

A GRADUATE CERTIFICATE IN COMPUTER NETWORK COMMUNICATIONS

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Abstract — *This paper describes a graduate certificate program and curriculum in computer network communications. First the paper introduces the concept of a "graduate certification" that has been in place for nearly five years at Rensselaer At Hartford. Graduate certificate programs have a selective focus and require that a student successfully complete four graduate-level courses in a specific area.*

Second, the specific course curriculum for the Computer Network Communications certificate is presented. Although the certificate is limited to just four graduate courses, we believe that the "content" includes a fair balance of traditional and innovative computer networking courses. The paper identifies the objectives of each course. Our intent is to provide solid graduate education - with an eye on diversity in computer network solutions. The program is not tied to any vendor specific solutions; rather the students are asked to use their fundamental knowledge of networking to evaluate several choices.

Third, the paper looks at the evolution of the computer network communications certificate. Feedback from working professionals in the field of network engineering, network management, and client/server applications support will influence the content of the program. Using preliminary student feedback (from students who have completed the requirements of the certificate), we propose some changes and additional electives within the certificate.

Index Terms — *Graduate certificate in computer network communications, curriculum evolution, computer science, computer engineering.*

INTRODUCTION

Today, a Bachelor of Science degree in Computer Science or Computer Engineering opens the door to many lucrative and exciting job opportunities. The annual salary and other employment benefits are often much more attractive than staying in school for an additional year or two to complete a Master of Science degree. Fortunately, many employers offer tuition reimbursement benefits and encourage their work force to continue their education by taking additional coursework that is relevant to their job assignments. Thus

we can describe as our first group of potential students as the set of young engineers and scientists working in industry, starting their professional careers.

Another potential group students can be described as individuals who have completed both a bachelor and a masters degree more than 10 to 15 years ago. Many have exemplary work experience, but may not be up-to-date in all the new technologies, methods, protocols, procedures. For these individuals, the Ph.D. is not an attractive choice for several reasons. The reasons ranging from balancing the time commitment to family, work, and one's individual education to the very narrow focus and research orientation of the Ph.D. program. Yet, many of these individuals would like to pursue some graduate studies to be prepared for the future. They want to be ready for new job assignments, and perhaps, a career change.

To address both of these cases, the concept of a Graduate Certificate was created. For the first case, we attract the young engineer or scientist into a graduate program, to study in a focused or applied area. Often the scope of courses for the Graduate Certificate is very much job related and the student will see an immediate benefit to career. The ultimate time commitment to a 30-credit masters degree is delayed.

For the second case, we attract the working and experienced professional. We offer the opportunity to catch up with the current or cutting edge technologies and to explore the immediate or imminent application of these new technologies. Also included in this group are those working individuals who choose to make a career change, and if necessary, additional prerequisite courses may be taken.

The advantages of the Graduate Certificates versus the trade or product certification is 1) graduate credits are earned with corresponding Rensselaer recorded transcripts; 2) credits can be applied to a relevant masters program; and 3) more emphasis is placed on fundamental educational value versus product specific training. These educational advantages are important to someone who is changing careers or making a re-direction to a new field.

Rensselaer At Hartford (formerly The Hartford Graduate Center) has offered several Graduate Certificate Programs since 1993. The first Graduate Certificate was offered by the School of Engineering on the topic area of pollution and waste prevention in manufacturing. The

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timing was right for this certificate as the government was placing pressure on many industries to minimize the environmental impact of their manufacturing operations. The “new” focus was pollution prevention. By late 1994 and early 1995, the Computer and Information Systems Department followed that leading idea and began offering Graduate Certificates in five different areas within the field of Computer Science. At that time many companies in Connecticut were restructuring their organizations and the work force. Unemployment was still high and student enrollments were low. The Graduate Certificate programs were a mutual benefit: helping the students keep or find new jobs while providing a boost in enrollments.

The following table identifies the certificate programs currently sponsored by the Computer & Information Sciences (CIS) Department and the number of Graduate Certificates awarded to date.

TABLE I
CIS GRADUATE CERTIFICATE PROGRAMS

Graduate Certificate Program	Certificates Awarded: 1995 to Date
Computer Network Communications	50
Database Systems	8
Graphical User Interface	19
Information Systems	30
Software Engineering	16

What follows is more detail about the Computer Network Communications Graduate Certificate, one of the five CIS Graduate Certificates.

