AC 2009-1453: REVISING A NETWORK ENGINEERING CURRICULUM TO REFLECT CURRENT INDUSTRY AND STUDENT TRENDS

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Revising a Network Engineering Curriculum to Reflect Current Industry and Student Trends

Abstract

One of the fastest changing areas of technology education is information technology. Within the Information Technology (IT) field, the area of network engineering and security is changing especially quickly. Ongoing issues such as machine and network security, malware and SPAM control, the continued evolution in wireless networks, and support for new application development and deployment models keep IT educators busy ensuring their courses and curricula are kept in sync with changes in the industry.

In addition to changes in the industry, there are changes in the student body. Today's students are much more technology savvy than those entering the program just five years ago. These students are also taking internships earlier in their college careers, creating a need to ensure they are prepared for these earlier industrial experience opportunities.

As part of our ongoing continuous improvement process the faculty in the Department of Computer and Information Technology at Purdue University has recently completed a significant curriculum revision of the undergraduate baccalaureate network engineering program. After analyzing industry trends, student performance, incoming student experience, and discussing their findings with industrial partners, several key opportunities for improvement were identified. Designed to reflect the aforementioned changes, materials were deleted, moved, or added to the curriculum as needed.

This paper provides a discussion on the identified issues, the curricular changes made to address them, and the rationale behind those changes. While a cursory review of the overall curriculum is included, this paper is not intended to be a comprehensive discussion of the curriculum as a whole, but rather a discussion of the recent improvement process. As many of these issues affect all IT and networking programs, it is hoped that this discussion is helpful to all programs.

Background

The Network Engineering Technology (NET) program in the Department of Computer and Information Technology (CIT) at Purdue University focuses on building infrastructure to support business application deployment. The general philosophy of the program is that business needs drive application and data needs, which require network and underlying system infrastructure. Students must understand business at a high level, application and data management at a medium level, and infrastructure in detail.

The core curriculum consists of two main areas: network engineering (NET) and systems/network administration and security. Students take a core that covers each of these areas and choose electives from one or both areas. Graduates of the program have a holistic knowledge of IT infrastructure that enables them to work in many areas of an organization. Their breadth of knowledge positions them well for advancement with many alumni rapidly progressing into IT management positions.

The core of the program consists of coursework in data communications, routing and switching, wireless networking, system administration, network administration, and network and system security. In addition to the networking core, students also take an information systems sequence that covers application development, systems architecture, analysis and design, and data management. Additional coursework includes significant composition and speaking courses, accounting and economics, physics and electrical engineering technology, and liberal arts/general education content.

The program is ever evolving to meet the changing needs of the IT industry. Periodically, a full scale curriculum review is undertaken to make broader ranging curriculum changes. This paper documents the findings of the most recent review and the changes made in the curriculum as a result.

The general industry trends noted are well documented in scholarly work and the popular press. Information about the requirements of our graduates was collected informally through conversations with the department industrial advisory board, discussions with employers of program graduates, and alumni. This anecdotal evidence was combined with general industry trends well documented in the industry press and the personal experience of the faculty to determine the needs of the curriculum. As all IT programs operate in slightly different areas of the overall field, the trends noted may or may not be applicable to other institutions and programs.

Incumbent Curriculum

The basic philosophy and structure of the program have remained consistent since its founding in 1996. Consistent with a baccalaureate program, students take a general education sequence that includes liberal arts, written and oral communications, and math and science. Students in the program take a minimum of twelve hours of written and oral communications with many choosing to take additional coursework in the area. Communication is enforced throughout the remainder of the curriculum by assigning a significant portion of course points to written reports in their core NET courses. Although they consistently complain about the required writing, the ability to effectively communicate in speech and writing has been proven to serve them well in both obtaining and advancing in their career.

The core of the curriculum can be divided into two main components: network engineering and system/network administration and security. The network engineering component focuses on the technologies and protocols used to deliver data between systems. Items covered include data communication and local area networking technologies, wide area network transmission technologies, routing and switching, and wireless networking.

The system/network administration and security component focuses on the deployment, maintenance, and support of computing platforms and the network services required for them to interoperate. Throughout the discussion on deploying platforms and services, care is taken to emphasize best practice methods to ensure high availability and security of systems. Items

covered include the deployment, support, and maintenance of Windows and UNIX systems, web servers, e-mail systems, and general support protocols such as DNS, SMTP, and NTP.

