has to be efficiently utilized.

**Florentin Smarandache – Unification of Fusion Theories and Rules, Filter Algorithms, and Target Tracking Methods for Applications to Air Force Problems Department of Mathematics University of New Mexico**

In this paper we propose a unification method in order to be able to check what fusion theory, what combination fusion rule, and what filtering method to use for data fusion, image fusion, and target tracking for each military application. We thus try to solving air force problems using a combination of fusion theories, rules, and target tracking algorithms.

**Joseph Kizza – Feige-Fiat-Shamir ZKP Scheme Revisited/ Department of Computer Science and Engineering the University of Tennessee, Chattanooga**

In networks and entity groupings that have sensitive resources, user identification is a crucial requirement for secure access, communication and transactions involving those resources. However, there are networks and entity groupings that require entity authentication while preserving the privacy of the entity being authenticated. There are several zero-knowledge protocols (ZKP) including the Fiege-Fiat-Shamir that authenticate an entity anonymously. We present a revised Feige-Fiat-Shamir ZKP scheme for the Airborne Networks (ANs) that reduces the ping-pong effect in the scheme

and speeds up the growth of the Verifier trust of the Prover, thus making the authentication process faster and more efficient.

**Shuvra Bhattacharyya – High Performance Computing Framework Layered Sensing/University of Maryland at College Park**

During this project, we have been working with collaborators in AFRL, Barcelona Super Computing Center, Technical University of Catalunya, and the University of Missouri to develop a broad-based framework for design and implementation of future high performance layered sensing applications. The framework emphasizes a multi-faceted approach targeting support for end-to-end application development (as opposed to conventional kernel-centric optimization), support for legacy code, model-based design, and high-level application analysis and optimization. Additionally, we have been building on our work on window processing patterns, which provides a well-defined taxonomy and associated design methodology for scalable development of high performance embedded software for image processing.

**Lixin Shen – De-blurring Images Corrupted by Mixed Impulse plus Gaussian Noise/ Department of Mathematics Syracuse University**

This work studies a problem of image restoration that observed images are contaminated by Gaussian and impulse noise. Existing methods in the literature are based on minimizing an objective functional having the `1 fidelity term and the Mumford-Shah regularizer. We present a new algorithm on this problem by minimizing a new objective functional. The proposed functional has a content dependent fidelity term. The regularizer of the functional is formed by the `1 norm of framelet coefficients of the underlying image. The selected tight framelet filters are able to extract geometric features of images. We then propose an iterative framelet based approximation/sparsity deblurring algorithm (IFASDA) for the proposed functional. Parameters in IFASDA are varying at each iteration and are determined automatically. It makes the algorithm more attractive and practical. In this sense, IFASDA is a parameter-free algorithm, hence our method can be applied in a much wider class of practical problems. The effectiveness of IFASDA is experimentally illustrated on problems of image deblurring with Gaussian and impulse noise. Improvements in both PSNR and visual quality of IFASDA over a typical existing method are demonstrated.

**Zhiyuan Yan – "Error Control for Network Coding in Wireless Computational Networks/ Department of Electrical and Computer Engineering Lehigh University**

One of the most significant challenges to the DoD's network-centric information systems is the provision of on-demand computational infrastructure to applications at the tactical edges. Wireless computational networks (WCNs) are a promising solution to this problem due to their flexibility in deployment and convenience in broadcasting. A wireless computational network consists of a collection of computing nodes interconnected by a wireless network. As a parallel computing system, the performance

of a WCN is usually constrained by the bandwidth of its interconnect. Wireless networks have some unique characteristics, such as broadcast advantage and data redundancy, but also face serious issues in bandwidth and reliability, when used as computational backplanes. Thus it is critical to take advantage of these unique characteristics to help address the throughput and reliability issues. Network coding is a promising candidate for a new unifying design paradigm for WCNs, as it leads to significant improvements in throughput, reliability, mobility, and management of wireless networks. However, a significant challenge to the adoption of network coding is how to alleviate the disastrous effects of errors, caused by noise, dropped packets, insufficient network capacity, or malicious nodes. Aiming to develop a theoretical framework for the application of network coding in WCNs, in this work we investigate several important problems in error control for network coding in wireless computational networks.

