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A GRADUATE PROGRAM IN WIRELESS TECHNOLOGY AND SYSTEMS ENGINEERING: OVERVIEW AND INITIAL EXPERIENCES

D. Mueller[1], T. Cooklev[2], H. Oloomi[3], C. Pomalaza-Ráez[4], and S. Walter[5]

[1] *Indiana University-Purdue University Fort Wayne; mueller@engr.ipfw.edu*
[2] *Indiana University-Purdue University Fort Wayne; cooklevt@ipfw.edu*
[3] *Indiana University-Purdue University Fort Wayne; oloomi@engr.ipfw.edu*
[4] *Indiana University-Purdue University Fort Wayne; raez@ipfw.edu*
[5] *Indiana University-Purdue University Fort Wayne; waltersj@ipfw.edu*

ABSTRACT

Northeast Indiana is home to several major defense/aerospace contractors and a number of smaller suppliers. Many of these companies design, develop, and manufacture ground command, control, and communication (C3) systems. These companies seek employees with a systems-engineering mindset and a strong background in wireless technology.The Science Master's Program: Concentration in Wireless Technology and Systems Engineering at Indiana University – Purdue University Fort Wayne (IPFW) addresses this need. This program has been supported, in part, by a grant from the National Science Foundation.

The integration of systems engineering and wireless technologyis a novel aspect of our new graduate program. The curriculum is designed so that students develop depth in the area of wireless technology and breadth via systems engineering. In addition to traditional courses, students areeligible to participate in an internship with a local company, perform research and produce a thesis, and manage an undergraduate student design team.

Characteristics of the program include (1) a unique, integrated graduate curriculumand (2) meaningful research, internship, and management experiences which promote peer and project-based learning. Graduates of the program will have a high-degree of workforce readiness and unique knowledge base. This program will ultimately strengthen the regional defense C3 industry which is of strategic importance to the state and the entire nation.

This paper provides an overview of our program and details our initial experiences with the launch.

1. INTRODUCTION

Wireless technology and systems engineering are increasingly important areas internationally, nationally, and especially regionally in Northeastern Indiana.

The defense industry in northeast Indiana has a long history of designing, building, and fielding large-scale tactical wireless systems for military customers and is a major DoD supplier.

Examples of systems that have been designed and manufactured in Fort Wayne are the Single-Channel Ground and Airborne Radio System (SINCGARS), Soldier Radio Waveform (SRW), and others. More than 430,000 SINCGARS platforms have been sold, thus making it the most widely deployed military radio system in the world. The majority of Joint Tactical Radio System waveforms have been developed with participation from companies based in Fort Wayne. It is interesting to note that the first commercial wireless system in Fort Wayne was developed and manufactured more than 80 years ago. Today the community of Fort Wayne has three generations of family members who have been instrumental in developing, designing, building, and fielding tactical communications. Therefore the defense industry in northeast Indiana is of strategic importance not only to the state of Indiana, but to the entire country.

Systems Engineering (SE) is a structured approach to developing technical solutions to satisfy customer needs (Defense Acquisition Press, 2001). Unlike traditional forms of engineering, i.e., electrical, mechanical, etc., systems engineering does not focus on a specific class of products or technologies. Rather it is the "glue" that ensures all the elements of a product fit together and function as one. For example, in a shipyard, the SE team is the organization responsible for making sure that the ship that they are contracted to develop is not too heavy, too slow, too expensive, or late (INCOSE, 2007). SE methodologies have been tailored to meet the needs of a wide range of industries, most relevant to northeast Indiana are industries that develop products for the defense, aerospace, and transportation sectors.