Many topics bridge these two components and are delivered in a vertical, holistic manner. Topics covered in this way include wireless network security and management, storage area networking, network security topics (such as intrusion detection systems and network access control), and IP telephony and video. Courses covering these items focus on both network engineering and systems administration/security material. In addition to the core technical curriculum, students select three additional networking courses from a list of advanced topics.

Students in the program take significantly more math and science courses compared to traditional information systems curricula. Two calculus courses and two calculus-based laboratory physics courses are required. Collectively, these courses provide students with a solid understanding of the physical manner in which data is communicated between devices, either electromagnetically or optically. A calculus-based statistics course sets a foundational understanding for quality of service and queuing concepts in the core curriculum.
Students take a series of business courses (general business, accounting, and economics) designed to give them a basic understanding of the business environment. A series of information systems courses in application development, systems analysis and design, and data management provide a detailed understanding of the IT application development process. A senior level course in IT program management is required and of great value to students.

While most graduates of the NET program will not work on developing business applications directly, an ability to understand the development process and speak to the developers using their native terminology is essential to ensuring the proper infrastructure is implemented to support the applications, due to the fact that most application developers have little to no knowledge of infrastructure. In addition to the required courses, students select two additional courses in the information systems area.

In addition to the main campus, Purdue University delivers courses at multiple remote locations. These satellite campuses traditionally have focused on delivering Associate Degree curricula. Baccalaureate curricula were designed to allow students completing their Associate's degrees at a satellite campus to transfer to the main campus and complete their Baccalaureate Degree coursework.

Known colloquially as the "2+2" system, this approach created a significant critical path concern in the networking degree plan of study. The satellite campuses do not have the faculty expertise, nor the space and funds to teach laboratory-based networking courses. As a result, all core laboratory-based networking courses had to be delivered in the junior and senior years. Students took the majority of their non-core courses in the first two years, then took predominately laboratory-based core courses in their last two years.

This created several curriculum design issues. Until the beginning of the junior year, students did not feel like they were learning anything in their chosen field of study. When taking summer internships after the sophomore year, they were limited to very basic positions, such as working the help desk, as they had no practical hands-on experience with networking technologies. In the

final two years, students were then forced to take three intense laboratory-based core courses each semester. This four semester core curriculum critical path also imposed a significant limitation on elective courses. This curriculum is shown in Figure 1 below.

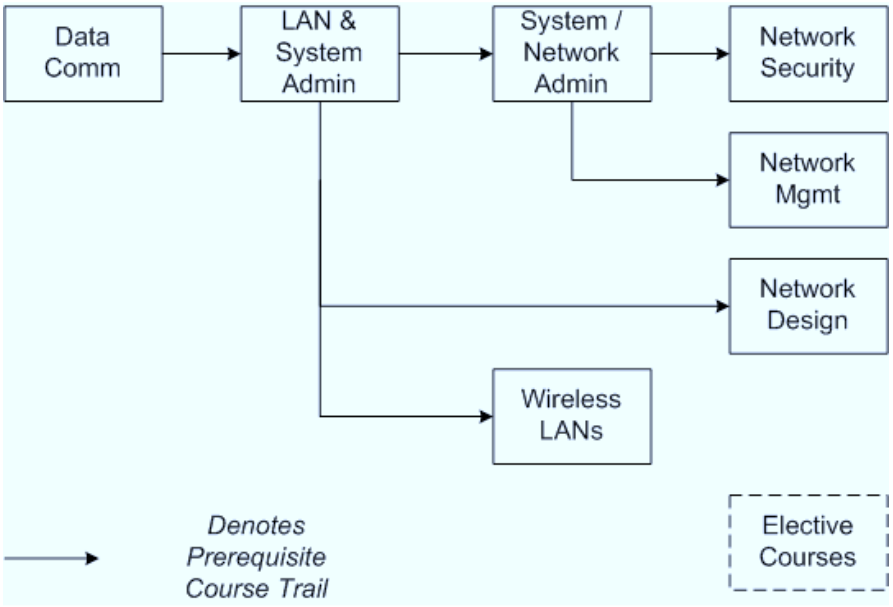

Figure 1 - Incumbent Curriculum & Critical Path

It should be noted that the figure shows only the required courses and the critical path associated with those courses. An additional number of elective courses were required to complete the prior student plan of study.