**COMPUTER NETWORK COMMUNICATIONS
GRADUATE CERTIFICATE**

The field of computer networks or network communications is interdisciplinary. It spans the disciplines of computer science, engineering and information technology management. Thus, the intent of a Computer Network Communications (CNC) certificate program is to include course work in all three disciplines.

From the viewpoint of engineering, we include master’s level course work in the subject area of digital data

transmission and communications. Including choices in transmission media (fiber, twisted pair copper, wireless), coding for broadband and baseband communications, switching, and the corresponding performance tradeoffs. The courses strive to provide up-to-date knowledge on Local and Wide Area Networks (LANs, WANs) technology.

From the viewpoint of computer science we add the investigation of many different internet and broadband protocols. Students investigate protocols that create the reliable and error-free end-to-end exchange of data as well as the supporting routing algorithms and flow/congestion control techniques.

From the viewpoint of information technology management , 25% of the certificate program provides a comprehensive exposure to the management of data and telecommunication networks. Students are challenged to augment their technical knowledge with the network management functions of fault, configuration, accounting, performance and security management.

Some might argue that to address all three disciplines thoroughly, i.e. covering many engineering, computer science and management topics, one should look seriously at one or more complete 30-credit graduate masters degrees. However, considering the limited time that many potential students have, the CNC Certificate is a focused program consisting of a minimum of four graduate courses (12-credits). The requirements are: ECSE-4670 (required) and any three of the following four courses: CISH-6210, CISH-6220, ECSE-6660 or CISH-6230 as elaborated in the following Table II. (Note: the ECSE courses are cataloged by the Electrical, Computer Systems Engineering department. CISH courses are cataloged by the Computer & Information Sciences department .)

TABLE II
CNC CERTIFICATE COURSES

ECSE-4670	Computer Communication Networks
CISH-6210	Computer Network Analysis & Design
CISH-6220	LANs, MANs and Internetworking
ECSE-6660	Broadband Communications
CISH-6230	Network Management

What follows is a discussion of the content and motivation for the above certificate requirements.

Computer Communication Networks (ECSE-4670) is a first course in data networks. It starts with the traditional 7-

layer reference model of networking. Yet more emphasis is placed on layers 1 through 4. Specifically, the physical layer (analog/digital signaling), the layer 2 datalink protocols (HDLC, LLC), the layer 3 networking/routing, internet protocols (IP) and the layer 4 end-to-end reliable transport of data (TCP). About equal time is spent on LANs and WANs. For WANs, attention is given to the connection-oriented concepts of frame-relay and cell-relay (ATM) services. For LANs we cover both Ethernet (802.3, CSMA/CD) and token ring (802.5). Although the market forces have selected Ethernet as the clear winner, the student is exposed to token ring as a unique media access control protocol and performance alternative. The course quickly covers layers 5, 6, and 7 with only a single lecture devoted to network security issues. Nearly all graduate students in computer science and many in computer engineering will take this course. Therefore, special care is taken to ensure that (if this is the only networking course on their plan of study) this first course is well balanced. We want to cover all the essential parts of a protocol stack, compare the tradeoffs in connection-oriented versus connection-less network services, LANs versus WANs, etc.

There are several texts available for this course and we have used texts written by Tanenbaum [12] and Stallings [8]. Currently, the 6th edition of Stallings's, *Data and Computer Communication* is the chosen text.

After completing of the course a student will understand:

- Behavior of data signals propagated through a transmission medium, twisted pair, coaxial cable, optical fiber, and wireless (microwave radio and infrared);
- Distinction between digital and analog data; and digital and analog transmission;
- Asynchronous vs synchronous communication;
- Datalink control protocols, the cooperative point-to-point exchange of data between two devices;
- Error detection, error and flow control;
- Frequency-division multiplexing (FDM) and time-division multiplexing (TDM);
- Packet-switched networks, network routing and congestion control;
- Basic concepts of frame relay and cell relay networks;
- Traditional LANs, Ethernet and token ring;
- Bridges, routers and basic principles of internetworking;
- Host to host transport protocol mechanisms (TCP); and
- Network security tools, techniques, and services.

Computer Network Analysis and Design (CISH-6210) begins with the fundamentals of probability and random variables, and then leads to network modeling and queueing theory. It is a course that will challenge the students to look at network performance. Often we ask the student, "if you had the money to spend (invest) in your company's enterprise network, where and how would you spend it?" Student's look at the characteristics of voice and

data communications, model the network and find the performance bottlenecks and offer possible solutions which will enhance throughput and minimize delay. Topics covered in the class include: stochastic processes, Markov chains, M/G/n and M/G/n queues, applications of graph theory, flow models and optimal routing. We have used Bertsekas and Gallager's text [1], *Data Networks*, for many years. Recently we have tried a new text by Petterson and Davie, *Computer Networks: A System Approach* [5] and supplemented the text with class notes..

