CCNA-based Communication Technology Courses

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Abstract

Many study programs include courses on communication technology. All these courses explain the basis of communication technology, but they have different levels in detail depending on the study program and the related organization. Several courses include experimental activities and some of these are based on certification related to a network device manufacturer. This article is based on the experience at the University of Stavanger (Norway), where two bachelor-level courses based on the Cisco Certified Network Associate (CCNA) are offered. This article generalizes the outcome from this experience and aims to provide a guideline to create similar courses in different study programs. This article will address the course syllabus, the laboratory activity, and the examination by giving some best-practice suggestions.

Introduction

Communication technology is a relevant topic in many different fields, such as Computer Science, Computer Engineering, Telecommunications, and Telematics. For this reason, communication technology courses are included in many study programs.

Communication technology is commonly presented by using the Open System Interconnect (OSI) model from the International Organization for Standardization (ISO) and/or the TCP/IP model (also called Internet protocol suite) maintained by the Internet Engineering Task Force (IETF). The content is therefore divided by each layer of the reference model, and a bottom-up approach is usually used, starting from the lowest layer (i.e. Physical) to the highest one (i.e. Application).

Depending on the study program and the field, the content of the courses on communication technology can have significant differences. For instance, in Computer Science there will be just one mandatory course, which includes basic knowledge and notions, without including many details. In Telematics, there will be many courses focusing on different layers and/or aspects (e.g., security, dependability, performance) and including a high level of details. The courses on communication technology can only focus on theoretical aspects or also include experimental activities, where the students can practice what they have learned in laboratories and/or by using emulators.

When a course on communication technology has experimental activities, most likely these activities are specific to a network device manufacturer (such as Cisco or Juniper Networks) and based on a related certification.

The Department of Electrical Engineering and Computer Science at the University of Stavanger (Norway) [1] offers two bachelor-level courses on communication technology, which are based on the Cisco Certified Network Associate (CCNA) [2].

This article will present this experience and generalize the related outcomes. The main target is to provide a guideline explaining how to create a CCNA-based communication technology course. The guideline will take into account the different needs of the various study programs and two other possible course implementations are briefly introduced. To fully replicate the implementation at the University of Stavanger, external funding and/or donations are needed to create a physical laboratory.

This article will focus on the course syllabus, the laboratory activity, and the examination by giving best-practice suggestions. Even if CCNA is the reference of this article, the guidelines and best-practice suggestions can also be used in courses based on a certificate from another network device manufacturer.

CCNA-based courses have been presented in [3] and [4]. These works present adaptive communication technology courses, where students have the opportunity to choose between practical and theoretical oriented courses. These courses are therefore different from the course at the University of Stavanger. Moreover, these works do not provide any guidelines or suggestions to create a similar course in a different context.

This article is organized as follows. Firstly, the background and motivations of the communication technology courses developed at the University of Stavanger are presented. Secondly, the CCNA syllabus is introduced, the organization at the University of Stavanger described, and the possible alternative implementations of a CCNA-based course presented. For the course implementation at the University of Stavanger, the lectures, the laboratory, and the examination are introduced, and the best-practice suggestions given. Successively, the course statistics and student feedbacks are presented. Finally, the conclusions are summarized.

Background

Given a directive from the Norwegian government for updating university curriculums, in 2012 the Department of

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Electrical Engineering and Computer Science at the University of Stavanger decided to introduce two new courses within communication technology.

The main guideline from the department was that the new courses should have emphasized the practical understanding of how a computer network works. Since the only communication technology course at that time was only theoretical, it was clear that a reorganization to a more practical oriented teaching in data communication would be resource-intensive. A new lab consisting of enough routers and switches had to be built. Besides, only CCNA-certificated instructors have the opportunity to use and teach CCNA courses.

In spring 2013, Atea, a leading company in IT infrastructure for businesses and public-sector, decided to donate the equipment required to build a modern and well-equipped data communication laboratory at the University of Stavanger. In addition, Atea assisted in building the lab and configuring all the equipment. The list below shows the equipment Atea donated to the University of Stavanger:

- 6 racks;
- 20 pods consisting of:
  - 3 Cisco 2901/K9 routers;
  - 3 Cisco C2960 switches;
  - All necessary types of cables.

