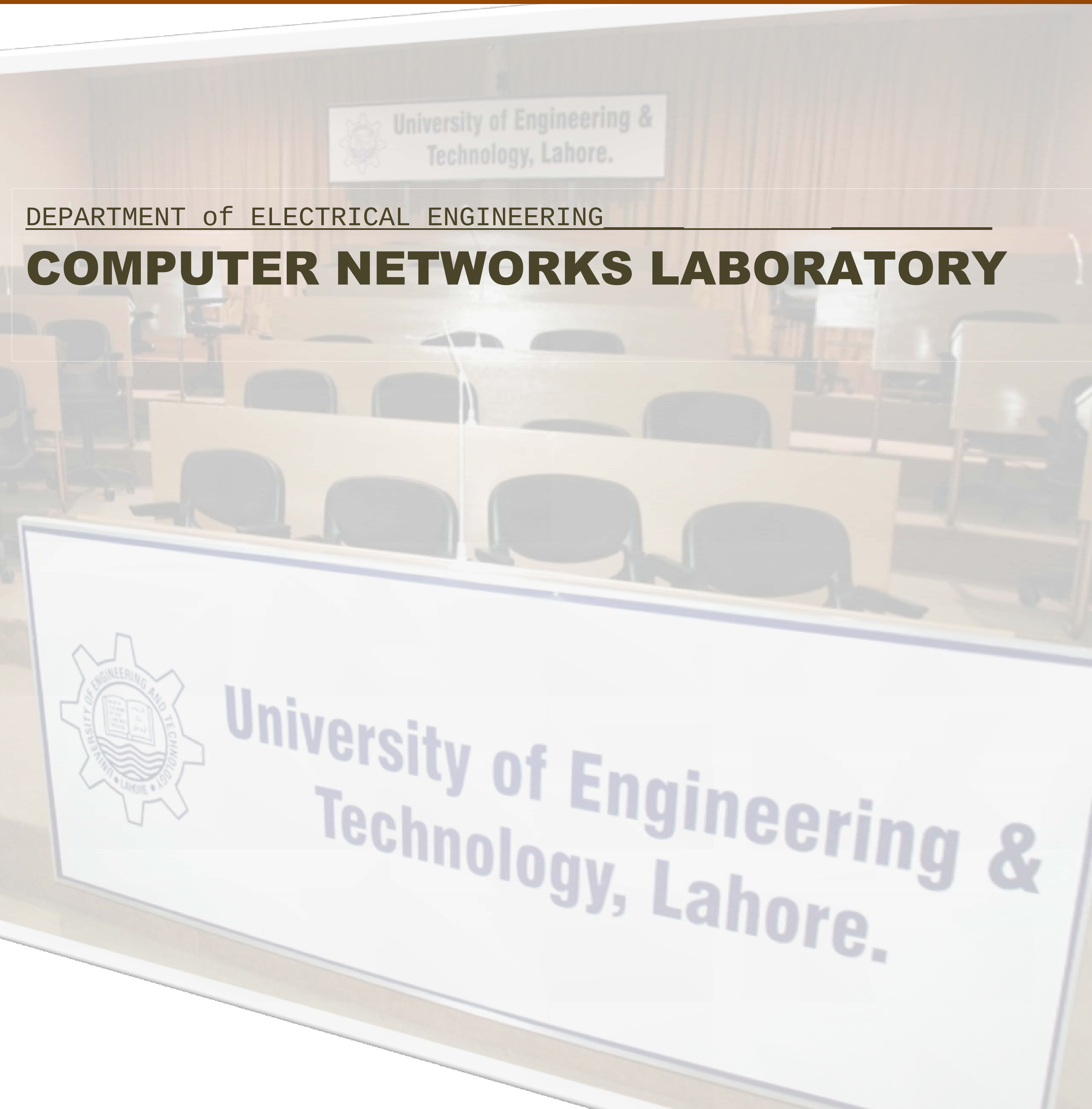
Thinking . Learning . Inovating

DEPARTMENT of ELECTRICAL ENGINEERING

COMPUTER NETWORKS LABORATORY



Abstract

Internet-based communication is assuming an increasingly important role in the developing world. It is thus crucial that students be exposed to contemporary networking equipment in a realistic setting, in order to connect theoretical material taught in lecture courses with the realities of physical hardware. To this end, a large computer networking laboratory has been set up to provide a realistic environment for teaching internetworking concepts. This laboratory provides university-level students with a test bed to experiment with fundamental issues of internetworking in a way that cannot be provided by simulators and to a degree of rigor not possible with the commonly available laboratory setups designed for technicians. Broacher describes the motivations for setting up the laboratory, its network structure and equipment, and the type of experiments students conduct along with a brief experiments list. The laboratory structure is influenced heavily by the limited funds at our disposal.

