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# Application Adaptive Bandwidth Management Using Real-Time Network Monitoring.

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# Application Adaptive Bandwidth Management Using Real–Time Network Monitoring

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# ABSTRACT

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Application adaptive bandwidth management is a strategy for ensuring secure and reliable network operation in the presence of undesirable applications competing for a network's crucial bandwidth, covert channels of communication via non-standard traffic on well-known ports, and coordinated Denial of Service attacks. The study undertaken here explored the classification, analysis and management of the network traffic on the basis of ports and protocols used, type of applications, traffic direction and flow rates on the East Tennessee State University's campus-wide network. Bandwidth measurements over a nine-month period indicated bandwidth abuse of less than 0.0001% of total network bandwidth. The conclusion suggests the use of the defense-in-depth approach in conjunction with the KHYATI (Knowledge, Host hardening, Yauld monitoring, Analysis, Tools and Implementation) paradigm to ensure effective information assurance.

# DEDICATION

To my parents Shri Suresh K Grover and Smt Asha Grover

and my brother Sumit Grover to whom I am

indebted for their constant encouragement and unwavering

support that helped me sail through trying times.

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CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

***"It's unimportant whether we take out a computer center [controlling key weapon systems, electrical girds and telecommunications] with a bomb…. or a denial of service program."***

Department of Defense spokesman discussing
the cyber-attack strategy in the run up to
Operation Iraqi Freedom[1].

***"…if we fail on [cyber] defense, the nation would be at risk…."***

Maj. Gen. J David Bryan, Commander of the
Joint Task Force-Computer Network Operations
and vice director of the Defense Information
Systems Agency[2].

## 1.0 Information Assurance

Operation Iraqi Freedom has etched in stone the role of information warfare, as this was the first major armed conflict that depended heavily on IT. Even in a war and sanctions-ravaged economy like Iraq with hardly any IT infrastructure, email messages to high ranking Iraqi military officials[3] were used to soften the Iraqis' attitude towards US military action by encouraging them to surrender and to help in toppling Saddam Hussein's regime.

Information Warfare is broadly classified into two branches, viz., Information Denial and Information Assurance. *Information assurance*, the study of how to ensure the availability and security of critical network operations at all times, is emerging as a key concern in military and corporate organizations alike. Maj. Gen Bryan, the coordinator of the Therminator project[2] (a network security tool being jointly developed by the DOD, National Security Agency and

Lancope Inc.) emphasizes the need for Therminator–like tools to deal more quickly and effectively with exploitation of vulnerabilities like the recent SQL Slammer worm.

This thesis is concerned with an aspect of information assurance: the use of *application adaptive bandwidth management* to counter the threats posed by undesirable and non-standard traffic on well-known ports. A network's *bandwidth* is the maximum amount of data that that network can carry, measured in bits per second (bps). *Bandwidth management* is the practice of allocating a network's bandwidth, based on considerations like perceived priority and fair use. *Application adaptive bandwidth management* is a form of bandwidth management that uses an application's perceived importance to allocate bandwidth, based on overall network traffic. Strategies for application adaptive bandwidth management attempt to ensure that the most mission critical applications get bandwidth—and that malicious codes do not.

This thesis describes the study of application adaptive bandwidth management and unauthorized use of standard network channels for communication. Covert channels of communication that use well known ports for non-standard traffic are a major threat to the security of any network. According to the Dshield[4] website, the top ten ports probed over a period of one month (from 15 May to 15 June 2003) as shown in table 1.1 indicates the main targets to be port 137 (netbios-ns) and port 80 (HTTP). Although port 80—one of the most widely used ports—has been assigned for World Wide Web HTTP services, the following[5] Trojans also use the same port: 711trojan, AckCmd, BackEnd, BO2000Plug-Ins, Cafeini, CGIBackdoor, Executor, GodMessage4Creator, GodMessage, Hooker, IISworm, MTX, NCX, Noob, Ramen, ReverseWWWTunnel, RingZero, RTB666, Seeker, WANRemote, WebDownloader and WebServerCT.

Table 1.1: Top Ten Probed Ports

| Service Name | Port Number | Explanation |
|---|---|---|
| netbios-ns | 137 | NETBIOS Name Service |
| www | 80 | World Wide Web HTTP |
| ms-sql-m | 1434 | Microsoft-SQL-Monitor |
| microsoft-ds | 445 | Win2k+ Server Message Block |
| netbios-ssn | 139 | NETBIOS Session Service |
| eDonkey2000 | 4662 | eDonkey2000 Server Default Port |
| smtp | 25 | Simple Mail Transfer |
| --- | 41170 | |
| ident | 113 | |
| --- | 0 | |

An open port is a potential security hole that can be used by hackers to access computers. Covert channels of communication render the target network susceptible to remote administration. The potential for damage depends solely on the maliciousness of the attacker's intent. The damage can range from a complete loss of critical data to involuntary use of the network for illegal transmission of copyrighted digital content. A compromised network may also be used to carry out a coordinated denial of service attack. Unauthorized activity on the network, even if it involves 'un-harmful probing', competes for available network bandwidth, an important institutional resource. With the ever-increasing number of users and applications, it becomes difficult to ensure adequate bandwidth and quality of service for mission critical applications. According to a Carnegie Mellon University review[6], "*…traditional Ethernet-and-IP network elements (routers and switches) perform well in lightly-loaded situations, but problems arise as traffic increases. For example, shared-access Ethernet rapidly degrades in throughput after about 30% utilization. In this situation, the number of collisions and retransmissions grows quickly, reducing the network efficiency…*" An increase in the link utilization might force the routers to drop the packets after a certain limit. Since resources are limited, the cost factor rules out an indefinite upgrading of the network bandwidth capacity as a viable solution.

The goal of this thesis was to identify and minimize the use of excessive bandwidth by undesirable applications and minimize port abuse and flow of malicious data on the ETSU campus network. In a typical university setting, students may use bandwidth for file swapping utilities aimed at downloading large multimedia files (pirated movies and MP3s) and warez. Other activities such as IRC applications and MUD games might be used as a gateway by Trojans that can compromise network security by allowing remote administration. These activities steal bandwidth from critical primary applications (administrational/educational), jeopardize the overall network security, and may even put the host institution into legal jeopardy. In October 2002, for example[7], four college students in San Jose, California were sued by the recording industry for exploiting the academic resources of their campus networks for file-swapping services. The Recording Industry Association of America accuses them of illegally swapping about a million songs without the permission of the copyright holders and seeks a maximum penalty of $150,000 per song from each student. According to the news report, *"The recording industry telegraphed its campus crackdown last October putting 2,300 university administrators on notice to curb student behavior—or face legal consequences"*. At ETSU itself there have been "several instances of abuses" of network resources as pointed out by President Paul E Stanton's memorandum[8] regarding "Utilization of Computer Resources at East Tennessee State University". The memorandum specifically prohibits all employees from indulging in "deliberate and wasteful use of [computer] resources" for unauthorized processing of data / files "that are not associated with their assigned duties".

## 1.1 Synopsis of the Approach Taken

In the initial stages of the study itself, the lack of a single-piece solution became apparent. To achieve the objectives, I used a combination of various tools such as firewalls, packet-shapers, protocol analyzers, port scanners, network traffic monitoring tools, anti-virus programs and service management tools. These tools are covered in detail in sections 2 and 3. The classic approach for securing a network against malicious code involves port based filtering and the quest for a solution led me to a firewall—the 'seemingly-obvious' choice for blocking undesirable data as well as restricting covert channels of communication.

## 1.2 Firewalling

This strategy involves identifying non-standard ports generally used by Trojans and other malicious code as 'rogue ports' and then blocking these ports using firewalls. While firewalls can be used effectively to block known rogue ports, they are ineffective against undesirable applications such as file swapping utilities or Trojans that can use http traffic to infect the machine and then switch to un-allocated ports that are not being blocked by firewalls. Secondly, firewalls by themselves cannot provide bandwidth management by ensuring availability of bandwidth for critical applications. This necessitates the use of a packet-shaper in conjunction with the firewall.

## 1.3 Packet-Shaping

Packet shapers manage network bandwidth usage to a finer degree than what is possible with only switches or routers. They help to prioritize network usage by identifying 'critical' as well as 'less desirable' components of the traffic stream and earmarking more bandwidth for critical applications while restricting the amount of bandwidth available for less desirable applications. Packet shapers classify network traffic by evaluating traffic flow on the basis of application-specific ports, protocol family (including transport protocols like TCP and UDP), IP address, port, the IP precedence value and URL. A CNN news report dated 10 October 2002 and titled '*Student's file sharing overloads college networks*'[9] indicates that about 740 educational institutes in America were using Packeteer's PacketShaper tool to manage bandwidth.

### 1.4 Hybrid Strategy

While a firewall would block data on Trojan ports and a packet shaper would allow bandwidth allocation for mission critical applications, their use does not solve the problem of non-standard traffic on standard desirable ports. This led me to explore the use of port scanners for identifying open ports and protocol analyzers for content based monitoring of the network traffic stream. Anti-virus tools were used for identifying known malicious code based on signature matching in the network traffic. While these tools allowed detection of malicious code in the traffic, to be able to trace the actual transmission route from the source to the destination, I relied on network traffic monitoring and service management tools. Thus the non-availability of a "silver-bullet"[10] solution led to the use of a hybrid strategy that didn't depend solely on any one single tool.

### 1.5 Key results

Yauld network monitoring, together with aggressive vulnerability management, helped to minimize bandwidth abuse on the ETSU network. Actual bandwidth measurements spread over a nine-month period from August 2002 to April 2003 indicated the percentage bandwidth abuse to be a mere 0.000073393%. These measurements were based on the actual network traffic inside the firewall and do not account for the substantial amount of undesirable traffic that is blocked by the firewall itself. The bandwidth measurements highlighted HTTP traffic as the most predominant protocol in the traffic stream—constituting as high as 76% of the total traffic. Of the incoming malicious code that passed through the firewall, the Klez virus code was the most predominant with 25,591 distinct occurrences in the period under consideration. Detailed bandwidth measurements for incoming as well as outgoing traffic—organized as mission critical, desirable, non-critical, and rogue—are tabulated in the section 4. The lessons learnt made me conclude that effective information assurance in an environment like ETSU's requires the use of the defense-in-depth security in conjunction with KHYATI (Knowledge, Host hardening, Yauld monitoring, Analysis, Tools and Implementation) network management. The defense-in-depth strategy relies on multiple layers of defense thereby eliminating one single point-of-failure for the entire system. Complementing this approach with the KHYATI paradigm would result in achieving information assurance goals in an effective and efficient manner.

### 1.6 Structure for the balance of the thesis

The balance of this thesis is divided into four sections. Section 2 discusses the concept of ports, how they can be abused to compromise security as well as techniques for detecting and blocking the invalid use of ports. Section 3 concentrates on specifics such as the tools and the methodology used to achieve the goals. Section 4 covers the results of the thesis in detail. Section 5 concludes with a discussion of defense-in-depth, the 'KHYATI' paradigm, and lessons learned.

# CHAPTER 2

# PORT ABUSE AND COUNTERMEASURES

## 2.1 Characteristics of the Transport Layer

The ISO's Open Systems Interconnection (OSI) Reference Model divides communications architectures into seven distinct layers. OSI Layer 4, the 'Transport' layer, is tasked with providing efficient and reliable end-to-end communication. According to Andrew S Tanenbaum[11],

> *"… (The Transport layer) is the heart of the whole protocol hierarchy. Its task is to provide reliable, cost-effective data transport from the source machine to the destination machine, independent of the physical network or networks currently in use. Without the transport layer, the whole concept of layered protocols would make little sense."*

Currently, the dominant communications architecture for wide-area communication is TCP/IP (Transmission Control Protocol / Internet Protocol). In TCP/IP's reference model, the Transport layer uses the third, Internet layer to provide a channel of communication between the source and destination endpoints. An endpoint consists of an IP address, a protocol identifier and a port number[12].

### 2.1.1 Mechanisms for Layer 4 Traffic Flow

Currently, the two dominant transport layer protocols are TCP/IP's Transmission Control Protocol (TCP) and User Datagram Protocol (UDP). TCP is a reliable, connection-oriented protocol. UDP is a connectionless protocol that does not incorporate transmission error checking.

TCP[13] connections are implemented as point-to-point full-duplex byte streams. The data exchange unit, known as a segment, consists of a 20-byte header pre-pended to a variable-length segment.

TCP ensures reliable data transmission using Automatic Repeat Requests (ARQs). An ARQ is an automatic re-transmission of data following a failure to receive a positive acknowledgement (ACK) from the receiving host.

TCP flow control is managed with a 'Sliding Window'[14] protocol. A typical TCP implementation supports variable window sizes and the selective-repeat form of sender-initiated ARQ. To ensure effective congestion-control, an effort is made to estimate the round-trip transmission delay as accurately as possible.

UDP[15] allows transmission of encapsulated raw IP datagrams without the overhead of establishing and releasing explicit connections. Since UDP lacks the reliability of TCP, UDP is ideal for situations where the rate of delivery is more important than reliable transmission without any packet loss. The size of the UDP segment header is 8 bytes.

#### 2.1.1.1 Notion of Ports

Computers connected to the Internet communicate with each other via endpoints known as *sockets.* A socket address is an identifying number derived from the combination of an IP address and a virtual port number. Clearly defined source and destination IP addresses as well as source and destination port addresses are the prerequisites for establishing communicating across a network. TCP and UDP support 65536 virtual or software ports, each of which is identified by a 16-bit number in the range of 0 through 65535. The 48-bit combination of a host's IPv4 address and port number is referred to as a Transport Service Access Points or TSAP. The transport layer protocols—TCP (Transmission Control Protocol) as well as UDP (User Datagram Protocol)—use these ports to form a virtual channel for information exchange. Any active port running a network based service is known as an 'open' port. A malicious user can use open ports to identify a target system's attributes, and then use this information as a starting point for compromising that host's security.

#### 2.1.1.2 Standard Uses of Ports

The Internet Assigned Numbers Authority (IANA)[16] associates various applications and services with specific port numbers and classifies the entire range of available ports into three categories—Well Known Ports, Registered Ports, and Dynamic and/or Private Ports.

*Well-known ports*, ports numbered from 0 through 1023, serve as contact addresses for various pre-defined services. Usually root privileges are required by the applications that service well-known ports. Commonly used ports are 21 (FTP), 22(SSH), 23 (TELNET), 25 (SMTP), 43 (Who Is), 53(DNS), 80(HTTP), and 137-139 (NETBIOS). A detailed list specifying all well-known ports and their associated services is available at http://www.iana.org/assignments/port-numbers.

*Registered ports*, ports numbered from 1024 through 49151, serve as the recommended ports for various services but are not bound to any particular service. Depending on the availability, a host might open a random port in this range to communicate over a network. Unlike the well-known ports, registered ports do not require system/root privileges for access. A detailed list specifying the Registered Ports and the services associated with them is available at the IANA website at http://www.iana.org/assignments/port-numbers.

*Dynamic ports*, ports numbered from 49152 through 65535, are typically used by applications that are not registered with the IANA. This range is of extreme significance for a system administrator as open ports in this range often indicate the presence of Trojan applications on a network host.

#### 2.1.1.2.1 "Trojan" Ports

Ports typically used by Trojan programs are known as 'Trojan Ports'. Fixed port numbers like TCP port 12345 (NetBus) and UDP port 31337 (Back Orifice) were typically used by earlier Trojans. Newer Trojans such as SubSeven use a wide range of port numbers. Common Trojan horse port assignments include 1243 (Sub-7, SubSeven), 6670 (DeepThroat), 6711 (Sub-7, SubSeven), 6969 (GateCrasher), 12345 (NetBus), 23456(EvilFtp), 27374(Sub-7, SubSeven), 30100(NetSphere), 31789 (Hack'a'Tack), and 31337 (BackOrifice). Detailed lists of Trojan ports are available at www.doshelp.com/trojanports.htm, http://www.simovits.com/trojans/trojans.html and www.commodon.com/threat/threat-ports.htm.

### 2.1.1.3 Covert Channels of Communication

One of the most common methods to evade detection is to use covert channels of communication. One form of covert channel involves the use of non-standard ports to avoid detection. Most Intrusion Detection Systems (IDSs)[17] typically monitor traffic on ports associated with standard protocols like DNS, IMAP, POP, SNMP, SYSLOG, TELNET, RLOGIN, RSH, FTP, or on ports associated with known backdoors / Trojans. Once a port is identified as being associated with malicious code, traffic through that port can be blocked using a firewall. This led to the development of the newer generation of Trojans that dynamically choose a port from a pre-defined range.

A second kind of covert channel, aimed at subverting firewall–based filtering, uses standard ports for passing non-standard traffic. Firewalls that enforce a “block-all-but-necessary” approach to regulating traffic are the typical targets of standard port abuse. A recent (25 Jan 2003) case of standard port abuse involved a Denial of Service (DOS) attack that was variously known as the ‘SQL Slammer’ worm, ‘Sapphire’ and “SQL-Hell’. The worm in question used a vulnerability in Microsoft SQL Server to subvert targeted systems. The worm spreads via UDP port 1434, which is officially assigned for ‘Microsoft-SQL-Monitor’ services. The infected host starts transmitting 376 byte long UDP packets at a very high rate to random IP addresses on the Internet thereby generating overwhelming traffic. The attack caused widespread denial of service and adversely affected online services throughout the world.

### 2.1.2 Typical Characteristics of Layer 4 Traffic Flow

Efficient bandwidth management requires a thorough understanding of layer-4 traffic based on actual flows as opposed to simulated flow characteristics. In 1997, Kevin Thompson, Gregory Miller and Rick Wilder[18] used traffic monitoring tools in MCI’s segment of the Internet backbone and the NSF sponsored vBNS to characterize typical layer 4 traffic “in terms of traffic volume, flow volume, flow duration, and traffic composition in terms of IP protocols, TCP and UDP applications, and packet sizes”. According to their observations,

(a) TCP traffic accounted for 95% of bytes, 85-95% of packets and 75-85% of the flows. The remaining IP traffic was predominantly UDP while ICMP accounted for less than 1% of all packets.

(b) Average packet size varied over time but followed a 24-hr pattern.

(c) About 40% of all packets were 40 bytes long indicating TCP ACKs, FINs or RSTs.

(d) Maximum application-based traffic was attributed to HTTP. Other TCP applications like FTP, NNTP etc. rarely exceeded 10% of the total traffic.

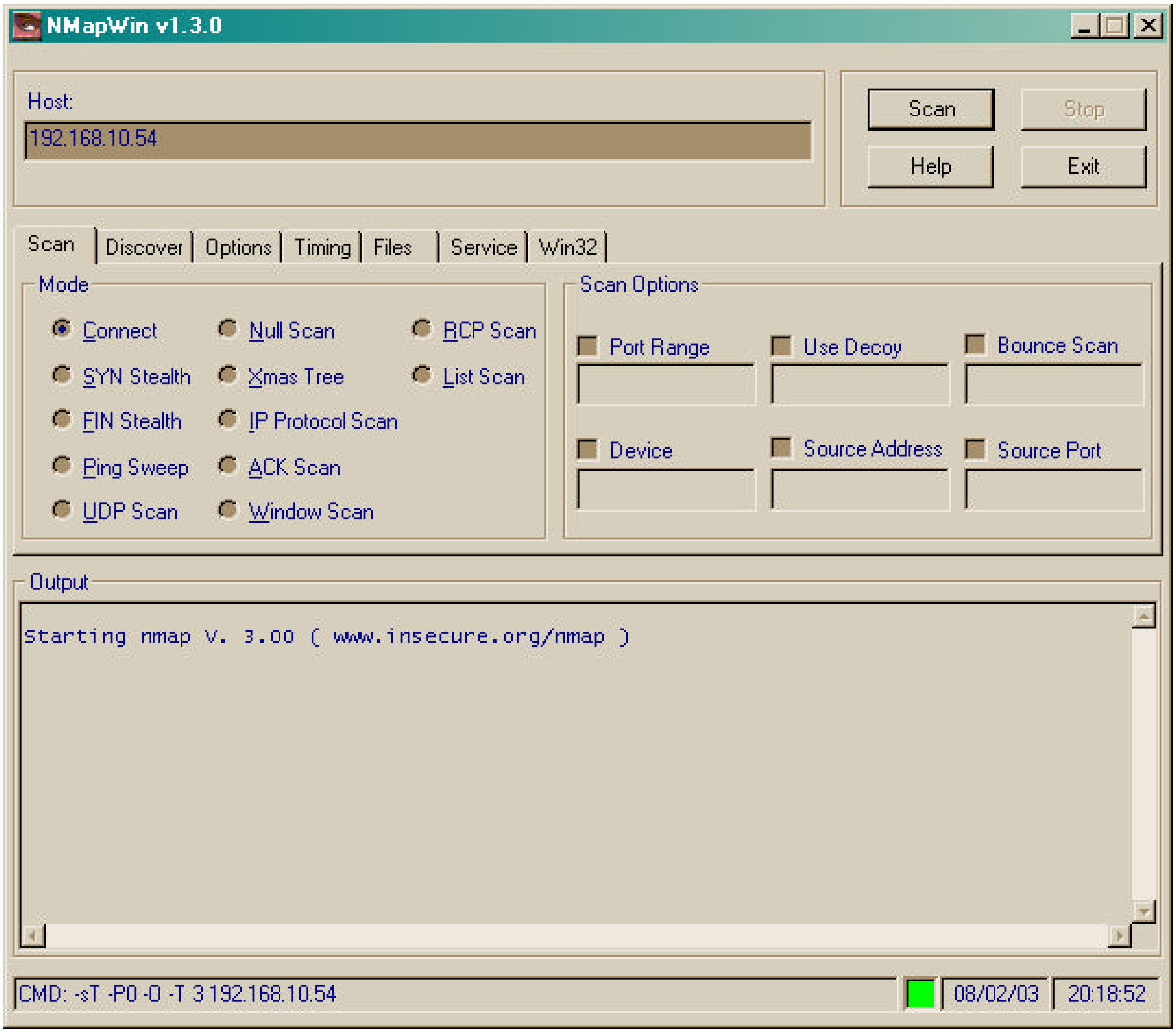
(e) For UDP, the maximum traffic varied between DNS traffic and RealPlayer services depending on the time of the day.

