



## **Learning IPv6: Becoming a Subject Matter Expert of a Technical Topic through a Year-Long Capstone Design Project**

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I am a cadet at the Coast Guard Academy graduating this year, 2015, and I am interested in being an active member of the cyber security realm within the Coast Guard and in the private sector after my military career.

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## *Introduction*

The purpose of education remains the subject of much vigorous debate and discussion. Education has been a part of the development of humans from the earliest times to the present with many different perspectives [1-4]. While university education contains many pedagogical aspects, the concept of a capstone design project is embraced by schools from Orono, Maine to San Diego, CA and many, many in between [5, 6]. The opportunity to practice project management principles, put theory into practice, and accomplish something of significance serves to enrich and motivate. Naturally this is no less true in the area of Electrical, Computer, Communications, and Telecommunications Engineering education.

This paper describes such a capstone project as conducted at the United States Coast Guard Academy (CGA) on Secure IPv6 Design. At this time education in networking at the CGA is focused almost entirely Internet Protocol Version 4 (IPv4) at the Internet layer. Through this year-long project, two senior students (known as cadets at CGA) successfully extended their classroom knowledge of IPv4 and its ancillary components to the realm of IPv6 and in so doing learned valuable lessons for the Coast Guard at large while improving the infrastructure of the Academy's engineering educational network.

## *The Course: Capstone Projects in Electrical Engineering*

The fall semester course description reads [7]:

This is the first of two capstone courses in Electrical Engineering during the senior year. The focus of this course will be taking students through the first half of the Engineering Design Cycle. Classroom discussions will focus on the engineering design process including needs identification, system requirements, system design process and engineering ethics. Additional lectures will center on contemporary electrical engineering topics. In the lab, cadets begin a two-semester major engineering design project. Working as an apprentice engineer alongside faculty members and contractors as part of a small Coast Guard project team, students are confronted with real-world engineering problems that require formal resolution with no predetermined outcome. A typical project includes requirements definition, computer programming, computer algorithm design and system implementation, data gathering and analysis, and presentation of results in a paper and oral presentation. Field trips to Coast Guard labs and project related trips to various locations are included.

In completing the first semester, students are paired with faculty advisors on a project usually sponsored by an external to CGA entity. For this project, the Coast Guard Academy's Information Systems division Chief and the technical lead for IPv6 migration for the Coast Guard at our Telecommunications and Information Systems Command (TISCOM) served in this capacity. This links work the cadets are engaging with real world issues being faced by the Service and provides network opportunities for the cadets to learn about some of their future opportunities. Each week the advisors and students conduct a meeting to discuss the previous week and agree on the individual and group tasks for the upcoming week. This is further

solidified by weekly status reports that provide additional reflection on the project progress, outline problems, and highlight effort expended. In addition, students are required to draft a Problem Statement, Requirements Specification, Functional Design, Project Plan, and Test Plan. The nature of the projects varies widely from continuing a previous project with well-defined expectations to venturing into uncharted waters with only a vague sense of a reasonable destination. Thus all of these documents are flexible in their nature. For example, the test plan could be for the final product or for a milestone. Either way it will contain similar complexity and comprehensiveness. Assessment for this semester consists of 20% for Homework/Quizzes/These Project Documents, 20% for the final Technical Specification, 10% for the final Project Presentation, 10% for Weekly Progress Reports, 20% for Advisor Tasking Assessments, and 20% for the final Advisor Team Assessment. This distributes the student's final grade in half between the course coordinator who handles the weekly course and its material and the design process/project management in general and the project advisors who focus on the particular project. Cadets are also required to produce a project poster which is displayed in the Electrical Engineering Section hallway until the final project posters replace them in May.

The subsequent spring course description reads [7]:

This is the second of two capstone courses in Electrical and Computer Engineering during the senior year. The focus of this course will be Project Management and taking students through the second half of the Engineering Design Cycle. Classroom discussions will cover system testing, system reliability, team management, budgeting and scheduling. Additional lectures will cover engineering ethics, engineering economics and contemporary electrical and computer engineering topics. During the Laboratory periods cadets bring their two-semester major engineering project to a close by continuing work on an engineering project, and present the results to Academy faculty and to professionals from Coast Guard Headquarters and various Coast Guard engineering commands. Field trips to Coast Guard labs and project-related trips to various locations are included