Introduction

This broacher describes experiences in setting up a large computer networking laboratory and its contribution at the Department of Electrical Engineering, University of Engineering and Technology, Lahore, Pakistan. As IP-based communication starts assuming a dominant role in worldwide communications, developing nations like Pakistan need to keep up with technological developments and prepare their engineers to use this technology in the near and far future. The graduates of our department occupy key positions in the telecommunications hierarchy of our country. We therefore need to keep our graduates fully aware of current and projected developments in communication technology. Setting up a computer networking laboratory is one of the key steps we have taken to support this objective.

THE STRUCTURE OF THE LABORATORY

The infrastructure of the laboratory was designed to simulate a nationwide network connecting three cities with different types of physical communications links. Three nodes, each housed in a full-height cabinet, represent three cities (named after the main cities of Pakistan) and are almost identical as far as equipment is concerned. By keeping the nodes identical we permit all students to perform the same experiments at the same time, simplifying administrative effort for the instructors. The interconnections between these virtual cities is slightly asymmetric, permitting interesting routing phenomena to be demonstrated. Figure 1 shows a photograph of the laboratory, Fig. 2 one of the cabinets.

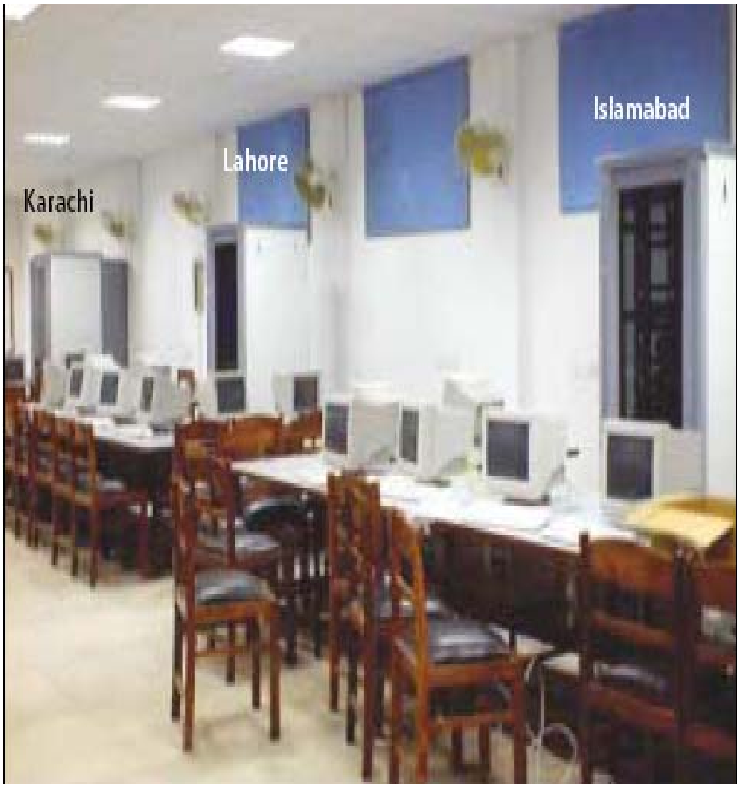


Fig 1: *Computer communication Lab*

Considerable effort was expended in making the network of the laboratory (Fig. 3) look as much as possible like the structure of a real nationwide network. The first step in this direction was to adopt a layered structure. Each simulated city has three layers, A, B, and C, that correspond to the core, distribution, and user layers generally used in industry.

TOP LAYER (A)

This layer mostly consists of high-speed links and powerful routers to accommodate the load of the lower layers. In real life the majority of top-tier data network operators (DNOPs) interconnect with each other in this layer. From an administrative point of view, the administrators of lower-layer DNOPs cannot enforce policy issues on this layer; they have to accept whatever is offered. This layer comprises Cisco 2620 routers. These routers are connected directly as well as via other media (e.g., microwave links).