## 2.2 Abusing Ports to Compromise Security

Open ports serve as potential access points for compromising a target host's security. Once a host's reachability has been verified using a utility like ping, a typical attack attempts to identify the target host' software, as a first step in exploiting known security vulnerabilities[19]. This task of software identification is achieved by mapping open ports to associated services. Two common techniques for getting this information include port scanning and fingerprinting.

### 2.2.1 Port Scanning

Port scanning is the discovery of open (listening) ports on a target host in order to ascertain the operating system and other services and applications running on the host. This typically involves scanning for TCP as well as UDP ports. One of the best-known port scanners, Fyodor's *nmap*[20], was used for collecting data for this thesis. A sample screen shot of nmap as shown below indicates the capability of this tool.



Host: 192.168.10.54

Mode: ● Connect

Output

```
Starting nmap V. 3.00 ( www.insecure.org/nmap )
```

CMD: -sT -P0 -O -T 3 192.168.10.54 | 🟩 | 08/02/03 | 20:18:52

Figure 2.1: Screenshot of the Windows version of ‘Nmap’

Various types of common port scanning techniques are described below.

### 2.2.1.1 TCP Connect Scan

This is the most fundamental type of scanning and involves the establishment of a TCP connection via its three-way handshake. The advantages of TCP connection scanning includes speed, in that scans can be done in parallel, and convenience, in that no special system privileges are required for scanning. However this type of scanning is easily detectable and any perimeter-monitoring device on the target host would eventually block access to the originator of these scans.

#### 2.2.1.2 TCP SYN (Half Open) Scan

SYN scans establish an incomplete connection with the target host. A SYN scan begins by sending a SYN packet to a target host. This packet evokes either a SYN/ACK response (if a particular port is open) or a RST response (if that port is closed). If the scanning host receives a SYN/ACK, it completes the scan in a non-standard way: i.e., with an RST to the target host, which terminates the connection. SYN scanning is therefore also known as "half-open" scanning. This technique is harder to detect than TCP connect scanning, but requires root privilege.

#### 2.2.1.3 TCP FIN (Stealth) Scan

TCP FIN scanning (also known as 'stealth' scanning) was developed to evade detection by firewalls and static packet filters that detect TCP SYN scanning. TCP specifications require open ports to ignore FIN packets and closed ports to reply to FIN packets with the proper RST. However, Microsoft’s TCP stack replies with a RST irrespective of the status of the port. This fact enables FIN scanning to differentiate between UNIX and Microsoft implementations.

#### 2.2.1.4 TCP Ftp Proxy (Bounce Attack) Scan

Ftp proxy scanning exploits a security flaw in the FTP protocol (RFC 959). Proxy ftp connections allow an intruder to connect to an ftp server behind a firewall and execute read-write operations. Any port scanning that is done using a proxy ftp server could then bypass the firewall-filtering rules, as the requests now seem to be generated from inside the network. This ability to carry out untraceable port scans makes ‘bounce attack’ scanning very attractive to potential intruders. The scanner typically connects to an anonymous ftp server and then scans the TCP ports from that proxy ftp server.

#### 2.2.1.5 TCP Xmas Tree Scan

Xmas Tree scans send TCP packets with the FIN, URG and PSH flags set. A response of RST from the target host indicates that particular port as closed. No response indicates that the port is open and listening. The response can be used as one of the factors in determining the target host’s operating system on the basis of established RFC 793—compliance information for different stack implementations.

#### 2.2.1.6 TCP Null Scan

Null scans send TCP packets with none of the flags set identify closed ports on the basis of a RST response from the host. RFC 793 specifies that open ports should ignore TCP NULL packets. However, certain TCP/IP stack implementations such as IRIX, HP-UX, Cisco IOS, MVS and Microsoft Windows are not fully compliant. This lack of full compliance results in different response to a TCP NULL scan by different operating systems and can be used for fingerprinting.

#### 2.2.1.7 TCP ACK Scan

TCP ACK scans send TCP ACK packets to a target host. ACK scanning will elicit responses from hosts that might have been configured to ignore ICMP pinging. Scans of port 80

(HTTP) can identify active web sites that block ICMP echo requests (pings): an open port will elicit a RST response. This type of scanning is slightly different in that it seeks to determine whether the firewall protecting the target host is based on simple rules or employs advanced packet filtering techniques.

#### 2.2.1.8 TCP Windows Scan

This technique seeks to identify open ports on a target system based on a system's window size characteristics. This exploits an anomaly in the AIX and FreeBSD systems in reporting the TCP window size. Depending on the operating system of the target host, the TCP windows scan might yield information about the status of certain filtered as well as non-filtered ports.

#### 2.2.1.9 TCP RPC Scan

Sun Microsystems' RPC (Remote Procedure Call) mechanism simplifies distributed client-server computing by allowing network communications to be framed as subroutine calls. The ports designated for RPC start at port number 32678. TCP RPC scans detect and identify ports being used by Remote Procedure Call services. This scanning technique also provides information on the version number and programs associated with the RPC services running on a target host.

#### 2.2.1.10 SYN / FIN Scan Using IP Fragments (Bypass Packet Filters)

SYN/FIN scans fragment probe packets before sending them, in an attempt to avoid detection by firewalls and packet filters. The TCP header is fragmented over a number of packets to bypass the filtering mechanism. While this approach works with many firewalls, it will not work against systems that queue all IP fragments and reassemble the incoming packets thus identifying the active status of the SYN / FIN flags.

#### 2.2.1.11 UDP Recvfrom() And Write() Scan

Users without root access to a scanning platform can recvfrom() and write() scans to identify open ports on some target hosts. The Linux UDP stack responds to an unsolicited readfrom() with error number 13 (EAGAIN-"try again") and error number 111 (ECONNREFUSED- "Connection refused"), according to whether the targeted port is open or closed.

#### 2.2.1.12 UDP Raw ICMP Port Unreachable Scan

Raw ICMP port unreachable scans are similar to TCP bounce attack scanning, but target the UDP protocol. The scan attempts to distinguish between closed and open ports by treating an ICMP_PORT_UNREACH error message as a response from a closed port, and no response as an indicator of an open port. However, this technique is not very reliable, as some UDP stack implementations don't respond to either. Root privilege is required for initiating UDP ICMP port unreachable scanning.

#### 2.2.1.13 ICMP Echo Scan (Ping – Sweep)

Strictly speaking, ICMP Echo Scanning is not a port scanning technique, in that ICMP does not support ports. This technique seeks to determine the active hosts by using the ICMP echo request (ping) command. An ICMP echo reply message (type value = 0; code value = 0) in response to an ICMP echo request message (type value = 8; code value = 0) indicates that the target host is alive and that the ICMP messages are not being filtered. A number of port scanners now support parallel ICMP scanning, making the process of scanning an entire network or a range of hosts time-efficient. Nmap supports non-blocking I/O and parallel scanning in all TCP and UDP modes.

#### 2.2.1.14 Reverse-ident Scan

This technique uses TCP's ident protocol (RFC 1413) to determine the owner of an open port's server process. Unlike the fragmentation scans, the TCP reverse ident scan requires a complete TCP connection with the target port. Potential attackers can use this feature to determine if a port is being serviced by a task with root privileges—and, if so, the task's associated account. The user name thus determined can be used for getting more information about the network.

#### 2.2.1.15 Idle Scan

Idle scanning is a highly sophisticated port scanning technique invented by Antirez[22]. In idle scanning, the attacker sends probes from a 'dumb' host; thereby giving a fictitious IP address to any Intrusion Detection System that detects the scanning. Because of its high stealth capability, it is also known as "blind port scanning". Idle scanning can additionally be used to establish IP-based share relationships between trusted hosts on a network.

### 2.2.2 Stack Fingerprinting

According to Stuart McClure, Joel Scambray and George Kurtz[23], "*stack fingerprinting is an extremely powerful technology for ascertaining each host's operating system with a high degree of probability*". Stack fingerprinting uses differences between vendor implementations of TCP/IP stacks to identify target host software. Stack fingerprinting can be active or passive.

#### 2.2.2.1 Active Stack Fingerprinting

In active stack fingerprinting, an attacker probes a target host's open ports, then compares the responses to a database of known 'signature-behavior mappings' to profile the target host. According to McClure et al, active stack fingerprinting can be achieved by using the various types of probes listed below:

##### 2.2.2.1.1 FIN Probe

FIN probes were discussed above, in Section 2.2.1.3.

##### 2.2.2.1.2 Bogus Flag Probe

Bogus flag probes monitor the response to a SYN packet with an undefined TCP flag set (bit 7 or 8) in the header. Some operating systems reset the connection on receiving a TCP packet with bogus flags set; others, like older Linux versions (ver. 2.0.35 and earlier) responded by mirroring the bogus flags in their response packet headers. Of late, however, the 8th bit is being used for the "ECN field" for TCP congestion control. The port scanner "Queso" was one of the first scanners to exploit this technique for OS-determination.

#### 2.2.2.1.3 Initial Sequence Number (ISN) Sampling

ISN sampling looks for patterns in the initial sequence numbers (ISNs) from target hosts. Operating systems may be identified on the basis of the sampling pattern of the response. Some known patterns along with their associated stack implementations are placed in table 2.1.

Table 2.1: ISN sampling pattern Vs Stack implementation

| # | Sampling Pattern | Stack Implementation |
|---|---|---|
| 1 | Traditional 64K | SCO Unix (and most earlier versions of Unix) |
| 2 | Random incremental | FreeBSD, Digital UNIX, Cray, Solaris, IRIX, and newer versions of Unix |
| 3 | True "random" | Linux 2.0.*, OpenVMS, newer AIX |
| 4 | Time dependent | Microsoft Windows |
| 5 | Constant | Apple LaserWriter printers and 3Com hubs |

#### 2.2.2.1.4 "Don't Fragment Bit" Monitoring

Certain operating systems such as Solaris set the "don't fragment bit" on the IP packets that they transmit. Different stack implementations handle this bit differently. The setting of this bit is monitored and compared with a known database to aid estimation of the target operating system.

#### 2.2.2.1.5 TCP Initial Window Size

Certain operating system stacks implement unique initial window sizes and this can be used as a signature attribute. While Microsoft Windows 2000, FreeBSD and OpenBSD use 0x402E; AIX uses 0x3F25. The initial TCP window size of the returned packets can thus help in OS determination of the target host.

#### 2.2.2.1.6 ACK Value

ACK Value probing examines ACK field sequence values, yet another signature attribute. On sending a TCP packet with the FIN, PSH, and URG flags set to a closed port, Microsoft Windows will send an ACK with the initial sequence number incremented by one whereas most Unix-based operating systems will send an ACK with the same ISN set as the probe packet. On sending a TCP packet with the SYN, FIN, PSH, and URG flags set to an open port, Microsoft Windows will respond with an ACK packet with a random value for the ISN.

#### 2.2.2.1.7 ICMP Error Message Quenching

Some operating systems such as Linux limit the generation of error messages (e.g. destination unreachable message) in accordance with the recommendations of RFC 1812. The ICMP error message quenching scan involves sending UDP packets on random ports and inferring the identity of the target's host stack from the number of unreachable messages in a given time period.

#### 2.2.2.1.8 ICMP Message Quoting

In accordance with the recommendations of the various RFCs, ICMP error messages contain part information regarding the error-causing packet. While most stack implementations send 8 additional bytes along with the IP header, Solaris and Linux typically return more information. ICMP error message quoting infers operating system identity from the diagnostic returned in response to an ICMP error as an estimation attribute. Using known responses to various errors, it might be possible to detect hosts running Linux as well as Solaris systems even if all their ports are closed.

#### 2.2.2.1.9 ICMP Error Message-Echoing Integrity

Echo integrity probing checks for changes to scanner-generated IP headers that are returned from the target host, in ICMP error messages. Many stack implementations inadvertently modify the packet header while processing them. Comparing the alterations made with an existing database of 'alteration-signatures' can pinpoint the target operating system with accuracy. Some commonly known alterations are tabulated in Table 2.2.

Table 2.2: Alterations to packet headers made by various operating systems

| # | Characteristics of returned header | Operating system |
|---|---|---|
| 1 | Alterations to the IP ID | BSDI, FreeBSD, OpenBSD, ULTRIX, and VAXen |
| 2 | Checksum errors | AIX and FreeBSD |
| 3 | 'Total length' field is 20 bytes longer than normal | AIX and BSDI |

#### 2.2.2.1.10 Type of Service (TOS)

The value in the TOS returned for "ICMP port unreachable" messages might vary for different stack implementations. While most implementations return '0' for ICMP port unreachable messages, Linux returns a value of '0xC0'.

#### 2.2.2.1.11 Fragmentation Handling

Different operating systems handle overlapping fragments of IP packets differently. The reassembled packets can give information about the reassembly process used. Fragmentation handling involves examining the method of reassembling of the probe packet-fragments to estimate the stack implementation.

#### 2.2.2.1.12 TCP Options

TCP options probing checks how target systems manage requests for “custom” TCP options, like window scale factor, timestamps, maximum segment size, no operation, and end of operation. (cf. RFC 793 and RFC 1323). These options, which are not mandatory as per the RFC, are only implemented by some TCP/IP stacks.

#### 2.2.2.2 Passive Stack Fingerprinting

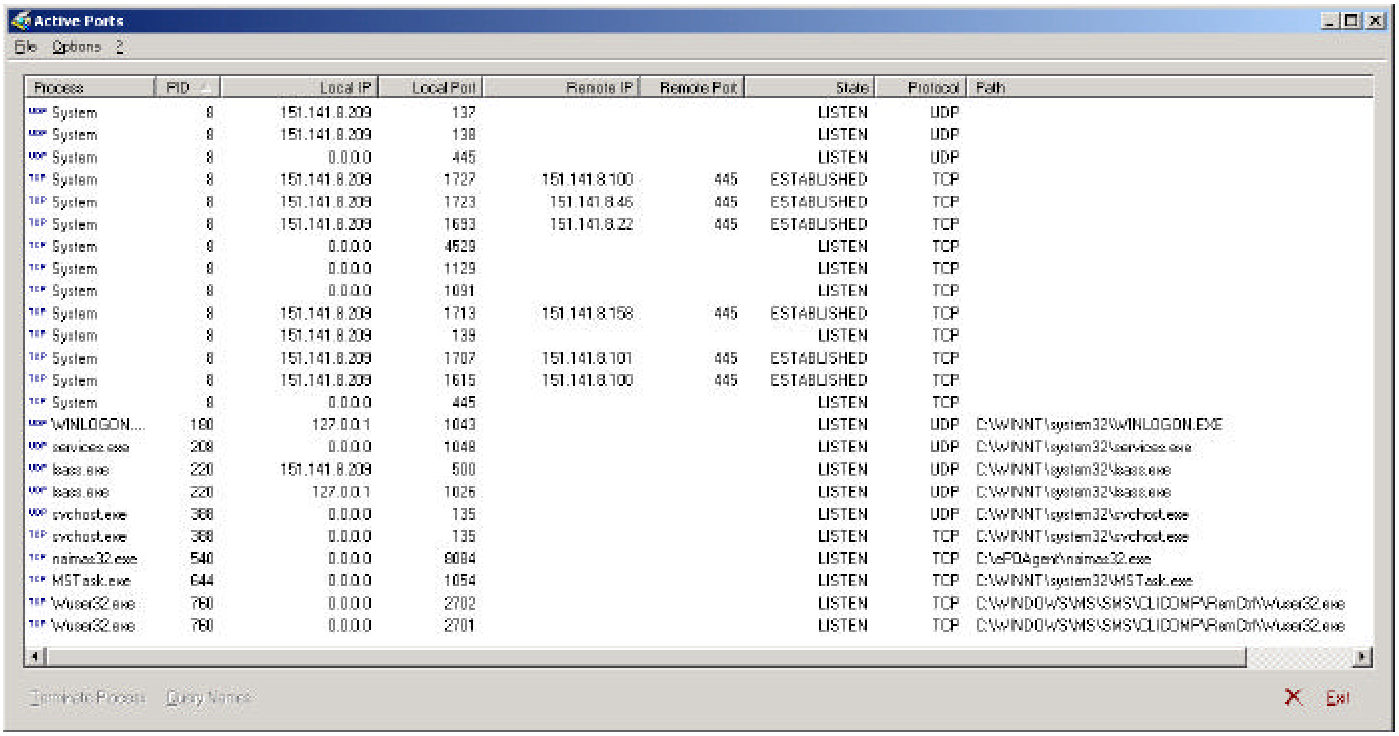
In passive fingerprinting, the attacker maps ports without specifically probing the target host. The target machine’s TCP/IP stack is reconnoitered by observing TCP/IP session attributes like TTL, ‘Don’t fragment’ bits, and window size. Passive fingerprinting, though not as accurate as active fingerprinting, is more difficult to detect.

## 2.3 Techniques for Detecting Invalid Use of Ports

Port abuse is detected by identifying malicious actions and abnormal behavior that might compromise the integrity, confidentiality, or availability of information resources. The various techniques can broadly be classified as use analysis, bandwidth analysis, content analysis and timing analysis.

### 2.3.1 Use Analysis

Use analysis checks for port abuse by monitoring the numbers of the actual ports in use. Services known to be associated with distinctive port numbers can be identified using a pre-established database to map services to port numbers. Commonly used tools for this technique include “netstat” as well as “Active Ports”. A sample screen shot of Active Ports listing all open ports on a host is given below:



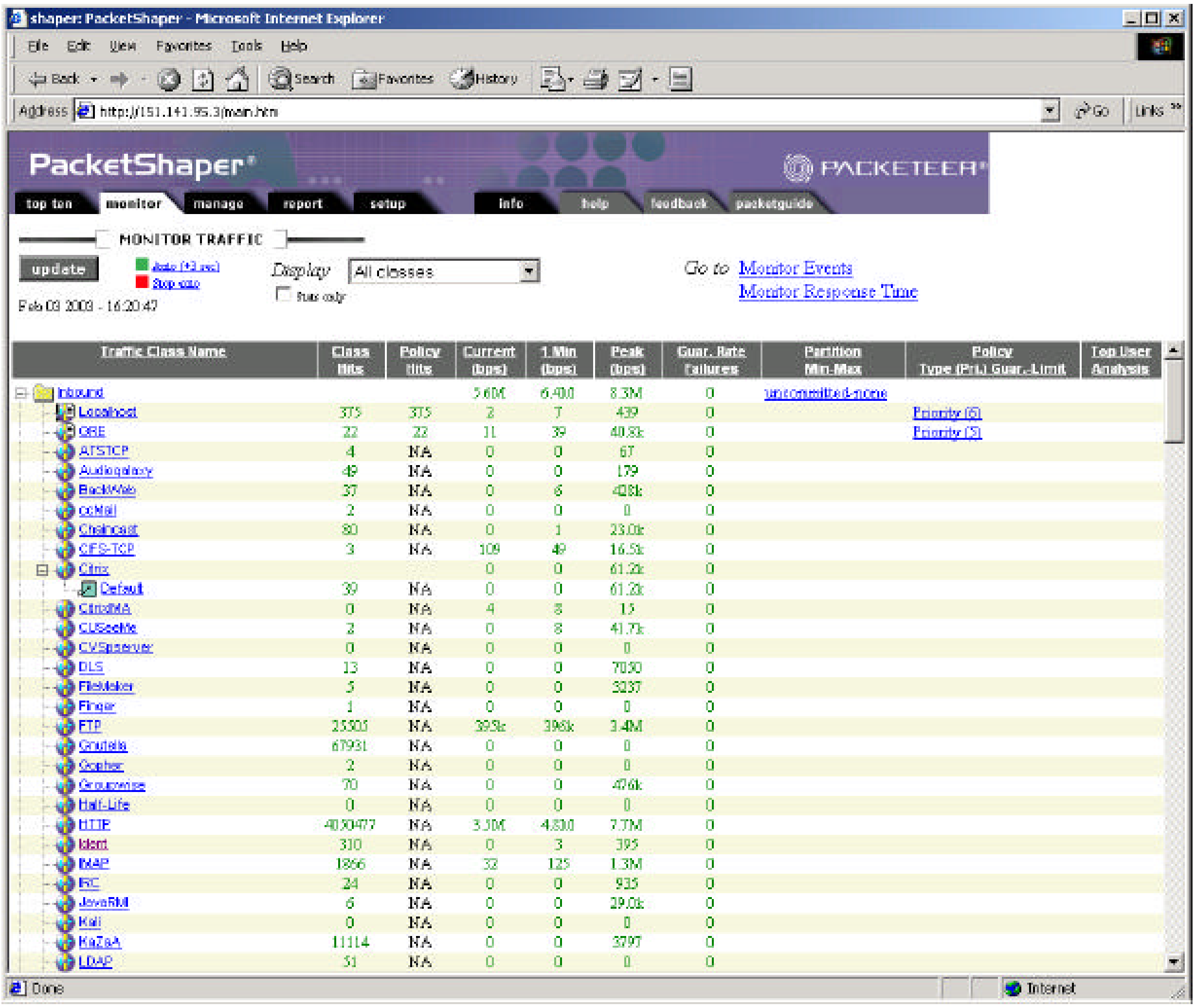
| Process | PID | Local IP | Local Port | Remote IP | Remote Port | State | Protocol | Path |
|---|---|---|---|---|---|---|---|---|
| System | 8 | 151.141.8.209 | 137 | | | LISTEN | UDP | |
| System | 8 | 151.141.8.209 | 138 | | | LISTEN | UDP | |
| System | 8 | 0.0.0.0 | 445 | | | LISTEN | UDP | |
| System | 8 | 151.141.8.209 | 1727 | 151.141.8.100 | 445 | ESTABLISHED | TCP | |
| System | 8 | 151.141.8.209 | 1723 | 151.141.8.46 | 445 | ESTABLISHED | TCP | |
| System | 8 | 151.141.8.209 | 1693 | 151.141.8.22 | 445 | ESTABLISHED | TCP | |
| System | 8 | 0.0.0.0 | 4529 | | | LISTEN | TCP | |
| System | 8 | 0.0.0.0 | 1129 | | | LISTEN | TCP | |
| System | 8 | 0.0.0.0 | 1091 | | | LISTEN | TCP | |
| System | 8 | 151.141.8.209 | 1713 | 151.141.8.158 | 445 | ESTABLISHED | TCP | |
| System | 8 | 151.141.8.209 | 139 | | | LISTEN | TCP | |
| System | 8 | 151.141.8.209 | 1707 | 151.141.8.101 | 445 | ESTABLISHED | TCP | |
| System | 8 | 151.141.8.209 | 1615 | 151.141.8.100 | 445 | ESTABLISHED | TCP | |
| System | 8 | 0.0.0.0 | 445 | | | LISTEN | TCP | |
| WINLOGON.... | 180 | 127.0.0.1 | 1043 | | | LISTEN | UDP | C:\WINNT\system32\WINLOGON.EXE |
| services.exe | 208 | 0.0.0.0 | 1048 | | | LISTEN | UDP | C:\WINNT\system32\services.exe |
| lsass.exe | 220 | 151.141.8.209 | 500 | | | LISTEN | UDP | C:\WINNT\system32\lsass.exe |
| lsass.exe | 220 | 127.0.0.1 | 1026 | | | LISTEN | UDP | C:\WINNT\system32\lsass.exe |
| svchost.exe | 368 | 0.0.0.0 | 135 | | | LISTEN | UDP | C:\WINNT\system32\svchost.exe |
| svchost.exe | 368 | 0.0.0.0 | 135 | | | LISTEN | TCP | C:\WINNT\system32\svchost.exe |
| naimas32.exe | 540 | 0.0.0.0 | 8084 | | | LISTEN | TCP | C:\ePOAgent\naimas32.exe |
| MSTask.exe | 644 | 0.0.0.0 | 1054 | | | LISTEN | TCP | C:\WINNT\system32\MSTask.exe |
| Wuser32.exe | 760 | 0.0.0.0 | 2702 | | | LISTEN | TCP | C:\WINDOWS\MS\SMS\CLICOMP\RemCtrl\Wuser32.exe |
| Wuser32.exe | 760 | 0.0.0.0 | 2701 | | | LISTEN | TCP | C:\WINDOWS\MS\SMS\CLICOMP\RemCtrl\Wuser32.exe |

Fig 2.2: Screen shot of ‘Active Ports’ showing all open ports on a system.

Rigorous logging and analysis of all remote-connection attempts is another way of detecting potential attacks.

### 2.3.2 Bandwidth Analysis

Bandwidth analysis is an important technique for identifying abnormal network usage. Packeteer Inc.’s ‘PacketShaper’ was used extensively to collect data for this thesis. PacketShaper allows application adaptive real time monitoring of network traffic and gives the ability to monitor/filter traffic on a port-to-port basis. A detailed account of the packet shaper is given in section 3. A sample screen shot depicting application-based monitoring using Packet Shaper is shown below:



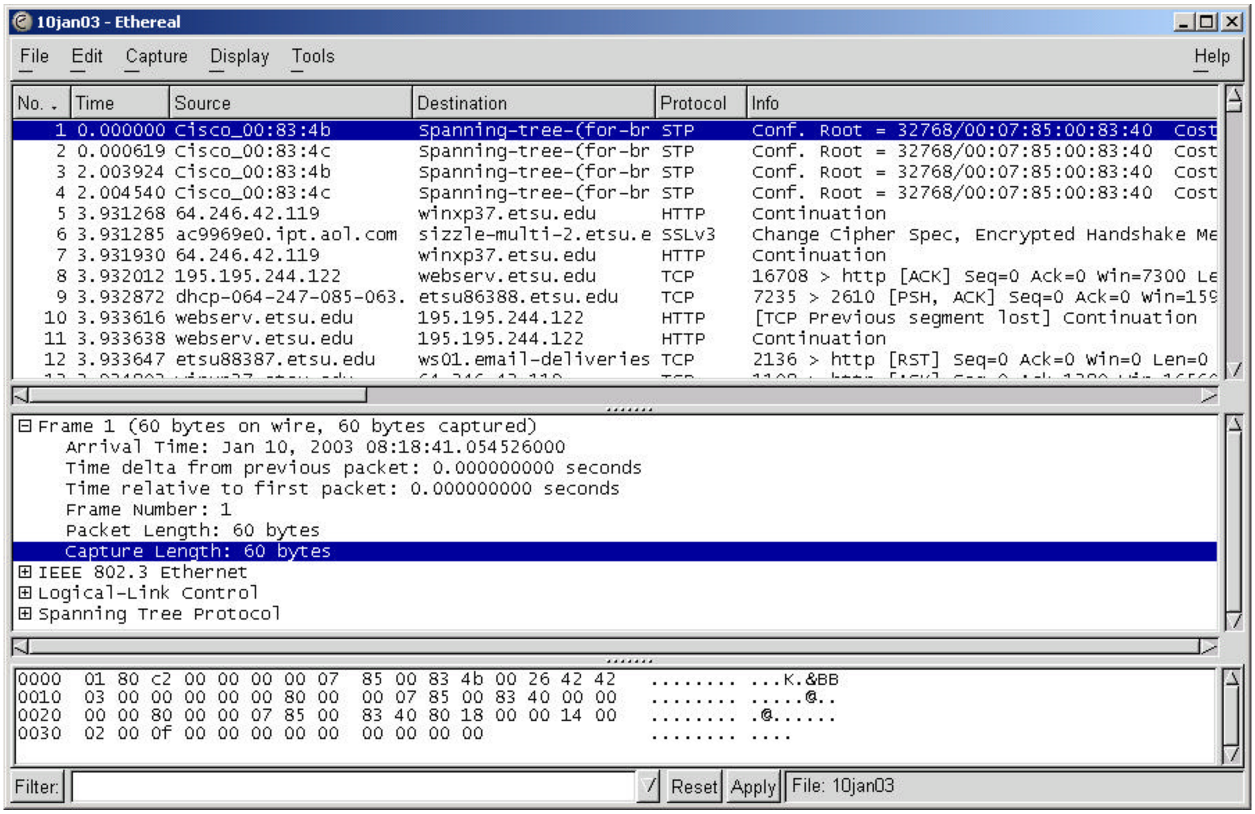
Feb 03 2003 - 16:20:47

| Traffic Class Name | Class Hits | Policy Hits | Current (bps) | 1 Min (bps) | Peak (bps) | Guar. Rate Failures | Partition Min-Max | Policy Type (Pri.) Guar.-Limit | Top User Analysis |
|---|---|---|---|---|---|---|---|---|---|
| Inbound | | | 5.60M | 6.40M | 8.3M | 0 | uncommitted-none | | |
| Localhost | 375 | 375 | 2 | 7 | 439 | 0 | | Priority (6) | |
| GRE | 22 | 22 | 11 | 39 | 40.8k | 0 | | Priority (5) | |
| ATSTCP | 4 | NA | 0 | 0 | 67 | 0 | | | |
| Audiogalaxy | 49 | NA | 0 | 0 | 179 | 0 | | | |
| BackWeb | 37 | NA | 0 | 6 | 428k | 0 | | | |
| ccMail | 2 | NA | 0 | 0 | 0 | 0 | | | |
| Chaincast | 80 | NA | 0 | 1 | 23.0k | 0 | | | |
| CIFS-TCP | 3 | NA | 109 | 49 | 16.5k | 0 | | | |
| Citrix | | | 0 | 0 | 61.2k | 0 | | | |
| Default | 39 | NA | 0 | 0 | 61.2k | 0 | | | |
| CitrixIMA | 0 | NA | 4 | 8 | 15 | 0 | | | |
| CUSeeMe | 2 | NA | 0 | 8 | 41.7k | 0 | | | |
| CVSpserver | 0 | NA | 0 | 0 | 0 | 0 | | | |
| DLS | 13 | NA | 0 | 0 | 7030 | 0 | | | |
| FileMaker | 5 | NA | 0 | 0 | 3237 | 0 | | | |
| Finger | 1 | NA | 0 | 0 | 0 | 0 | | | |
| FTP | 25303 | NA | 393k | 396k | 3.4M | 0 | | | |
| Gnutella | 67931 | NA | 0 | 0 | 0 | 0 | | | |
| Gopher | 2 | NA | 0 | 0 | 0 | 0 | | | |
| Groupwise | 70 | NA | 0 | 0 | 476k | 0 | | | |
| Half-Life | 0 | NA | 0 | 0 | 0 | 0 | | | |
| HTTP | 4030477 | NA | 3.30M | 4.83M | 7.7M | 0 | | | |
| Ident | 310 | NA | 0 | 3 | 395 | 0 | | | |
| IMAP | 1866 | NA | 32 | 125 | 1.3M | 0 | | | |
| IRC | 24 | NA | 0 | 0 | 935 | 0 | | | |
| JavaRMI | 6 | NA | 0 | 0 | 29.0k | 0 | | | |
| Kali | 0 | NA | 0 | 0 | 0 | 0 | | | |
| KaZaA | 11114 | NA | 0 | 0 | 3797 | 0 | | | |
| LDAP | 51 | NA | 0 | 0 | 0 | 0 | | | |

Fig 2.3: Screen shot depicting application-based monitoring of traffic

### 2.3.3 Content Analysis

Invalid port use can be detected by analyzing the content of the IP packets being transmitted on a network. This approach is useful to detect covert information exchange when malicious programs use well-known ports to pass non-standard data thereby subverting firewalls. Commonly used strategies for content analysis include network protocol analysis (or packet sniffing) and intrusion detection. A well-known protocol analyzer, 'Ethereal', was used for collecting data for this thesis. Sample output from Ethereal is shown below:



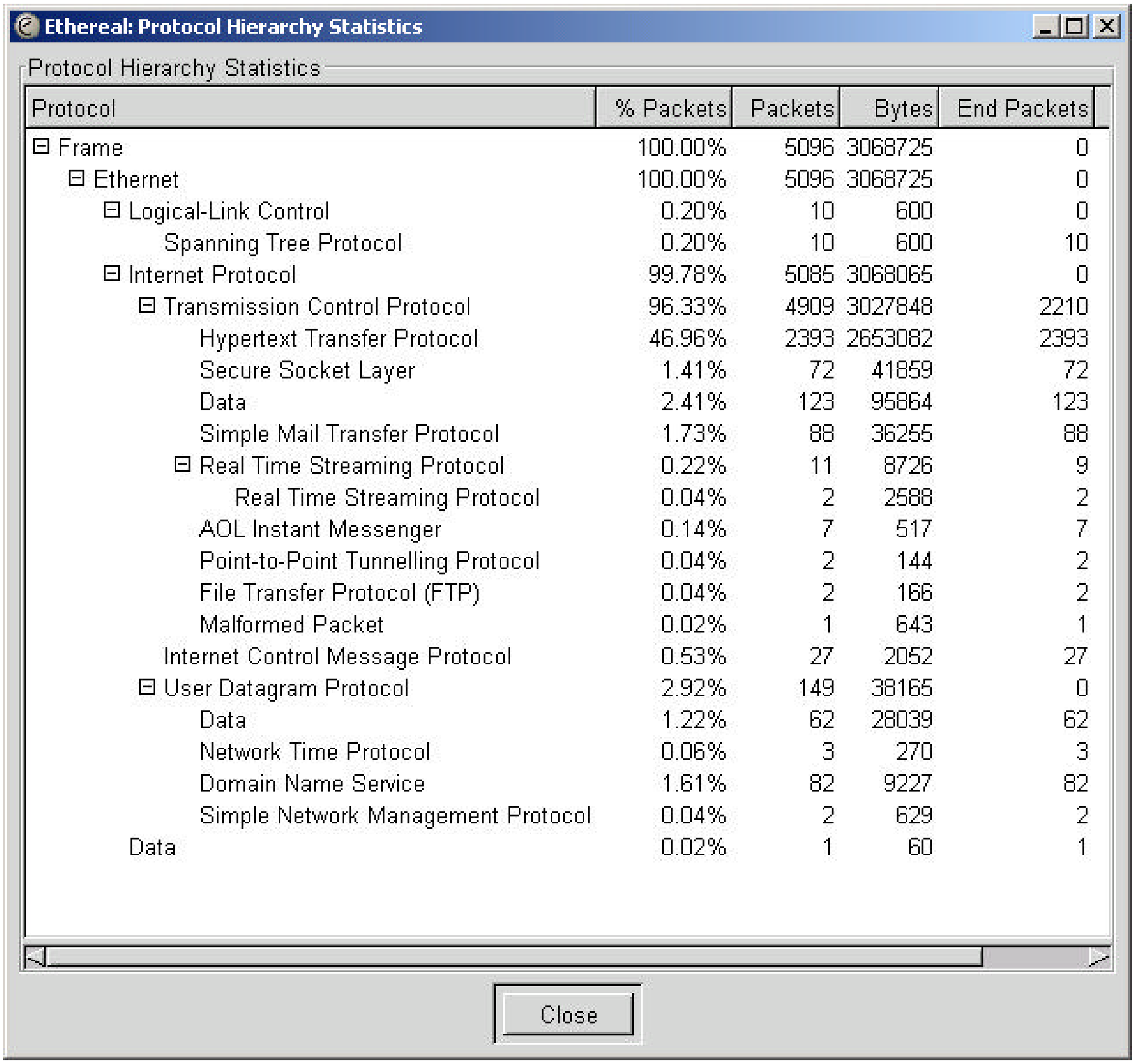
```
No. . Time     Source                     Destination               Protocol  Info
    1 0.000000 Cisco_00:83:4b             Spanning-tree-(for-br     STP       Conf. Root = 32768/00:07:85:00:83:40  Cost
    2 0.000619 Cisco_00:83:4c             Spanning-tree-(for-br     STP       Conf. Root = 32768/00:07:85:00:83:40  Cost
    3 2.003924 Cisco_00:83:4b             Spanning-tree-(for-br     STP       Conf. Root = 32768/00:07:85:00:83:40  Cost
    4 2.004540 Cisco_00:83:4c             Spanning-tree-(for-br     STP       Conf. Root = 32768/00:07:85:00:83:40  Cost
    5 3.931268 64.246.42.119              winxp37.etsu.edu          HTTP      Continuation
    6 3.931285 ac9969e0.ipt.aol.com       sizzle-multi-2.etsu.e     SSLv3     Change Cipher Spec, Encrypted Handshake Me
    7 3.931930 64.246.42.119              winxp37.etsu.edu          HTTP      Continuation
    8 3.932012 195.195.244.122            webserv.etsu.edu          TCP       16708 > http [ACK] Seq=0 Ack=0 Win=7300 Le
    9 3.932872 dhcp-064-247-085-063.      etsu86388.etsu.edu        TCP       7235 > 2610 [PSH, ACK] Seq=0 Ack=0 Win=159
   10 3.933616 webserv.etsu.edu           195.195.244.122           HTTP      [TCP Previous segment lost] Continuation
   11 3.933638 webserv.etsu.edu           195.195.244.122           HTTP      Continuation
   12 3.933647 etsu88387.etsu.edu         ws01.email-deliveries     TCP       2136 > http [RST] Seq=0 Ack=0 Win=0 Len=0
```

```
⊟ Frame 1 (60 bytes on wire, 60 bytes captured)
    Arrival Time: Jan 10, 2003 08:18:41.054526000
    Time delta from previous packet: 0.000000000 seconds
    Time relative to first packet: 0.000000000 seconds
    Frame Number: 1
    Packet Length: 60 bytes
    Capture Length: 60 bytes
⊞ IEEE 802.3 Ethernet
⊞ Logical-Link Control
⊞ Spanning Tree Protocol
```

```
0000   01 80 c2 00 00 00 00 07  85 00 83 4b 00 26 42 42   ........ ...K.&BB
0010   03 00 00 00 00 00 80 00  00 07 85 00 83 40 00 00   ........ .....@..
0020   00 00 80 00 00 07 85 00  83 40 80 18 00 00 14 00   ........ .@......
0030   02 00 0f 00 00 00 00 00  00 00 00 00               ........ ....
```

Fig 2.4: Screen shot showing 'packet sniffing' in action with detailed information about captured data from the ETSU network.

A detailed protocol hierarchy breakdown of the captured data is shown below in yet another screen shot from Ethereal.


Ethereal: Protocol Hierarchy Statistics
Protocol Hierarchy Statistics
Close

| Protocol | % Packets | Packets | Bytes | End Packets |
|---|---|---|---|---|
| ⊟ Frame | 100.00% | 5096 | 3068725 | 0 |
| ⊟ Ethernet | 100.00% | 5096 | 3068725 | 0 |
| ⊟ Logical-Link Control | 0.20% | 10 | 600 | 0 |
| Spanning Tree Protocol | 0.20% | 10 | 600 | 10 |
| ⊟ Internet Protocol | 99.78% | 5085 | 3068065 | 0 |
| ⊟ Transmission Control Protocol | 96.33% | 4909 | 3027848 | 2210 |
| Hypertext Transfer Protocol | 46.96% | 2393 | 2653082 | 2393 |
| Secure Socket Layer | 1.41% | 72 | 41859 | 72 |
| Data | 2.41% | 123 | 95864 | 123 |
| Simple Mail Transfer Protocol | 1.73% | 88 | 36255 | 88 |
| ⊟ Real Time Streaming Protocol | 0.22% | 11 | 8726 | 9 |
| Real Time Streaming Protocol | 0.04% | 2 | 2588 | 2 |
| AOL Instant Messenger | 0.14% | 7 | 517 | 7 |
| Point-to-Point Tunnelling Protocol | 0.04% | 2 | 144 | 2 |
| File Transfer Protocol (FTP) | 0.04% | 2 | 166 | 2 |
| Malformed Packet | 0.02% | 1 | 643 | 1 |
| Internet Control Message Protocol | 0.53% | 27 | 2052 | 27 |
| ⊟ User Datagram Protocol | 2.92% | 149 | 38165 | 0 |
| Data | 1.22% | 62 | 28039 | 62 |
| Network Time Protocol | 0.06% | 3 | 270 | 3 |
| Domain Name Service | 1.61% | 82 | 9227 | 82 |
| Simple Network Management Protocol | 0.04% | 2 | 629 | 2 |
| Data | 0.02% | 1 | 60 | 1 |

Fig 2.5: Protocol Hierarchy Breakdown

### 2.3.3.1 Real Time Intrusion Detection

Real time intrusion detection[26] systems such as Vern Paxon's 'Bro' can effectively defend against overload, crash as well as subterfuge attacks against the network host. Bro consists of an *event engine* that converts a stream of filtered packets to high-level network events, and an *interpreter* for a specialized language for writing the security policy.

Bro has a layered structure. Its lowest layer, *libpcap*, is the packet capture directory used by the *tcpdump* protocol analyzer utility. This layer isolates Bro from the network link technology and enhances Bro's portability. The filtered packet stream from *libpcap* is passed to the event engine, which is the next layer. The event engine confirms the integrity of packet headers. All packets failing this check are discarded. Packets passing the integrity check are sent for further processing in separate streams for TCP and UDP packets. The processing involves invoking a handler to process the data payload of the packet. The processed event stream is then passed to the policy script interpreter, which generates a real-time notification of intrusions. Bro is specifically designed to handle high speed (FDDI–rate) large volume monitoring with an emphasis on extensibility and on avoiding packet filter drops.

#### 2.3.3.1.1 Overload, Crash and Subterfuge Attacks

Depending on the events generated by the event engine's processing of a data packet, Bro executes event-handler commands until the queue is empty. Paxson claims that Bro has been designed to survive *overload, crash* and *subterfuge* attacks against the network monitor.