LANs, MANs, and Internetworking (CISH-6220) is a follow-on course from the first course and extends the student's knowledge of Local Area Networks. The first part of the course deals with the newer and faster local area network technologies. We can assume that the student is comfortable with the 10 Mbps Ethernet and 16 Mbps token ring. We show the evolution of Ethernet from 10 Mbps through 100 Mbps Fast Ethernet to 1 Gigabit Ethernet and beyond. The choices of network media are examined; namely coax, twisted pair (Category 3, 5, 5e and higher) and fiber (multimode, single mode) as well as the structured cabling of the EIA-5658-A standard. Wireless LANs are introduced with a closer look at the IEEE 802.11 wireless standard; its physical layer options of spread-spectrum and infrared and the media access control layer CSMA/CA.

The second half of this course focuses on internetworking. Starting with the bridge, the Ethernet switch, and the functions of the sub-net or network router. Next the interior and exterior routing protocols (BGP, OSPF, MPLS) are investigated. The course has a pair of project/lab assignments using the Comnet III simulation software (provided by CACI, La Jolla, CA). The student will get hands-on modeling experience by starting with a simple sub-net model (investigating the differences in the various media access control protocols, CSMA/CD versus token ring) and then moving on to examine the set of subnets attached to a higher capacity backbone. The challenge for the students is to carefully select the probability distributions that characterize typical LAN subnet and backbone traffic.

As a whole, the course focuses on the current LANs and MANs and the newer and evolving high speed Local Area Network technologies and protocols. Two texts have been selected for this course. The first text, *Gigabit Ethernet: Technology and Applications for High Speed LANs* by Seifert [7] provides adequate coverage of high speed LAN technology and the second text, *TCP/IP Illustrated: The Protocols, vol. 1* by Stevens [10] supports the lectures on TCP/IP and related internetworking protocols.

At the end of the course a student will understand:

- The essential network topologies, and transmission media;
- The media access control protocols; including traditional LANs (Ethernet and Token Ring); High speed Ethernet, e.g. 100BASE-T, Gigabit Ethernet; FDDI, Fibre Channel, DQDB, ATM LAN Emulation, Wireless LANs;

- LAN/MAN Performance;
- LAN Switches, Bridges, Routers; and
- Internetworking with TCP/IP, joining subnets into a larger enterprise network.

Broadband Communications (ECSE-6660) is a relatively new course for the certificate program. It looks at the high-speed wide area network design that is based on broadband ISDN (B-ISDN), and more importantly the cell relay or ATM communication methods. Again the opportunity exists for the students to look at the hardware, the new optical technologies, the protocols, and the overall performance of these new high speed wide area networks.

Network Management (CISH-6230) is the capstone course and if scheduling permits, should be taken as the last of the four course certificate program. Clearly there is a stronger dependence on voice and data networks in the corporate world. The availability and reliability of a network is critical to the success of the business. Thus, this course looks at the essential aspects of monitoring, controlling and managing a significantly large enterprise network. The course begins with the five functional areas of network management: Fault, Configuration, Accounting, Performance and Security Management. We introduce the network management protocols SNMPv3 and CMIP followed by the structure of network management information with MIBs (Management Information Base), CIM (Common Information Model) and web-based management. The students get the opportunity to look at the big picture as they work in teams to create a plausible network management plan/proposal for a significantly large enterprise network. As a capstone course, the student will draw upon previous courses and experiences to model the corporate LAN, consider alternatives for WAN access, VPN (Virtual Private Network) and network security. The selected texts for this course include Leiwand & Fang-Conroy's text *Network Management: A Practical Perspective* [4] and Stalling's 3rd Edition of *SNMP, SNMPv2, SNMPv3 and RMON 1 and 2* [9].

At the end of the course the student will understand:

- The five major functional areas of network management, namely: Configuration and Fault Management, Accounting Management, Performance and Security Management;
- SNMP Management Information Base and the Standard MIBs;
- Abstract Syntax Notation One (ASN.1);
- Standard SNMP protocols (version 1, 2, and 3);
- Security in networking monitoring and control;
- Remote network monitoring (RMON) for statistics collection, alarms and filters; and
- The extent, breadth and depth of a complete network management plan for a moderate to large network enterprise.