This gives us a degree of asymmetry in connectivity that is interesting from a routing point of view.

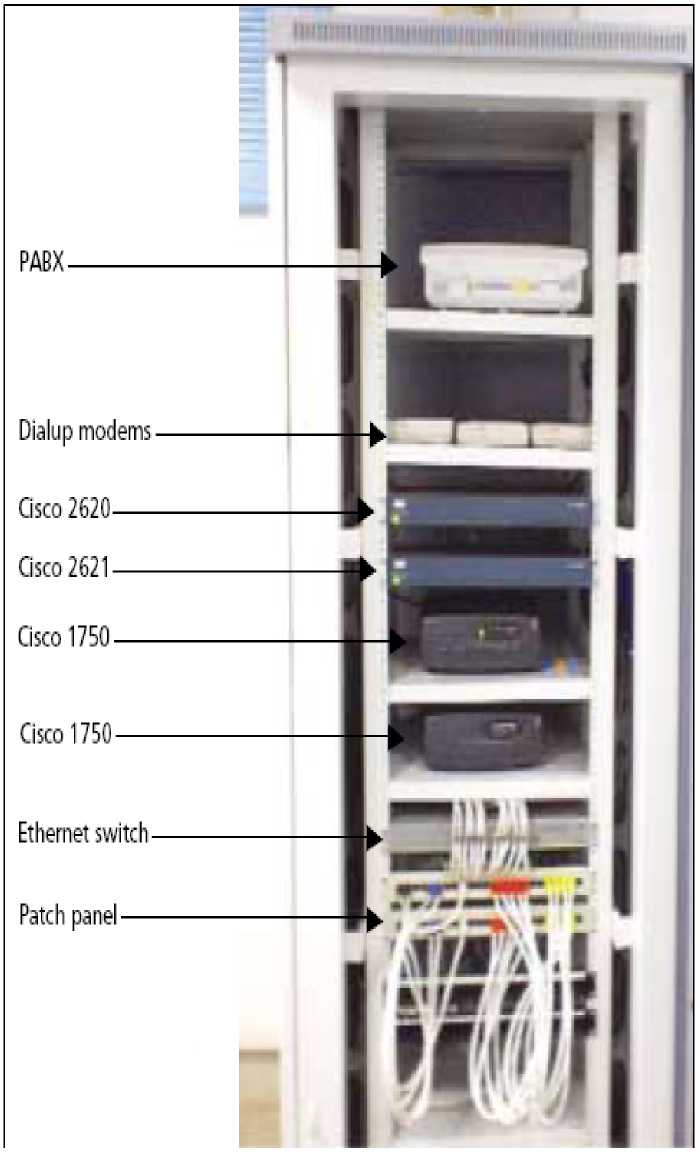


Fig 2: *One of the three equipment cabinets in the laboratory.*

MIDDLE LAYER (B)

Layer B acts as an intermediate layer and provides connectivity between the lower layer and the backbone. The routers on this layer can be considered regional nodes and can permit a regional DNOP to implement routing policies of its choosing.

This layer comprises Cisco 2621 routers that have both Foreign Exchange Station (FXS) and Foreign Exchange Office (FXO) modules installed in them. FXS modules connect to a telephone/fax or private automatic branch exchange (PABX) and generate suitable telephone signals. FXO modules are designed to be connected to the PSTN. In our laboratory we simulate the PSTN with small PABXes.

At the present time the 2621 routers communicate with each other through the upper-layer 2620 routers. We plan, in the future, to get fiber optic equipment and connect all the layer A 2620 routers through a fiber backbone. When this happens, we will interconnect the layer B 2621s through high-speed links to create a multi-layer backbone. Until then, we have the capability to connect the 2621s via Ethernet to simulate a backbone should the need arise.

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BOTTOM LAYER (C)

This layer comprises all leaf users. There are two Cisco 1750 routers available at this layer. The 1750 routers do not communicate with each other directly; they do so only through the 2621 routers of layer B. Students can be permitted unsupervised access to the routers of this layer, as any misconfiguration of these routers has very limited impact on the laboratory as a whole.