An *overload attack* first overwhelms the monitor with excessive data to ensure that it is unable to keep with the data stream. The actual network intrusion starts after the monitor has been overwhelmed. As long as the attacker doesn't have access to the policy scripts, Bro provides reasonable defense against overload attacks.

A *crash attack* incapacitates the monitor by exhausting its resources. The actual network intrusion takes place after the monitor has been rendered useless. Bro has been provided with specific capability to avoid crash attacks.

A *subterfuge attack* depends on the attacker's ability to mislead the network monitor regarding the nature of the traffic it analyses. The nature of these attacks makes it extremely difficult to detect or prevent subterfuge attacks. Successful subterfuge attacks rely on modifying the traffic pattern in a manner that renders the traffic stream open to different interpretations by the network monitor and the intended recipient. To protect against subterfuge attacks, Bro analyzes a system's rules for classifying network content for flawed assumptions. Paxson gives the example of texts embedded with a NUL to persuade the network monitor to ignore data thereafter and fragmenting the IP datagrams in a manner that might not be reassembled correctly by the monitoring device. Paxson claims that this equips Bro with a formidable intrusion detection capability while admitting that it still doesn't provide absolute security.

### 2.3.3.2 Traffic Normalization

Bro, which has its strengths, can unfortunately be bypassed by exploiting ambiguities in the network traffic stream. In "Network Intrusion Detection: Evasion, Traffic Normalization, and End-to-End Protocol Semantics", Handley[27], Paxson, and Kreibich describe the use of a network-forwarding element called a traffic normalizer to eliminate the traffic ambiguities by 'patching-up' or 'normalizing' the packet stream. Normalizers are similar to protocol scrubbers[28] but cover a wider range of conditions, and are optimized to defend coordinated attacks against the normalizers themselves.

### 2.3.3.3 Intrusion Detection Wrappers

In "Detecting and Countering System Intrusions Using Software Wrappers", Ko[29], Fraser, Badger and Kilpatrick suggest the use of *ID wrappers*, in conjunction with intrusion detection techniques, to intercept problem events and take countermeasures if an event suggests the possibility of an intrusion. According to these authors, "*an ID wrapper is a software layer dynamically inserted into the kernel that can selectively intercept and analyze system calls performed by processes as well as respond to intrusive events*".

ID wrappers facilitate program monitoring to detect unauthorized modifications that might be overlooked by traditional audit mechanisms. Wrapper countermeasures include denial, transformation or augmentation of the event. ID wrappers may also generate specialized events that would be intercepted by other intrusion detection wrappers in the system. The various ID wrappers are configured and managed by the 'wrapper support subsystem'. Multiple ID wrappers can be used in a layered composition for more effective intrusion detection. The *'Common Intrusion Detection Framework'* uses multiple ID wrappers to enhance performance.

### 2.3.3.4 Intrusion Detection Based on Expert Systems

Expert systems depend on extensive knowledge bases and sophisticated *IF-THEN-ELSE* rule sets. Depending on the status of critical events, they are designed to initiate actions in conformance to their driving rule sets. Ulf Lindqvist and Phillip A Porras[30] have described the use of PBEST (Production Based Expert System Toolset)—an expert system development toolset to develop a generic signature based IDS specifically for detecting SYN flooding and buffer overflows.

### 2.3.3.5 Intrusion Prevention

The ability to detect and isolate attacks before they compromise a system's core functionality is a prerequisite for building systems capable of surviving directed attacks. *Intrusion prevention*, as described by R. Sekar[31] and P. Uppuluri, uses patterns of system calls to monitor and disallow calls that deviate from specifications. Since a potentially damaging system call can be modified before the damage is done, this technique gives the system time to prevent the damage.

Sekar and Uppuluri's intrusion prevent ion system consists of an offline and a runtime component. The offline system generates detection engines from specifications characterizing normal and abnormal program behavior as patterns of system call sequences, and the runtime system provides the execution environment for these engines. The authors claim that their algorithm, whose runtime is almost independent of the number of patterns, is suitable for any intrusion detection method involving pattern matching.

### 2.3.4 Timing Analysis

Yin Zhang[32] and Vern Paxson, in "Detecting Backdoors", describe a generalized timing-based algorithm for detecting interactive network traffic using non-standard ports. The algorithm's goal is to detect the use of such ports to facilitate re-entry into systems that have already been breached. The authors use a timing-based algorithm instead of a content-based algorithm to render their work insensitive to encryption and decryption, and to reduce the algorithm's overhead. The algorithm accounts for packet size and directionality and the packet inter-arrival timing. The directionality helps in filtering the network traffic based on the premise that an interactive connection is always initiated by the client.

A high frequency of false alarms generated by this generalized algorithm prompted Zhang and Paxson to develop fifteen protocol-specific algorithms that detect backdoors on the basis of protocol-specific signatures. Depending upon the protocols or services used, the authors have classified the backdoors into various types—viz., SSH, Rlogin, Telnet, FTP, Root prompt, Napster and Gnutella—and developed specific algorithms to deal with each type.

## 2.4 Techniques for Blocking Invalid Use of "Mainstream" Ports

Authors like John E Canavan[33], Rolf Oppliger[34], Chris Benton and Cameron Hunt[35] identify a variety of techniques for blocking undesirable traffic. Nine of the more important of these techniques are discussed below.

### 2.4.1 Shutting Down Unneeded Services

*Shutting down unneeded services* is the simplest and most basic technique for preventing port abuse. Since open ports are potential access points on the network, care should be taken to disable all unnecessary services thereby closing all unnecessary ports on the host. Though this technique is the simplest to implement, it fails to provide a reasonable level of security as malicious programs target commonly used ports for compromising a target host's security.

### 2.4.2 Port Re-Mapping

*Port re-mapping* involves running important services on non-standard ports thereby increasing the degree of difficulty involved in compromising such a system. This technique is effective only against 'script-kiddies' as experienced and dedicated hackers are generally able to figure out if certain services are running on non-standard ports. If port re-mapping is not done properly, it might actually increase the system's vulnerability as new ports are opened.

### 2.4.3 Static Packet Filtering

*Static packet filtering* involves filtering incoming as well as outgoing data packets on the basis of the header information. The packets are denied or allowed access depending on the access control policies defined for the system. Static filtering controls traffic flow by analyzing information such as the source and destination IP address or subnet, the source and destination port addresses and the TCP flag field. This technique is difficult to implement for controlling UDP traffic, as the UDP header does not use flags to indicate a session's state.

### 2.4.4 Dynamic Packet Filtering

*Dynamic packet filtering* enhances static packet filtering by controlling traffic based on packet attributes as well as connection-state monitoring. Unlike static filtering which can only provide protection against a TCP SYN scan attack, dynamic packet filtering provides protection against TCP ACK scan as well as TCP FIN scan attacks. Dynamic packet filtering is also referred to as "intelligent filtering". This technique can also handle traffic-control effortlessly with UDP traffic, as it no longer relies on the UDP header for session-state information.

### 2.4.5 Stateful Filtering

*Stateful filtering*, an advanced filtering technique, tracks session context in addition to session state. Stateful filtering involves analyzing individual data packets in the traffic flow and monitoring information regarding the application protocol in addition to the contents of the packet header and payload. The term ‘stateful’ signifies the ability to remember the connection status. Also known as "Stateful Multilevel Inspection", this allows protocol-specific monitoring of even connectionless protocols like UDP, NFS and RPC.

### 2.4.6 Proxy Filtering

*Proxy filtering* uses proxy servers or application gateways to act as mediators between the source and the destination systems. Since all communication between the two hosts is controlled, this provides a simple and effective defense against port abuse.

### 2.4.7 Plug Gateways

*Plug gateways* use stripped-down proxies that are not application-specific. They allow connectivity for specified ports and the traffic control is based on the principle of dynamic packet filtering.

### 2.4.8 Port Address Translation

*Port address translation* routes incoming packets to pre-defined private IP addresses on the local network based on the port number-service mapping. This strategy can be used to foil specific port-based attacks.

### 2.4.9 Traffic Management

*Traffic management*, also known as bandwidth management, helps in identifying traffic on a port-by-port basis and allows implementation of policies to detect and control port abuse. Not only can traffic be denied to specific ports but the acceptable volume of traffic can also be specified for any port. Traffic management can also be achieved by regulating traffic flow on the basis of applications or protocols.

# CHAPTER 3

# BANDWIDTH MANAGEMENT

This section of the thesis is broadly divided into three subsections—Goals, Preliminaries, and Bandwidth Management. While the first subsection is a formal statement of the goals of this thesis, the second subsection deals with the infrastructure issues associated with the tools used for conducting the research. The third subsection describes the methodology followed and lessons learnt.

## 3.1 Goals

The goal of this thesis was to study bandwidth management techniques. This thesis describes the lessons learnt as part of this study. The task involved was divided into two subtasks with the following goals:

(a) Identify and minimize the use of excessive bandwidth by non-critical and undesirable applications (application-adaptive strategy)

(b) Monitor bandwidth use to minimize port abuse and flow of malicious data (rogue traffic on legitimate ports)

## 3.2 Preliminaries

This section, which deals with the preliminaries, is divided into three subsections—'Background study', 'Data Collection Tools' and 'Monitoring Station'. While the first part gives a brief overview of the background study, the second part describes the various tools used for data collection along with the rationale for their selection. The third part deals with the network configuration aspects of the traffic monitoring station and the PacketShaper settings.

### 3.2.1 Background study

The primary sources for the background study were the websites, http://citeseer.nj.nec.com/cs and http://www.sans.org and ACM and USENIX journals. Other frequently visited security related web sites included http://www.neohapsis.com, http://www.dshield.org, http://www.insecure.org, http://www.securityfocus.com, and http://www.incidents.org. While work has been done in the field of Quality of Service (QOS) and network bandwidth management based on traffic classification, no study was found that concentrated on application adaptive bandwidth management or that measured desirable vs. undesirable bandwidth in a university setting. Most professional organizations have a clearly defined set of "topics of professional interest". However, a university setting is unique in the sense that given the wide variety of courses taught, the topics of "professional interest" cover almost everything, thus making it difficult to clearly classify traffic into 'desirable' and 'undesirable' parts based only on the topic content. Also, a typical university network is more prone to exploitation by students using P2P file swapping services and other applications that subject the network to a considerable risk of Trojans and other malicious code.

### 3.2.2 Data Collection Tools

Data collection for the current thesis involved the use of various tools such as the PacketShaper system, PacketPup, Network Probe, Ethereal, Active Ports and the Action Request System software. The selection of the tools was influenced by financial considerations. In the absence of any specially allotted funds, an effort was made to optimally use the existing infrastructure. While PacketShaper and the Action Request System were part of ETSU's existing infrastructure, all the other tools used were freeware, thereby keeping the budgetary overheads to a bare minimum.

### 3.2.2.1 PacketShaper

Packeteer's PacketShaper system consists of a combination of hardware and software components. ETSU has the PacketShaper 2500 hardware console and the associated software version presently being used is 5.3. PacketShaper supports application-adaptive bandwidth management across enterprise WANs and can be used for controlling inbound as well as outbound traffic. As part of this thesis, the PacketShaper tool was used extensively to monitor and analyze bandwidth utilization on the campus network. The PacketShaper client, being web–based, is platform independent. PacketShaper is used actively by OIT for assuring quality of service to the network users. The policies are regularly reviewed since requirements often change with the discovery of new threats and vulnerabilities. Findings of this thesis served as an input parameter fo r the choice of strategy adopted while using the PacketShaper.

### 3.2.2.2 Active Ports

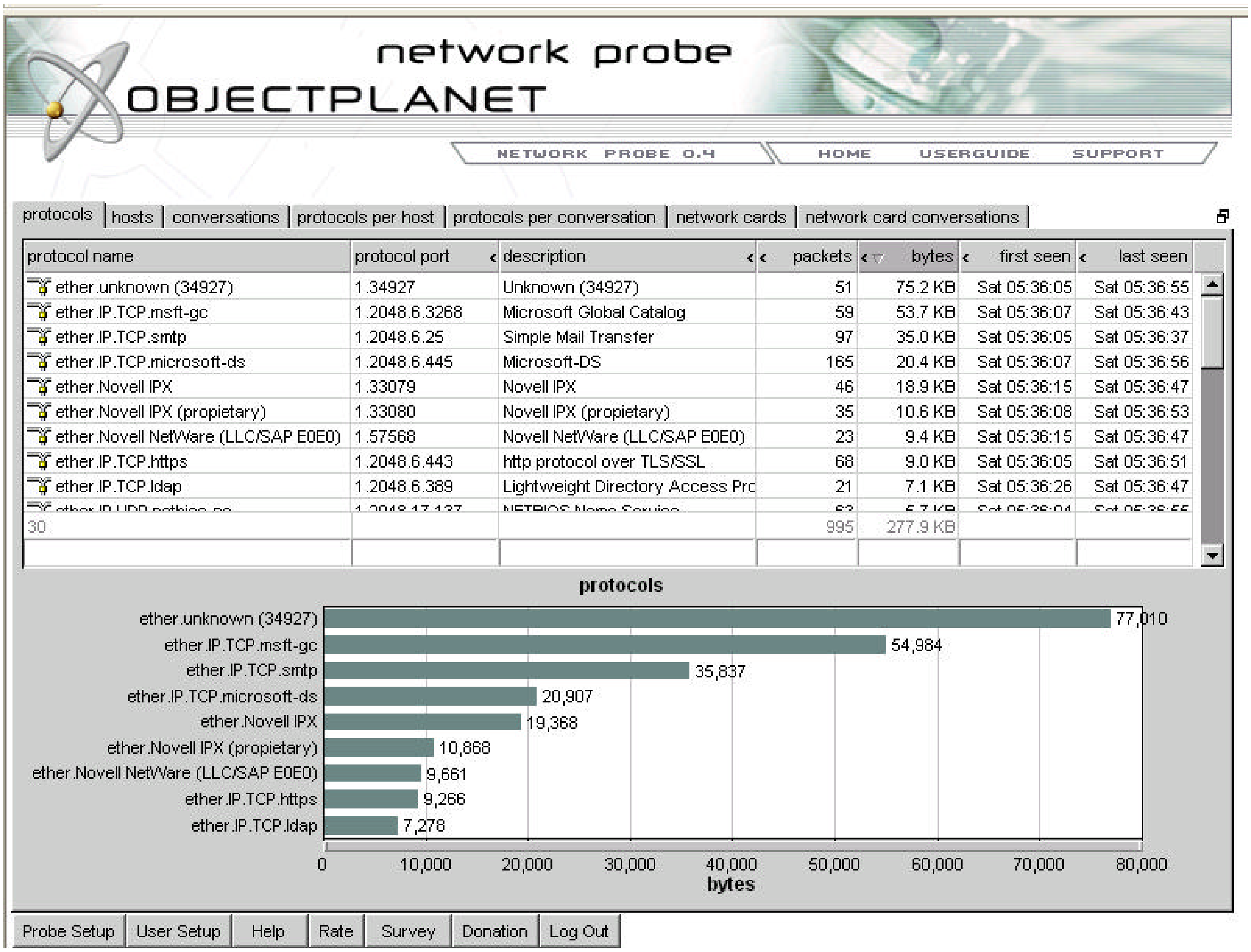
SmartLine Inc's Active Ports version 1.4 is a freeware tool designed for the Windows NT/2000/XP platform. It was used extensively to monitor all open TCP and UDP ports on the local host. Active Ports displays all active connections on the host along with the IP addresses and port numbers of both the connection endpoints. It also facilitates monitoring applications on the basis of that application's associated ports. This helps in identifying open ports associated with Trojans or other vulnerabilities and allows its user to terminate suspect processes.

#### 3.2.2.3 PacketPup

Palisade systems' PacketPup version 2.2 is a limited-time freeware trial package. PacketPup is a bandwidth-monitoring tool that aids in detecting P-2-P file-sharing or streaming media traffic on the network. PacketPup's biggest drawback is its lack of support for controlling traffic. PacketPup was used to verify the classification-effectiveness of PacketShaper.

#### 3.2.2.4 Network Probe 0.4

Network Probe version 0.4 from Object Planet is a freeware protocol analyzer and network traffic monitoring tool. Network Probe was used to identify and track rogue traffic in real-time, and to obtain information about the network interface cards (NICs) of the communicating hosts. A sample screen shot depicting real-time network analysis using Network Probe is shown in figure 3.1.



| protocol name | protocol port | description | packets | bytes | first seen | last seen |
|---|---|---|---|---|---|---|
| ether.unknown (34927) | 1.34927 | Unknown (34927) | 51 | 75.2 KB | Sat 05:36:05 | Sat 05:36:55 |
| ether.IP.TCP.msft-gc | 1.2048.6.3268 | Microsoft Global Catalog | 59 | 53.7 KB | Sat 05:36:07 | Sat 05:36:43 |
| ether.IP.TCP.smtp | 1.2048.6.25 | Simple Mail Transfer | 97 | 35.0 KB | Sat 05:36:05 | Sat 05:36:37 |
| ether.IP.TCP.microsoft-ds | 1.2048.6.445 | Microsoft-DS | 165 | 20.4 KB | Sat 05:36:07 | Sat 05:36:56 |
| ether.Novell IPX | 1.33079 | Novell IPX | 46 | 18.9 KB | Sat 05:36:15 | Sat 05:36:47 |
| ether.Novell IPX (propietary) | 1.33080 | Novell IPX (propietary) | 35 | 10.6 KB | Sat 05:36:08 | Sat 05:36:53 |
| ether.Novell NetWare (LLC/SAP E0E0) | 1.57568 | Novell NetWare (LLC/SAP E0E0) | 23 | 9.4 KB | Sat 05:36:15 | Sat 05:36:47 |
| ether.IP.TCP.https | 1.2048.6.443 | http protocol over TLS/SSL | 68 | 9.0 KB | Sat 05:36:05 | Sat 05:36:51 |
| ether.IP.TCP.ldap | 1.2048.6.389 | Lightweight Directory Access Prc | 21 | 7.1 KB | Sat 05:36:26 | Sat 05:36:47 |
| ether.IP.UDP.netbios-ns | 1.2048.17.137 | NETBIOS Name Service | 63 | 5.7 KB | Sat 05:36:04 | Sat 05:36:55 |
| 30 | | | 995 | 277.9 KB | | |

Figure 3.1: Network Probe in Action

### 3.2.2.5 Ethereal

Ethereal is a free network protocol analyzer for the Unix and Windows platforms. Ethereal version 0.9.7 was used to monitor network traffic in real time to identify rogue and undesirable traffic streams. Ethereal allows access to detailed traffic information on a packet-by-packet level. It was used extensively to reconstruct the traffic stream for different TCP sessions to allow a detailed investigation of the traffic contents. Ethereal's cost, together with its broad support for a wide variety of hardware and software platforms, cross-platform compatibility of data files and its powerful network analysis capabilities made it the protocol analyzer of choice for this thesis. At present Ethereal claims to be able to successfully “dissect” 366 protocols. A detailed list of these protocols is given in Appendix A.

#### 3.2.2.6 Action Request System

The Action Request System (ARS) is a Service Management utility marketed by Remedy Corporation. OIT uses ARS version 4.05.02 for managing its helpdesk services and inventory management functions. ARS was used in this work to help identify the various hosts on the campus network.

#### 3.2.2.7 McAfee’s GroupShield Exchange 5.0 Enterprise Suite

GroupShield Exchange 5.0 Enterprise Suite consists of three components. The first, GroupShield, is a network based content filtering and anti-virus package with built in support for Microsoft’s Virus Scanning API. The second, ePolicy Orchestrator (ePO), facilitates centralized protection from malicious threats that include known exploits and malicious scripts aimed at subverting a network. The last, Outbreak Manager contains outbreaks of new viruses by monitoring network activity for malicious outbreak patterns.

### 3.2.3 Monitoring station

A monitoring station was set up for primary data collection at the OIT data center in Lucille Clement Hall. The station consisted of two computers at different topological positions on the ETSU network. One, a Windows 2000 platform, served as a network normal host. The other, a Redhat Linux 8.2 box positioned outside the firewall and the packet-shaper, afforded access to the entire incoming network traffic before it encountered any perimeter access control or security device. I had started with two different operating systems to allow flexibility in selecting the best possible tools. This monitoring port is represented by a ‘star’ symbol as shown in Figure 3.2, depicting a part of the ETSU network’s topology.

