The ITLab Primer

- An Introduction to the Internet Teaching Lab -

Developed by:

For information on the VINTLab contact:

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Acknowledgements

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We gratefully acknowledge the help and energy of Kevin Thompson from Worldcom and David Meyer from Cisco Systems, and Theresa Ott Boisseau from CAIDA, who have been instrumental in realizing the Internet Teaching Lab project.

Authors

This lab document is prepared by Jörg Liebeherr and Jianping Wang from the University of Virginia. Many students have contributed to the development of lab: Yonathan Amazene, Vinod Balakrishnan, Nicolas Christin, Justin Moore, Haiyong Wang and Joel Winstead.

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Some Q&A

Q: Who is the target student group for the ITLab?

A: The ITLab is intended for undergraduate students in their 3rd year or 4th year of studies. Students should have background knowledge in computer networks, for example, through an introductory course in computer networking.

Q: What type of lecture should accompany the ITLab?

A: The ITLabs can be part of a lecture course on details of the protocol architecture of the Internet. For example, the author of this lab manual teaches a course entitled "Internet Engineering". The syllabus of the course is attached in the appendix of this primer. The textbook for the course is "TCP/ IP Illustrated, Volume 1" by W. Richard Stevens published by Addison-Wesley.

Powerpoint slides for the lecture can be made available to lecturers of the ITL sites. Please send email to jorg@cs.virginia.edu.

Q: Where can I find additional information on ITLabs?

A: A website for the ITLabs with pointers to resources and information has been set up at URL www.cs.virginia.edu/~itlab.

Q: Is it possible to modify, extend, or customize the lab manual?

A: Sources of the lab manual can be made available to faculty of the ITL sites. Please send email to jorg@cs.virginia.edu. The lab manual is written using Microsoft Word 2000 and Microsoft Visio 2000.

Faculty of ITL sites may obtain the source material to the lab manual, if they agree to (a) not distribute, copy, or disseminate the source material, (b) distribute the modified lab manual exclusively to students at their own institution, (c) not distribute solutions to the prelab exercises to anyone, (d) include a statement in each modified document that states that "this document is a modified version of the ITLab manual developed at the University of Virginia".

Q: Has the lab manual been used in an actual class?

A: The Internet Engineering course and associated networking labs have been offered at the University of Virginia in Spring 1999, 2000, and 2001. In each semester the course had between 36 and 48 students. In 1999, there were three labs, initially with Sun Sparc and SGI Indy workstations, and with FreeBSD PCs towards the end of the semester. In 2000 and 2001, six labs were offered with a setup similar to the ITLab setup described in this document. A major change in 2001 was the use of Linux on the PCs (instead of FreeBSD), and a switch from *tcpdump* to *ethereal* as traffic capture tool.

Purpose of the ITLab Primer

The ITLab (Internet Teaching Lab) primer accompanies the ITLab manual prepared at the University of Virginia. The ITLab manual describes a set of six closed lab sessions. In the lab sessions, students conduct supervised experiments on equipment similar to that found in an Internet backbone network. Students gain hands-on experience with networking hardware and software, and learn how the protocols of the Internet work and interact.

The target audience for this primer consists of instructors of "ITL Sites" who are in the process of setting up networking teaching labs ("ITLabs"). ITL Sites are institutions that have received equipment grants of Cisco 7000 class routers. In addition to ITL sites, the ITLab primer may be of interest to any instructor who considers setting up a networking lab.

In this primer, we will discuss our approach to teach a hands-on networking course and we will share some experiences with setting up and running a teaching lab with Internet routing equipment. Finally, we will provide some information on the equipment requirements for running the exercises in the ITLab manual.

What the ITLab Primer does not provide ?

The type and number of problems that are encountered when setting up an ITLab can be significant. Anticipating and addressing all possible problems is beyond the scope of this document. Below, we list some topics that need to be addressed when setting up an ITLab, but are not covered in this ITL primer. Some of the topics are addressed at the ITL summer workshop.