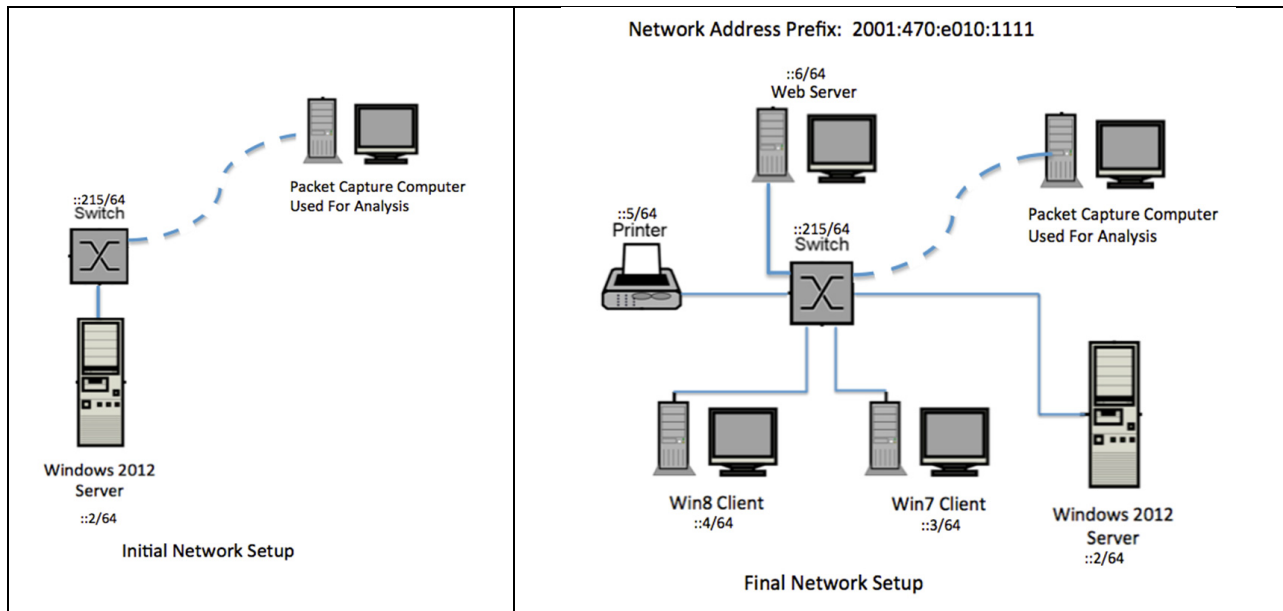
While much of the first semester is spent on design and preliminary implementation, the project moves into full swing during the second semester with a focus on implementation and validation. The grading shifts to reflect this with 20% based upon Homework, Quizzes, and two interim Status Report presentations (open to the entire faculty), 20% for the Final Paper, 10% for the Final Presentation, 10% for Weekly Progress Reports, 20% for Advisor Tasking Assessments, and 20% for the final Advisor Team Assessment.

### *The Project: Secure IPv6 Design*

The purpose of this Capstone Design Project is to research and examine the implementation of Internet Protocol version 6 (IPv6) for use by the Coast Guard. IPv6 differs from IPv4 in numerous ways including added security and efficiency, however it is the diminishing number of available IPv4 addresses that is driving the need to transition to IPv6. Another compelling reason for the Coast Guard to transition to IPv6 is that the US Government has mandated the switch by the end of 2014. This project consists of completing research, experimentation, and implementation of the IPv6 protocol. The project advisors determine the reasonable steps to guide this research, while the sponsors provide the overall final goals desired. Throughout the first semester, the team follows the design process through identifying the needs and objectives,

forming test plans based on the requirements set by the project sponsors, and creating a timeline to complete the research, experimentation, and implementation. The research is to be completed using textbooks and other publications and through reaching out to various agencies, governmental and industry, to determine the status of IPv6. A test bed is to be designed and built as an emulation of the Coast Guard Academy network for the use of collecting data to be analyzed. The lessons learned from these steps will be helpful as the Coast Guard Academy looks to transition to IPv6, and may be useful Service-wide. This process will lead to the final product of a transition plan with lessons learned for the Coast Guard Academy and ultimately the entire Coast Guard, as well as a final implementation on some portion of the Coast Guard Academy network.