A brief summary of PacketShaper settings is given below:

Table 3.1: Summary of PacketShaper settings

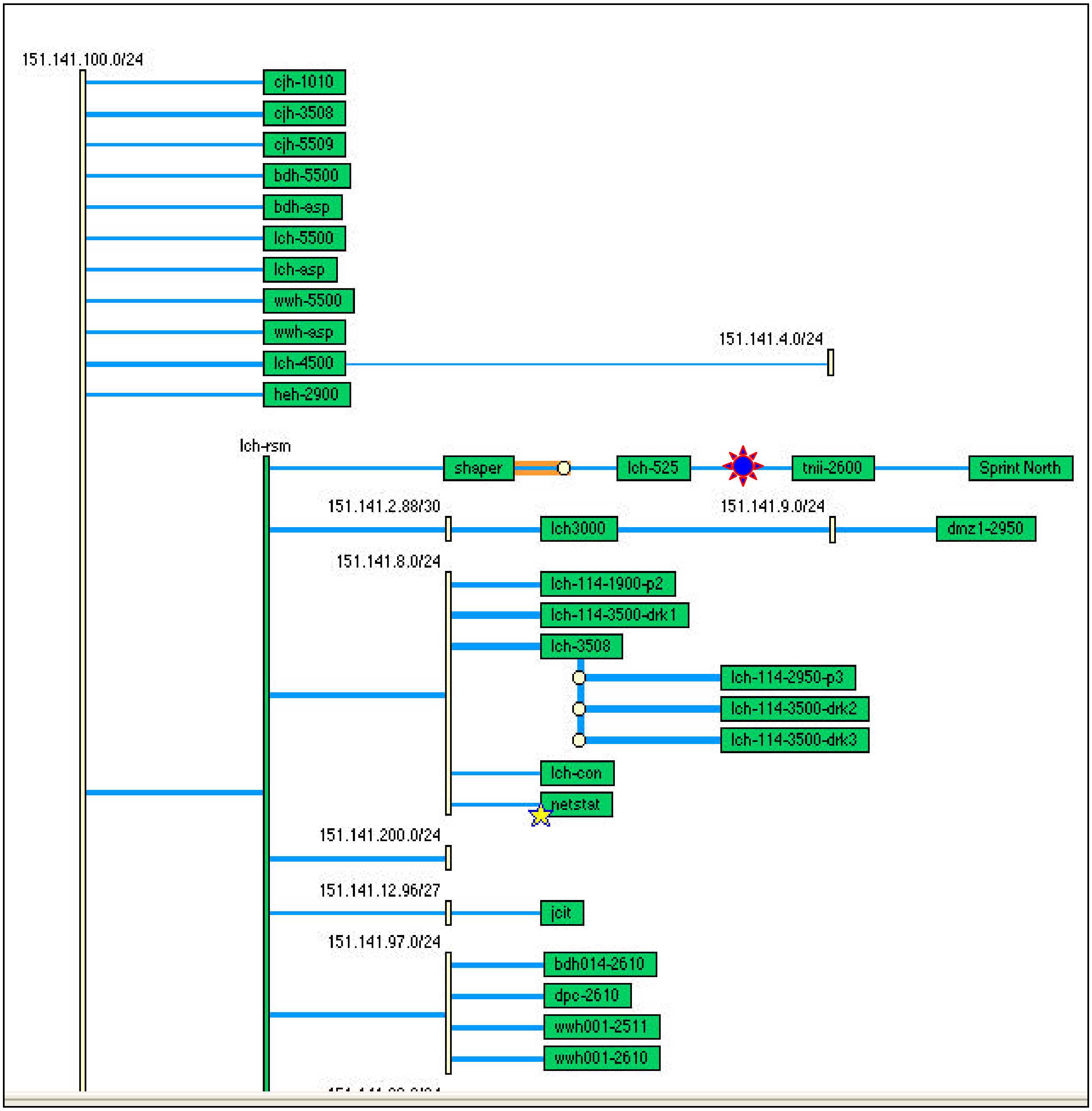
| **Non-sharable (local) settings:** | | **Sharable settings:** | |
|---|---|---|---|
| IP address: | 151.141.95.3 | Site router: | 151.141.95.2 |
| Subnet mask: | 255.255.255.0 | Link speed: | 9264k |
| Gateway: | 151.141.95.1 | Packet shaping: | on |
| DNS server(s): | 151.141.8.100 | Traffic discovery: | on |
| Default domain: | etsu.edu | Automatic policy: | off |
| Inside nic speed: | 100BaseT full-duplex | | |
| Outside nic speed: | 100BaseT full-duplex | | |

## 3.3 Bandwidth Management

Section 3.3 describes the methodology for achieving real-time bandwidth management. The process was divided into three distinct stages—classification of the network traffic, analysis and interpretation of the classified traffic, and enforcement of management policies.

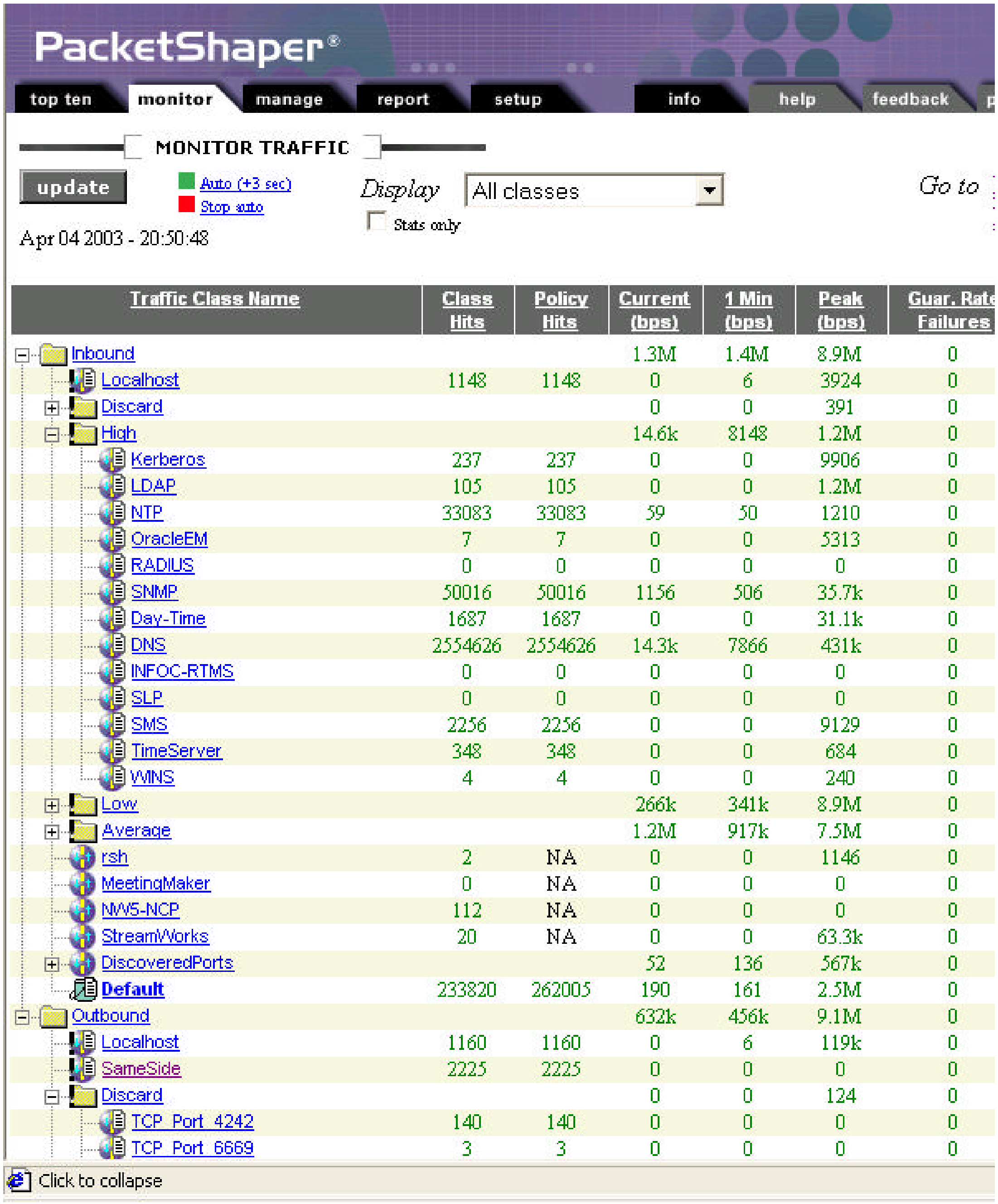
### 3.3.1 Classification of the Network Traffic

A detailed analysis of the network traffic is a prerequisite for achieving efficient bandwidth management. To aid this analysis, the entire network traffic was classified in real time, using PacketShaper, into distinct categories or classes. The classification was achieved using 'matching rules' to identify different types of traffic in the network stream. Depending on requirements, the matching rules were configured to classify data on the basis of, port number, protocol family, application / service, and web attributes. When a certain traffic flow satisfied a particular matching rule, a corresponding entry was added to the classification tree. A typical hierarchical traffic tree depicting the various classes is shown in the figure 3.3.



Sprint North: ISP
TNII-2600: Connection to the Tennessee Information Infrastructure (service provider for Tennessee state organizations).
✹ : Monitoring Station
LCH-525: Cisco PIX 525 Firewall
Shaper: Packeteer’s PacketShaper 2500 Hardware console.

Figure 3.2: Position of the Monitoring Station



🟩 Auto (+3 sec)
🟥 Stop auto

Display: All classes

□ Stats only

Apr 04 2003 - 20:50:48

| Traffic Class Name | Class Hits | Policy Hits | Current (bps) | 1 Min (bps) | Peak (bps) | Guar. Rate Failures |
|---|---|---|---|---|---|---|
| Inbound | | | 1.3M | 1.4M | 8.9M | 0 |
| Localhost | 1148 | 1148 | 0 | 6 | 3924 | 0 |
| Discard | | | 0 | 0 | 391 | 0 |
| High | | | 14.6k | 8148 | 1.2M | 0 |
| Kerberos | 237 | 237 | 0 | 0 | 9906 | 0 |
| LDAP | 105 | 105 | 0 | 0 | 1.2M | 0 |
| NTP | 33083 | 33083 | 59 | 50 | 1210 | 0 |
| OracleEM | 7 | 7 | 0 | 0 | 5313 | 0 |
| RADIUS | 0 | 0 | 0 | 0 | 0 | 0 |
| SNMP | 50016 | 50016 | 1156 | 506 | 35.7k | 0 |
| Day-Time | 1687 | 1687 | 0 | 0 | 31.1k | 0 |
| DNS | 2554626 | 2554626 | 14.3k | 7866 | 431k | 0 |
| INFOC-RTMS | 0 | 0 | 0 | 0 | 0 | 0 |
| SLP | 0 | 0 | 0 | 0 | 0 | 0 |
| SMS | 2256 | 2256 | 0 | 0 | 9129 | 0 |
| TimeServer | 348 | 348 | 0 | 0 | 684 | 0 |
| WINS | 4 | 4 | 0 | 0 | 240 | 0 |
| Low | | | 266k | 341k | 8.9M | 0 |
| Average | | | 1.2M | 917k | 7.5M | 0 |
| rsh | 2 | NA | 0 | 0 | 1146 | 0 |
| MeetingMaker | 0 | NA | 0 | 0 | 0 | 0 |
| NW5-NCP | 112 | NA | 0 | 0 | 0 | 0 |
| StreamWorks | 20 | NA | 0 | 0 | 63.3k | 0 |
| DiscoveredPorts | | | 52 | 136 | 567k | 0 |
| **Default** | 233820 | 262005 | 190 | 161 | 2.5M | 0 |
| Outbound | | | 632k | 456k | 9.1M | 0 |
| Localhost | 1160 | 1160 | 0 | 6 | 119k | 0 |
| SameSide | 2225 | 2225 | 0 | 0 | 0 | 0 |
| Discard | | | 0 | 0 | 124 | 0 |
| TCP_Port_4242 | 140 | 140 | 0 | 0 | 0 | 0 |
| TCP_Port_6669 | 3 | 3 | 0 | 0 | 0 | 0 |

Figure 3.3: Typical Hierarchical Network Traffic Classification Tree

*Port-based classification* classifies Layer 4 traffic by port number or port number range. The use of ranges helps in identifying and restricting traffic directed at undesirable port numbers. It also helps in measuring the volume of traffic directed at commonly used well-known ports.

*Protocol based classification* classifies traffic by protocol type. PacketShaper[36] supports traffic classification based on transport protocol (viz. TCP and UDP) as well as protocol family, such as IP, SNA, Net BIOS, AppleTalk, and IPX etc. This classification was of tremendous value for managing bandwidth on the basis of protocols used.

*Application-adaptive classification* uses Layer 7 application signatures to identify a communication's participating applications. While protocol-based and port-based traffic classification is helpful for standard applications using static-port assignments, the strategy falls short for applications using non-standard ports or dynamically negotiated ports. This sort of tracking is supported by PacketShaper's ability to track traffic with migrating port-assignments, and to use application-specific identifier to differentiate among applications using the same port number. Examples of applications using dynamically negotiable ports include passive FTP, AOL instant messaging, and peer-to-peer file sharing applications like KaZaA, Gnutella, and Napster. Another example of application-adaptive classification for applications using the same port (port # 23) include differentiating traffic streams for TN3270 and TN5250 data from other Telnet traffic. Application-adaptive classification can also isolate different types of traffic for a single application based on different matching rules. This application sub-classification allows separation of Oracle netv2 traffic based on version (Oracle 7 Vs Oracle 8i/9i), as well as participating database. Similarly VoIP data can be sub-classified based on CODEC. Packeteer claims that PacketShaper can classify more than 150 types of traffic streams. A complete list of applications, protocols and services classified[37] by PacketShaper is placed in Appendix B.

*Web Classification* was motivated by the initial indication that Web-directed HTTP traffic consumed the bulk of ETSU's network bandwidth. In order to differentiate desirable and undesirable traffic, various identifying attributes such as IP addresses, subnets, URLs, server location, mime type, HTTP tunnel, and traffic direction (inbound vs. outbound) were used for finer classification. This facilitated identification of mission-critical traffic from entertainment-oriented media traffic using HTTP. Streaming media data uses the real-time protocol (RTP), which uses various identifying attributes such as the media type (audio vs. video), the encoding name and the clock rate. With the help of these identifying attributes, a very fine classification of the network traffic is possible.

### 3.3.2 Analysis and Interpretation

An initial traffic analysis of the ETSU network, conducted in August 2002, was used to identify the top ten types of consumers of ETSU network bandwidth, relative to average flow, peak flow, and total volume of traffic. Network traffic trends were monitored on almost a daily (except weekends) basis. Any knowledge of new vulnerabilities or increased network transaction delays prompted an analysis of host-level bandwidth usage for the affected traffic class. The host analysis thus formed a secondary step used for precision-tuning the bandwidth allocation. The top talkers (originators of network traffic) and listeners (recipients of network traffic) were identified over different time intervals. Sample data showing the DNS name, IP address and percentage bandwidth usage for the top users of outbound FTP and the pcAnywhere remote monitoring application is shown in tables 3.2 through 3.5.

Table 3.2: Top sending IP hosts in class /Outbound/Low/FTP

| Top Talkers | | | |
|---|---|---|---|
| | **DNS Name** | **IP Address** | **Usage** |
| 1 | infoserv | 151.141.8.184 | 26% |
| 2 | ftp | 151.141.8.164 | 11% |
| 3 | antivirus | 151.141.8.167 | 5% |
| 4 | techweb | 151.141.48.21 | 5% |

|  |  |  |  |
|---|---|---|---|
| 5 | webserv | 151.141.8.154 | 3% |
| 6 | casanetn | 151.141.8.172 | 3% |
| 7 | cscidbw | 151.141.30.36 | 2% |
| 8 | ats | 151.141.30.127 | <1% |
| 9 | qcom | 151.141.8.171 | <1% |
| 10 | Server refused request | 151.141.56.101 | <1% |

Table 3.3: Top receiving IP hosts in class /Outbound/Low/FTP

| **Top Listeners** |  |  |  |
|---|---|---|---|
|  | **DNS Name** | **IP Address** | **Usage** |
| 1 | No such name | 216.145.70.254 | 9% |
| 2 | ool-182f71d9.dyn.optonline.net | 24.47.113.217 | <1% |
| 3 | 62-101-125-229.fastres.net | 62.101.125.229 | <1% |
| 4 | pcp03046746pcs.grey01.tn.comcast.net | 68.62.247.7 | <1% |
| 5 | No such name | 205.227.136.41 | <1% |
| 6 | jc-c-24-158-136-55.chartertn.net | 24.158.136.55 | <1% |
| 7 | hosting.web-axis.net | 216.127.80.46 | <1% |
| 8 | morristown-68-118-102-92.chartertn.net | 68.118.102.92 | <1% |
| 9 | No such name | 161.69.201.238 | <1% |
| 10 | No such name | 161.69.201.237 | <1% |

Table 3.4: Top sending IP hosts in class /Outbound/Average/pcANYWHERE

| **Top Talkers** |  |  |  |
|---|---|---|---|
|  | **DNS Name** | **IP Address** | **Usage** |
| 1 | yan | 151.141.55.207 | 83% |
| 2 | krish | 151.141.55.172 | 13% |
| 3 | housing | 151.141.8.177 | <1% |
| 4 | blackboard | 151.141.8.51 | <1% |
| 5 | einstein | 151.141.30.144 | <1% |
| 6 | Server refused request | 151.141.28.215 | <1% |
| 7 | etsu81240 | 151.141.55.159 | <1% |
| 8 | etsu82375 | 151.141.60.233 | <1% |
| 9 | wrl-voyager | 151.141.112.103 | <1% |

Table 3.5: Top receiving IP hosts in class /Outbound/Average/pcANYWHERE

| Top Listeners | | | |
|---|---|---|---|
| | **DNS Name** | **IP Address** | **Usage** |
| 1 | p50862209.dip0.t-ipconnect.de | 80.134.34.9 | <1% |
| 2 | acaen-105-1-6-114.abo.wanadoo.fr | 81.48.27.114 | <1% |
| 3 | host241-107.pool80117.interbusiness.it | 80.117.107.241 | <1% |
| 4 | pd9e3d083.dip.t-dialin.net | 217.227.208.131 | <1% |
| 5 | host157-174.pool80116.interbusiness.it | 80.116.174.157 | <1% |
| 6 | 213-208-104-231.dyn.gotadsl.co.uk | 213.208.104.231 | <1% |
| 7 | pd9e7e1ec.dip.t-dialin.net | 217.231.225.236 | <1% |
| 8 | 198.knoxville-05rh16rt-ca.dial-access.att.net | 12.93.225.198 | <1% |
| 9 | 42.knoxville-04rh15rt-ca.dial-access.att.net | 12.93.222.42 | <1% |
| 10 | No such name | 209.126.214.41 | <1% |

### 3.3.3 Enforcement of Management Policies

Management strategies used included implementation of application-based traffic flow policies. These policies allowed assured levels of bandwidth for desirable traffic, while restricting undesirable traffic flows. The various policy types employed were priority, flow rate, discard, and ignore.

*Priority policies* were used to assign priority levels for various traffic classes. PacketShaper priorities range from 0 (minimum priority) to 7 (maximum priority) with a default of 3. Assigning priority policies are most suitable for non-continuous or short, unpredictable, non-IP traffic such as RADIUS authentication, Telnet, and DNS queries.

*Flow rate policies* were used to assign a minimum acceptable flow-rate for specific traffic classes. Using the 'burstable at priority' feature of flow rate policies grants applications higher-than-minimum assigned bandwidth subject to availability. If all assigned classes already have their minimum flow rate and more bandwidth is available, then individual class-priority becomes the deciding factor for distribution of excess bandwidth. Flow rate policies also allow the setting of a limit on the maximum acceptable bandwidth for different traffic classes. Flow rate policies are most suitable for bursty IP-based traffic such as FTP and HTTP as well as for latency-sensitive applications such as Voice over IP. These policies were implemented using PacketShaper's proprietary TCP rate-control technology.

*The discard policy* was used to discard all packets from pre-identified, non-desirable traffic classes. This policy must be applied with care to managing session-oriented TCP, since the resulting time-outs will delay feedback to the user. An alternative policy, *never-admit*, enforces flow control at the entry point while informing the user immediately whenever certain traffic is blocked. Traffic classes that are presently being blocked on the ETSU network using 'discard' include TCP_Port_4242, TCP_Port_6669, Audiogalaxy, CUSeeMe, Doom, eDonkey, Gnutella, IRC, KaZaA, Napster, Net2Phone, Quake, Unreal, Webshots, YahooGames, Battle.net, Blubster, Mythic, and SonyOnline.

*The ignore policy* classifies traffic that should be ignored, but nevertheless measured. ’Ignore’ traffic is typically pass-through traffic that does not affect the bandwidth at routers and other access points of interest for a particular network. On the ETSU network, currently outbound DHCP and RIP traffic is being ignored.

In addition to these five policies, partitions were used to allocate bandwidth among the competing tasks. A partition is a virtual-pipe-like mechanism that can assure a pre-defined bandwidth capacity for any particular traffic class. Like policies, partitions assure minimum required bandwidth for desirable traffic classes while restricting bandwidth for undesirable classes. Unlike policies, partitions are typically used for aggregate traffic classes.

Partitions can also be fixed or burstable. While a fixed partition always allows a pre-defined amount of bandwidth, a burstable partition allows a class to use any excess bandwidth available over and above the pre-defined amount of bandwidth set for that class. The ETSU network uses a burstable partition of 2kbps size for inbound as well as outbound ICMP traffic:

irrespective of the amount of network traffic, a minimum of 2kbps of bandwidth is always set aside specifically for ICMP. Monitoring ICMP traffic is of utmost importance as many denial of service (DOS) attacks extensively use ICMP services.