Change Factors

The curriculum review identified several change factors that were impacting the educational needs of our students: a change in policy that resulted in the end of the "2+2" system, industry trends, employer expectations and desires, and changes in the students themselves.

Institutional Policy Changes

While the aforementioned "2+2" system created opportunity for students at the satellite locations, few took advantage of the opportunity. In a given year, only a handful of students, out of the hundreds who completed their associate's degree at the satellite campuses, actually transferred to the main campus to complete their baccalaureate degrees. Instead, students lobbied to get baccalaureate degree programs established at the satellite campuses. Combined with pressure in the Associate's degree marketplace from an expanding community college system, this demand resulted in a decision to either offer the baccalaureate degree at a satellite location or close the program at that site. With the requirement of supporting the "2+2" system removed, laboratory-based core networking courses in the freshman and sophomore years are now possible.

Industry Trends

The information technology industry is consistently changing with the advent and commercialization of new technologies. While this change is constantly ongoing, the mid 2000's were a period of significant change that directly impacted the networking and infrastructure area. Many of the specialized skills that once differentiated our students in the marketplace have become commoditized. In the 1990's, for example, IP subnetting knowledge was a differentiating factor in the student marketplace; today it is background knowledge. This commoditization of knowledge is ever ongoing, resulting in today's hot skills (such as IP telephony) becoming tomorrow's background knowledge.

As cutting edge technologies have become more mainstream, the manner in which they are implemented moves toward the appliance model. Where building and maintaining a firewall once required command line knowledge of IP routing and port numbers, today's firewall appliances use point and click web interfaces that use common language to mask the technical detail from the user.

Similarly, many technologies that were once stand-alone are being integrated into other devices. Five years ago, routers and wireless access points were independent devices that were integrated by network engineers. Today they're frequently combined into a single device that also includes DHCP and DNS servers. These integrated devices have greatly reduced the amount of time and money required to manage IT infrastructure at small offices.

Where wireless technologies were once added to an existing wire line networks to support mobile devices, new implementations are being designed from the ground up to support wireless natively, with some implementations relying exclusively on wireless communication links. In today's IT environment, wireless is a core component, carrying with it the expectation that the wireless implementation should provide wire line speed and security with minimal connectivity delay.

Security was once a secondary consideration in most networks. The continued evolution of the Internet to higher speeds and its ever increasing importance to the business has greatly increased the risk to network assets. This risk not only comes from external parties on the Internet, but from the requirement to allow telecommuting employees access to the internal network. While the business forces in play continue to demand more and more external network access, the need for better and increased security does not deminish.

The number of devices that could connect to the network at one time was relatively low, with little risk of anyone walking off with large quantities of data or injecting malware into the network. Today, employees and visitors commonly plug laptops with dual core processors, gigabit connectivity, and a terabyte or more of attached storage into the network. The need to control network access and protect data and hosts has never been greater.

Another changing facet of IT infrastructure is storage. Demand for storage is increasing at an exponential pace with the once unheard of capacity of a terabyte now being available at your local Best Buy or Fry's for $100. Audio and video content, along with traditional database data,

continue to demand more and more storage. This ever increasing storage requirement brings with it challenges in terms of moving data across the network and data archival methodologies. System engineers are being ever pressed to develop solutions to archive more and more data within the same time window.

Virtualization has become a key technology in the system deployment and management area. The combination of relatively inexpensive multiple core processors and memory, combined with storage area networking technologies, have allowed IT professionals to consolidate multiple virtual servers onto a single physical machine. The initial benefit of virtualization focused on reduced expenses coming from lower power consumption, lower heat generation, and easier and more comprehensive disaster recovery. Such systems also provide architectural benefits such as the ability to move live virtual systems from one physical machine to another and to dynamically scale server clusters to meet demand. These capabilities have given rise to cloud computing architectures that have the potential to change the face of the IT landscape as much, or more, than anything that has preceded them.

Employer Expectations

In addition to changing industry trends, the expectations of employers have evolved. Both employers and students have moved from wanting a formal cooperative education to embracing a series of summer internships. Both students and employers are interested in internships between a students' sophomore and junior years as well as between the junior and senior years. In the original curriculum, students' internship opportunities were limited as all of the laboratory- based networking courses were taken in the junior and senior years to support the "2+2" program discussed earlier.