Systems engineers are in demand, and producing engineers with an understanding of systems engineering techniques and theory is vital for both our national security and economic well-being. A month ago, CNN Money magazine and PayScale.com ranked systems engineering as the *Best Job in America* based on pay, job growth, and quality of life (CNN, 2009). To quote the CNN Money article:

> "*Demand is soaring for systems engineers, as what was once a niche job in the aerospace and defense industries becomes commonplace among a diverse and expanding universe of employers, from medical device makers to corporations like Xerox and BMW.*"

Over the next decade, CNN Money estimates there will be 45% growth in the number of systems engineering jobs, earning it the second highest ranking in the job growth category. The November 2008 issue of IEEE Spectrum tells a similar story about the shortage of systems engineers in their article on *What's Wrong with Weapons Acquisitions* (Charette, 2008). Referring to large DoD programs that have failed to be delivered on time, on schedule, and with required functionality and performance, the article states:

> "*Another factor contributing to program failure is the shortage of technically trained people, especially systems engineers. A systems engineer translates technical needs into an overall system architecture that creates the best operational capability at the most affordable cost. As a project proceeds and goals or needs shift, systems engineers have to determine the difficult but necessary cost, schedule, and performance trade-offs to keep everything on track. As programs get bigger and more complex, the need for rigorous systems engineering increases.*"

Overall, in the long run, progress in systems engineering will lead to increased economic competitiveness. Clearly, advancing the state-of-the-art of wireless systems and educating future technology leaders is of fundamental importance and of benefit to the entire country.

The defense and aerospace industries of northeast Indiana need workers with a strong background in wireless technology and systems engineering. For the defense industry in northeast Indiana to preserve its competitive advantage in this critical field, the companies require a trained workforce that has been prepared with the mindset, knowledge, skills, and tools required to address both the system (breadth) and technical (depth) aspects of wireless systems. Necessary attributes for these designers include a systems-engineering mindset, technical depth in a component area, and a working knowledge of areas across the breadth of the system. This type of education and training is beyond the undergraduate curriculum and better suited to a graduate degree program. At the graduate level, students possess the technical proficiency to specialize in the area of wireless technology and the maturity to appreciate the breadth aspect of systems engineering.

This paper provides an overview of our program and details our initial experiences with the launch.

2. OVERVIEW OF ENGINEERING AT IPFW

The Department of Engineering at Indiana University–Purdue University Fort Wayne (IPFW) is the leading engineering department in northeast Indiana. The department currently has over 400 undergraduate and over 50 graduate and post-baccalaureate students, mainly from northeast Indiana. The department offers ABET-accredited undergraduate degrees in electrical, computer, and mechanical engineering, and has recently started a program in civil engineering. The department has 19 faculty members—eight are in the electrical and computer engineering areas. The graduate program has been identified as an area of growth for the department, and wireless communication and systems engineering have core competencies.

In 2004, the Department of Engineering at IPFW began the development a Master of Science in Engineering (MSE) degree program to satisfy the market demand for highly qualified engineers with training beyond the Bachelor degree. The objectives of the graduate program are:

- To provide opportunities for qualified individuals who wish to work towards a Master of Science in Engineering (MSE)

- To provide a nationally recognized graduate program in engineering of high quality through the combination of theoretical and practical education, especially the education that develops professional expertise based upon the skills of discovery and synthesis that support problem solving and innovation.

- To meet the need for a comprehensive engineering program in Northeastern Indiana at the graduate level.

The current Master's degree program, which received final approval in 2007, is extremely flexible (Mueller, et al., 2008). Thirty credit hours are required, and both thesis and non-thesis

options are available. Students may select one of four areas of specialization: electrical, computer, mechanical, or systems engineering. The majority of the MSE students are specializing in systems engineering, are employed full time, are taking only one class per semester, and are not pursuing the thesis option.

In 2006, the IPFW systems engineering program was initiated to provide training in modern systems engineering techniques, processes, and management. With funds from the local defense industry and the Lilly Endowment, an endowed chair in systems engineering was established. In 2006, Dr. S. Walter was hired a Distinguished Professor of Systems Engineering and the Director of the Center of Excellence in Systems Engineering. The center is active in providing symposia to local industry and in promoting certification efforts.

In 2008, the ITT Chair in Wireless Communication was established as a result of the endowment made by ITT Corporation. Dr. T. Cooklev was hired as the Director of the Wireless Technology Center (WTC). This Wireless Technology Center operates in close collaboration with industry and has an Advisory Board. The WTC is doing research in digital signal processing algorithms for wireless systems, software-defined radio systems, and other aspects of modern wireless systems.