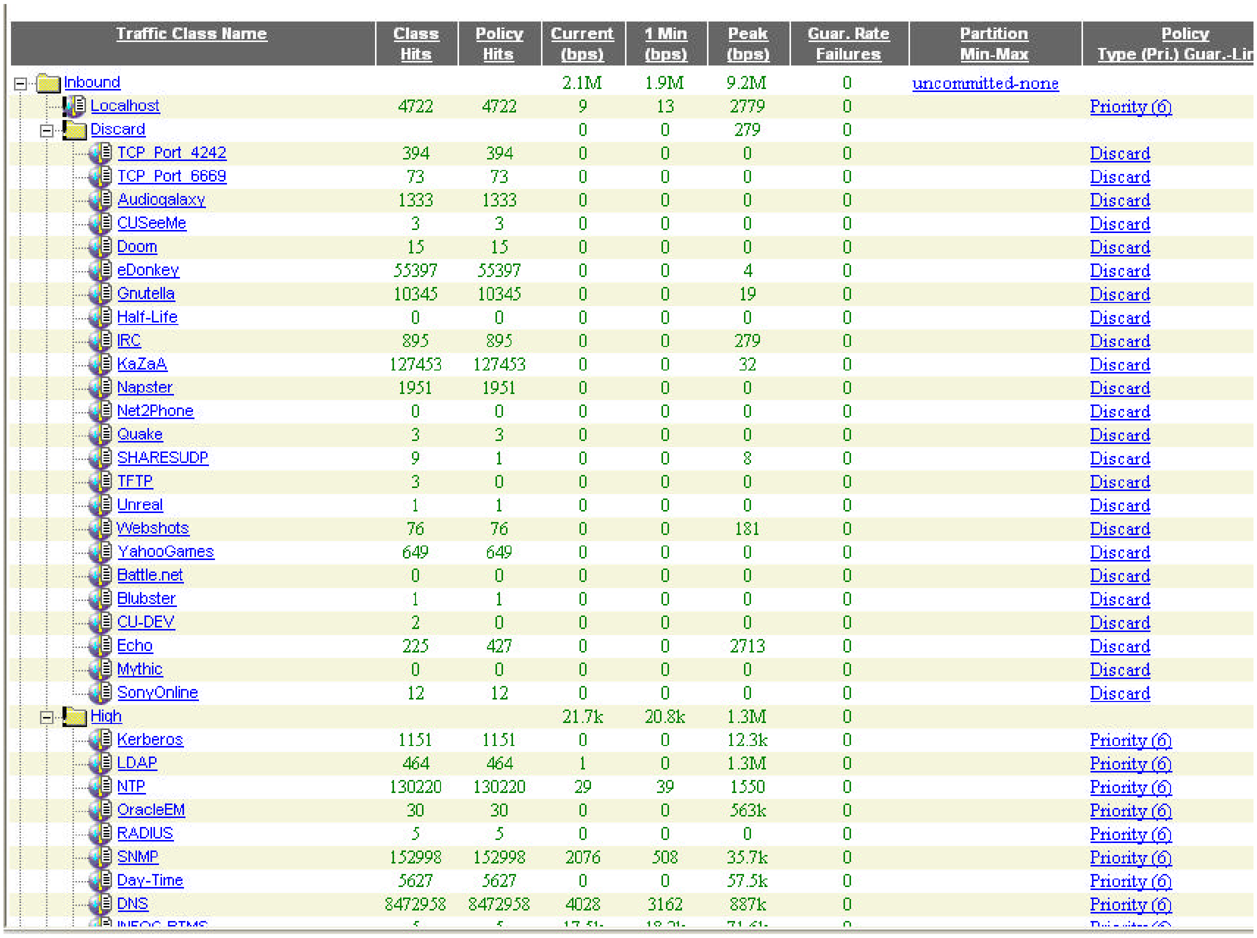
Table 3.6 shows the partition summary for ICMP traffic as implemented on the ETSU network.

Table 3.6: Partition Summary for ICMP Traffic

| Partition | | | Dynamic sub partition | | | |
|---|---|---|---|---|---|---|
| **Name** | **Size-Limit** | **Current Guar./Excess** | **Size-Limit** | **Current Active/Idle** | **Max** | **Overflow** |
| **/Inbound** | Uncommitted-none | 0/9.2M | - | - | - | - |
| **/Inbound/Average/ICMP** | 2000-none | 0/0 | - | - | - | - |
| **/Inbound Max Total** | 2k-none | 0/0 | - | 0/0 | 0 | - |
| **/Outbound** | Uncommitted-none | 0/9.1M | - | - | - | - |
| **/Outbound/Average/ICMP** | 2000-none | 0/0 | - | - | - | - |
| **/Outbound Max Total** | 2k-none | 0/0 | - | 0/0 | 0 | - |

### 3.3.3.1 Feedback-Oriented Fine-Tuning

Subsequent to the implementation of various policies and partitions, ETSU network bandwidth utilization was analyzed by studying various parameters such as the number of class hits, the number of policy hits, and the current as well as peak values for the rate of flow of traffic (in bps) for different traffic classes. A typical screen shot used for monitoring these parameters is shown in the Figure 3.4.



| Traffic Class Name | Class Hits | Policy Hits | Current (bps) | 1 Min (bps) | Peak (bps) | Guar. Rate Failures | Partition Min-Max | Policy Type (Pri.) Guar.-Li |
|---|---|---|---|---|---|---|---|---|
| Inbound | | | 2.1M | 1.9M | 9.2M | 0 | uncommitted-none | |
| Localhost | 4722 | 4722 | 9 | 13 | 2779 | 0 | | Priority (6) |
| Discard | | | 0 | 0 | 279 | 0 | | |
| TCP_Port_4242 | 394 | 394 | 0 | 0 | 0 | 0 | | Discard |
| TCP_Port_6669 | 73 | 73 | 0 | 0 | 0 | 0 | | Discard |
| Audiogalaxy | 1333 | 1333 | 0 | 0 | 0 | 0 | | Discard |
| CUSeeMe | 3 | 3 | 0 | 0 | 0 | 0 | | Discard |
| Doom | 15 | 15 | 0 | 0 | 0 | 0 | | Discard |
| eDonkey | 55397 | 55397 | 0 | 0 | 4 | 0 | | Discard |
| Gnutella | 10345 | 10345 | 0 | 0 | 19 | 0 | | Discard |
| Half-Life | 0 | 0 | 0 | 0 | 0 | 0 | | Discard |
| IRC | 895 | 895 | 0 | 0 | 279 | 0 | | Discard |
| KaZaA | 127453 | 127453 | 0 | 0 | 32 | 0 | | Discard |
| Napster | 1951 | 1951 | 0 | 0 | 0 | 0 | | Discard |
| Net2Phone | 0 | 0 | 0 | 0 | 0 | 0 | | Discard |
| Quake | 3 | 3 | 0 | 0 | 0 | 0 | | Discard |
| SHARESUDP | 9 | 1 | 0 | 0 | 8 | 0 | | Discard |
| TFTP | 3 | 0 | 0 | 0 | 0 | 0 | | Discard |
| Unreal | 1 | 1 | 0 | 0 | 0 | 0 | | Discard |
| Webshots | 76 | 76 | 0 | 0 | 181 | 0 | | Discard |
| YahooGames | 649 | 649 | 0 | 0 | 0 | 0 | | Discard |
| Battle.net | 0 | 0 | 0 | 0 | 0 | 0 | | Discard |
| Blubster | 1 | 1 | 0 | 0 | 0 | 0 | | Discard |
| CU-DEV | 2 | 0 | 0 | 0 | 0 | 0 | | Discard |
| Echo | 225 | 427 | 0 | 0 | 2713 | 0 | | Discard |
| Mythic | 0 | 0 | 0 | 0 | 0 | 0 | | Discard |
| SonyOnline | 12 | 12 | 0 | 0 | 0 | 0 | | Discard |
| High | | | 21.7k | 20.8k | 1.3M | 0 | | |
| Kerberos | 1151 | 1151 | 0 | 0 | 12.3k | 0 | | Priority (6) |
| LDAP | 464 | 464 | 1 | 0 | 1.3M | 0 | | Priority (6) |
| NTP | 130220 | 130220 | 29 | 39 | 1550 | 0 | | Priority (6) |
| OracleEM | 30 | 30 | 0 | 0 | 563k | 0 | | Priority (6) |
| RADIUS | 5 | 5 | 0 | 0 | 0 | 0 | | Priority (6) |
| SNMP | 152998 | 152998 | 2076 | 508 | 35.7k | 0 | | Priority (6) |
| Day-Time | 5627 | 5627 | 0 | 0 | 57.5k | 0 | | Priority (6) |
| DNS | 8472958 | 8472958 | 4028 | 3162 | 887k | 0 | | Priority (6) |
| INFOC_RTMS | 5 | 5 | 17.5k | 18.2k | 71.6k | 0 | | Priority (6) |

Figure 3.4: Class Hits, Policy Hits and Traffic Volume for Different Classes

All traffic that generated interesting parametric values was then studied in depth. The shaping policy effectiveness was studied. The criteria used were comparison of expected and actual outcome for a particular traffic class on the basis of its associated policy. For example, it was found that a particular faculty host machine was persistently connected to the Kazaa file-swapping service for more than 36 hours in a particular session. The traffic measurements indicated that the entire traffic for this class was being discarded before it reached the host. Since the discard policy had been associated with Kazaa, this actual measurement was consistent the expected outcome and indicated that this particular policy implementation achieved its goal. Similarly, if the flow rate policy were assigned to a particular traffic class, the shaping effectiveness would be determined by measuring whether the minimum flow rate as specified by the policy was indeed available for that traffic class. Other parameters examined included network efficiency, average and peak rate, class and partition utilization, utilization with peaks, transaction delays, response time, and bytes transmitted for a particular class, partition or a link. This data was collected over various time intervals (hourly, daily, weekly, and monthly) depending on the required precision of the sampling frequency and the total observation time-period for any particular class. An observation interval range of 1 to 7 days will have a sampling frequency of one hour whereas the same would be one minute for an observation interval of less than 24 hours. Sample screenshots shown in Figures 3.5 and 3.6 depict the outbound as well as inbound traffic patterns for average and peak flow rates for a typical month during fall semester, 2002. Hourly, daily, and weekly graphs for the corresponding period are in Appendix C.

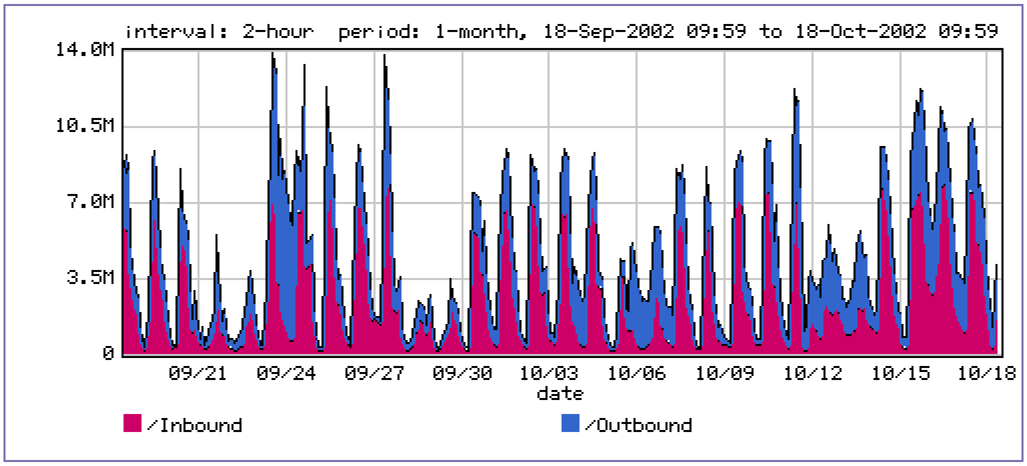


Figure 3.5: Monthly Average Rate (from 18 Sep 2002 to 18 Oct 2002)

The distribution curve in Figure 3.5 indicates a dip in the average traffic rate for both inbound as well as outbound traffic on Sep 21, 22, 28, and 29, and on Oct 5, 6,12, and 13, 2002. All these dates correspond to weekends and the decreased flow rate is thus easily explained.

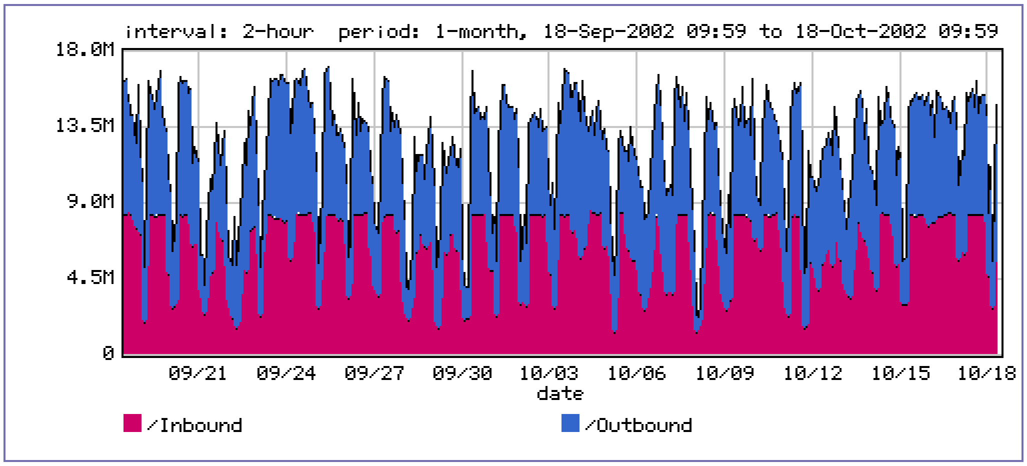


Figure 3.6: Monthly Peak Rate (from 18 Sep 2002 to 18 Oct 2002)

The distribution curve in Figure 3.6 shows less variance throughout the entire month. This is an indication of the stability of the packet shaping wherein the peak flow rates are maintained at an almost similar level irrespective of the actual volume of traffic encountered.

The inbound as well as outbound network utilization and efficiency curves along with the top ten classes for 17-18 Oct 2002 are shown below in Figures 3.7 through 3.12. During this time period (24 hours), the total inbound traffic was 44917399 Kbytes whereas the total outbound traffic was 21853781 Kbytes. The corresponding data for hourly, weekly and monthly time intervals is in Appendix D.

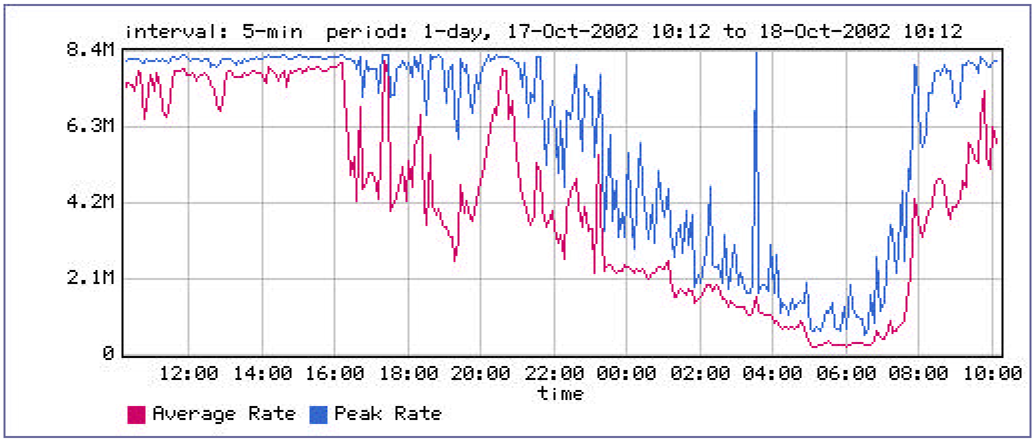


Figure 3.7: Inbound Utilization (from 17 Oct 2002 to 18 Oct 2002)

The inbound link utilization as shown above indicates the lean period for the average rate (in bits per second) to be from midnight to 8:00 AM. This was expected.

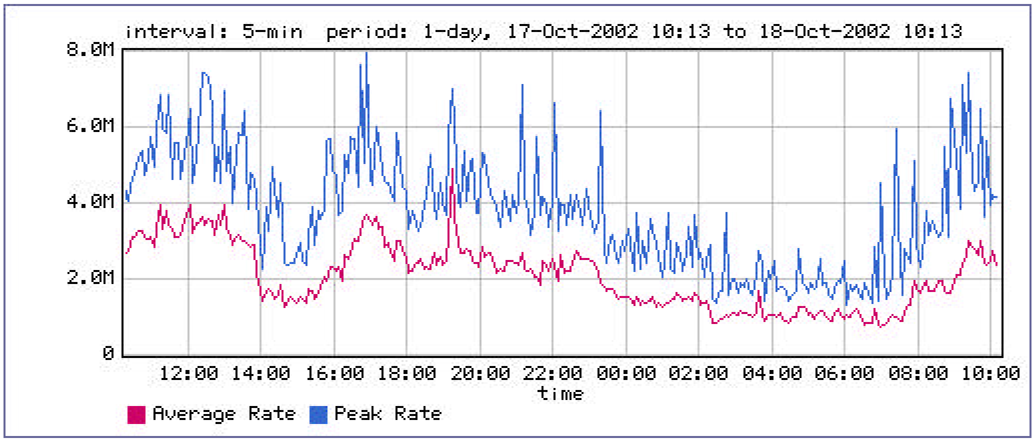


Figure 3.8: Outbound Utilization (from 17 Oct 2002 to 18 Oct 2002)

Unlike for inbound utilization, the outbound network utilization curve indicates that the severity of the dips is much less. The average rate rises around 7:00PM, when the campus computer labs have most students. Also, the relative dip in the average outbound rate is predominant from 2:00 AM to 8:00 AM—the exact time when the student computer labs are shut.

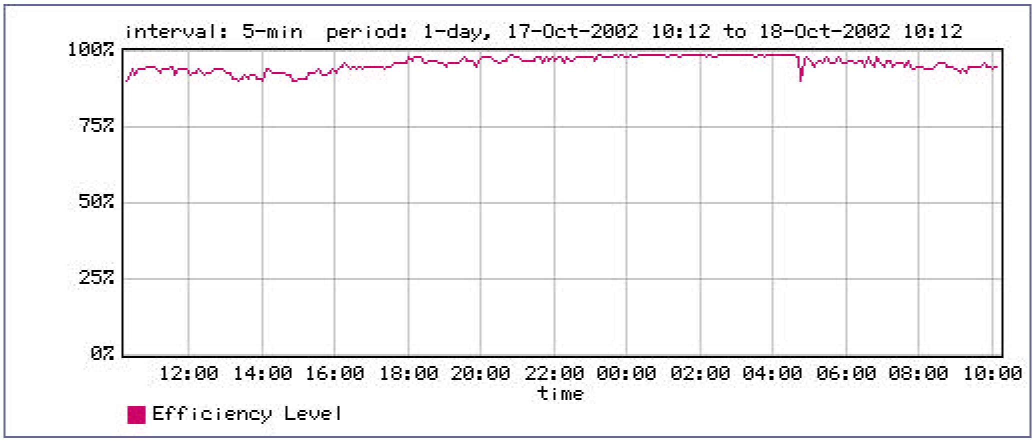


Figure 3.9: Inbound Network Efficiency (from 17 Oct 2002 to 18 Oct 2002)

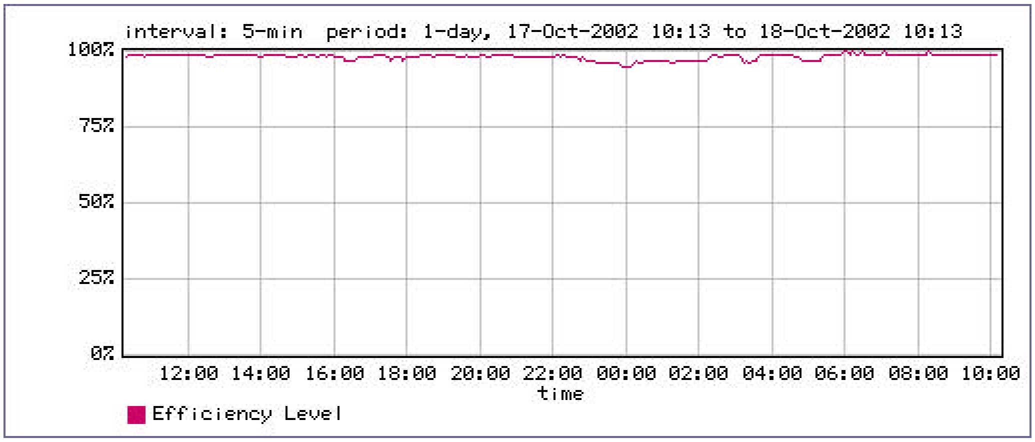
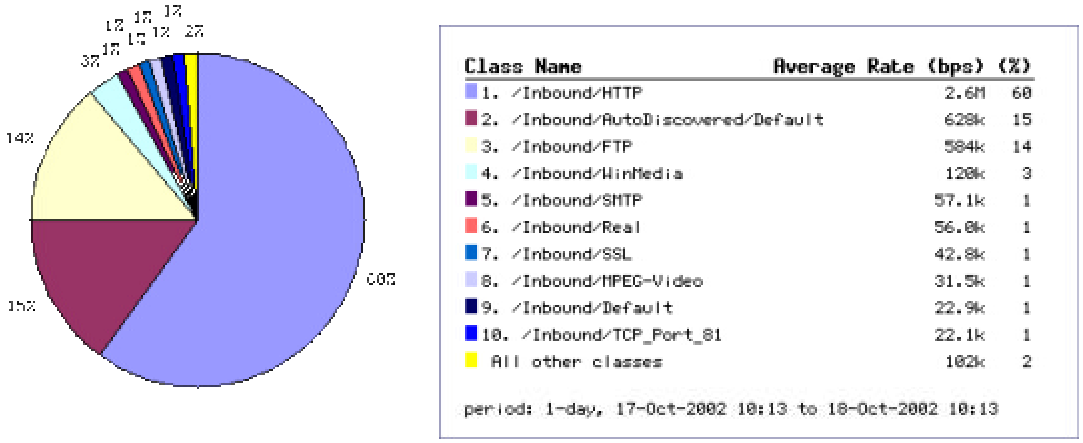