Globalization is another topic consistently mentioned by industrial advisory board members and employers alike. Information technology is somewhat uniquely positioned for globalization as projects can be worked on around the globe, allowing work to progress around the clock. Creating and maintain the infrastructure necessary to allow this worldwide collaboration requires new technologies and methods, along with an understanding of different cultures and processes.

In addition to these evolving needs, several basic demands of graduates remain among the key items employers desire: solid troubleshooting skills, the ability to work both independently and in teams, and good communication skills.

The Ever Evolving Student

In the twelve years since the inception of the program, the background knowledge and psychology of incoming students has changed significantly. With information technologies becoming more mainstream and with the broad penetration of the Internet, incoming students are coming into the program with more knowledge of basic networking. They have been exposed to networked computers in school and in their homes and are far more comfortable with these technologies than their predecessors.

This increased comfort level has two sides. While students are more savvy in basic networking, it has resulted in today's incoming students having far less knowledge in basic underlying concepts and technologies. Where once they had to really understand data communications concepts to be able to implement a local area network, today's students merely need to know how to plug in an RJ-45 connector and open a web browser. From their perspective, many key technologies are simply magic: you plug it in and it works.

There are two key ramifications of this enchanted view of IT. Students expect that everything should be "automagical" and therefore, they resist reading a manual or searching to find information to help them understand why things work. Even with the myriad of resources widely available on the Internet, they prefer to play with settings hoping to find the answer through brute force or happenstance. Without a deep understanding of the underlying technologies, it is not possible to troubleshoot and resolve complicated network problems. Yet, they prefer to avoid developing that knowledge through reading manuals, guides, and online help.

This problem is exacerbated in students who attend Cisco Network Academies and similar technical "boot camps". While they know how to configure switches and routers when given a design, they are giving little to no foundation on why to implement that specific technology in that manner. As a result, students have no idea how to design a solution for specific business purpose or why a particular design was chosen. This "content without context" tends to act as an obstacle to students' learning asthey feel they already "know it" and feel they don't need to learn the in-depth knowledge required to properly implement and utilize the technology.

Curriculum Changes

Based on these change factors, several changes were made in the curriculum. A course was deleted with its materials reassigned to other courses, laboratory activities were added to an earlier course, materials were moved between courses, topics were added to existing courses, and several new courses were created.

Overview

With the removal of the aforementioned "2+2" limitation, two laboratory-based courses were instituted at the sophomore level. The existing first semester sophomore data communications and networking course was renovated to include a laboratory component. With the addition of a laboratory experience, basic networking and subnetting concepts were pulled forward from the follow-up system administration and networking course, resulting in a single focused, in-depth course. Adding a laboratory to the course enables students to get hands-on experience with packet sniffers, VLANs, and routers a year earlier than they did in the old curriculum.

This change also greatly improved the follow on system administration and networking course. Moved from the junior year to the second semester of the sophomore year, the revised course now has a single system administration focus. The removal of the networking components from the course has allowed for a better discussion of enterprise level administration concepts and an in-depth exploration of virtualization technologies. These changes also ease the critical path

through the required core courses and better prepare students for meaningful summer internships after the sophomore year.

Prior to the latest curriculum revision, a course in wireless networking was an elective. Although it was the most popular networking elective with virtually all students choosing to take it, it was still possible to earn the degree without any formal instruction in wireless networking. This course is now required and two more courses in wireless wide area networks and wireless network security and management have been developed and implemented as electives for students interested in additional wireless networking technologies and operations.

The existing routing and switching course was restructured and an elective follow-on course has been added. The initial course continues to be primarily centered on intra-network routing and switching while the new course focuses on inter-network routing using BGP, MPLS, and similar technologies. A new course offering focused on IP telephony and video transmission has drawn significant student and industry interest.

A single pre-existing course on UNIX and network administration has been expanded into two separate courses. The new UNIX administration and scripting course expands the students' knowledge of UNIX administration with increased coverage depth of existing topics and the addition of new material on shell scripting. The new network administration course expands on the existing topics by adding new modules on storage area networking, centralized authentication systems, and an introduction to cloud computing concepts.
These changes can all be seen in Figure 2, which is included after the following section, which details the changes made on a course-by-course basis.