EVOLUTION OF THE CNC GRADUATE CERTIFICATE

If we keep the original goals of the Graduate Certificate in mind, it is essential that the curriculum keep pace with current practices. For the new engineer/scientist starting a career in network communications the certificate program provides an immediate boost of applied science/engineering with emphasis on current technologies and their network applications. For the returning graduate student, one who has completed at least one graduate degree, the certificate should have the most up-to-date courses to provide a valuable "professional edge" for today's working network engineer/scientist or IT Manager.

There are many reasons to update the Graduate Certificate in Computer Network Communications. Most if not all of the reasons deal with change, for example (and certainly not the complete and exhaustive set of reasons)[6]:

IP telephony and Integrated Services. That is, telephone or voice communications is now making use of the packet-switched network technology; in particular the popular and pervasive Internet. It is an opportunistic evolution from circuits to packets. A change from the traditional telephone using direct circuit connection to desktop/laptop/handheld computers using an Internet connection via your chosen Internet Service Provider (ISP). While traditional circuit switching will not be replaced in its entirety, we do expect a integration of voice and data services. Today's performance and quality of communications via IP telephony can be debated and problems do exist. But these performance and quality problems stimulate further research and development, thus shaping the communication systems of the future and the corporate management structure as well.

Wireless Communication. More and more computers are untethered from the corporate LAN at work and the telephone modem dial-up connection at home. Computers and network appliances are smaller and much more mobile today with built-in wireless interfaces (typically using the IEEE 802.11 standard). Cellular telephones, laptops, palmtops or personal digital assistants (PDA) are now connected without wires to the global internet. Will it extend to our kitchen and other home appliances?

In the academic world, wireless communications will be a major building block for the computer classroom for the future. Students and their laptops can form ad hoc wireless networks with a connection to a wireless base station and the campus wide network.

In the corporate world, wireless communications will offer many economic and technical advantages. It can provide the means to attach the remote and mobile sales force to the central or home office. It can accomodate the network access needs of the temporary or consulting work force. However, the corporate world will need to look closely at the security issues of wireless communications.

World-wide wireless networks. Consider the deployment of a network of Low Earth Orbiting Satellites (LEOs) as a means of providing “fiber-like access” world wide. While this may not be a “sure thing” as originally envisioned, but the intent is to connect the most sparsely populated regions of the planet to the internet and the dense population and economic centers of the globe. We are moving closer to the goal of ubiquitous connectivity. Communicate with anyone, anywhere, at anytime.

Real-time applications or bandwidth-on-demand. Many network users would like to have the appropriate and requested data rate (bandwidth) to transfer voice, video, or data to anywhere, at anytime. Whether it is for mere entertainment to access any popular video via the Internet (Video-On-Demand), for real-time monitoring of the stock market, or for efficient corporate communications, the request is always for more bandwidth and less network delay.

Vinton Cerf, the father of the Internet, expresses concern over the “scaling-up” of the Internet[2]. The growth will continue. We can expect more users, more computers, and more network appliances. Yet will the network be able to handle the growth? Will it meet the requested performance goals and serve the users? Will it be resilient and robust? Can we effectively manage the beast?

Each of the above questions will drive further research in the field of computer network communications. We can expect enhancements to existing protocols and even new protocols. We can expect new communication technologies. We will no doubt see old protocols and technologies drop by the wayside.

IPOs and mergers. Certainly the competitiveness of the communications market and the arrival of new companies with fresh new ideas, hastens the transition of state-of-the-art research results into innovative application. We have small companies and large companies and no clear monopolies. The growth of our global network and the growth of communications technologies will continue for many years to come. There can be no reason not to anticipate growth. We expect change for the better.

CHANGES MADE TO THE CNC CERTIFICATE

We have seen substantial changes in LAN technology over the past 5 years; leaving us with a strong dependence on Ethernet solutions. TCP/IP plays a major role in internetworking. Twisted pair, fiber and wireless media are being deployed rapidly. In addition, the means to manage enterprise networks (LANs and WANS) is evolving, e.g. new standards for web-based network management.

In the first course, Computer Communication Networks (ECSE-4670), we maintain the fundamental knowledge that will have lasting value and provide a balance between Local Area and Wide Area Networks (LANs and WANS). The Open Systems Interconnection (OSI) reference model for

network communications remains along side of the more popular TCP/IP protocol suite. We have added more current examples to illustrate the principles of network design and architecture. Less class time is devoted to the Aloha network, Token Ring, X.25 and ISDN. More time is spent on Ethernet, Ethernet Switches, digital subscriber line technologies (ADSL, xDSL) and WAN access technologies (Frame Relay and ATM).