At the department, an associate professor and an engineer were responsible for implementing the two new courses in the study program. The required CCNA courses and certifications were completed during 2013 and spring 2014.

One course started in the spring semester 2014 and the other course started in the following semester. After this, these two courses have been given regularly as part of the Bachelor program in computer science at the University of Stavanger.

After completing each course, the students need to take an ordinary university exam. Students completing both courses may choose to take a CCNA certification, but this certification is voluntary, and the university is not involved in the organization.

Course Organization

In this section, first, the CCNA syllabus is introduced, then the course organization at the University of Stavanger is presented, and in the end, different course implementations are presented and discussed.

CCNA

The CCNA syllabus consists of four modules. Each module has a theoretical and a practical lab part with many lab exercises. For each of these parts, there is a textbook and a lab manual with all the lab tasks, both from the Cisco Network Academy (NetAcad) [5]. In NetAcad, there are also chapter tests after each chapter in the textbook and tests that cover all the material covered in one textbook, the final test.

Table 1 shows the CCNA syllabus highlighting the content for each module. The first module has the classical bottom-up approached, briefly assessing each layer. The second module mainly introduces the routing. The third module presents the routing more in detail. The fourth module concludes the routing and introduces some advanced features. Note that the presented CCNA syllabus is related to version 6, and version 7 will introduce several modifications, including the reduction from four to three modules. Therefore, a different organization will be needed in the future.

Table 1: CCNA Syllabus

Module	Content
Introduction to Networks	• Explore the Network • Configure a Network Operating System • Network Protocols and Communications • Network Access • Ethernet • Network Layer • IP Addressing • Subnetting IP Networks • Transport Layer • Application Layer • Build a Small Network
Routing and Switching Essential	• Routing Concepts • Static Routing • Dynamic Routing • Switched Networks • Switch Configuration • VLANs • Access Control Lists • DHCP • NAT for IPv4 • Device Discovery, Management, and Maintenance
Scaling Networks	• LAN Design • Scaling VLANs • STP • EtherChannel and HSRP • Dynamic Routing • EIGRP • EIGRP Tuning and Troubleshooting • Single-Area OSPF • Multiarea OSPF • OSPF Tuning and Troubleshooting
Connecting Networks	• WAN Concepts • Point-to-Point Connections • Branch Connections • Access Control Lists • Network Security and Monitoring • Quality of Service • Network Evolution • Network Troubleshooting

Organization at the University of Stavanger

Within the bachelor program in computer science of the University of Stavanger, the CCNA syllabus is covered by two courses of 10 credit points each. The first course, called *Communication Technology I,* is mandatory for all computer science students and is lectured in the fourth semester [6]. The second course, called *Communication Technology II,* is optional and is lectured in the fifth semester [7].

Communication Technology I is a basic computer networking course and covers the first two modules of the CCNA syllabus. Communication Technology II introduces more advanced networking features and covers the last two modules of the CCNA syllabus.

These are the only courses on computer networking of the whole bachelor program. Communication Technology I does not have any prerequisite, Communication Technology II requires to have passed Communication Technology I-

In both courses, there is not any compulsory attendance. Having a compulsory attendance is not a common practice, this is due to the fact that it is common in Norway that students are also working during the university studies.

In the master´s program in computer science at the University of Stavanger, there is another course in communication technology, which is the Wireless Communication course. Wireless Communication is held in the first semester and it is mandatory for the curriculum on "reliable and secure systems". Wireless Communication is mainly a theoretical course and is not connected to the CCNA. The students that come from the bachelor course can surely benefit from Communication Technology I, but it is not a prerequisite since many students in the master's program are international students coming from other universities.

Course Implementation

The communication technology courses based on CCNA can be implemented in different ways. Three properties that can be considered are the following: the balance between theoretical and practical parts; the strictness in following the CCNA syllabus; the presence of a physical laboratory. These properties are not independent, therefore one property can imply another property.

Figure 1 depicts three possible course implementations and related properties. A course similar to the one at the University of Stavanger has been called *CCNA-adapted course*; a second implementation has been called *CCNA-inspired course*; a third implementation has been called *CCNA laboratory course*.