In 2009, an additional $4.5 million was received from the Lilly Endowment specifically for the areas of wireless technology and systems engineering. Out of this amount, $750,000 is dedicated to the wireless laboratory and $750,000 for a systems engineering facility. The wireless laboratory will have state-of-the-art instrumentation equipment and will provide hands-on experiences to students. The systems engineering facility will have high-end computer systems with modeling and simulation capabilities. The remainder of the funding will be used as an endowment to support two additional researchers – one in systems engineering and one in wireless technology. This funding cannot be used to support students.

IPFW and the Department of Engineering have assembled many components required for a successful program in systems engineering and wireless technology, i.e.

- a flexible, graduate degree program
- a highly-qualified team of active researchers
- centers of Systems Engineering and Wireless Technology
- state-of-the-art laboratories furnished with equipment from the Lilly Endowment

The missing piece is a dedicated cohort of qualified, focused students. Funding from the National Science Foundation is being used to help attract students to our program.

3. OVERVIEW OF THE PROGRAM

Our proposed graduate program with a concentration in wireless technology and systems engineering consists of four unique components: education, internship, research, and management. The required internship, research, and management components add significant value to the carefully designed integrated wireless technology and systems engineering curriculum. All four components of our program have novel aspects:

1. The curriculum includes an integrative approach to wireless technology and systems engineering. Students will begin as a group taking fundamental and intermediate coursework. Later, they will select elective courses that can be chosen to support specific research projects.

2. Students will participate in a summer internship with a local company. This experience will be supported by a company mentor and a seminar series devoted to issues related to the workplace.

3. Students will be required to complete a hands-on research project in wireless technology. The results of this project will be reported in a thesis and presented at an appropriate conference. This research experience will be supported by an innovative seminar series on research methods.

4. During the last year of the program, students will apply their education and training in systems engineering, by serving as technical advisor and project manager to an undergraduate, capstone senior design team.

The duration of our proposed program is two years.

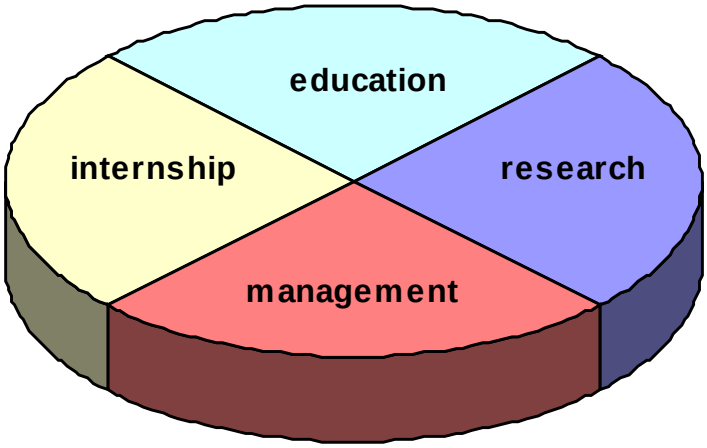

Figure 1: Four components that comprise the proposed program

Our new program is much more than a simple extension of our current Master's program. Our existing degree program is flexible; thus, the coursework and research experience will fit within the current degree framework. However, this new structured program with the required internship, research, and management components is expected to bring about substantial, transformational changes to the Department of Engineering at IPFW and, more importantly changes to the local defense/aerospace industry in northeast Indiana and the wireless technology and systems engineering research community in general. This program will enhance the current research and teaching efforts at IPFW and will firmly establish the department as resource in wireless technology and systems engineering for local industry and the nation as a whole.

4. EDUCATION AND TRAINING

The curriculum of this program is designed to be completed in two years with a schedule as shown in Table 1. During most of the first year, the curriculum is common for all students in the program. During the second year, students may select elective courses that are related to their interests and their selected research project. The courses that are part of the program are described below in this section.