- **Setting up and maintaining Cisco 7000 hardware:**

One of the biggest challenges when starting an ITLab is to get the Cisco 7000 routers to a state where they boot up properly. Generally, the Cisco 7000 routers arrive in an unknown condition and with unknown passwords. We refer to the Cisco website for information on troubleshooting Cisco equipment. Some sites may need to seek outside help to get a Cisco 7000 router into a state, where one can log in and access the Internet operating system (IOS).

- **Learning about IOS**:

IOS is the operating system software of Cisco routers. We strongly recommend ITL instructors to familiarize themselves with the basic commands of IOS. The Cisco website contains a lot of information on IOS. The following books may be helpful as references:

  - Cisco IOS Essentials, by John Albritton, 1999, McGraw-Hill Professional Publishing; ISBN: 0071347437.
  - Introduction to Cisco Router Configuration, by Laura A. Chappell (Editor), 1999, MacMillan Publishing Company; ASIN: 1578700760

In addition, Lab 4 may be a good source for reviewing basic IOS commands and command modes.

- **Installing Linux and installing software on a Linux system:**

The ITLab exercises are run on Linux PCs and require that certain (free) software packages be installed. Hence, a certain familiarity with the Linux operating system is necessary. If you are not very familiar with Linux, the following book may be helpful:

  - Running Linux (3rd Edition), by Matt Welsh et. al., 3rd edition (August 1999), O'Reilly & Associates; ISBN: 156592469X.

- **Network Programming:**

The ITLab has no programming component, such as BSD socket programming exercises or modifications of network mechanisms in the Linux kernel (e.g., modifications to traffic management algorithms).

A Few Thoughts on Networking Labs

Before getting involved in the effort of setting up and running a lab course for computer networking education, it may be helpful to reflect on the objectives of such a lab course. What follows are the author's thoughts on the objectives of a hands-on course in computer networking. Ideally, the discussion below will help instructors of ITLabs with formulating their own objectives.

Objective 1: Make education in computer networking more concrete.

Our main objective with setting up our networking lab, called the VINTLab, was to make teaching of computer networking more concrete. Traditional courses in networking do not provide hands-on access to Internet equipment and software. In fact, Internet engineering courses which provide exposure to actual network environments are mostly absent in an undergraduate curriculum. As a result, even after an introductory networking course, key concepts such as the dynamics of routing algorithms and other networking protocols are viewed by students at an abstract algorithmic level. In the networking lab, we try to remedy this situation and provide students with hands-on experience of networking concepts.

Objective 2: Don't teach a vendor-specific course on router configuration

Teaching a system or network administration course is a non-goal of our lab course. We are not interested in teaching students details of router configuration commands. For such purposes, several certification and training programs which cover details of router configuration and troubleshooting already exist.

Objective 3: Use science labs as model

We have used lab courses in the sciences as model for our networking labs. The labs are organized so that guided observations and measurements by students lead to insight and understanding of the subject. The object of study is network traffic. Instead of scales and voltage meters, students work with network traffic measurement tools, e.g., *tcpdump*. As an example, in one experiment, students saturate a T-1 link with TCP traffic, and, by measuring and comparing the throughput of individual TCP flows, they discover fairness properties of TCP.

Objective 4: Build on prior knowledge

The Internet Engineering course is intended as a second course in computer networking. After an introductory networking course, students understand the notions of flow control or routing algorithms in computer networks, but have never observed these algorithms running in a real network. In the lab course, students add to their knowledge of computer networking by experimenting with protocols in an actual network.

Objective 5: Cisco 7000 routers are tools and not the object of study

Our lab course does not try to make students experts in configuring or troubleshooting Cisco routers. The knowledge of router configuration provided in the labs is just sufficient to complete the lab exercises. However, students should take away from the lab an appreciation for the complexity of IP router configuration.

Objective 6: Exploit students' familiarity with PCs

The labs try to exploit the familiarity with PCs and, therefore, use PCs extensively. The (unsubstantiated) conjecture is that students understand a concept better if it is executed on a PC. As an example, before students work on routing algorithms on the Cisco 7000 routers, they perform routing experiments on PCs.