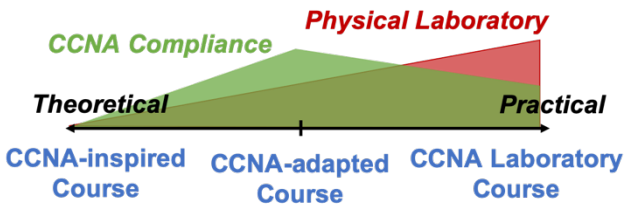

Figure 1: Course Implementations

We are aware that further categories of course implementation can be present in reality, but we believe that the ones above give us enough variety to discuss and suggest guidelines and best practices, which may be relevant also for most of the additional types of course implementation.

A *CCNA-adapted course,* such as the one at the University of Stavanger, is characterized by an equal balance of theoretical and practical parts; full compatibility with the CCNA syllabus; and the presence of a physical laboratory.

A *CCNA-inspired course* is similar to a conventional course and is characterized by a predominant theoretical part. This kind of course is often characterized by a loose connection to the CCNA syllabus and lack of a physical laboratory. The motivations to implement a course belonging are various: the course teacher prefers the theoretical aspects, the lack of a CCNA-certified instructor, or the lack of resources for building a physical laboratory.

A *CCNA laboratory course* is instead characterized by a predominant practical part. This kind of course needs a physical laboratory and is only focusing on the practical part of the CCNA syllabus. This course is connected to study programs with many courses on communication technology because it needs to be preceded by a theoretical course first.

One example is the course "Laboratory of Protocols and Routing Architectures" at the University of Pisa (Italy). This course is not based on the CCNA, but on another certification, Juniper Networks Certified Internet Specialist (JNCIS).

In the next section, the best practices and guidelines for a CCNA-adapted course are discussed by focusing on lectures, laboratory, and examination.

CCNA-ADAPTED COURSE

In this kind of course, the theoretical and practical parts are balanced, and the syllabus is fully compliant with the one in the CCNA. The courses on communication technology at the University of Stavanger belong are CCNA-adapted courses. In the following, the lectures, laboratory, and examination will be presented, and best practices will be suggested.

Lectures

As mentioned in the previous section, at the University of Stavanger the CCNA syllabus has been divided between two courses. The first two modules have been included in the first mandatory course and the last two in the second optional course.

For Communication Technology I, the course has 80 hours of lectures divided into 20 4-hour lectures. In each lecture, two chapters (corresponding to the contents in Table 1) are presented.

The CCNA syllabus can be followed quite strictly, but a suggestion is to adapt the content by explaining more carefully some topics.

For Communication Technology I, the different layers can be more extensively presented. In particular, Physical and Data Link Layers by presenting additional technologies, especially related to wireless communications. For the

Physical Layer, more details about modulation and encoding can be added. For the Data Link Layer, coding and error control should be introduced and more Multiple Access Control schemes should be presented. The routing part of the Network Layer can be extended, by better introducing the related protocols. The Transport Layer needs to be more extensively presented by better explaining congestion control and flow control.

For Communication Technology II, emerging networking technologies, such as Software-Defined Networking, can be introduced. Moreover, the CCNA syllabus should be complemented by also introducing Linux Networking with the related lab activity.

During the lectures, the theoretical syllabus is reviewed by using a modified version of the slides provided for the CCNA.

After the lecture, the students go to the laboratory for another 4 hours. For this reason, the content explained at the lecture and the laboratory activity need to be synchronized in order to allow the student to benefit from a direct connection between theory and practice. This requires the lectures and laboratory tasks to be carefully planned.

Laboratory

At the University of Stavanger, at the start of each course, the students are organized into groups, each group consists of two students. These groups are used both in the laboratory activity and on the oral exam.

During the laboratory, the groups get the approval for the lab assignments of the previous week and work on the lab assignment of the current week.

Working on the lab assignment in groups is important and useful because challenges and problems can be discussed and solved together. If the solution is not found, the students are helped by student assistants.