Figure 3.10: Outbound Network Efficiency (from 17 Oct 2002 to 18 Oct 2002)

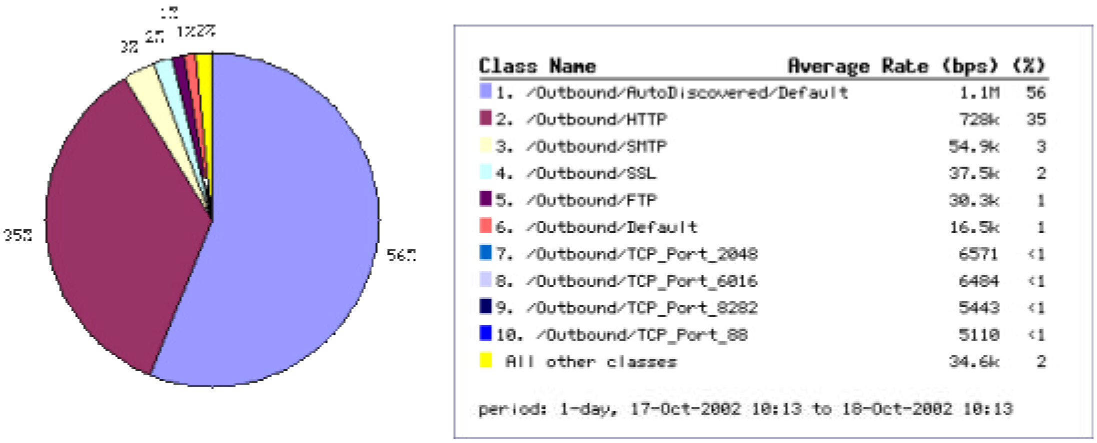
The network efficiency curves show the percentage of packets that are properly transmitted in the first attempt itself. The dips in the efficiency curve indicate retransmissions as well as lost packets. The efficiency level is calculated as a value = (Total bytes - Retransmitted bytes) / Total bytes and then expressed in percentage. These curves can thus be used as broad indicators of the network's health.



| Class Name | Average Rate (bps) | (%) |
|---|---|---|
| 1. /Inbound/HTTP | 2.6M | 60 |
| 2. /Inbound/AutoDiscovered/Default | 628k | 15 |
| 3. /Inbound/FTP | 584k | 14 |
| 4. /Inbound/WinMedia | 120k | 3 |
| 5. /Inbound/SMTP | 57.1k | 1 |
| 6. /Inbound/Real | 56.0k | 1 |
| 7. /Inbound/SSL | 42.8k | 1 |
| 8. /Inbound/MPEG-Video | 31.5k | 1 |
| 9. /Inbound/Default | 22.9k | 1 |
| 10. /Inbound/TCP_Port_81 | 22.1k | 1 |
| All other classes | 102k | 2 |

period: 1-day, 17-Oct-2002 10:13 to 18-Oct-2002 10:13

Figure 3.11: Inbound Top 10 Classes (from 17 Oct 2002 to 18 Oct 2002)



|  | Class Name | Average Rate (bps) | (%) |
|---|---|---|---|
| ■ | 1. /Outbound/AutoDiscovered/Default | 1.1M | 56 |
| ■ | 2. /Outbound/HTTP | 728k | 35 |
| ■ | 3. /Outbound/SMTP | 54.9k | 3 |
| ■ | 4. /Outbound/SSL | 37.5k | 2 |
| ■ | 5. /Outbound/FTP | 30.3k | 1 |
| ■ | 6. /Outbound/Default | 16.5k | 1 |
| ■ | 7. /Outbound/TCP_Port_2048 | 6571 | <1 |
| ■ | 8. /Outbound/TCP_Port_6016 | 6484 | <1 |
| ■ | 9. /Outbound/TCP_Port_8282 | 5443 | <1 |
| ■ | 10. /Outbound/TCP_Port_80 | 5110 | <1 |
| ■ | All other classes | 34.6k | 2 |

period: 1-day, 17-Oct-2002 10:13 to 18-Oct-2002 10:13

Figure 3.12: Outbound Top 10 Classes (from 17 Oct 2002 to 18 Oct 2002)

For the 24-hour period under consideration, the top ten inbound and outbound classes by percentage volume of traffic and their average flow rate in bits per second is shown in Figures 3.11 and 3.12.

The application response time data for the outbound AOL-IM-ICQ traffic class based on 24 hour time period from 24 Oct 2002 to 25 Oct 2002 can be studied using the transaction delay curves as well as the histograms depicting the distribution of the transaction delay for that class. These two graphs are shown in the figures 3.13 and 3.14.

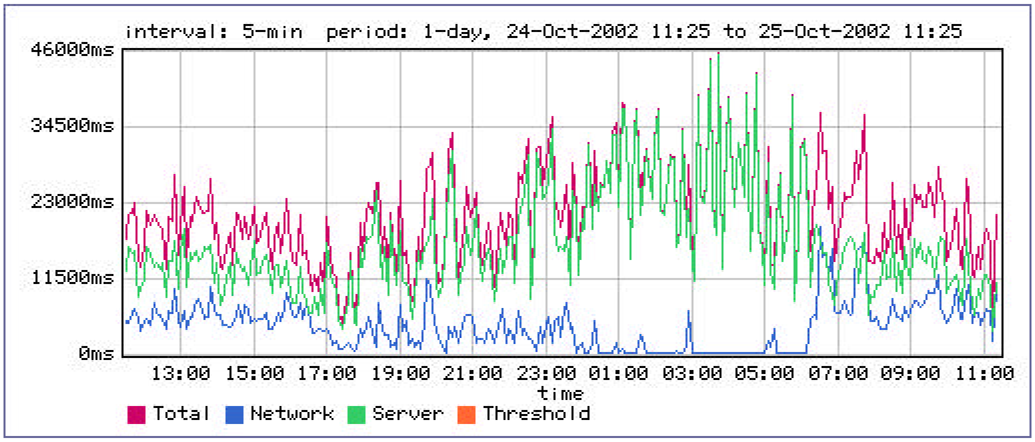


Figure 3.13: Transaction Delay

The graph in Figure 3.13 represents a timeline of the average response time (in ms) for the outbound AOL-IM-ICQ traffic class over a 24-hour period. Pink, blue and green lines indicate the total, network and server transaction delays. Any sudden or drastic increase in the transaction delays for traffic classes indicates possible bandwidth congestion on that link. The sampling frequency used in this graph is 5 minutes.

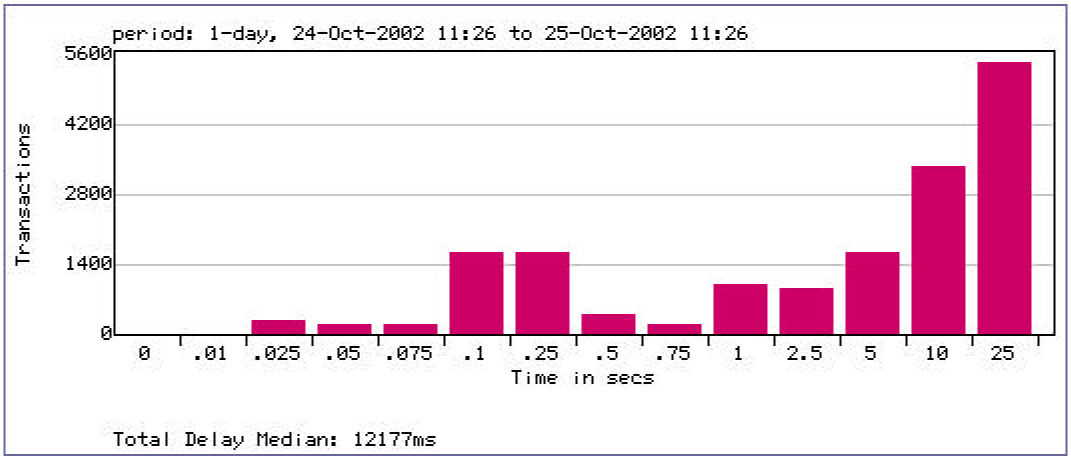


Figure 3.14: Transaction Delay Distribution

The transaction delay distribution histogram is based on 14 distinct categories (ranging from 0 to 25 seconds) of response times plotted against the frequency of transaction delays in each category. The median delay value (12177 ms) is indicative of the actual transaction delay experienced by most network hosts. This use of a median value, as opposed to an average value, gives a more realistic indication in the event of a few extreme values.

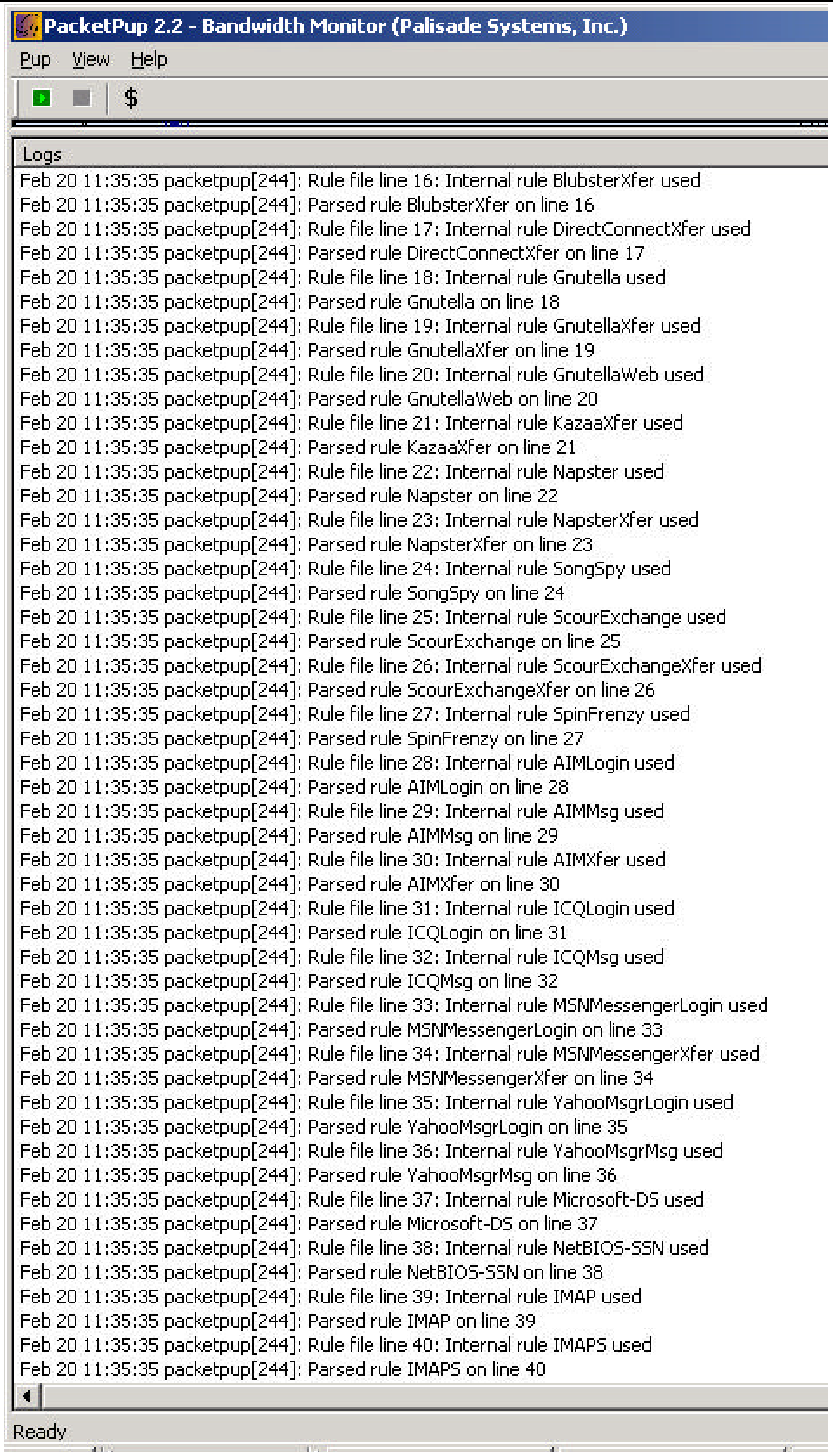
Inputs based on traffic monitoring and other relevant data such as discovery of new vulnerabilities or threats were used to tweak policies for all desirable traffic classes until a minimum of 99% flow rate efficiency was achieved. The detailed traffic tree as on 01 April 2003 is given in Appendix E.

### 3.3.4 Data Integrity Verification

PacketShaper data was verified using a second, independent utility, PacketPup. Verification involved checking whether PacketShaper correctly identified bandwidth usage on a class-by-class basis. Discrepancies between the tools' classifications were attributable to PacketShaper's support for finer degrees of traffic classification (see Appendix F for a detailed list of protocols and services recognized by PacketPup). For example, PacketShaper divides SNMP traffic, which PacketPup classifies as one stream, into distinct classes such as SNMP Mon (monitor) and SNMP Trap (traps). PacketShaper can also subclassify the traffic for the game "Quake" depending on the transport protocol used (TCP or UDP) or the game's version. A sample screenshot depicting the parsing of the various rules by PacketPup is shown in figure 3.15. Sample log file data showing the identification of various protocols in the network traffic using PacketPup is placed in Appendix G.

### 3.3.5 Non-Standard Traffic

Neither PacketShaper nor PacketPup detects non-standard, rogue traffic in standard traffic flow. This rogue traffic includes non-standard traffic on standard ports that cannot be classified further on the basis of standard traffic-identifying attributes. Identification of non-standard traffic in standard channels of data exchange is important as there are certain ports that cannot be blocked even if they are known Trojan ports, since they are required for certain basic standard services. A step-by-step analysis of sample data is given below to illustrate the use of Network Probe 0.4 for identifying rogue traffic directed at standard ports. This analysis was carried on a 'Friday night–early Saturday morning' session as that is one of the most preferred times for students on the campus network to generate undesirable traffic.



```
Feb 20 11:35:35 packetpup[244]: Rule file line 16: Internal rule BlubsterXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule BlubsterXfer on line 16
Feb 20 11:35:35 packetpup[244]: Rule file line 17: Internal rule DirectConnectXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule DirectConnectXfer on line 17
Feb 20 11:35:35 packetpup[244]: Rule file line 18: Internal rule Gnutella used
Feb 20 11:35:35 packetpup[244]: Parsed rule Gnutella on line 18
Feb 20 11:35:35 packetpup[244]: Rule file line 19: Internal rule GnutellaXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule GnutellaXfer on line 19
Feb 20 11:35:35 packetpup[244]: Rule file line 20: Internal rule GnutellaWeb used
Feb 20 11:35:35 packetpup[244]: Parsed rule GnutellaWeb on line 20
Feb 20 11:35:35 packetpup[244]: Rule file line 21: Internal rule KazaaXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule KazaaXfer on line 21
Feb 20 11:35:35 packetpup[244]: Rule file line 22: Internal rule Napster used
Feb 20 11:35:35 packetpup[244]: Parsed rule Napster on line 22
Feb 20 11:35:35 packetpup[244]: Rule file line 23: Internal rule NapsterXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule NapsterXfer on line 23
Feb 20 11:35:35 packetpup[244]: Rule file line 24: Internal rule SongSpy used
Feb 20 11:35:35 packetpup[244]: Parsed rule SongSpy on line 24
Feb 20 11:35:35 packetpup[244]: Rule file line 25: Internal rule ScourExchange used
Feb 20 11:35:35 packetpup[244]: Parsed rule ScourExchange on line 25
Feb 20 11:35:35 packetpup[244]: Rule file line 26: Internal rule ScourExchangeXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule ScourExchangeXfer on line 26
Feb 20 11:35:35 packetpup[244]: Rule file line 27: Internal rule SpinFrenzy used
Feb 20 11:35:35 packetpup[244]: Parsed rule SpinFrenzy on line 27
Feb 20 11:35:35 packetpup[244]: Rule file line 28: Internal rule AIMLogin used
Feb 20 11:35:35 packetpup[244]: Parsed rule AIMLogin on line 28
Feb 20 11:35:35 packetpup[244]: Rule file line 29: Internal rule AIMMsg used
Feb 20 11:35:35 packetpup[244]: Parsed rule AIMMsg on line 29
Feb 20 11:35:35 packetpup[244]: Rule file line 30: Internal rule AIMXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule AIMXfer on line 30
Feb 20 11:35:35 packetpup[244]: Rule file line 31: Internal rule ICQLogin used
Feb 20 11:35:35 packetpup[244]: Parsed rule ICQLogin on line 31
Feb 20 11:35:35 packetpup[244]: Rule file line 32: Internal rule ICQMsg used
Feb 20 11:35:35 packetpup[244]: Parsed rule ICQMsg on line 32
Feb 20 11:35:35 packetpup[244]: Rule file line 33: Internal rule MSNMessengerLogin used
Feb 20 11:35:35 packetpup[244]: Parsed rule MSNMessengerLogin on line 33
Feb 20 11:35:35 packetpup[244]: Rule file line 34: Internal rule MSNMessengerXfer used
Feb 20 11:35:35 packetpup[244]: Parsed rule MSNMessengerXfer on line 34
Feb 20 11:35:35 packetpup[244]: Rule file line 35: Internal rule YahooMsgrLogin used
Feb 20 11:35:35 packetpup[244]: Parsed rule YahooMsgrLogin on line 35
Feb 20 11:35:35 packetpup[244]: Rule file line 36: Internal rule YahooMsgrMsg used
Feb 20 11:35:35 packetpup[244]: Parsed rule YahooMsgrMsg on line 36
Feb 20 11:35:35 packetpup[244]: Rule file line 37: Internal rule Microsoft-DS used
Feb 20 11:35:35 packetpup[244]: Parsed rule Microsoft-DS on line 37
Feb 20 11:35:35 packetpup[244]: Rule file line 38: Internal rule NetBIOS-SSN used
Feb 20 11:35:35 packetpup[244]: Parsed rule NetBIOS-SSN on line 38
Feb 20 11:35:35 packetpup[244]: Rule file line 39: Internal rule IMAP used
Feb 20 11:35:35 packetpup[244]: Parsed rule IMAP on line 39
Feb 20 11:35:35 packetpup[244]: Rule file line 40: Internal rule IMAPS used
Feb 20 11:35:35 packetpup[244]: Parsed rule IMAPS on line 40
```

Figure 3.15: PacketPup in Action

#### 3.3.5.1 Step I: Initiate Network Probe

This step involved configuring the network probe application and the local client to monitor data flow on a given network. This data was tabulated as shown below to divide the traffic stream on the basis of protocols. The details include the protocol's name, the IANA assigned number for the protocol-port combination, the protocol's description, the number of packets transmitted, the number of bytes in the traffic and each flow's start and end time. An example for interpreting the protocol port column is depicted by selecting the corresponding value from the first row. Here, the number 1.2048.6.443 denotes the following:

1 == Ethernet

2048 == (0x0800) or IP

6 == TCP

443 == the port number for the HTTPS protocol (HTTP over TLS/SSL)

Table 3.7 below shows the entire traffic at the monitoring point.