Objective 7: Students should feel in control of the equipment

The labs are written so that students can completely understand the networking configuration of each lab. We attempt to minimize layers of abstractions between students and the equipment they operate. For example, when students work on the Cisco 7000 routers for the first time, the routers are not configured, and students access the router with a serial cable to configure the IP address of an interface.

Objective 8: Closed lab sessions

The lab manual is written for "closed lab sessions", where students are always supervised by a lab instructor or teaching assistant. The concept of "closed labs" is borrowed from labs in the sciences. Due to the need for supervision we try to maximally utilize the time that students work on the equipment. So, before each lab session, students have to complete preliminary exercises (prelab exercises) and read background material. During a lab session, which lasts 2 hours, students are asked to collect data. The data is analyzed in reports to be completed after a lab session.

Objective 9: Have Fun!

While hands-on networking courses are time-consuming for instructors and teaching assistants, trying out unconventional network configurations can be quite fascinating. Working in the lab environment can teach everything you always wanted to know about networks but were afraid to ask.

"Standard" ITLab Equipment

Since the number and configuration of Cisco 7000 routing equipment varies across different ITL sites, we have developed a lab manual for a "standard" ITLab setup, which assumes availability of a certain set of equipment. The estimated cost for the "standard" ITLab equipment (in addition to the Cisco 7000 routers) is approximately $20,000.

If your lab equipment does not comply to the standard ITLab setup, you may need to customize the lab exercises or work with a reduced set of lab experiments.

The "Standard" ITLab Equipment:

- **3 Cisco 7000 Routers:**

We assume that each router has at least 2 interface cards, one of which is a FDDI interface. We recommend to place the Cisco 7000 routers in a sturdy 19-inch rack.

> Comment:
> *A challenge for developing this lab manual has been that only a small number of ITL sites have Cisco 7000 routers with Ethernet Interfaces.*

- **6 Linux PCs:**

Each PC should have two 100/10 Mbps Ethernet interface cards.

- **2 FDDI Ethernet cards for PCs:**

Two Linux PCs should have a FDDI Ethernet card so that at least some PCs can be directly connected to a Cisco 7000 router.

- **5 Ethernet Hubs:**

The hubs should be dual-speed, that is, support both 100 Mbps and 10 Mbps. Hubs are preferred over Ethernet switches since they allow you to read all traffic that is flowing on an Ethernet segment. Ethernet switches, on the other hand, generally only forward traffic on a port if the source or destination of traffic is connected to this port.

- **Cables and connectors:**

We assume that sufficient cables and connectors are available in each lab. The cost of cables can be considerable:

  - *Cat5 unshielded twisted pair with RJ-45 connectors*. These cables are used for wiring Ethernet equipment. Both straight-through and rollover (null modem) cables will be used.
  - *Unshielded twisted pair cables to connect serial ports*. Note that serial cables come with all different types of connectors, each with different gender types, in both straight-through or rollover version. We recommend to use RJ-45 cables and have enough adaptors available for all types of connectors needed.
  - *Multimode fiber cables with MIC connectors.* The MIC connectors are used for FDDI interfaces.

- *FSI and HSSI Nullmodem cables for Cisco routers.* These are high-end rollover serial cables to interconnect FSI (Fast Serial) and HSSI (High Speed Serial) interfaces of Cisco routers.

Recommended Equipment:

In addition to the above, the following additional equipment will make it easier to send traffic through the Cisco 7000 routers.

- **FDDI concentrators:**

An FDDI concentrator, essentially a hub for FDDI LANs, can be used for interconnecting routers or connecting routers and PCs.

- **FDDI/Ethernet bridge:**

This bridge translates between Ethernet and FDDI.

> **Note:** Since FDDI is an outmoded and expensive technology, we recommend against purchasing new FDDI concentrator or FDDI/Ethernet bridge.

- **Small Cisco routers (e.g., 2500 or 2600 class):**

A small router can help to connect PCs to Cisco 7000 routers. Suppose your Cisco 7000 routers have FSI interface cards, but no Ethernet interface card. A Cisco 2514, which has two Ethernet and two FSI interfaces, can be connected to the Cisco 7000s via its FSI interface and to the PCs via its Ethernet interface.
We recommend Cisco routers (only) because they use the same command language (namely: IOS) as the Cisco 7000 equipment.