The lab assignments consist of a subset of the Packet Tracer [8] assessments from NetAcad. Every week, circa four tasks are required the be accomplished by the students. The tasks consist of various activities (configuration, troubleshooting, testing) spanning across the whole syllabus. The students receive the plan of the lab assignments at the beginning of the semester. Given that two chapters are lectured each week, on average there are two tasks per chapter. Anyway, depending on the type and relevance of the content, there are chapters with five lab tasks and chapters with none. For example, with respect to the first module, chapters 1 and 3 have no lab tasks, 9 and 10 only one, but 7 and 11 have 5 tasks.

It is worth mentioning that the groups have free access to the lab premises. This means that they can carry out the lab assignments also outside the weekly laboratory hours.

We suggest using a similar approach. It has to be noted that laboratory activity is also dependent on the number of students. At Communication Technology I, there are 70/80 students. This means that only a subset of groups can work on the actual devices, the remaining groups can practice on Packet Tracer.

In general, if a physical laboratory is not present, the students have to practice by only using Packet Tracker or similar emulators, such as GNS3 [10]. A packet analyzer, such as Wireshark [11], could be also be used.

A comparison between a physical laboratory and emulators can be found in [12]. A pedagogical evaluation and more tools can be found in [13] and [14], respectively.

Examination

For the Communication Technology courses at the University of Stavanger. The examination is composed of mandatory activities, a written exam, and an oral exam.

Mandatory activities: To be able to take the exam, the candidates must have completed at least 90% of the chapter tests from NetAcad and the lab assignments. The deadline for the chapter tests is at the end of each module. The lab assignments must be approved every week according to the stated deadlines. This way of organizing the mandatory assignments can be perceived as demanding at first, but after the initial weeks, the students are satisfied with the organization, including having lectures and laboratory on the same weekday.

Written Exam: The written exam has a weight of 45% on the final score and is an ordinary multiple-choice exam, and the questions are similar to the questions given in the chapter tests or CCNA final exam tests. These tests are appropriate for a bachelor's course, but it is often possible to find the solutions to the tasks by a simple web search.

Oral Exam: The oral exam has a weight of 55% on the final score and is conducted as a group exam and is supposed to be a supplement to the multiple-choice test. The oral exam has a duration of 20 minutes, 10 minutes for the practical part and 10 minutes for the theoretical part. In the practical part, the students need to solve two exercises, one on IP addressing and another on troubleshooting. In the theoretical part, the students answer questions related to the theory learned during the lectures, and it can be included the content of the syllabus that has been modified and added to the original CCNA syllabus. The oral exam includes a practical part to test the understanding and the ability to solve problems. Given the number of students attending the courses, it is impossible to organize a practical test at the lab.

In general, for the examination, we advise using an approach similar to the one used at the University of Stavanger. We recommend keeping the mandatory activities to push the student to study throughout the semester. The written and oral exams can be eventually changed depending on what the students are used to in the study program.

COURSE EVALUATION

The courses of Communication Technology I and II have been taught since 2014. Before 2014, there was one course called *Computer Networks and System Administration*. In this course, the total number of students that took the exam from 2010 to 2013 has been 33, 24, 37, and 29, respectively.

In Communication Technology I, the total number of students from 2014 to 2019 has been 59, 38, 57, 48, 60, and 72, respectively. Comparing with the previous course, the

number of students doubled. This is motivated by an increase in the number of students in the bachelor program, but it can also due to external students. The external students can come from the master's program, another bachelor program, or they can be a person that wants to just attend a particular course. This confirms the improved attractiveness of the course.

In Communication Technology II, the total number of students from 2014 to 2018 has been 23, 22, 23, 19, and 26, respectively. This means that every year around half of the students chooses Communication Technology II as an elective course.

Course Statistics

The grades of the students that took the exams of Computer Networks and System Administration and Communication Technology I and II have been registered from 2010. At the University of Stavanger, the grades are distributed across the percentage of correct answers as follows: F, the only failing grade, from 0% to 39%; E from 40% to 49%; D from 50% to 59%; C from 60% to 79%; B from 80% to 89%; A from 90% to 100%.