Table 1: Two-year curriculum of the integrated wireless and systems MSE program

	Number	Title	Credits	Students…
Fall 1	ECE 547	Intro to Comm. Networks	3	– are exposed to introductory concepts in wireless and systems – investigate and select faculty mentor and research project
	SE 510	Systems Engineering	3	
	ECE 600	Random Variables Proc.	3	
Spring 1	ECE 549	Software Defined Radio	3	– build on first semester coursework – investigate and select summer industry internships – select engineering, computer science, physics, or math elective to support research experience
	SE 530	Systems Management	3	
	TE 5xx	Technical Elective Course	3	
Sum1	ENGR 595	Graduate Seminar	1	– participate in an internship at local company – attend a weekly graduate seminar dealing with workplace issues
Fall 2	ENGR 698	Research – Thesis	3	– start research projects supported by a graduate seminar – select engineering, computer science, physics, or math elective to support research experience – advise/mentor a senior design project team
	TE 5xx	Technical Elective Course	3	
	ENGR 595	Graduate Seminar	1	
Spring 2	ENGR 698	Research – Thesis	3	– continue research projects – select engineering, computer science, physics, or math elective to support research experience – advise/mentor a senior design project team
	TE 5xx	Technical Elective Course	3	
	ENGR 595	Graduate Seminar	1	
Sum 2	ENGR 698	Research – Thesis	—	– complete research, *if necessary*; most will graduate in spring – present results at a technical conference

It should be noted that several of these are courses are interconnected, i.e., they bring together material from several other courses. At present, engineering students study their disciplines primarily in separate courses. Hence, the students largely do not see how these areas are interrelated within a system. This approach results in engineers that specialize in a narrow area, but are unable to communicate with engineers that specialize in other areas.

In addition to traditional courses, students in the proposed program will also be required to enroll in a one-credit hour graduate seminar in the summer and participate in a summer internship at local company. These unique aspects of the program are described below in this section.

4.1 Course Sequence in Systems Engineering

One focus area of our proposed Master's program is systems engineering. Systems engineering is a robust approach to the design, development, verification, and validation of interdisciplinary products or systems (Defense Acquisition Press, 2001). Engineers design products and the processes that create those products (Software Enterprise, 2006). The scope and quality of the products determine success, while the development process determines the level of success. Systems engineering seeks to develop and implement effective and efficient processes to integrate people, tools, hardware, and software to create new products that satisfy specific needs (Software Enterprise, 2006). Systems engineering is primarily concerned with the processes that are used for product and system development. Students in the program will take a two-course sequence in systems engineering. The first course is SE 510–*Systems Engineering*, and the second course is SE 530–*Systems Management*.

SE 510–*Systems Engineering*is designed to provide the foundation for understanding and applying an end-to-end systems approach to scoping, architecting, designing, building, integrating, verifying and validating complex and interdisciplinary products using a framework which is consistent with national and international standards (ISO/IEC, 2008; Mil Standard 499B, 1994). A list of the topics covered in this course is provided in Table 2. This course was developed and taught by Dr. S. Walter.

The second course in the sequence is SE 530–*Systems Management*. The systems engineering management team is responsible for planning and managing all systems engineering activities that are required to successfully develop complex products and systems. They are in charge of ensuring that all system elements are compatible, available on-schedule and on-budget, work together seamlessly, and satisfy customer requirements. SE 530–*Systems Management* addresses advanced topics in systems engineering and techniques for managing and coordinating product development. A list of the topics covered in this course is provided in Table 2. This course was developed and taught by Dr. S. Walter.