- **T1 DSU/CSU:**

A DSU/CSU can be used to emulate a DS1 carrier ("T1 link") at 1.544 Mbps. If an ITL site has 2 routers with FSI interfaces, they can be each attached to a DSU/CSU. The DSU/CSUs are then connected by a serial cable with RJ-45 connectors.

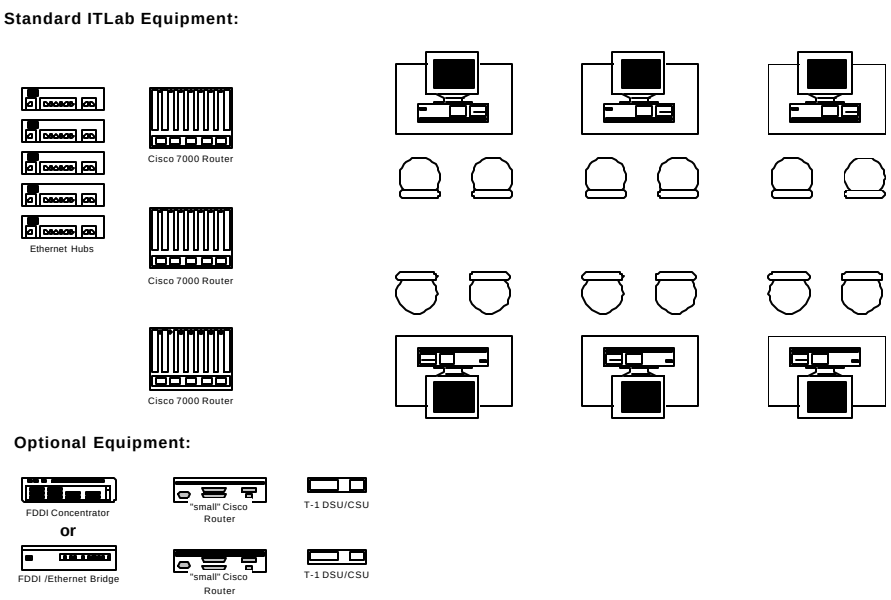


Figure 3. Equipment of a Standard ITLab.

"Standard" ITLab Software Installations

We assume that IOS Version 11.0 (or later) is installed on the Cisco routers. We assume that Linux Redhat 6.2 is installed on the Linux versions. Most of the lab experiments can run with different Linux distributions.

In addition, we require that system and/or user software be installed. The software is listed in Table 1. We refer to the ITLab website for information on downloading the software. All of the software is available without cost.

Since most exercises on the machines require system administrator access privileges, the Linux PCs only need a root account.

Name of the software package	Description
RedHat6.2	Linux kernel source code
X11.6	X window software
Tcpdump 3.4a6	Network monitor tool
Ethereal 0.8.14	Visual network monitor tool
C-Kermit 7.0	Utility which, among others, can provide terminal emulation over a serial cable
Ttcp 1.4.1	Utility used to test TCP and UDP throughput
Gated 3.6	Network routing daemon for dynamic routing protocols such as RIP and OSPF
Inetd	Unix superserver daemon
in.telnetd	Telnet server software
in.ftpd,	Ftp server software
in.rshd and in.rlogind	Remote access and login server software
Libpcap library 0.4	System-independent interface for user-level packet capture

Table 1. Download information for ITLab software installation.

The Lab Structure

The ITLab manual contains six labs. Each lab has three parts: (1) a prelab, (2) a supervised time-limited lab session, and (3) a lab report.
For each lab, we also provide instructor notes which contain information on the setup of the equipment, common problems, and solutions to the prelabs.

Phase 1: Pre-laboratory Assignments ("Prelabs")

These are exercises to be undertaken in preparation for a lab. The prelab is completed individually by a student before the beginning of the associated lab session. The prelabs ask students to acquire skills and knowledge necessary to complete the lab exercises.