**Dr. Chin Tser Huang – Automatic Early Filtering of Malicious Botnet Traffic Using Hardware Routers/ Department of Computer Science & Engineering University of South Carolina**

Botnets have become the top threat to Internet security. When receiving the order from the attacker, the bots can simultaneously generate and transmit huge amounts of malicious traffic toward the victim. As an Air Force Summer Faculty Fellow, the PI's goal is to develop a technology that filters malicious botnet traffic early using routers close to the bots, and forwards the malicious traffic to a diagnosis center. We have experimented with various filtering methods using only routing software. We currently focus on constructing a theoretical model to find the best locations for hardware routers in a network to block or forward malicious traffic. The extension grant is to conduct experiments in order to develop the reliable theoretical model for router-based early filtering.

**Dr. Yuan Xue – "A Model-Based Integration of Network Emulation with HLA-based Heterogeneous Simulation Environments/ISIS/EECS, Vanderbilt University**

Evaluation of Command and Control (C2) concepts requires a sophisticated modeling, simulation and experiment infrastructure. This requires the integration of existing simulation tools, system prototypes and experiment platforms that can interact in a coordinated way. The "Command and Control Wind Tunnel (C2W)" tool suite addresses this urgent need and enables rapid synthesis of heterogeneous simulation environments using a model-based approach, where an overarching C2 modeling environment is developed based on GME (Generic Modeling Environment) to integrated different platform specific simulation models. Network components and policies (such as security configurations) are essential aspects of C2 systems. Their impact on the performance and the behavior of C2 systems need to be accurately characterized when evaluating C2 systems. However, the current network simulators, which lack the implementation details of network protocols and algorithms, are insufficient in providing the level of accuracy required by the evaluation of C2 systems. This report presents our work on introducing the network emulation into the C2 Wind Tunnel environment as a solution to this problem. Network emulation environments allow the use of real network devices,

components and systems, thus providing greater realism in the network experiment. Integrating network emulation into the C2W system, however, is a challenging issue. (1) Being a simulation environment, the C2W system runs under the discrete event-driven time model and uses the RTI time management; on the other hand, the network emulation platform runs in continuous real time. The time synchronization issue between the simulation and emulation environment is a non-trivial issue. (2) There is potentially large volume of data communicated between the simulation and emulation environment. Controlling the communication overhead while still ensuring the accuracy of the experiment is also a challenging issue. This report presents our approaches to these two issues and shows our models and algorithms developed for such system integration.

**Dr. Vijay Kumar – Self Synchronizing Moving Objects/ Computer Science Electrical Engineering University of Missouri-Kansas City**

Moving objects share space for managing their mobility. For example, vehicles share roads, airplanes and UAVs share the sky or under-water space, etc. The problem then can be stated as "*how moving objects can self-synchronize over the use of common resource (space, intersections, etc.) to maintain a conflict-free movement without the aid of a third party?*" In this paper we describe our self-synchronization scheme for traffic movement through intersections. We claim that our scheme will be able to introduce fairness, reduce or eliminate the accidents (conflicts), and significantly reduce the cost of traffic management by eliminating the traffic lights that have very little intelligent and other traffic signs such as stop, give way, etc. Our scheme not only implements traffic-light logic but also human drivers' discretion to some extent. We present a simulation model to illustrate the working of our mechanism using simulated mobile cars.

**Dr. Enrique Galvez – Setup And Diagnosis of Entangled-Light Sources for Quantum Computing/ Department of Physics and Astronomy Colgate University**

The activities of this research centered about producing and diagnosing photon pairs in polarization-entangled states for the purpose of performing quantum processing and computing. An imaging technique was developed to align optical components for generating beams of polarization-entangled light in predetermined directions. A quantum tomography technique was implemented and used for diagnosing the entangled-state output of several types of sources using the process of spontaneous parametric down conversion. A third activity involved setting up a Hong-Ou-Mandel interferometer for obtaining additional diagnosis and characterization of the light sources.