Table 2: List of topics covered in the systems engineering course sequence

Week	SE 510–*Systems Engineering*	SE 530–*Systems Management*
1	Systems Engineering Overview/Product Lifecycle	Overview of SE Management and CMMI
2	Concept Development and System Scope	Systems Engineering Plans
3	Requirements and Specifications	Make/Buy Decisions and Subcontracting
4	Functional Analysis and Allocation	Performance and Progress Measures
5	Design Synthesis	Technology Management
6	System Trades / Exam 1	Verification and Validation/Technical Reviews
7	System Architecture	Change Control
8	System Analysis and Control	Project Organization and IPDT
9	Configuration Management	Human Resources/Communications/Motivation
10	The -ilities and Human Factors Engineering	Team Building and Dynamics
11	Verification and Validation 1	Negotiation/Conflict Resolution
12	Verification and Validation 2 and Planning	Project Management Overview
13	System Engineering Processes and Standards	Project Execution and Control
14	Ethics and Putting It Together: the B-2 Case Study	Managing and Controlling Risk
15	Final Exam	Cost Management and Control

4.2 Course Sequence in Wireless Technology

The second focus area of the Master's program is wireless technology. Students in the program will take a two course sequence in wireless technology. The first course is ECE 543–*Wireless Communication Networks*, and the second course is ECE 549–*Software Defined Radio*.

ECE 543–*Wireless Communication Networks* provides an overview on the protocols and architectures of existing and emerging wireless networks. Specifically, this course involves the study of wireless networks working with existing protocols and new proposed protocols that are more suitable to the particular characteristics of the wireless technology. Protocols for medium access control, routing, and reliable transport, as well as middleware and applications for wireless networks, are covered.

Within the broad area of wireless technology, software-defined radio (SDR) is one of the fastest growing segments. An SDR is a communications system comprised of general-purpose reconfigurable components that are programmed to define its operational characteristics (Mitola, 1995; Buracchini, 2000). For instance, bandwidth and modulation are completely determined by programming the reconfigurable parts, not by hardware such as filters, mixers, amplifiers, or other "traditional" components. An SDR may use multiple sampling rates for signal processing: high-speed work is done in an FPGA while the lower frequency work can be performed via a DSP (Benson and Lall, 2003). To implement SDRs, a broad skill set is needed. The defense and aerospace industry is interested precisely in SDR. IPFW is one of only a few universities that currently offer a course in SDR.

The objective of ECE 549–*Software Defined Radio* is to develop and integrate a series of thematic engineering topics focused on SDR. The main concept of the course will be the understanding of SDR systems and how to design them. A necessary attribute of a wireless designer is the systems-thinking mindset (Dym, et al., 2005). Indeed, modern software-defined radios have been referred to as a "*Systems*-Defined Radios" (Pearson, 2001).

The course addresses both the systems (breadth) and technical (depth) aspects of SDR system development. The defining aspect of SDR is its extremely multidisciplinary nature, requiring a tremendous breadth of knowledge and background in a wide variety of subjects. SDR development is contingent on the successful integration and synthesis of material taught across the entire electrical engineering (EE) and computer engineering (CmpE) undergraduate curricula. The cornerstones of SDR development are contained in several classes: Signals & Systems, Electromagnetics, Communication Systems, Digital Signal Processing on the EE side and FPGAs and Digital Hardware on the CmpE side. Additional background is provided by the graduate-level classes on Wireless Communications, and RF circuit design. An SDR course, therefore, would be highly integrative of all components of the EE and CmpE curricula, as well as facilitating the development of systems thinking and cross-domain learning.

The course serves the dual purposes of introducing students to the systems engineering approach and employing the EE and CmpE concepts learned within their majors and in this course. The main concept of the course will be the understanding of SDR systems and how to design them.

Because hands-on experience is important for the students to internalize their knowledge, there is a lab based on the Universal Software Radio Peripheral (USRP) [http://www.ettus.com/].

In addition to technical material, ECE 549–*Software Defined Radio* presents a unique opportunity to address an important curricular need: the understanding of the complete engineering design process (Dym, 2005; Dutson, 1997). Integrating engineering design into the curriculum is paramount for development of productive engineers. Most engineering science courses include "design examples" to emphasize theoretical principals. Each design example typically emphasizes a single concept. Engineering design, however, involves considerably more than these design examples (Dym, 2003). By definition, it focuses on how engineers think and emphasizes how engineers create, assess, and select ideas (Dym, 2005). High performance can only be achieved if design decisions are considered together. Therefore cultivating a systems-thinking mindset in the students is essential. Another important aspect of engineering design, now beginning to be addressed by educators, is that engineers must consider the social impacts of their designs. The diffusion of wireless technologies throughout society will significantly impact the way we work, communicate, and interact. Hence, it should be recognized that the highly interdisciplinary nature of wireless communication communicates these concepts better than most traditional engineering courses.