The three PABXes in each city can be interconnected to form a small but realistic PSTN. This permits students to compare the voice quality available on a packet-switched voice over IP (VoIP) network against a circuit-switched PSTN at varying levels of traffic. In many developing nations part of IP communications takes place over the PSTN, so this is a useful facility for our students. We use our own PABXs rather than our university's central telephone exchange for security reasons, as we wish to keep our laboratory completely isolated from the outside world. This isolation keeps any errant experiments from interfering with the real Internet. It also protects our laboratory from the unwelcome attention of outside hackers.

HARDWARE AND SOFTWARE

This section describes the hardware and software choices made during the setting up of the laboratory. For hardware the overriding consideration in a developing nation is the issue of technical support. Equipment like routers, radio modems, and switches is expensive but not costly enough to justify a technician flying in from overseas for emergency repairs (as was the case for the mainframe computers of the '60s and '70s). Thus, whatever is acquired must be backed up by maintenance support, preferably in-city.

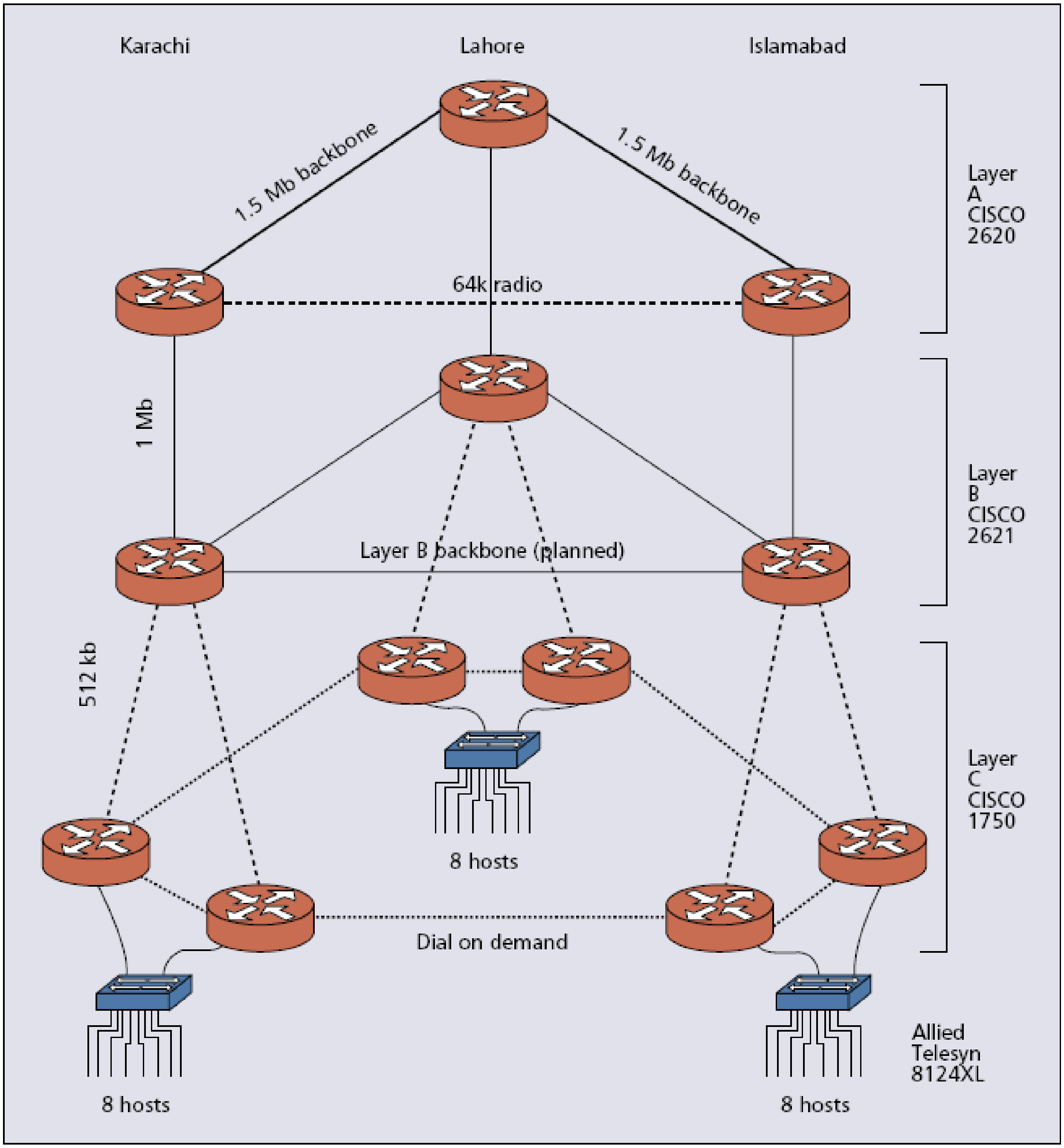


Figure 3: *The network structure of the laboratory.*

At the time laboratory was designed (2000), Cisco was the major player in the router market in Pakistan, with a large fraction of the market share and extensive technical support. At the present time many other companies have entered the field, and a new laboratory being designed today could, in addition to Cisco, choose from 3Com, Alcatel, Allied Telesyn, Huawei, and Motorola, among others. Another important consideration for choosing Cisco routers was that most potential employers were using Cisco equipment, so students trained on these would be in great demand. Similar considerations applied to the other equipment discussed below.

ROUTERS

The routers chosen for this laboratory are the Cisco 2620, 2621, and 1750. All of these routers are modular; that is, they have plug-in modules that can be replaced as the need arises (so, e.g., one may replace an Ethernet port with a Gigabit Ethernet port.) This is an important consideration for future expansion and modification of our laboratory.

SWITCH

An Allied-Telesyn model AT-8124XL Fast Ethernet switch is installed in each cabinet and can be used for virtual LAN (VLAN) experiments. In addition to introducing VLAN technology to our students, these switches reduce the cost of our network experiments, as each can simulate multiple switches that would be distributed over a real-world organization.

RADIO MODEM