In the third course, LANs, MANs and Internetworking (CISH-6220), the primary LAN technologies covered are Ethernet, Fast Ethernet, Gigabit Ethernet, Wireless 802.11, and FDDI. We have eliminated most of Token Ring 802.5, all of the 100-VGAnyLAN or demand access protocol 802.12. We have put much more emphasis on the TCP/IP protocol suite and the ability to internetwork and route packets. We have included two LAN simulation projects to allow students to investigate tradeoffs in LAN performance. One significant benefit of network modeling is that the student gains an appreciation of the existing traffic loads on a LAN by data type and by application. Since many students are working in industry, they investigate the existing traffic patterns used at their workplace and often acquire real traffic profiles.

In the fourth course, we have kept up with the evolution of SNMP (Simple Network Management Protocol) from its original version 1 to the most recent SNMP version 3. There have been significant changes to the security model for SNMP. The standards documentation of SNMP version 3, the major result in security, has only been available since January 1998.

The course on Broadband Communications has been added elective, expanding and strengthening the coverage of wide area networking.

FUTURE CHANGES FOR THE CNC CERTIFICATE

We have kept in touch with many of the students who have completed the CNC Graduate Certificate. Most if not all the students speak favorably about the certificate and have advanced their professional career as a result of the program. They appreciated the time spent with TCP/IP protocols and suggest that more time, possibly hands-on experience and experimentation, be given to IP switching, routers and network configuration. Students who are involved with wide-area network services suggest that more time should be spent on telecommunications, specifically the integration of voice and data. In the area of cellular and wireless communications, students appreciate the exposure to the IEEE standard 802.11 as many are starting to use wireless communications in the workplace.

For a four-course (12-credit) certificate program, it is going to be hard to span the entire spectrum of network communications and not slight some technology or some protocol suite. Yet we do feel that we can continue to evolve the LANs and internetworking area and put more

effort into network simulation and modeling. With collaboration with industry we could obtain a better and more meaningful trace of actual traffic patterns - the input and driving force of network models.

It is our intent to look closer at the diversity of telecommunications and the evolution of wide area network technologies. Fiber optics and wave-division multiplexing is changing the current global communications picture. Multi-media applications with multicast and any-cast communications is new and needs further investigation with respect to coverage in class and selection of texts.

One of our strong points in our certificate program, as mentioned by many of our students, is the time spent on network management. However, that course needs a work-over or update as there is not just "one way" to manage networks. The goals and objectives we establish for network management may still be consistent. We continue to consider both telecommunications (circuit switching systems) and the Internet (packet switching). But, the viable choices in protocols are many and they include SNMP, CMIP, TMN, web based network management and a few proprietary solutions. Newer texts [3],[11] have been written on integrated network management and thus we will make an effort to shift to a more balanced look at network management during the summer semester 2000. We will move away from the Internet centric SNMP, to include more coverage of telecommunication management and web-based management schemes.

Another area of interest to the communications field is network security and e-commerce applications. One lecture in the first course Computer Network Communications, ECSE-4670, and one lecture in Network Management, CISH-6230, have been devoted to security topics, e.g. encryption/decryption, authentication, digital certificates. Current events suggest that more educational opportunities be given to network security. We will need to investigate where we can adequately cover security issues in the curriculum. One obvious option is to add another 3-credit course and allow the student the option to select three courses out of five available elective networking courses.

CONCLUSIONS

It is obvious, technical courses must evolve. It is expected that voice and data network courses will certainly change over the coming decade. Our CNC Graduate Certificate program is successful and of significant value to our students. Based on modest input, from our "graduated" students, there appears to be a satisfactory balance between theory and applied focus of the courses offered. What they

ask for is more - more experience, more exposure and more choices. As we keep an eye to the future, some technologies will have to be dropped from the courses and new technologies added. We believe that we can satisfy most with just four courses; yet additional special topics, e.g. network security & e-commerce, might be beneficial.

Our certificate program has been successful in another respect, we have added more students to our computer science and computer engineering graduate masters programs. The students have continued their studies to complete a 30-credit masters degree. As an additional benefit, some (less than 10) management students have been able to tailor their management degree to include four networking courses. No doubt these are upcoming network and IT managers.

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