Prelabs are graded. In the UVA Internet Engineering course, a prelab accounts for 20% of the grade for a lab. Prelab assignment may require that a student has a user account on a UNIX computer of the campus network.

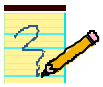
Phase 2: Lab Session

These are the activities to be undertaken during an appointed laboratory session. Lab sessions are limited to two hours. In the UVA Internet Engineering course, there is always a supervisor present during a lab session. **Activities in a lab session are not graded!**

Each lab session is subdivided into a set of exercises. Each exercise consists of configuration and/or measurement experiments.

A checkmark in the lab manual (as shown in the left margin), marks the end of an exercise or a group of exercises. At these checkpoints, the instructor "checks off" the completion of the exercise on a check-off sheet. The check-off list, which is part of the lab manual, provides information to the lab instructor on the progress of students. Note that the check-off list is not intended to evaluate a student's performance.

Students analyze their findings and measurement data in a lab report. A floppy disk symbol in the lab manual indicates that students need to save data to a file for their lab reports.



Students are asked to summarize the findings and measurement made in the lab session in their postlab report (Phase 3). A symbol in the lab report (see left margin) indicates an assignment for the postlab report.

At the end of a lab session, students fill out an anonymous feedback form, where they evaluate the difficulty and the interest level of individual lab exercises. The feedback sheets are a good indicator if the lab manual requires revisions.

Phase 3: Lab Reports

After each lab exercise, students are asked to finish a lab report, where they summarize and analyze the findings from the lab session. The lab reports are submitted at the beginning of the following lab session. In the UVA Internet Engineering course, the lab reports account for 80% of the grade for a lab.

Overview of Labs

This edition of the ITLab manual has 6 labs. Only three labs make use of the Cisco 7000 routers. In the following, we provide a brief overview.

- **Lab 1: Introduction to the ITLab**
  Overview of the equipment, basic Unix exercises, basics of traffic capture.
- **Lab 2: Single Segment IP Networks**
  Configuring a network interface for IP networking, interpreting the output of the netstat command, experiments with ARP, password snooping.
- **Lab 3: Multiple Segment IP Networks and Static Routing**
  Setting up a computer as a router, static routing, routing table updates via ICMP, subnetting.
- **Lab 4: Configuring a Commercial IP Router**
  Access to Cisco 700 routers via a serial port, basic router configuration, basics of Cisco IOS.
- **Lab 5: Dynamic Routing Protocols (RIP and OSPF)**
  Dynamics of routing protocols, convergence of routing protocols after topology changes under RIP and OSPF, split-horizon and triggered updates with RIP.
- **Lab 6: Transport Layer Protocols: UDP and TCP**
  IP fragmentation, throughput measurement of TCP, TCP slow start and congestion avoidance, TCP error control.