Radio modems operating on the unlicensed frequency band (2300–2400 MHz) are very popular for data networking in the third world as well as rural areas of the industrialized world, where existing copper infrastructure is poor and unreliable for last mile connectivity. We have installed two Aircom Airlink S-band radio modems in two of our cities. Managing these modems is a useful exercise for students.

The wireless link provided by these modems reduces the hop count between Islamabad and Karachi by one (Fig. 3). We can set up our routing algorithm to use this link as the preferred path between these two cities. However, as the capacity of the radio link (64 kb/s) is far less than the capacity of the alternate 1.5 Mb/s path, the routing algorithm switches over to the alernate path when the radio modems saturate. This experiment vividly illustrates the behavior of routing algorithms under load conditions.

DIALUP MODEMS AND PABXS

We have added dialup modems to our lower layer to simulate automatic dialup connections between routers in case of loss of backbone connectivity. This is an important consideration in the developing world, and illustrates to students how the PSTN and IP networks coexist at the present time. The PABXs and dialup modems allow students to experiment with “dial backup” schemes. This equipment can also be used to simulate a model Internet service provider (ISP) setup.

PATCH PANELS

Patch panels (bottom of Fig. 2) save wear and tear on ports of expensive switches and routers because of repeated plugging and unplugging of connectors. It is standard practice to terminate the most frequently used ports on patch panels. We have terminated each and every port of every piece of equipment on these patch panels. This permits us to rewire the entire laboratory without disturbing any expensive equipment.

HOSTS

We have 44 Intel PIII (733 MHz) PCs in our laboratory to act as hosts. They have 256 Mbytes RAM and 20-Gbyte hard disks. These machines have the Intel 815e motherboard but are otherwise unbranded. The machines are assembled within Pakistan from mostly imported parts, although casings and such are locally made. Such machines perform well, and are cheaply maintained and repaired. Use of such unbranded machines results in large cost savings. Furthermore, such machines can be freely opened, modified, and reconfigured, something that is not possible in most branded systems.

LINUX OPERATING SYSTEM

Our laboratory is completely Linux-based. This is because of its stability, reliability, and low cost, and our extensive prior experience with this operating system. All networking functions are freely available for this operating system; in addition, a wide range of free software is available for it through the Gnu project. Students trained on Linux are comfortable with other variants of UNIX as well as Solaris. Finally, Linux is commonly used by ISPs and other potential employers of our students in Pakistan.