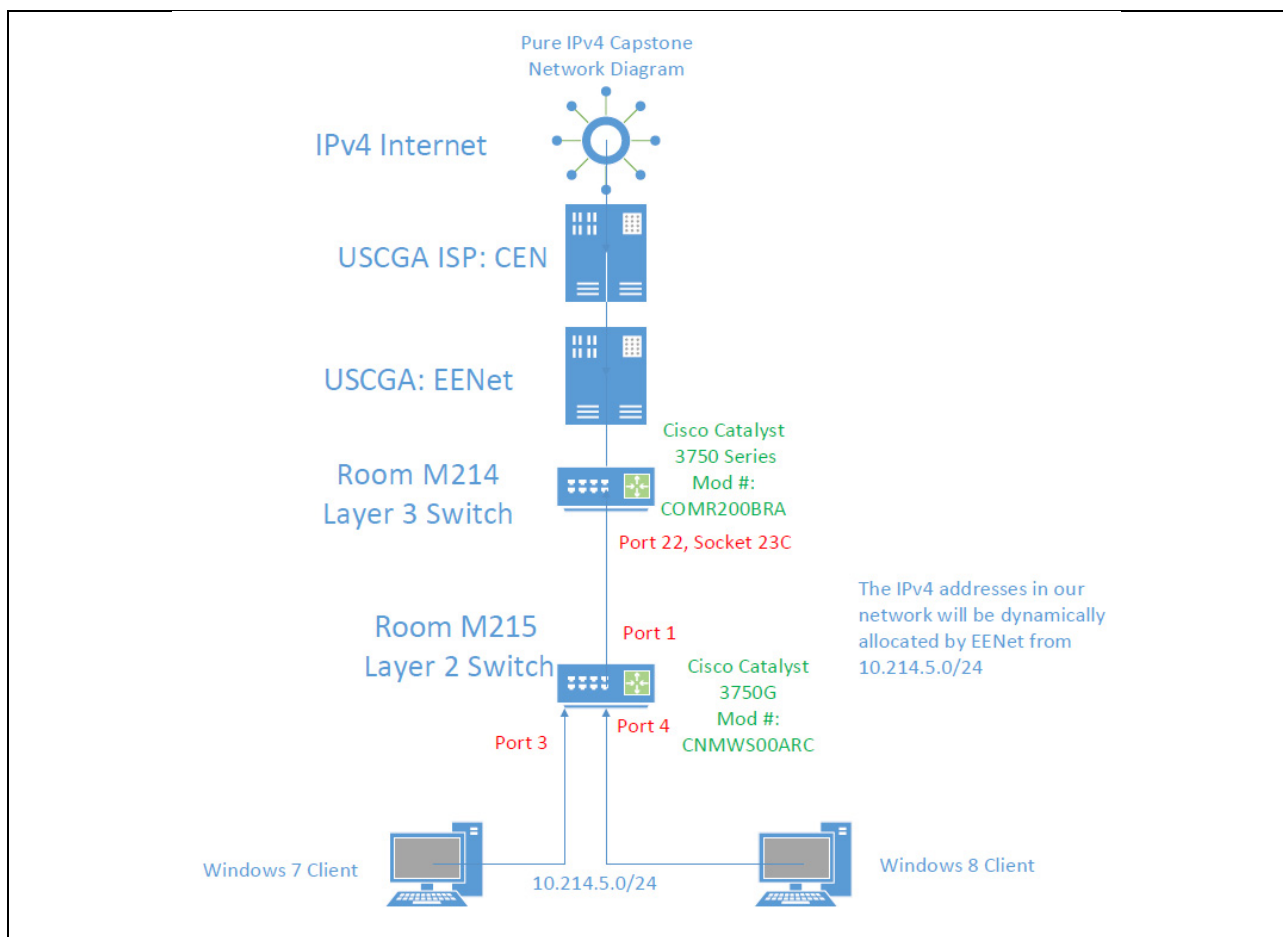
The cadets identified the need for this project (lack of IP addresses to support the “network of things” envisioned for the future along with governmental mandates) and established as its objective to become subject matter experts on the next Internet protocol, to establish a transition plan, and commence this transition by implementing IPv6 on some aspect of the USCGA educational network. They started by researching IPv6 and creating test networks to compare new aspects of the protocol with the old protocol, IPv4. From this they established marketing requirements and a full requirements specification, which in turn lead to a functional design with enumerated design alternatives. As it was premature to build out the complete functional design of what it would look like to bring IPv6 connectivity to current IPv4 networks, their functional design focused on their test-bed configuration, and can be seen in Figure 1. This lab environment was then used, along with the comprehensive test plan they devised with the input of their CGA IS sponsor, to further enrich their understanding of the protocol and experiment with various IPv6 features.