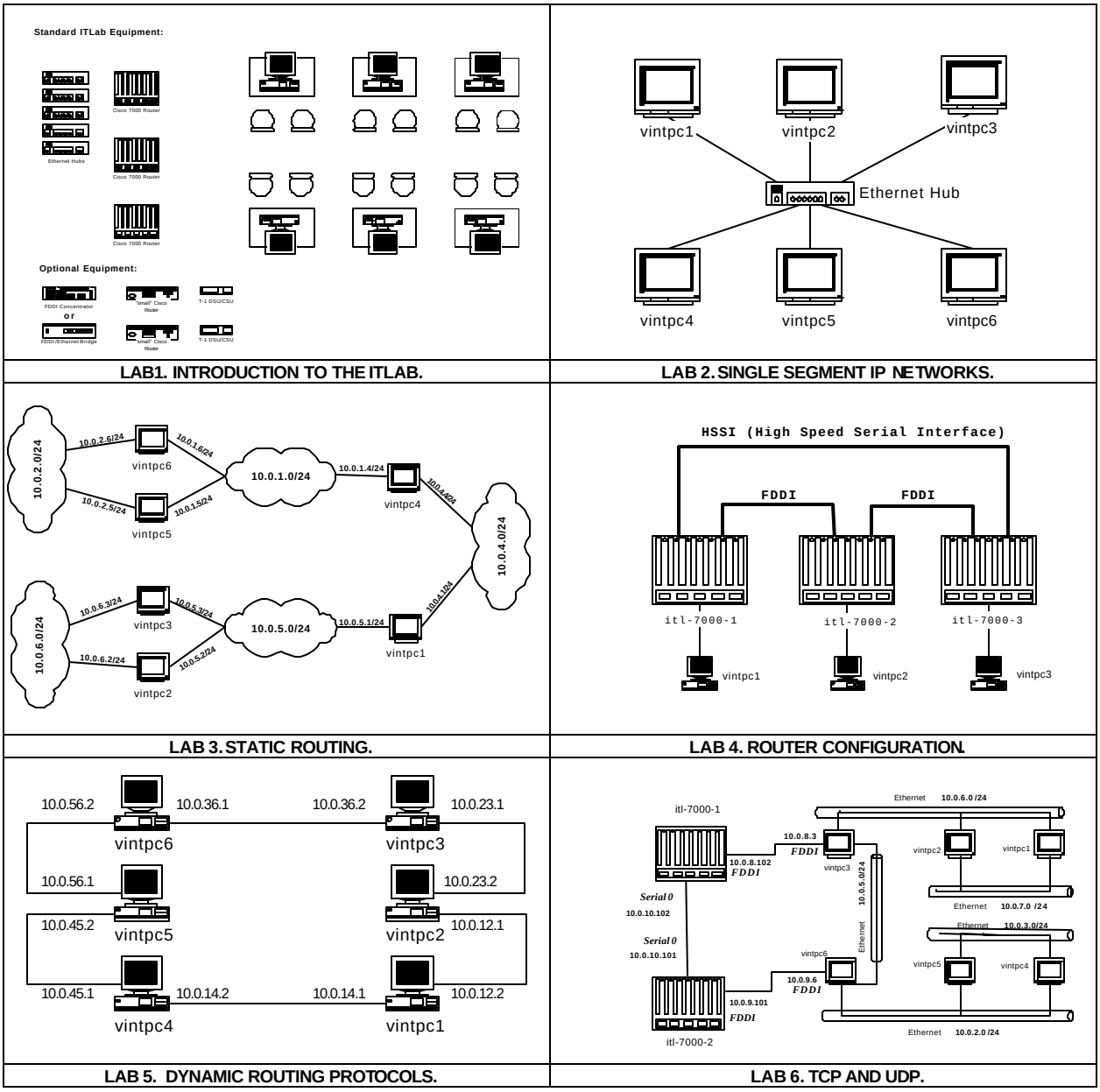


Figure 6. Overview of the ITLabs.

Additional Labs

We have developed four additional labs. These labs are currently only available for the VINTLab equipment and for FreeBSD PCs.

- **Lab 7: Network Topology Design**
  Design of a network topology.
- **Lab 8: IP Multicast**
  IGMP, IP Multicast routing, multicast applications.
- **Lab 9: NAT, DHCP, DNS**
  Domain Name System, dynamic IP assignment, IP address masquerading.
- **Lab 10: Network Management**
  Accessing a MIB, SNMP traps, network configuration with SNMP.