Experiments

Our students carry out a number of experiments during 14 laboratory sessions of 2 h each. The topics covered are described below. We have experience with most of the popular textbooks on computer networking, such as Comer, Peterson and Davie, Stallings, and Tanenbaum for our lecture course. We are currently using Kurose-Ross and find its top-down approach useful in motivating student interest. For example, we start our students off with Java network programming very early in the course (we use Java as our primary teaching language for this course, so this is easy for us). The material covered in laboratory sessions is easily transported to students' home machines, and many students enthusiastically run client-server applications between their homes or dormitory rooms. The Ethereal Network Analyzer (www.ethereal.com) is a major tool in later experiments. Versions of this powerful but free software can be loaded by students into their personal machines (or into shared machines set up for them elsewhere in the university), thus creating further opportunities for learning and reinforcement of laboratory material.

In the following, we describe the concepts covered by our experiments in a top-down fashion. The introductory material in each layer is covered in the first half of the course, while the remaining topics are covered in the second half once students have had a chance to develop some sophistication.

APPLICATION LAYER

- Introductory problems in Java network programming
- Basic concepts of client-server programming using TCP and UDP
- Introduction to Ethereal as an analysis tool
- Using Ethereal to analyze the behavior of HTTP, FTP, telnet, SMTP, POP, and DNS

Domain Name Service (DNS), in our opinion, deserves the greatest attention due to its centrality to the Internet. Discussion of *mail servers* is also important since most students use Web-based email (e.g., Yahoo or Hotmail) and are thus ignorant of the ramifications of SMTP and POP.

VoIP — The laboratory supports full VoIP equipment, permitting us to conduct many interesting experiments. It is important for us to prepare our students for a future in which most telephony will be over IP. Many corporations in Pakistan and other developing nations already use VoIP over their internal networks.

There are a number of possibilities to experiment with VoIP in our laboratory. Some of the routers have H.323-based voice interface cards (VICs). We also have Session Initiation Protocol (SIP) based hardware that can be installed in some of the host computers. Finally, we can also use H.323-based Gnomemeeting (www.gnomemeeting. org) on our Linux machines.

Some of our students have developed Linux-based VoIP solutions using hardware cards [2]. This approach can be contrasted with software-based approaches and the facilities available on the routers.

Security — Here we provide an introduction to security issues, such as how an unencrypted password can be captured using a sniffer, the importance of using ssh or equivalent for logging on, using access lists to block access, and low-cost firewalls implemented with Linux. It is regrettably all too easy to provide students with details of recent security breaches from the daily press.

TRANSPORT LAYER

- Capture a TCP/UDP segment and dissect its contents.
- Capture and study a TCP three-way handshake and termination.
- Observe framentation of TCP segments: one link in a specific path is set to have a low MTU. Students are required to show fragmentation taking place.
- Observe TCP flow control.
- Observe the impact of TCP congestion control by increasing traffic between two end systems.

NETWORK LAYER

- Check if a target computer is alive using ping.
- Interpret the output of ping.
- Use netstat on your host machine.

Traceroute — List the path taken by a packet from source to destination. Justify why a specific path is being followed. The laboratory administrator sets up a static path, and students are required to trace it and compare it with the dynamic path used earlier. Note the delays between various cities in the network. This material can be usefully augmented by homework assignments in which students are challenged to find the most distant host computer from their PCs (in terms of hops, time delays, or geographical distance). Also covered are dissecting RIP broadcasts and analyzing Open Shortest Path First (OSPF) messages.

Students log into a router and use IOS to investigate its characteristics (amount of memory, etc.), investigate the processes that are running, look at the status of all interfaces, and study the status (load, queuing strategy, I/O packet drops, I/O errors) of each router in a city in detail. This is repeated under different load conditions. They use extended access lists to control access to a router, and verify that their configurations work as expected.

Dial on Demand Routing (DDR) — This is a cost-effective solution when we want to provide backup support for a network, if traffic is limited, if email only access is required, and in situations where real IP connectivity is not yet set up. DDR is of great relevance to the developing world, where Internet connectivity is nonuniform. In Pakistan small businesses use DDR extensively.

Network Management Systems — Commercially available network management systems, such as Cisco Works, are beyond our financial resources. We have, however, developed a Javabased network management system based on Simple Network Management Protocol (SNMP) to introduce students to this area.