**Dr. Aniruddha Gokhale –– Real Timeliness and Fault-Tolerance in Cyber Physical Systems/ Vanderbilt University**

The software and hardware that comprise current and planned missions of the United States Air Force (USAF) often fall into a category of systems called Cyber Physical Systems (CPS). CPS is a form of distributed, real-time and embedded (DRE) systems that tightly integrate the computation and communication artifacts of the mission with that of the physical traits and constraints of the system. CPS often involves multiple smaller

subsystems that form the larger systems-of-systems perspective prevalent in typical USAF missions. Timely and reliable dissemination of information is a key requirement for the USAF missions despite the high degree of mobility of fighter aircrafts, the fluctuating wireless communication capabilities, constraints on available resources, and often the hostile terrain. Assuring the quality of service (QoS) properties (e.g., end-to-end latencies, reliability, security) and Quality of Information (QoI) in general, and possessing the ability to fight through software failures in particular, is a key requirement for USAF missions. During the summer of 2009, as a participant in the AFRL Visiting Faculty Research Program (VFRP), we conducted research on designing and prototyping solutions for assuring the QoS properties of real-timeliness and fault-tolerance in cyber physical systems that are synergistic to the interests of the Air Force. We developed multiple simulation scenarios of increasing complexity each of which highlighted a set of problems. For the extension grant we focus on developing a reusable library of components that can be used to build simulations of CPS synergistic to USAF missions. Within these simulations the goal will be to demonstrate the ability to disseminate information reliably. Approaches to improve software producibility will be documented.

**Dr. Sanjay Madria -Performance Analysis of Memory Efficient Caching Model to Improve Data Accessibility in Mobile Ad hoc Networks/ Missouri University of Science and Technology**

Improving data accessibility using caching and replication in mobile ad-hoc networks (MANET) is an extensive area of research. The topology changes play a vital role in determining the efficacy of any caching model including for MANET. Though, caching bears its own advantage such as saving bandwidths, reducing roundtrip time, and power, it too has to overcome its own challenges such as consistency issues, cache replacement, memory, mobility and load distribution. Moreover, caching can bring data closer to the source in multi-hop wireless networks thus help in conserving overall energy as wireless transmission consumes lot of battery power. Furthermore, shared memory in MANET is also limited and therefore, it has to be efficiently utilized.

### 4.2 2010 Extension Grants

**Qiang Zhao – Development and Enhancement of User Interfaces for the SITA System/Mercer University, Computer Science Department, Macon, Ga.**

As an extension to the summer VRFP effort, this phase of R&D work focuses on finishing up with the design and implementation of two components of the *Tools For SITA* suite, namely the *MissionMapEditor* and the *VulnerabilityTracker* subsystems. Preliminary studies for proposed sabbatical research in spring 2011 have also been carried out.

**Lizhong Zheng – Futuristic Computational Networking Concepts/Department of Electrical Engineering and Computer Sciences Massachusetts Institute of Technology**

This activity will examine computational and storage ideas that could have significant impact on the future of the DoD's communications and networking capability. In this spirit, three ideas are given below that illustrate the kinds of activities that will be examined.

Evolvable Protocols – use of processing to adapt protocols in real-time based on the kind, quantity, and acceptable latency of data being transferred. Traditionally protocols have been designed with a single objective in mind, thus making generalizations in other kinds of data very ad-hoc.

Distributed Storage-Aided Communications Network – in several emerging paradigms, including Cloud Computing and high data rate sensor networks, there appears to be a requirement for a large amount of distributed storage. If distributed storage was present in a communications network then what would be its advantages with respect to information assurance, overall throughput, etc.? A recent paper by Cover on "coordination capacity" provides hints about the theoretical foundations of such a concept.

Instantaneous Efficiency of Communications – Shannon focused on coded communications that work really well when there are very few errors and the interval you are observing the information is arbitrarily long. Maybe there is a better way to think about communications metrics in terms of its instantaneous efficiency. Recent work by Prof. Zheng suggests that such studies can result in new interpretations of classical results, especially with regard to optical communications.