Revised Data Communication and Networking Course

The most significant change in revising the data communications and local area networking course was the migration from a lecture-only course to a lecture course with a laboratory component. The laboratory potion of the course now allows for hands-on reinforcement of lecture materials. This is accomplished through several laboratory assignments that cover concepts of the physical, data link, and network layers of the OSI model. There are several positive results of this direct hands-on interaction by students, including a more complete understanding of the operations of the specified layers of the OSI model, an introduction to network troubleshooting earlier in their academic careers, and better preparation for completion of upper-level courses throughout the remainder of the curriculum. Since this course became the first course the students took with a laboratory, these results were not gained without experiencing the proverbial "growing pains."

Because of the addition of the laboratory to this course, major changes needed to be enacted within the course content to meet the credit hour requirement. The biggest changes to the course content were to deemphasize the importance of the PSTN and specific network operating systems. The fundamentals of PSTN and WAN operations are covered in other courses, meaning the redundancy could be removed without a significant negative impact. Additionally, much of the content was refocused to concentrate on communication architectures, LAN technologies and interconnections.

Material was also added to this course from another existing course that was revised and modified as part of this process. These changes allow students to be introduced to IP and classful and classless subnetworking as part of the discussion of the network layer of the OSI model, which provides a foundation for additional discussions of the TCP/IP model and its usage. This change allows for students to experience troubleshooting of LAN environments and allows them to internalize the lecture material earlier in their academic experience.

Revised System Administration Course

The incumbent curriculum included a single networking and system administration course that introduced students to both networking and administration concepts. Once the networking content was moved into its own course, the result was a more complete, in-depth exploration of enterprise-class system administration topics.

Content in the revised systems administration course focuses on core concepts and expands into new and exciting areas. Fundamental topics include name resolution, system security and AAA, directory services, network printing and backup, and Windows client management. Students also gain an in-depth understanding of Windows-based domain implementations using Active Directory including FSMO roles, group policy deployments and Windows Script Host usage. In addition to these core subjects, new topics are explored, such as client and server virtualization and cloud computing.

The laboratory requires students to build a complete Windows-based client/server environment using Active Directory and incorporates such themes as redundant domain controllers, replication, FSMO role configuration, printing, backup, security and group policy enforcement. Additionally, students investigate virtualization technology and how virtualization can be used to enable efficiency of resources and disaster recovery. Objectives will require students to take their existing client/server configuration and transform it to run in a completely virtualized environment.

Required Wireless Networking Course

Introduction to wireless networking is the initial course offering in the wireless networking curriculum. Starting with freshman pursuing a Network Engineering Technology degree in the fall of 2008, the course has been changed from an elective to a required course. The reasoning behind this decision was two-fold. First, based on industry feedback it was felt that all networking professionals should have a basic understanding of wireless networking, as it continues to proliferate in almost all industries. Secondly, several upper-level wireless courses have been added that include this introductory course as a prerequisite.

Much of the introductory course has been revised over the last several years to reflect trends in industry. In its early years, wireless networking was often considered a convenience (or even a novelty) for many industries. Obviously, in recent years, implementation of wireless networks has changed dramatically to the point that wireless networks are considered a commodity, and are often being used as replacements for wired network infrastructure.

The course was originally taught from a "radio-centric" perspective, with most lecture and lab activities focused on RF theory and concepts. This has been revised to be more of a true wireless "networking" course. The emphasis has been placed on end-to-end network connectivity, integration into wired networks, and overall facility network design including wireless components from inception. In addition, as industry acceptance of controller based, lightweight access point (LWAP) networks has become a more accepted practice for control and management of wireless networks, these topics have been integrated into the course as well.

The result of these changes is a course that takes students from understanding the IEEE 802.11 series of standards on a single access point and client to being proficient at designing and implement enterprise level, managed, controller-based networks integrated with the wired infrastructure needed to transport the data from client to server in switched and routed network environments. Much of the material that is introduced at a cursory level has been expanded and became the new upper level courses described in the following sections.

Revised UNIX Administration Course

The existing advanced system and network administration course has been broken into two parts. The first course focuses on UNIX administration with emphasis on building enterprise network systems using UNIX and Linux systems. Students leverage the system administration knowledge and skills learned in the previous Microsoft Windows-based system administration course into the UNIX paradigm. The key system administration areas of user management, name resolution, file and print sharing, backup and disaster recovery, service implementation, and system security are reiterated on the UNIX platform. This reinforces the knowledge gained in the previous course while teaching the techniques unique to the UNIX paradigm.