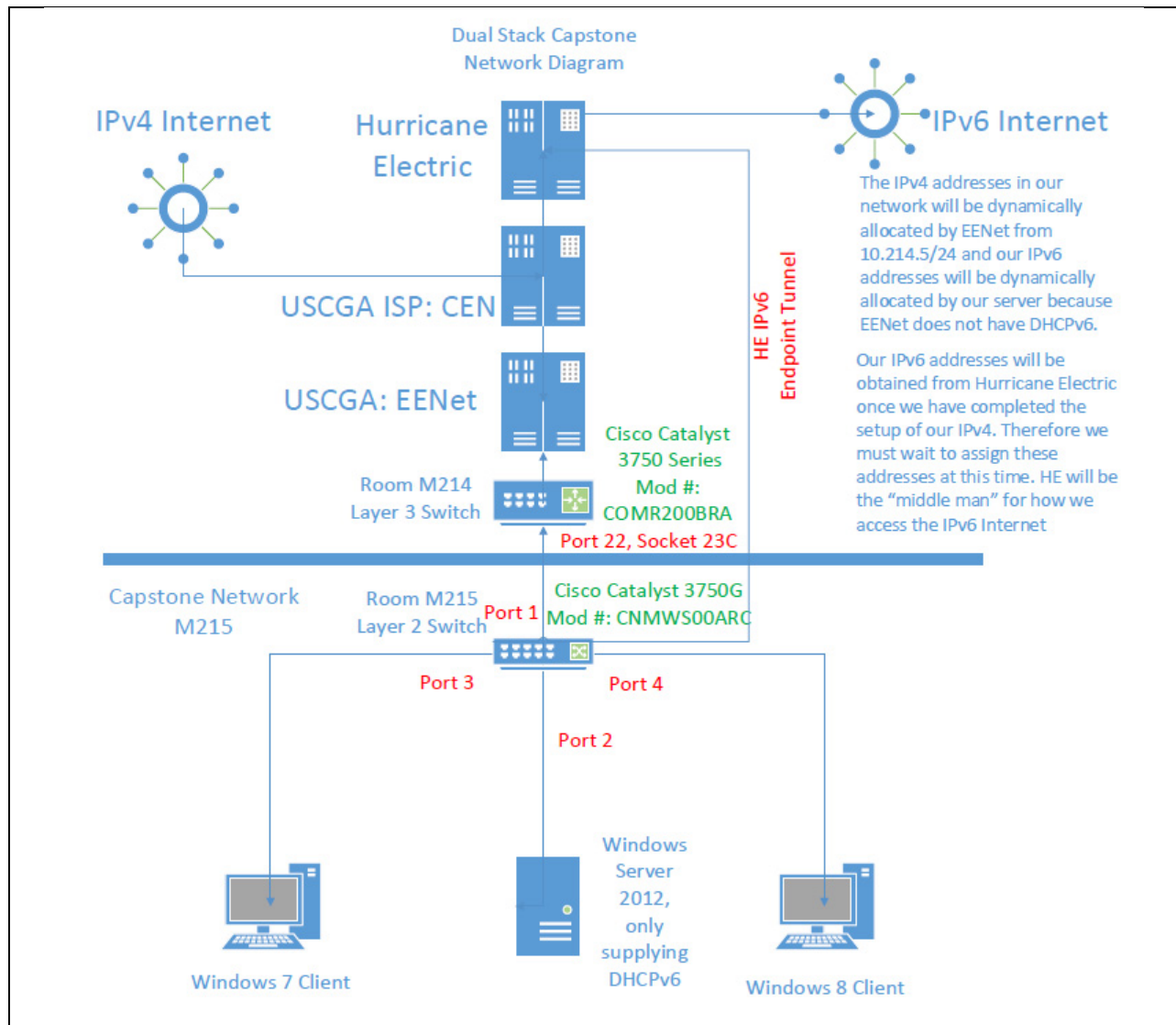
**Figure 1. Functional Design of First Semester Test Bed**

The fall project also included the development of a project plan including a work breakdown structure, GANTT chart, and network diagram of their critical project path.

The second semester has seen the students harness what they have learned and moved in a direction that will yield valuable results for the Electrical Engineering program, CGA, and potentially for the Coast Guard. Shifting from a simple test bed to compare IPv4 and IPv6 functionality, and based upon a feedback cycle with their customer, the students have shifted their focus to bringing IPv6 connectivity to a site with only a typical IPv4 –compatible connection to their ISP. This would bring the power of IPv6 to potentially any subnet **without having to adjust the contractual connectivity** to that site and thus can be done with greater ease and flexibility. This is realistic as it reflects isolated sites, cutters (ships), or a portion of a larger network at a site and a more likely approach during transition from pure IPv4 to IPv6. The network one would expect to encounter initially is presented in Figure 2 and was modeled in their lab space. Figure 3 represents their solution to bring full IPv6 connectivity as a dual stacked subnet within a IPv4-only core network.