**Jay Urbain/Upstream Development LLC – Probabilistic Mulirelational Models for Entity and Event Consolidation:A Multievidentiary Information Retrieval Approach/ Milwaukee School of Engineering**

Entity and event identification involves the monitoring of heterogeneous streams and collections of text to detect and consolidate references of events and related named entities. The ability to detect new events, aggregate multiple facets of the same event, and identify related entities to satisfy an analyst's information need is one of the most significant challenges in intelligence analysis. Current tools include document-level key word search systems and named entity extraction systems. Key word search works in a top-down fashion, i.e., an analyst provides a natural language query expressing an information need and the search system retrieves a set of documents that are *relevant* to this need based on the frequency and distinctiveness of document terms that match query terms. Such systems are good at identifying information within the broad context of an entire document, but fail to identify information within the narrower context of a phrase, sentence, or passage that is more likely to answer a specific information need. Such systems are also not adept at identifying and relating specific named entities, phrases, or events. Named entity extraction systems work in a bottom-up fashion, i.e., a collection of documents is processed offline using natural language processing techniques and handcrafted lexicons to identify noun-phrases relating specific entities such as people, organizations, and locations. Analysts are restricted to identifying entities that were discovered *apriori* during this offline process. Such extraction systems do not readily

adapt to new information, having difficulty identifying entities expressed in different ways. These systems do not support natural language search using terms that are not present in an extracted entity or relation and that may provide important contextual clues. These systems do not typically provide an explicit mechanism for an analyst to provide feedback to the system on the relevance of results to adjust retrieval models. Our research to date has involved research and development of an online search system that integrates search, entity extraction, and relevance feedback. Our approach is based on statistical models and a novel multidimensional indexing framework that allows flexible integration of multiple forms of evidence at multiple levels of document context. Preliminary empirical results achieved by the system are excellent and the system satisfies an important need not yet available.

**Chin Tser Huang – Automatic Early Filtering of Malicious Botnet Traffic Using Hardware Routers/ Department of Computer Science and Engineering University of South Carolina**

Botnets have become the top threat to Internet security. When receiving the order from the attacker, the bots can simultaneously generate and transmit huge amounts of malicious traffic toward the victim. As an Air Force Summer Faculty Fellow, the PI's goal is to develop a technology that filters malicious botnet traffic early using routers close to the bots, and forwards the malicious traffic to a diagnosis center. We had experimented with various filtering methods using only routing software. We currently focus on constructing a theoretical model to find the best locations for hardware routers in a network to block or forward malicious traffic. The extension grant will conduct experiments in order to develop the reliable theoretical model for router-based early filtering.

**Yang Cai –Video Analysis for Smart Camera on UAV/ Carnegie Mellon University, Cylab**

This project is an extension of the PI's summer VFRP work of UAV camera and analyst interface at AFRL. Vehicle is one of the important objects in UAV videos. Currently, the object metadata only contains the coordinates of the selected motion object blobs without classification or registration. The objectives of this project include 1) analyzing the VIRAT and VIVID data from DARPA, 2) literature review about related algorithms, and 3) designing the vehicle classification and detection algorithms for UAV metadata. In this project, we use 3D vehicle models to generate training samples for vehicle classification from any viewpoint. Then we use Fourier Transform to match the contour of the target object to the closest vehicle model in the database. Although we have had the motion-based vehicle detection algorithm, we are usually not able to detect parked vehicles because they are motionless. To solve the problem, we have looked into the algorithms for detecting parked vehicles from single still images, which is harder than moving vehicles. In this report we describe a car detection system based on the Histogram of Oriented Gradients (HOG) method, which was originally invented for human detection for a DIA-sponsored video analytics project. The results show that it is feasible to detect vehicles from still images. However, the current algorithm is scale-

dependent. In our UAV case, this impact could be minimized, using altitude data to estimate the vehicle sizes. In future work, we will develop scale-free and robust vehicle detection and classification algorithms for UAV applications. We definitely need more training samples for vehicle detection and classification. The VIRAT and VIVID videos are not enough. We have to collect our own samples. The deliverables include the final report, source code and data for vehicle classification and detection, as well as a copy of VIRAT and VIVID videos.