In addition to learning how to administer UNIX systems, students also learn to write, test, and deploy shell scripts. A key tool for managing UNIX systems, shell scripts provide a means to ensure consistency between servers and modify service and daemon behavior. System backup, response to signals from an uninterruptable power supply, daemon startup and shutdown, and other low level administrative tasks are routinely performed through the use of scripts. In the laboratory, students deploy, maintain, and manage BSD UNIX and Linux systems and integrate them with Microsoft Windows systems in a heterogeneous environment consistent with most real world infrastructures. The use of virtualization technologies in the laboratory enables students to work individually, ensuring each student gets a hands-on experience while reinforcing the virtualization knowledge learned in previous courses.

Revised Network Administration Course

The other half of the existing laboratory-based system and network administration course has been expanded to cover several new topics identified to be added to the curriculum. Topics retained from the existing course include DNS, SMTP, e-mail servers, SPAM management, NTP, HTTP and web proxies, servers, and load balancing. New topics include a module on storage networking covering network attached storage, storage area networks, and network booting and a centralized authentication module covering methods to integrate user and machine

authentication among heterogeneous systems. Technologies covered include RADIUS, LDAP, and Kerberos.

In the laboratory, students build a comprehensive IT infrastructure to provide services to both internal and external clients. A basic firewall is implemented to create a DMZ that houses servers that provide DNS, e-mail, and web services to the Internet. Internally, two locations separated by a routed link are implemented. One location is predominately UNIX-based while the other is predominately Microsoft Windows-based. DNS, e-mail, file sharing, network printing, iSCSI-based storage area networking, and time synchronization services are deployed with replication and integration between the disparate platforms across the zones.

Revised Routing & Switching Course

The basic routing and switching course of this curriculum was intended to provide students with foundational knowledge in a variety of topics relating to the design, construction, maintenance, and monitoring of enterprise networks. The lecture and laboratory components of this course primarily include discussion of LANs and WANs from an enterprise perspective. However, in introducing and expanding on advanced infrastructure topics, such as BGP, much of the course content and time was utilized providing perspectives on ISP-centric networks. This, in and of itself, was not a bad thing, except many students felt confused about implementations in an enterprise when discussions in lecture and experiences in laboratory were centered on the ISP's deployments.

The modifications made to both the lecture and laboratory components of this basic network design course could be realized through the creation of an advanced routing and switching course that alleviated the pressure to cover the vast amounts of material in a single courseover a single semester format. The major lecture content change was to reduce coverage of the BGP from approximately four weeks' (seven lectures) worth of material into a single weeks' worth of lectures. Additionally, because subnetworking had been moved to a lower level course and introduced at a more detailed level, a shortened review could be completed instead of the need to establish this material. This also freed several lecture periods from the previous curriculum. Together, these changes allowed several other concepts to be covered in greater detail (VLANs, STP, and IGP interaction), benefitting the students. This also allowed for the continued problem of dealing the students who have been exposed to networking "content without context", as previously discussed.

The laboratory component of the course has now been changed to have a more applicable approach for students who wish to become network engineers at an enterprise-level. This makes the students more appropriate for a larger scope of employment opportunities as well. The changes made to the laboratory concentrate on the utilization of the three-tiered architecture at both the LAN and WAN instead of deployment of an ISP network. Additionally, much of the BGP policy-based routing concepts have been reduced to instead concentrate on students' comprehension of route aggregation, routing protocol preferences in heterogeneous environments, and additional troubleshooting skills for the enterprise network.

New Advanced Routing Course

To facilitate the evolution of the network engineering curriculum, a new course was created and designed to provide students with a deep understanding of routing protocols and switching technologies. Course content builds upon subject matter taught in previous courses, including the new data communication and networking course and the redesigned routing design and implementation course. Education will revolve around carrier-class routing technologies, including label switching and advanced BGP implementations. In addition, students will learn about some of the more advanced options available with Interior Gateway Protocols, such as OSPF and EIGRP. On the local area network side, core switching topics such as Spanning Tree and switch /router redundancy protocols will be reinforced and expanded upon.

The laboratory section of the course will involve the students creating their own carrier class network environments using advanced routing protocol features and label switching technology. Students will test router features between themselves and see how changes to the environment can impact stability.

Students who successfully complete the course objectives will have an understanding of switching and routing protocols that goes beyond what has ever been taught by the department before. Students will be well prepared for positions in industry that require in-depth routing and switching expertise.