Figure 2 shows the distribution of the grade across the students for each year from 2010 to 2013 for the course on Computer Networks and System Administration. The figure shows that every year from 10% to 25% of the students was failing. The number of students with the top grade was normally lower than 5%, the number was almost 10% just in 2010. This highlights that the performance of the students was poor, since the target of the university is to have at least 10% of students with the top grade and maximum the 10% of failing students.

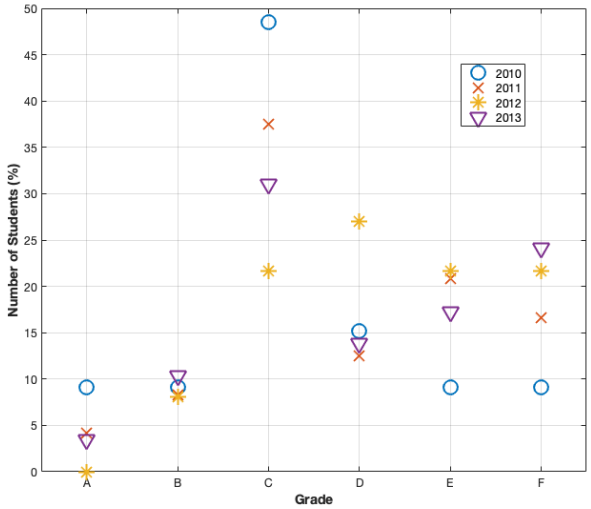

Figure 2: Statistics for Computer Networks and System Administration

Figure 3 shows the distribution of the grade across the students from 2014 to 2019 for the course on Communication Technology I. The figure shows that less than 10% of the students failed every year and that usually, the 10% of the students achieved the top score. This highlights how the students are performing better with the new course format.

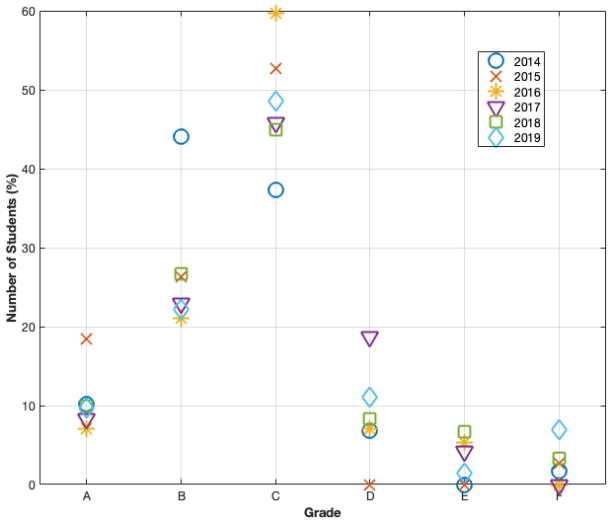

Figure 3: Statistics for Communication Technology I

Figure 4 shows the distribution of the grade across the students from 2014 to 2018 for the course on Communication Technology II. The figure depicts a trend similar to one for Communication Technology I, the main difference is the number of failing students, which has been zero for all the years except for 2016 when it was around 5%.

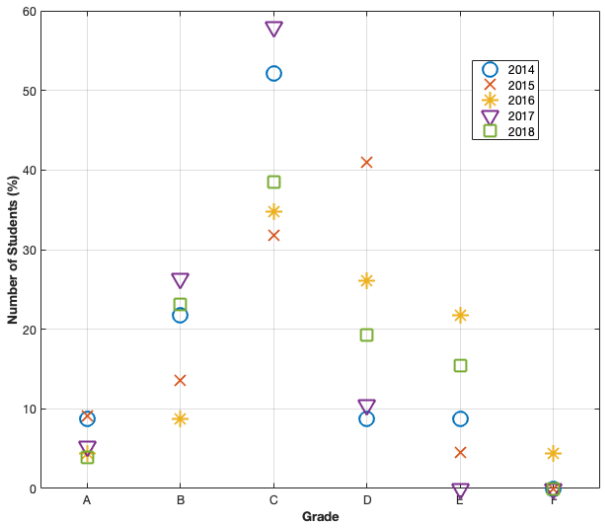

Figure 4: Statistics for Communication Technology II

Exact numbers are not available, but according to student feedback, around 5 students every year get the CCNA certification. This is around 20% of Communication Technology II students, which is a good number given that belongs to a master's program in Computer Science, and not in Telematics. According to the same feedbacks, most of the students get the certification after graduation, when they start working as a network administrator in a company that requires it.