**Warner Miller – Optimization of Information Flow Across Networks: An Exploration Utilizing Emulab, Jplex and Ricci Flow/ Florida Atlantic University**

During the extension period under the Visiting Faculty Research Program (VFRP) we primarily concentrated on providing explicit techniques and algorithms to extend the DRF techniques from 2-D to arbitrarily higher dimensions - dimensions that naturally appear in complex networks. In particular, we used the techniques of Regge Calculus and Discrete Exterior Calculus to define the Ricci Tensor and Riemann Scalar curvature in arbitrary dimensions, and to use this to define for the first time the DRF equations (Sec. 2) for arbitrary dimension. We applied the diffusive discrete Ricci Flow (DRF) equations to two separate model networks embedded in 4-dimensions. Both had the topology of a 3-sphere. In particular, we developed a numerical approach to explicitly analyze the (topological and geometric) dynamics of a 600-cell simplicial polytope (120 vertices, 720 edges, 1200 triangles and 600 tetrahedrons) generated by discrete RF. Secondly, we also explicitly solved the DRF equation for a axisymmetric 4-dimensional geometry with the topology of a 4-sphere that had 17 nodes and 30 edges. Finally, we installed the Stanford Plex algorithm on AFRL computers and analyzed the PH of a distorted 600-cell 3-sphere geometry. We successfully demonstrated DRF in 4-dimensions and reported our results to AFOSR at their annual Complex Network Program Review in November, 2010. In future research, we hope to analyze its structure (geometry and topology) and function using the highly efficient Plex simulation coupled with a discrete RF simulation we will make on the 600-cell model. In this effort, and in this report we concentrate on our formulation of the DRF equations for our two model problems.

**Vijay Kumar – Object Discovery, Identification and Binding/University of Missouri-Kansas City, Kansas City, Missouri**

A tracking process captures the *state* of an object. The state of an object is defined in terms of its dynamic and static properties such as location, speed, color, temperature, size, etc. The set of dynamic and static properties for tracking very much depends on the agency who wants to track. For example, police need a different set of properties to track people than the Air Force to track a vehicle. The tracking scenario also affects the selection of parameters. Tracking is done by a system referred to in this paper as a "Tracker." It is a system that consists of a set of input devices such as sensors and a set of algorithms that process the data captured by these input devices. The process of tracking has three distinct steps (a) object discovery, (b) identification of discovered object, and (c) object introduction to the input devices. In this paper we focus mainly on the object discovery part with a brief discussion on introduction and identification parts. We

develop a formal tracking framework (model) called “Discover, Identify, and Introduce Model (DIIM)” for building efficient tracking systems. Our approach is heuristic and uses reasoning leading to learning to develop a knowledge base for object discovery. We also develop a tracker for the Air Force Research Laboratory program NCET.

**Lixen Shen – Mathematical Analysis of Hub Matrices for Wireless Computational Networking/ Syracuse University**

A wireless computational networking system is ideal if the corresponding Grammian is a k-vector arrowhead matrix. However, this is not the case in general. Since leading eigenvalues and eigenvectors of the underlying system inherit the intrinsic properties of the system. We are interested in the question whether any wireless computational network is equivalent to an ideal one in the sense that leading eigenvalues and corresponding eigenvectors for both systems are identical. If so, we are able to evaluate any system and provide useful information by analyzing its equivalent ideal system. The primary goal of this proposal is to give a mathematical analysis of k-vector arrowhead matrix for applications in wireless computational networking systems. Under certain circumstances and constraints, such as low battery power, it is prohibitive to evaluate eigenvalues and corresponding eigenvectors of k-vector arrowhead matrices using costly numerical schema, especially for the matrices with a large size in wireless computational networking systems. Therefore, it is highly needed to develop a scheme which can estimate eigenvalues and corresponding eigenvectors effectively in a timely fashion. To response these needs we investigate the following three research topics: (1) Computing eigenvalues of 1-arrowhead matrices; (2) Bounds of eigenvalues of k-arrowhead matrices and numerical algorithms for computing eigenvalues; (3) Equivalent wireless computational networking systems.