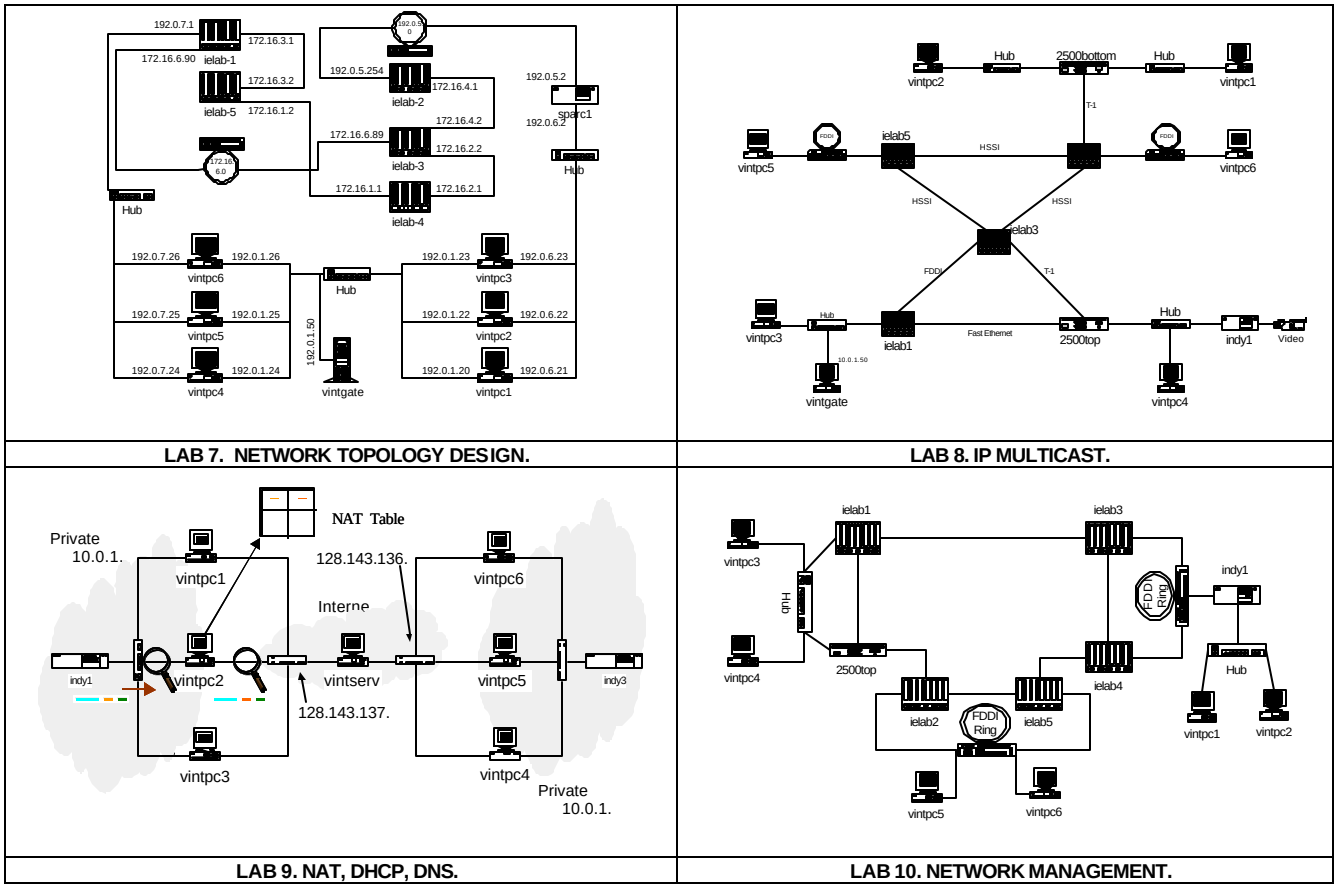


Figure 6. Additional Labs (currently not available for ITLabs).

The VINTLab

The Virginia Internet Teaching Laboratory (VINTLab) has been established in Spring 1999 at the University of Virginia, with the help of a donation of Cisco 7000 routing equipment from Cisco Systems and Worldcom. The VINTLab has been used as the lab component of an Internet Engineering course, an advanced undergraduate course on computer networking which covers details of the protocols of the Internet. The VINTLab manual is the basis of the ITLab manual. Previous versions of the labs described in the ITLab manual have been taught in the VINTLab since 1999.

The VINTLab is located in a raised-floor machine room. With exception of one PC ("vintgate"), the equipment in the VINTLab is not connected to the campus network. Students can access the VINTLab equipment only if they are in the VINTLab.

(a) Equipment Rack in the VINTLab.

(b) Students Workstations

Figure 5. Photographs from the VINTLab.

Figure 5 shows two photographs of the VINTLab. Figure 5(a) shows the equipment racks, which hold the Cisco 7000 routers and other equipment. The student workstations are located next to the equipment rack. Figure 5(b) shows the student workstations. During a lab session students work in groups of two at a workstation.