DATA LINK LAYER

- Analysis of Ethernet frames
- Analysis of ARP messages

PHYSICAL LAYER

This is perhaps the most interesting topic from the electrical engineer's point of view, and an area where our students can differentiate themselves from computer science and information technology graduates. Topics include the waveforms used in various parts of the system (Ethernet ports, etc.) and the effect of externally applied noise on the error rate in a data link.

EDUCATION and COURSES

Various courses are taught at both graduate and undergraduate levels. These courses provide students a sound knowledge and wide range of concepts in computer networking.

UNDERGRADUATE COURSES

Computer Networking
Design and Analysis of Algorithms

GRADUATE COURSES

Advanced Computer Networking
Cryptanalysis

Attached is the list of experiments part of the computer networking lab work at undergraduate level.

FUTURE PLANS

The laboratory has already encouraged many students to carry out interesting research projects on VoIP [2] and the Linux router [3]. Although we planned the laboratory to be a resource for undergraduate students, we have found it to be of interest and value to Master's students as well. A recent graduate level course was enthusiastically received, although it did require greater effort to develop experiments at a more sophisticated level.

Finances and human resources permitting, our future plans call for the augmentation of this laboratory with:

Fiber optic links. These will permit demonstration of and experimentation with high-speed links. Students will be able to experiment with extremely high-bandwidth data transfers and observe the performance of the routers under these stressful conditions. Our plan is to acquire multikilometer spools of fiber so that latencies can be realistically experienced.

A live VSAT connection from one cabinet to another. This will permit us to experiment with the contrasting bandwidths and latencies of VSAT connections and fiber optic or copper links.

Wireless networking. This technology is slowly gathering momentum in the developing world; it behooves us to keep our students abreast of its developments.

List of Experiments

Lab(s)	Experiments	Work
1	**Experiment # 1** To familiarize with the Lab Network Topology. Locating different interfaces, routers and switches. Studying different pools of IP addresses.	**Lab Manual**
1	**Experiment # 2** To learn and observe the usage of different networking commands e.g. PING, TRACEROUTE. Learning remote login using telnet session. Measuring typical average delays between different locations of the network.	**Lab Manual**
1	**Experiment # 3** To explore the working of netstat command. Observing network messages like ICMP and TCP. Debugging the network to find down links.	**Lab Manual**
1	**Experiment # 4** To familiarize with the network packet sniffer, ethereal. Analyzing HTTP request and response messages. Locating methods like GET, HEAD, POST etc. Establishing FTP connection with the server and downloading different data files.	**Lab Manual**
1	**Experiment # 5** Case study of client/server scenario. Observing the difference between UDP and TCP servers.	**Lab Manual**
1	**Experiment # 6** To explore the non-privileged mode of the installed routers. Observing the status and working of different interfaces of routers.	**Lab Manual**
1	**Experiment # 7** To compare the working of 1750, 2620 and 2621 series of routers on the basis of bandwidth, reliability, txload, rxload, queuing strategy, queue drops, input errors and output errors.	**Lab Manual**

1	**Experiment # 8** To observe the working of TCP three-way-hand-shaking procedure. Locating different packets like, SYN, SYN-ACK and ACK. Comparing different fields of these packets	**Lab Manual**
1	**Experiment # 9** To learn different congestion avoidance techniques. Exploring the working of two TCP congestion avoidance methods.	**Lab Manual**
2	**Experiment # 10** To observe the working of IP protocol. Exploring the routing tables for different routers.	**Lab Manual**
1	**Experiment # 11** To explore Inter-Autonomous System Routing. To explore the routers, autonomous systems and BGP peers in the lab. Observing IBGP and EBGP on different routers.	**Lab Manual**
1	**Experiment # 12** To explore Broadcast and Multicast routing. To explore the usage of IGMP in Multicasting.	**Lab Manual**
1	**Experiment # 13** To observe the working of Address Resolution Protocol (ARP). To explore different fields of ARP packets.	**Lab Manual**
2	**Experiment # 14** To configure the routers for performing IP routing.	**Lab Manual**