**Dr. Zhiyuan Yan– Error control for network coding in wireless computational networks/ Lehigh University**

One of the most significant challenges to the DoD's network-centric information systems is the provision of on-demand computational infrastructure to applications at the tactical edges. Wireless computational networks (WCNs) are a promising solution to this problem due to their flexibility in deployment and convenience in broadcasting. A wireless computational network consists of a collection of computing nodes interconnected by a wireless network. As a parallel computing system, the performance of a WCN is usually constrained by the bandwidth of its interconnect. Wireless networks have some unique characteristics, such as broadcast advantage and data redundancy, but also face serious issues in bandwidth and reliability, when used as computational backplanes. Thus it is critical to take advantage of these unique characteristics to help address the throughput and reliability issues. Network coding is a promising candidate for a new unifying design paradigm for WCNs, as it leads to significant improvements in throughput, reliability, mobility, and management of wireless networks. However, a significant challenge to the adoption of network coding is how to alleviate the disastrous effects of errors, caused by noise, dropped packets, insufficient network capacity, or malicious nodes. Aiming to develop a theoretical framework for the application

of network coding in WCNs, in this work we investigate several important problems in error control for network coding in wireless computational networks. This report summarizes this research effort.

**Dr. Rong Pan –A Study of Nation-State Stability and Important Variables/ Arizona State University**

In this report, we use national variables, which are available in public domains, to classify nations. Two datasets are tested. The first dataset, which has smaller number of variables but more nations, is used for (1) clustering countries and (2) identifying important national variables. The second dataset, which has larger number of variables but less nations, is used for validating the important national variables indenfied in the first dataset. Three statistical methods are introduced and their performance on clustering and classifying failing countries are discussed.

## 5. Expenditures

The expenses under this effort were broken down on a faculty/week and student/week basis. These rates were:

### 5.1 Faculty Labor

| | |
|---|---|
| Outstanding Limited Research Faculty | $1,100/week |
| Assistant Professor | $1,300/week |
| Associate Professor | $1,500/week |
| Full Professor | $1,700/week |

Outstanding Faculty and those with unique qualifications were addressed individually.

#### 5.1.1 Faculty Per Diem

Those faculty members whose home residence/university is more than 50 miles from AFRL/RI were entitled to: $250/week

### 5.2 Students

Were compensated based on a sliding scale according to published government rates, based on the below table which are commensurate with "lab-demo" hourly rates for new hire employees at RRS. Doctoral students with unique qualifications were addressed individually.

Undergraduate Student – GS 5 approximately $14.24/hour
Graduate Student – GS 7 approximately $17.64/hour
Doctoral Student - GS 9 approximately $21.58/hour

Students were also given a meal allowance of $100/week and $160/week for housing allowance.

Under terms of placement agreements, the candidates were only paid for actual days worked. Absences were not paid; this included non-lab sponsored meetings or symposiums. Federal holidays were also not to be paid.

Faculty and students were paid for their travel to Rome Lab from their home at the beginning of their participation in the Visiting Faculty Research Summer Program. They were also reimbursed for their expenses incurred to travel home from the Lab at the end of their participation.

### 5.3 Other Costs Associated with Program

Occasionally expenditures for supplies were required for the program. Other expenditures made on this award included:

--Administrative Assistant salary and fringe
--Paid SUNYIT for dorm rooms for some students
--Paid Griffiss Institute for room rental/refreshments for VFRP meeting
--Paid Rome Conference Center for dorms rooms for some students
--Registration Fees for VFRP faculty/students to Info Challenges Conference
--Consultant services and travel for Jonathan Katz (Cryptography workshop)
--Presenter Rao Vemuri travel expenses for 2010 Info Challenges Conference
--Polytechnic Institute of New York University-Cyber Security Awareness Week
--Eye exams for two students working in Lab on VFRP Summer Program