4.3 Elective Courses

The curriculum allows for students to select three elective courses. One of these courses must be in mathematics or computer science; the other two most likely will be engineering or physics courses. Possible electrical and computer engineering and computer science courses include: ECE 538–*Digital Signal Processing I*, ECE 565–*Computer Architecture*, ACS 560–*Software Engineering*, as well as many others.

Students may also choose elective courses in systems engineering. SE 520–*Engineering Economics* provides an overview of financial accounting and economic principles employed by engineers involved in product and system development. This course familiarizes engineers with methods in project accounting, budgeting, cost estimation, financial management, design optimization, and economics. SE 540–*Systems Architecture* is designed to provide theoretical and practical knowledge to efficiently develop optimized and compliant architectures for complex and interdisciplinary products. The course uses an approach that is aligned with government and industrial standards that serve as a basis for industrial systems engineering architectural frameworks and processes.

5. INTERNSHIP, RESEARCH, AND MANAGEMENT EXPERIENCES

Students in this program will have a required (if available) summer internship at a company in Fort Wayne. The original companies involved with our proposal include ITT, Raytheon, and Northrop Grumman. Internships will be coordinated through the Advisory Board. These internships will provide very valuable learning opportunities for the students. The students will learn technical as well as professional skills in a practical setting. These professional skills include ability to work in teams and an understanding of social and ethical aspects of the engineering profession.

A meaningful research experience is another integral part of our proposed program. The graduate students will conduct research primarily within the Wireless Technology Center Lab and the Systems Engineering Modeling and Simulation Lab. The engineering department has additional labs with equipment and activities closely related to this project; thus, some projects may also be conducted in the RF/Microwave Lab, the Robotics Lab, or the Controls Lab. Students will have office space and will use the instrumentation and other equipment.

Several ECE faculty members (Pomalaza-Ráez, Liu, and Chen) are already working closely with Dr. Cooklev and the Wireless Technology Center. Active projects include interference detection and mitigation in IEEE 802.15.4 networks, and real-time wireless smart camera networks, and new DSP techniques in multi-carrier modulation. Graduate students in this program will significantly enhance the research activities within the department (Chen and Pomalaza-Ráez, 2009; Liu and Pomalaza-Ráez, 2009).

During the last year of the program, students will apply their knowledge of systems engineering by serving as technical advisor and project manager to an undergraduate, capstone senior design team.

The Department of Engineering has two-semester capstone senior design sequence. During the first semester students implement the design process, i.e. establish requirements, generate concepts, evaluate concepts, perform detailed design. Projects undergo a systems requirement review (SRR), a preliminary design review (PDR), and at the end of the first semester a critical design review (CDR). During the second semester, student teams build, and then verify and validate their first semester designs. Projects are advised by faculty within the engineering department. This program has been praised by ABET-evaluators.

Students in our program will replace the engineering faculty member as the technical advisor and project manager for the undergraduate student team. This activity will allow students to apply material from SE 510–*Systems Engineering* and SE 530–*Systems Management* and experience the role of a systems engineering in a simulated real-world project.

6. CURRENT STATE OF THE PROGRAM

The program admitted a cohort group of five students in the fall 2010. One student left the program to return to full-time employment. The other four students are progressing through the coursework. They have all been working on research projects with faculty advisors. The topics of the research are:

- Software Defined Radio Testbed: A Platform Enabling Cognitive Radio Research
- Active Self-Landmarking to Mobile Robot Navigation through Wireless Communications
- UHF RFID Component Design
- Wireless Robot Communications System

In the fall 2011, three more students have been admitted to the program. These students are just beginning their second semester of coursework.

ACKNOWLEDGEMENT

This work is supported in part by the National Science Foundation through Science Master's Program: Concentration in Wireless Technology and Systems Engineering – NSF 1010908.

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