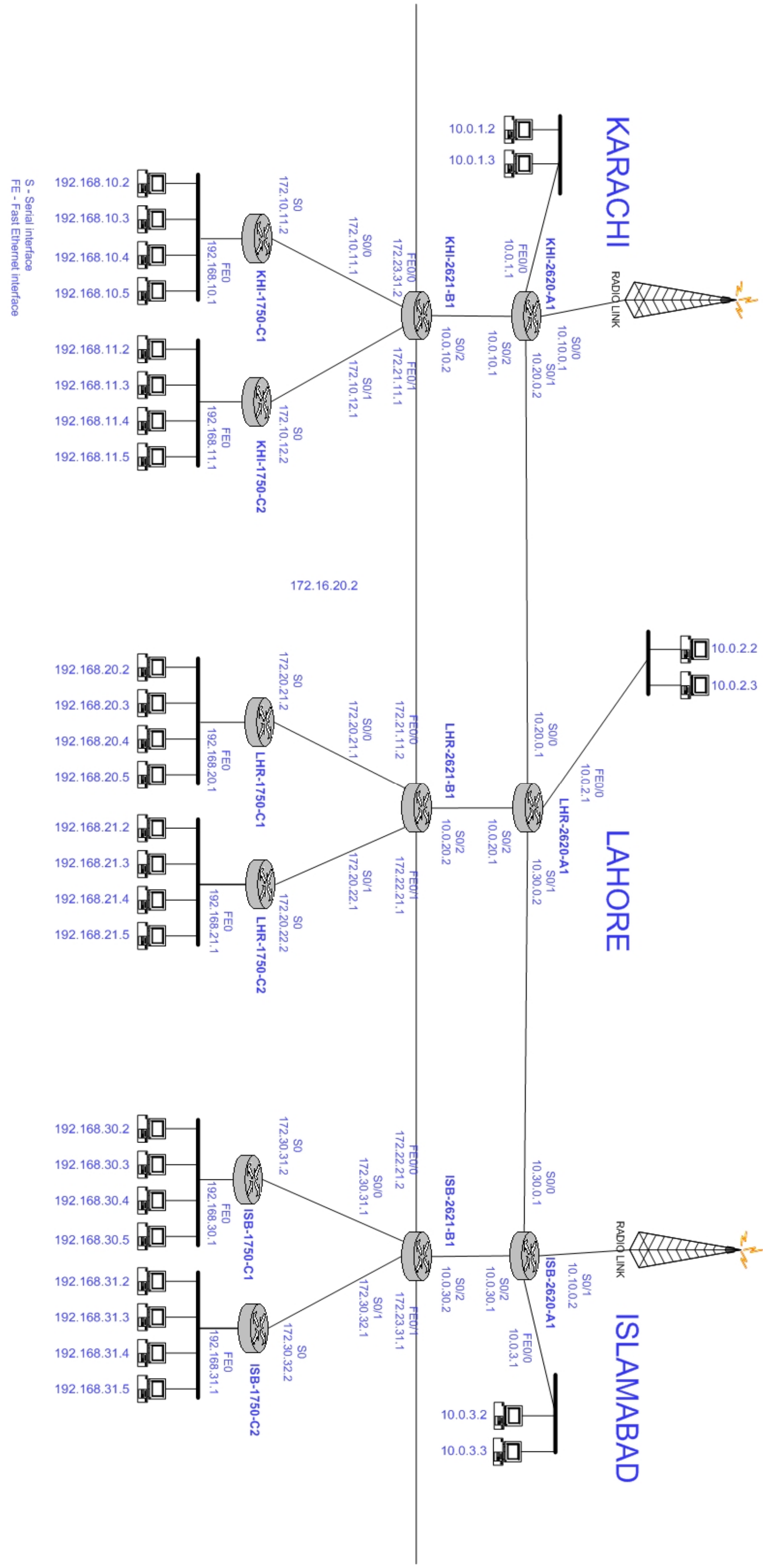
PAPERS PUBLISHED

Various papers have been published, selected ones are given.

[1] *"A Networking Laboratory for the Developing World," IEEE Communications, vol. 42, no. 2, pp. 106-113, February 2004. With M. Ahmed, S. Sohail, R. H. Khan. J. A. Mirza and M. Ali*. S. H.

[2] N. Z. Butt, M. J. Awan, and A. Nadeem, "Experiments With New Methods in Voice over IP," *Linux J.,* Nov. 16, 2002; http://www.linuxjournal.com/article.php?sid= 5941

[3] K. Anwar *et al.*, "The Linux Router," *Linux J.*, , Aug. 2002, http://www.linuxjournal.com/article.php?sid=5826, pp. 121–24.



Network picture, part of various experiments

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