New IP Telephony and Video Course

This new course on IP telephony and video introduces students to the underlying systems of services they use on a daily basis. Since PSTN-based concepts are introduced in the data communications and local area networks course and further expounded upon in a digital communications course, the basics of circuit-switched voice communication is already known to the students. Also, since they are required to complete the network design course prior to enrollment in this course, the students also understand the operations of routing and switching within the packet-switched network. This means that introducing the packet-based approach to voice communications is not entirely foreign to the students. So then, additional insight can be given into network operations via quality of service and network management to ensure reliability with the voice network overlay.

The IP video component of this course examines the many varieties of video operations over an IP network. These include streaming video and videoconferencing, which students typically understand at a conceptual level, and IP video surveillance, which students tend to have little knowledge in this area. This discussion also integrates other topics, both previously discussed (QoS, SIP vs. H.323, and converged services) and new, such as multicasting vs. broadcasting vs. unicasting of video.

The laboratory component of this course exposes students to both hardware and software solutions available to the enterprise. This includes IP PBXs that allow for a variety of codecs to be used, support of multiple call initiation, maintenance, and termination protocols, and reporting services available in each. These concepts can be examined from an array of situations ranging

from a single small office location to a multi-location international firm to the interactions between enterprises. Additionally, the laboratory allows students to experience the complexities of interactions between converged/unified communications systems such as messaging, email, voice, and video systems.

New Wide Area Wireless Networking Course

Technologies such as Broadband Wireless Access (BWA), cellular networks, and wireless point-to-point technologies are being implemented in huge numbers world-wide. These important "outdoor" wireless technologies were becoming ways to extend existing networks and applications in both mobile as well as fixed environments. Several years ago, it was recognized as being important for students to not only study these networks, but experience the hands-on challenges involved with applying large-scale, wide area networks using radio frequency technologies.

Some of the topics that are introduced at a high level in the final weeks of the introductory course such as 3G, 4G, WiMAX, and LTE are expounded during lecture in this new course. The technologies are examined more closely to understand their basic building blocks, advantages, strengths and weaknesses. Lecture also covers theory and appropriate implementation of major wide area wireless technologies.

Lab activities stress urban, rural, as well as underserved markets using technologies such as Broadband Wireless Access, mesh networking, SAFECOM (4.9 GHz) public safety networks, and large outdoor coverage with 802.11. In addition, understanding the security and management issues on all of these types of networks is considered critical.

With this in mind, a laboratory environment was established on the roof of the College that extended fiber optic and copper cabling from the main networking labs inside the building. The lab allows students to plan, build and implement many forms of outdoor wireless networks as well as learning the intricacies of creating long-haul point-to-point links. The lab has also proved not only to be a good teaching facility, but an effective location for sponsored, graduate, and independent studyresearch, as the campus environment is a combination of both rural and urban settings.

New Wireless Security and Management Course

The topic of wireless security and management is an elective available to students who have completed the introductory wireless networking course. By the time they have finished the prerequisites for this course, students have already completed courses within the networking curriculum in wire line design and security, and have been introduced to a number of topics including basic security theory, single sign-on, VPNs, Network Access Control (NAC), basic cryptography and encryption principles as well as management methodologies and tools (FCAPS, SNMP, etc.)

However, it became apparent that a course was needed to blend students' basic knowledge of security and management with the rapidly changing methods of securing and managing large,

(perhaps hundreds or thousands of access points and clients) wireless networks. This new course, based on both lecture and lab took on a "problem-based" flavor from the beginning, challenging students with specific issues faced by industry, and allowing them to research and implement the solution.

Security specific lecture topics include an overview of various wireless security models, a section on vulnerabilities and related exploitations, and 802.11 standards- based security as well as vendor- specific solutions. Additionally, commonality with existing "wire line" security methods and how they have been extended to the wireless network paradigms such as EAP, 802.1X and centralized authentication methods are presented.

The final eight week block of the course challenges students with the exact problem they will face in industry; that of building, securing and managing a large integrated wireless and wired network. During this time students are given the opportunity to gain experience firsthand by being split into two teams that must secure their network against attack from each other, while simultaneously managing their network to be aware of any connectivity, throughput, or security problems on the network. During these "War Games", the teams compete for points based on successful attacks and defensive recognition and thwarting of the other teams attacks, while also earning points for keeping their managed network at optimum performance for users. Students are allowed to use any equipment the department has available, and it is up to the team to design the network using best practices after evaluating numerous architectures and methodologies.