The VINTLab currently has 9 Cisco 7000 routers, 2 Lightstream 2020 ATM switches, 2 Cisco 2514 routers, 4 T1 DSU/CSUs, a 24-Port Ethernet switch, several Ethernet hubs, and a terminal server.

The VINTLab has one dual-homed FreeBSD PC ("vintgate"), which can used by students to transfer traffic measurement data from the VINTLab to the outside campus network. This solution has been shown to be more convenient than transferring data via floppy disks. Students upload their measurement data in the VINTLab to vintgate. A student can download the measurement data from vintgate from outside the VINTLab. Each student obtains a

restricted user account on vintgate, where they can run "ftp", but cannot directly login to vintgate. [1]

The efforts to establish the VINTLab and to develop an Internet Engineering course at the University of Virginia have been met with a number of responses.

- "….MCI Telecommunications, together with Cisco Systems, Inc., is committed to forming an Internet laboratory at the University of Virginia […]."
  "… the lab itself will immediately become one of the premier facilities for Internet technology across major universities in the United States."
  Vint Cerf, Senior Vice President MCIWorldcom, in: Letter to Dean of Engineering of University of Virginia, August 1998
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- "The Internet economy is transforming the way we work, live, play and learn. By establishing an Internet Engineering course, the University of Virginia is ensuring that today's students are prepared for tomorrow's jobs."
  John T. Chambers, Cisco Systems President and CEO, in: UVA News (Press Release), April 5, 1999.
- "Mr. Speaker, I rise today as co-chairman of the bipartisan Congressional Internet Caucus to recognize a major step taken last week to develop the growing Internet economy of the United States. In my home state of Virginia, just a few hours from the United States Capitol, the University of Virginia took the first step last week toward developing America's most technologically advanced Internet Engineering curriculum."
  Remarks by Hon. Bob Goodlatte, US Congress, April 14, 1999.

Figure 4. Opening of the VintLab. In the foreground from right to left: Vint Cerf (Worldcom), Jim Massa (Cisco Systems), Donald R. Upson (Virginia's Secretary of Technology).

[1] We refer to the appendix of Lab 1 for additional details on the setup of a "vintgate".

Appendix

Syllabus

CS 551 - Internet Engineering

Spring 2001

- **Instructor:** Jorg Liebeherr, 209 Olsson Hall, 982-2228, jorg@cs.virginia.edu
- **Course Hours**: TR 1230-1345
- **Laboratories:** There are 6-8 Lab exercises, times TBD.
- **Office Hours:** Thursday 2-4pm and by appointment via email.

Prerequisites: CS 457 (strictly enforced)

Textbooks and Reading Material:

- TCP/IP Illustrated, Vol. I, by W.R. Stevens (Addison Wesley)
- Reading material made available on the website
- (The CS457 textbook) A. Tanenbaum, Computer Networks, 3rd edition, Prentice-Hall 1996.

Evaluation:

- Midterm Exam (25%)
- Final Exam (25%)
- Lab Reports (40%)
- Class Participation and Quizzes (10%)

Summary: This course covers the technologies and protocols of the Internet. The lecture covers the design principles of the Internet protocols, including the Internet Protocol (IP), Address Resolution Protocol (ARP), Internet Control Message Protocol (ICMP), User Datagram Protocol (UDP) and Transmission Control Protocol (TCP), the Domain Name System (DNS), routing protocols (RIP, OSPF, BGP), network management protocols (SNMP), and application-level protocols (FTP, TELNET, SMTP). A set of laboratory experiments will provide hands-on experience with engineering a wide-area network.

Help and Pledge Policy: Examinations will be conducted under the Honor code. The Prelabs are to be individual work, though discussion of issues, principles and background material for the assignment may be discussed. The Postlabs assignments are done in groups of two.

Laboratory Description: The VINTLab has been set up and will be used throughout the semester. The VINTLab features extensive network equipment, including nine Cisco 7000 routers, two Cisco 2500 routers, two Lightstream 2020 ATM switches, two Cisco/Crescendo FDDI concentrators, four T1 DSU/CSU, and six PC Linux workstations.