**Figure 2. Initial IPv4 Network Diagram without IPv6 Connectivity**



**Figure 3. Network Diagram of IPv6 Solution**

Once the cadets complete their testing of the IPv4 network using a second test plan (modified from their original fall semester one), they will build this network and document all the changes they had to implement to do so. This will in turn produce a transition guide for the CGA’s IS division (and the Coast Guard) to enact this transition anywhere within the enterprise. Finally, the cadets are going to use their guide to fully transition the entire Electrical Engineering Capstone Lab to IPv6 connectivity and if time permits the entire EE education network. It is then hoped that members of IS will be able to use this guide to transition elements of the Academy’s production network to IPv6.

*Methodologies*

The cadets had to expand their networking expertise beyond what they learned in class and scripted labs to complete this project. This is reflected in their IPv6 network design. After the experimentation of the first semester it became clear that a pure IPv6 network would not be

robust enough to be widely embraced. Fortunately nearly all computers and networking equipment can carry both IPv6 and IPv4 traffic simultaneously in what is referred to as a dual-stack architecture. Getting onto the IPv6 Internet from an IPv4 provisioned network required “tunneling” to an IPv6 provider. A protocol has been developed which the cadets employed accomplish this.

Having brought IPv6 into their network the cadets were able to quickly configure the portions of IPv6 that are copied from IPv4. The bigger challenge was configuring the features that are new or different in IPv6. The two most difficult issues the cadets confronted were address assignments and router advertisements. The cadets (and advisors) learned that these two functions are intimately intertwined. Using the Dynamic Host Configuration Protocol (DHCP) in IPv6 gives the designer control of address assignments however without a router advertising its presence, hosts are unable to communicate. Using the router advertisements, which are new to IPv6, hosts will assign themselves an address using Stateless Auto Address Configuration (SLAAC). The downside to this is that the hosts still need to learn where to find a Domain Name Server. DHCP provides this information so the cadets choose to use both DHCP and SLAAC.

In the end the cadets were able to bring IPv6 connectivity to their previously IPv4 only, laboratory network. They were then able to study the performance of this network relative to an IPv4 network to ensure that the addition of IPv6 did not cause users to experience any degradation in performance and explore the features and efficiencies that IPv6 offers.

### *Conclusions*

This project was rewarding challenging for all parties. The resulting network went beyond the previous experience of the cadets and faculty advisors. Many parts of IPv6 are directly derived from IPv4 where the faculty members were comfortable. However the areas where the protocols differ were a learning experience for everyone.

As a learning experience the faculty advisors were challenged to evaluate the performance of the cadets in an area where they are building their expertise at the same time. The cadets were evaluated on the quality of their plans, reports, presentations and results. Evaluating plans, reports and presentations was straightforward. Setting reasonable, measurable goals for results was more difficult and required a strong relationship with the cadets to ensure that they were working hard, in an intelligent way to design and evaluate their network.

### *Implications*

Education is much more than papers, books, and iPads. First it is worth noting that this project has successfully demonstrated the synergistic benefit of a capstone project in uniting the efforts of students, faculty, institutional support, and practitioners. Cadets learned more, gained practical job skills in learning about and extending their academic and professional knowledge, and were provided greater motivation knowing external entities were interested in their work. Faculty learned more, found more enjoyment in the process, and built stronger ties to other divisions within the Academy. The IS Division was able to engage in an academic exercise providing

enrichment and fulfilment in the intellectual development of others while gaining valuable insights into a technology time and budget has not permitted them to investigate. The Coast Guard's network Center of Excellence was able to mentor senior students and also gain insight into a technology time and budget had not permitted them to investigate either.

Secondly, with tight budgets and increasing demands on resources, tapping into the energy and intelligence of students is and has been a great way to explore margin of excellence activities (even at the undergraduate level). When this mutually and proportionally benefits students and the institution, this appears something to be lauded. However if the students' interests are subservient to the institution or the benefit is greatly imbalanced, then this can provide a scenario of marginalization and exploitation. Thus transparency, oversight, and strong ethical and moral principles are required to ensure the validity of such efforts.

Finally, this project only solidified the strong position capstone design projects hold in the education of students. Providing cadets an opportunity to apply aspects of their engineering education in the completion of a year-long project serves to reinforce the value of education to extending knowledge and ultimately set a course for lifelong learning. These two students began with a decent understanding of IPv4 and ended with a complete and thorough understanding and the experience of implementing IPv6, thus establishing themselves as subject matter experts in this area.

The authors hope that this paper serves to motivate others to engage in similar network and cyber focused capstone design projects while integrating institutional and external parties with the result of implementing improvements within your institution and developing students to know, understand, and experience the sorrows and joys of learning!

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