Student Feedback

At the University of Stavanger, every three years every course is subject to a mid-term evaluation, where a feedback

about the courses is asked to the students and an external censor is part of the different parts of the examination.

In the spring of 2019, Communication Technology I went through the midterm evaluation. Students led by a nominated responsible student had more than half an hour for discussing the course based on the things that they would like to be kept, removed, and changed.

Keep: The students appreciated the slides and NetAcad resources. The slides have been based on the one provided to the certified instructors, but they have been modified and the lacking theoretical parts integrated.

Remove: The students suggested to remove the content already done in previous courses, for example, the conversion between decimal and binary numbers. Moreover, they considered the 4-hour lectures too heavy. They would appreciate a stricter connection between the lectures and the slides.

Change: Finally, the students highlighted some issues in the management of the laboratory, especially in the over-queueing during the delivery and correction of the tasks from the previous week. They also asked for more information about exams.

Given this feedback, the students appreciate the organization and the learning resources given by the certification. Anyway, the content needs to be modified to fit the target of the course and the context of the study program.

The timing is critical. The 4-hour lecture needs regular 15 breaks every hour to allow the students to relax and do not get tired fast. Keeping a strict synchronization between lecture and laboratory is difficult. Usually, the lectures are faster than the laboratory, this can overcome by having weeks without lectures.

Finally, the laboratory management can become tricky when the number of students increases (there were 72 students in spring 2019). Therefore, it is advised to have an efficient organization of the laboratory.

Discussion

The main benefit of a CCNA-based course is that it allows the students to acquire practical insights and skills in communication technology by using a well-known mature international framework.

This has two main advantages. From one side, the students can better understand the theoretical content by giving them an insight into the importance of what they are learning. From the other, the industry is willing to hire people with already practical knowledge and skills.

The benefit and advantages have been confirmed by the presented course evaluation. The number of students on the mandatory bachelor courses at the University of Stavanger has increased and many students are attending also the optional course. This shows that such a course is attractive to the students. Moreover, the distribution of the grades shows the increase in the performance of the students and, therefore, the students are better learning and practicing with this kind of course.

A course on communication technology can be implemented with different levels of practical study. Having a course implementation rather than another can be due to various factors, such as the economical contest, the kind of study program, and the number of students.

The CCNA-adapted course is mainly suitable for study programs not specifically on communication technology, such as a study program on computer science like at the University of Stavanger. These study programs have only one or two courses on communication technology. This course implementation requires a physical laboratory; therefore, funds need to be available. The required funds will increase with the number of students since more resources would be needed. The funds or resources can be provided by a local company, such as Atea for the University of Stavanger, or by a network device manufacturer, such as Juniper Networks for the University of Pisa.

The CCNA-inspired course is similar to a conventional course on computer networking. This kind of course implementation can be included in a study program on communication technology. In this context, the course would be a basic course mostly theoretical and the practical courses will follow. This kind of course can be also included in study programs that are not on communication technology if there are not enough funds for building a physical laboratory. For this course implementation, there are no limitations in the number of students.

The CCNA laboratory course is a practical course and is mainly suitable for study programs on communication technology. This kind of course implementation will be preceded by one or more courses focused on the theoretical part. As for the CCNA-adapted course, extensive resources can be needed, especially if the number of students is high.

In conclusion, CCNA-based courses are recommended over a conventional course for the reasons presented above, but a proper organization is highly connected to the specific context where the course will be inserted.

CONCLUSION

In this article, a guideline to create a course on communication technology based on CCNA is presented.

Based on the experience of two bachelor-level courses at the University of Stavanger, the outcomes have been generalized. Three course implementations have been identified and best-practice suggestions have been provided from a CCNA-adapted course by focusing on the lecture, the laboratory activity, and the examination. The course statistics and the student feedback show as the courses at the University of Stavanger have been successful. This article will hopefully help to develop similar successful CCNA-based communication technology courses in other universities.

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