Legal and ethical issues are addressed throughout the course in order to develop network engineers that understand effective and safe methods of probing both internal and external networks for vulnerabilities lawfully.

Figure 2 below shows the significant changes made to the curriculum and its effect on the critical path. In this change, a new concept was introduced and is termed a *concurrent prerequisite*. A prerequisite course is a course that must be completed prior to the beginning of the next course in the sequence. A co-requisite course (which is not inlcuded in this curriculum) is a course that must be taken simultaneous to another course. A concurrent prerequisite course is a course that may be taken prior to or simultaneous with the next course in the sequence. In this current curriculum, most courses have a simple prerequisite trail while there are two course series that can be taken in a concurrent prequisite format.

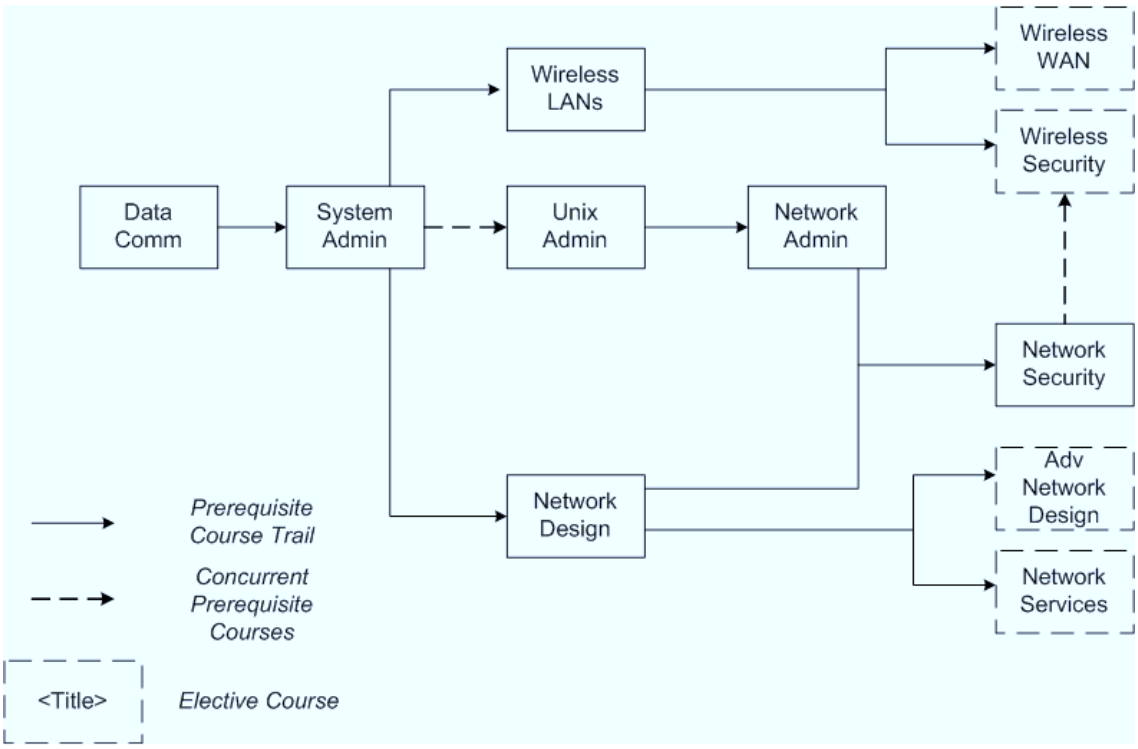

Figure 2 - Revised Curriculum & Critical Path

Conclusion

Based on preliminary feedback from students, employers, and the department industrial advisory board, these revisions made have significantly improved an already solid curriculum. While the first students to complete the new curriculum will not graduate until 2011, students in the incumbent curriculum have already benefited by the addition of the new elective courses and the temporary courses designed to test the new materials.

Despite the detailed analysis and significant revisions made to the curriculum, continual changes will be required to remain abreast of the rapidly evolving IT industry. By leveraging current and future industry contacts, employers of our graduates, and the knowledge and experience from members of our industrial advisory board, Purdue University's Department of Computer and Information Technology is poised to remain at the forefront in this dynamic field.