Table 3.7: Network Traffic Flow Data

| Protocol Name | Protocol Port | Description | Packets | Bytes | First Seen | Last Seen |
|---|---|---|---|---|---|---|
| ether.IP.TCP.https | 1.2048.6.443 | http protocol over TLS/SSL | 2868 | 366946 | Fri 23:34:23 | Fri 23:42:34 |
| ether.Novell IPX | 1.33079 | Novell IPX | 813 | 361167 | Fri 23:34:23 | Fri 23:42:29 |
| ether.Novell NetWare (LLC/SAP E0E0) | 1.57568 | Novell NetWare (LLC/SAP E0E0) | 406 | 179933 | Fri 23:34:23 | Fri 23:42:29 |
| ether.unknown (34927) | 1.34927 | Unknown (34927) | 490 | 739900 | Fri 23:34:23 | Fri 23:42:33 |
| ether.ARP | 1.2054 | ARP | 541 | 32442 | Fri 23:34:23 | Fri 23:42:31 |
| ether.IP.TCP.pop3s | 1.2048.6.995 | pop3 protocol over TLS/SSL (was spop3) | 224 | 15334 | Fri 23:34:23 | Fri 23:41:54 |
| ether.IP.TCP.smtp | 1.2048.6.25 | Simple Mail Transfer | 10143 | 11120362 | Fri 23:34:23 | Fri 23:42:32 |
| ether.IP.UDP.kerberos | 1.2048.17.88 | Kerberos | 143 | 192010 | Fri 23:34:25 | Fri 23:42:32 |
| ether.IP.TCP.ldap | 1.2048.6.389 | Lightweight Directory Access Protocol | 270 | 173354 | Fri 23:34:25 | Fri 23:42:32 |
| ether.PCS Basic Block Protocol | 1.16962 | PCS Basic Block Protocol | 245 | 14700 | Fri 23:34:24 | Fri 23:42:33 |
| ether.IP.TCP.msft-gc | 1.2048.6.3268 | Microsoft Global Catalog | 465 | 462637 | Fri 23:34:24 | Fri 23:42:32 |
| ether.IP.UDP.ldap | 1.2048.17.389 | Lightweight Directory Access Protocol | 8 | 1642 | Fri 23:34:24 | Fri 23:41:02 |
| ether.IP.UDP.netbios-ns | 1.2048.17.137 | NETBIOS Name Service | 136 | 12680 | Fri 23:34:24 | Fri 23:42:33 |
| ether.IP.ICMP | 1.2048.1 | Internet Control Message [RFC792] | 170 | 8793 | Fri 23:34:24 | Fri 23:42:24 |

|  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|
| ether.IP.TCP.pop3 | 1.2048.6.110 | Post Office Protocol - Version 3 | 94 | 41796 | Fri 23:34:24 | Fri 23:41:49 |
| ether.unknown (34925) | 1.34925 | Unknown (34925) | 922 | 55320 | Fri 23:34:24 | Fri 23:42:34 |
| ether.IP.TCP.domain | 1.2048.6.53 | Domain Name Server | 260 | 19303 | Fri 23:34:31 | Fri 23:42:32 |
| ether.IP.UDP.bootps | 1.2048.17.67 | Bootstrap Protocol Server | 54 | 20244 | Fri 23:34:30 | Fri 23:42:31 |
| ether.IP.ESP | 1.2048.50 | Encapsulating Security Payload [RFC1827] | 3181 | 4429190 | Fri 23:34:29 | Fri 23:42:33 |
| ether.IP.UDP.anarchy-online | 1.2048.17.7500 | Anarchy Online | 31 | 3726 | Fri 23:34:28 | Fri 23:41:58 |
| ether.IP.OSPFIGP | 1.2048.89 | OSPFIGP [RFC1583,JTM4] | 44 | 3432 | Fri 23:34:27 | Fri 23:42:25 |
| ether.IP.UDP.netbios-dgm | 1.2048.17.138 | NETBIOS Datagram Service | 62 | 15084 | Fri 23:34:26 | Fri 23:42:13 |
| ether.Novell IPX (propietary) | 1.3308 | Novell IPX (propietary) | 533 | 197750 | Fri 23:34:25 | Fri 23:42:33 |
| ether.IP.EIGRP | 1.2048.88 | EIGRP [CISCO,GXS] | 212 | 15688 | Fri 23:34:25 | Fri 23:42:34 |
| ether.DEC LAT | 1.2458 | DEC LAT | 16 | 1872 | Fri 23:34:45 | Fri 23:42:19 |
| ether.IP.TCP.nntp | 1.2048.6.119 | Network News Transfer Protocol | 48 | 3456 | Fri 23:34:41 | Fri 23:41:41 |
| ether.IP.UDP.mdns | 1.2048.17.5353 | Multicast DNS | 1 | 130 | Fri 23:34:35 | Fri 23:34:35 |
| ether.IP.TCP.www-http | 1.2048.6.80 | World Wide Web HTTP | 247 | 28563 | Fri 23:34:32 | Fri 23:42:32 |
| ether.IP.TCP.imaps | 1.2048.6.993 | imap4 protocol over TLS/SSL | 199 | 18690 | Fri 23:34:32 | Fri 23:42:32 |
| ether.unknown (417) | 1.417 | Unknown (417) | 25 | 1500 | Fri 23:34:55 | Fri 23:42:15 |
| ether.unknown (418) | 1.418 | Unknown (418) | 25 | 1500 | Fri 23:34:55 | Fri 23:42:15 |
| ether.IP.TCP.msexch-routing | 1.2048.6.691 | MS Exchange Routing | 2 | 108 | Fri 23:34:54 | Fri 23:39:54 |
| ether.IP.UDP.svrloc | 1.2048.17.427 | Server Location | 8 | 728 | Fri 23:35:08 | Fri 23:35:40 |
| ether.IP.UDP.domain | 1.2048.17.53 | Domain Name Server | 22 | 2806 | Fri 23:35:00 | Fri 23:42:30 |
| ether.IP. UDP.snmp | 1.2048.17.161 | SNMP | 24 | 6976 | Fri 23:35:22 | Fri 23:42:22 |
| ether.unknown (8192) | 1.8192 | Unknown (8192) | 8 | 2904 | Fri 23:35:17 | Fri 23:42:17 |
| ether.IP.TCP.imap | 1.2048.6.143 | Internet Message Access Protocol | 110 | 12800 | Fri 23:35:13 | Fri 23:42:13 |
| ether.IP.TCP.netbios-ssn | 1.2048.6.139 | NETBIOS Session Service | 47 | 43165 | Fri 23:36:27 | Fri 23:38:18 |
| ether.IP.TCP.microsoft-ds | 1.2048.6.445 | Microsoft-DS | 132 | 26562 | Fri 23:36:27 | Fri 23:42:20 |
| ether.IP.TCP.trellisagt | 1.2048.6.2077 | TrelliSoft Agent | 21 | 5639 | Fri 23:36:27 | Fri 23:36:27 |
| ether.IP.TCP.epmap | 1.2048.6.135 | DCE endpoint resolution | 16 | 1540 | Fri 23:36:27 | Fri 23:36:46 |
| ether.IP.TCP.unknown | 1.2048.6.-1 | Unknown | 10 | 5924 | Fri 23:36:46 | Fri 23:40:05 |
| ether.DEC MOP Remote Console | 1.24578 | DEC MOP Remote Console | 2 | 2298 | Fri 23:36:55 | Fri 23:38:53 |
| ether.IP.UDP.unknown (42342) | 1.2048.17.42342 | Unknown (42342) | 1 | 118 | Fri 23:39:00 | Fri 23:39:00 |
| ether.IP.UDP.isakmp | 1.2048.17.500 | isakmp | 3 | 482 | Fri 23:41:23 | Fri 23:41:26 |
| ether.IP.UDP.bootpc | 1.2048.17.68 | Bootstrap Protocol Client | 4 | 1368 | Fri 23:41:01 | Fri 23:41:25 |

A study of the above traffic shows incoming traffic on port 119 (as highlighted above) using the Network News Transfer Protocol. As listed in the websites mentioned in section 2.1.1.2.1, port 119 is a known target port of the Trojan ‘Happy99’. According to the CERT® Incident Note[38] IN-99-02, the ‘Happy99’ Trojan is known to have a number of aliases such as

SKA, Win32.ska.a, Ska.exe, Wsock32.ska, I-worm.Happy, PE_SKA, Happy, and W32/Skanew and affects the Microsoft Windows family of Operating Systems. The worm includes the files[39] Happy99.exe (or Happy00.exe) of size exactly 10,000 bytes, Ska.exe, Ska.dll, Wsock32.dll, and Liste.ska. Happy99.exe displays fireworks[40] in a window titled "Happy New Year 1999" (cf. Figure 3.16), while infecting WSOCK32.dll and modifying the registry in the background. Once the system is infected, a message with the subject 'HAPPY99' or 'HAPPY00' and with a uuencoded attachment of the Happy99.exe file is sent to all email and Usenet addresses that receive mail from the infected system. The file 'liste.ska' keeps track of all the addresses to which the Trojan is sent from a particular host. Other symptoms[41] of Happy99 infection include the possibility of the following error messages encountered while attempting to transmit information on the Internet:

(i) "Outlook caused an Invalid Page Fault in module Unknown"
(ii) "Explorer caused an invalid page fault in module Mailnews.dll at 014f: 62060a0f"
(iii) "MSIMN caused an invalid page fault in module unknown"
(iv) "MSIMN caused an invalid page fault in module Inetcomm.dll"
(v) "MSIMN caused an invalid page fault in module Kernel32.dll"

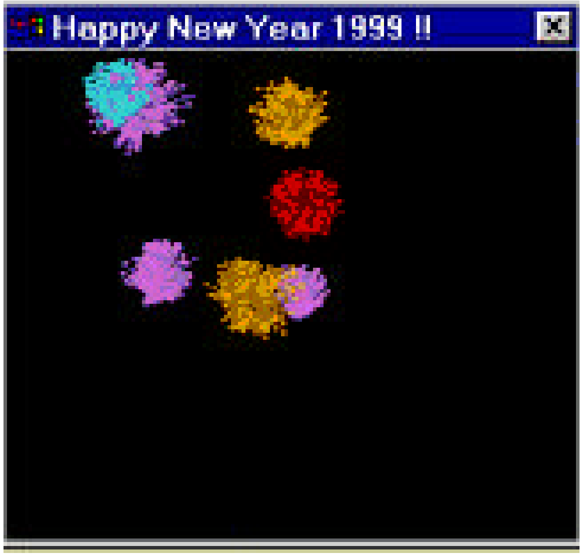


Fig 3.16: Execution of the Happy99 Trojan

### 3.3.5.2 Step II: Isolate Communication for Interesting Ports

The next step of the investigation identified ETSU hosts involved in conversations using NNTP. Host usage of port 119 was tabulated for all hosts actively using this port, as shown in Table 3.8. This table shows NNTP usage by mail.etsu.edu and netstat.etsu.edu. Mail.etsu.edu is an ETSU campus mail server that primarily services faculty and staff email traffic. Netstat.etsu.edu, an InterMapper server, provides a graphical representation of real-time traffic flow and aides in monitoring the health of the campus network.

Table 3.8: Hosts using NNTP

| Host Name | Address | Protocol | Packets In | Bytes In | Packets Out | Bytes Out | First Seen | Last Seen |
|---|---|---|---|---|---|---|---|---|
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.nntp | 94 | 8060 | 0 | 0 | Fri 23:34:41 | Fri 23:34:41 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.nntp | 0 | 0 | 94 | 8060 | Fri 23:34:41 | Fri 23:48:41 |

The information in the 'Packets/bytes in' and 'Packets/bytes out' indicates that netstat.etsu.edu is the source and mail.etsu.edu is the destination host.

### 3.3.5.3 Step III: Identification of Potential Secondary Target Ports

While Happy99 uses port 119, one of the versions uses port 25 if port 119 is unavailable. Port 25 is officially assigned to the Simple Mail Transfer Protocol for both TCP as well as UDP. In order to make a detailed analysis of the traffic flow and to rule out rogue data directed at secondary target ports, data was collected giving details of all the protocols used by the source as well as the destination hosts. This is tabulated in tables 3.9 and 3.10 respectively. This additional information (as highlighted below) was used to monitor traffic associated with SMTP.

Table 3.9: All Protocols used by source host (netstat.etsu.edu)

| Host Name | Address | Protocol | Packets In | Bytes In | Packets Out | Bytes Out | First Seen | Last Seen |
|---|---|---|---|---|---|---|---|---|
| netstat.etsu.edu | 151.141.8.57 | ether.IP.UDP.snmp | 0 | 0 | 72 | 20723 | Sat 00:00:23 | Sat 00:20:24 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.pop3s | 0 | 0 | 84 | 6888 | Sat 00:00:41 | Sat 00:20:41 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.nntp | 0 | 0 | 131 | 11236 | Sat 00:00:41 | Sat 00:20:41 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.UDP.bootps | 0 | 0 | 21 | 12684 | Sat 00:00:41 | Sat 00:20:41 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.imaps | 0 | 0 | 211 | 24923 | Sat 00:00:32 | Sat 00:20:32 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.smtp | 0 | 0 | 152 | 13252 | Sat 00:00:32 | Sat 00:20:34 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.TCP.www-http | 0 | 0 | 345 | 26684 | Sat 00:00:04 | Sat 00:20:32 |
| netstat.etsu.edu | 151.141.8.57 | ether.IP.UDP.svrloc | 0 | 0 | 12 | 1260 | Sat 00:05:32 | Sat 00:20:53 |
| netstat.etsu.edu | 151.141.8.57 | ether.ARP | 0 | 0 | 38 | 2280 | Sat 00:03:17 | Sat 00:19:59 |

Table 3.10: All Protocols used by destination host (mail.etsu.edu)

| Host Name | Address | Protocol | Packets In | Bytes In | Packets Out | Bytes Out | First Seen | Last Seen |
|---|---|---|---|---|---|---|---|---|
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.pop3s | 407 | 35009 | 0 | 0 | Sat 00:00:05 | Sat 00:00:05 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.nntp | 145 | 12428 | 0 | 0 | Sat 00:00:41 | Sat 00:00:41 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.smtp | 12217 | 14141882 | 0 | 0 | Sat 00:00:06 | Sat 00:00:06 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.https | 4294 | 610157 | 0 | 0 | Sat 00:00:04 | Sat 00:00:04 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.imaps | 500 | 54406 | 0 | 0 | Sat 00:00:32 | Sat 00:00:32 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.TCP.www-http | 465 | 38864 | 0 | 0 | Sat 00:00:04 | Sat 00:00:04 |
| mail.etsu.edu | 151.141.8.105 | ether.ARP | 5 | 300 | 0 | 0 | Sat 00:04:23 | Sat 00:04:23 |
| mail.etsu.edu | 151.141.8.105 | ether.IP.ICMP | 2 | 1612 | 0 | 0 | Sat 00:09:25 | Sat 00:09:25 |

#### 3.3.5.4 Step IV: Isolating Conversations from ‘Suspect’ Hosts

This step involved isolating all possible conversations originating from the ‘suspect’ host. This step gives all the destination hosts for the entire traffic from the source under investigation. It also helps in minimizing damage to the network when the source host is transmitting malicious data. This data is tabulated below in table 3.11.

Table 3.11: Conversations originating from netstat.etsu.edu

| Source Host | Source Address | Destination Host | Dest Address | Packets | Bytes | First Seen | Last Seen |
|---|---|---|---|---|---|---|---|
| netstat.etsu.edu | 151.141.8.57 | 151.141.8.255 | 151.141.8.255 | 4 | 2416 | Sat 00:00:41 | Sat 00:03:41 |
| netstat.etsu.edu | 151.141.8.57 | etsufe1.etsu.edu | 151.141.8.104 | 15 | 4570 | Sat 00:00:23 | Sat 00:04:23 |
| netstat.etsu.edu | 151.141.8.57 | mail.etsu.edu | 151.141.8.105 | 194 | 17056 | Sat 00:00:04 | Sat 00:04:16 |
| netstat.etsu.edu | 151.141.8.57 | 151.141.8.215 | 151.141.8.215 | 1 | 60 | Sat 00:03:17 | Sat 00:03:17 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| netstat.etsu.edu | 151.141.8.57 | etsusms | 151.141.8.58 | 1 | 60 | Sat 00:03:41 | Sat 00:03:41 |
| netstat.etsu.edu | 151.141.8.57 | calserv.etsu.edu | 151.141.8.155 | 1 | 60 | Sat 00:03:55 | Sat 00:03:55 |
| netstat.etsu.edu | 151.141.8.57 | softserv.etsu.edu | 151.141.8.175 | 1 | 60 | Sat 00:04:03 | Sat 00:04:03 |
| netstat.etsu.edu | 151.141.8.57 | ult01.etsu.edu | 151.141.8.45 | 1 | 60 | Sat 00:04:00 | Sat 00:04:00 |

Since Happy 99 spreads with the help of an attachment 10,000 bytes long, the check for a possible infection continued with a check of transmissions of more than 10,000 bytes from mail.etsu.edu. Using Ethereal, candidate traffic streams were reconstructed, then searched for the worm’s signature strings (Viz.”Happy99”, “Happy00”, “Is it a virus, a worm, a trojan?”, “ MOUT-MOUT Hybrid (c) Spanska 1999”, “Happy New Year 1999 !!”, “begin 644”, “Happy99.exe”, “ \Ska.exe”, “\liste.ska”, “\wsock32.dll”, “\Ska.dll”, and “\Ska.exe”). A negative result indicated that the NNTP traffic originating from netstat.etsu.edu with the destination host, as mail.etsu.edu did not have the Happy99 worm.

### 3.3.5.5 Step V: Target Host Investigation

Though the traffic from netstat.etdu.edu to mail.etsu.edu seemed to be clear, the above data did not rule out the possibility of simultaneous exploitation of multiple vulnerabilities in a system resulting in the use of a spoofed IP address or a compromised host (or launching pad) for sending the payload after dynamically changing the target port number. This motivated the collection of data representing the entire traffic aimed at the destination host mail.etsu.edu. This data is listed below in table 3.12

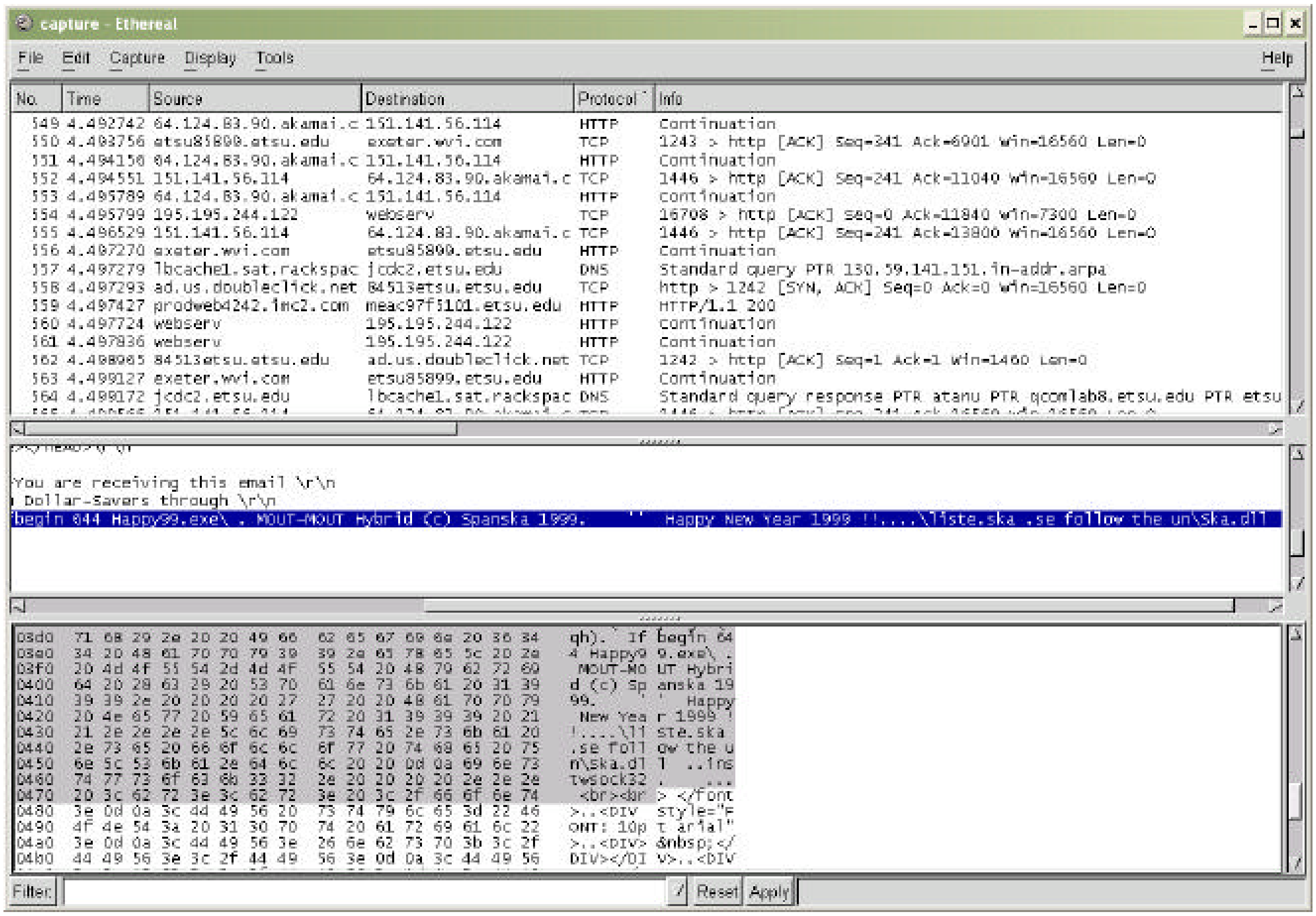
Table 3.12: Conversations for destination host (mail.etsu.edu) using NNTP and SMTP

| Source Host | Source Address | Destination Host | Dest Address | Packets | Bytes | First Seen | Last Seen |
|---|---|---|---|---|---|---|---|
| jc-c-24-159-44-87.chartertn.net | 24.159.44.87 | mail.etsu.edu | 151.141.8.105 | 6 | 526 | Sat 00:00:14 | Sat 00:00:29 |
| pcp02974522pcs.grey01.tn.comcast.net | 68.62.246.204 | mail.etsu.edu | 151.141.8.105 | 96 | 9682 | Sat 00:02:21 | Sat 00:07:40 |
| loyd.etsu.edu | 151.141.31.77 | mail.etsu.edu | 151.141.8.105 | 33 | 3147 | Sat 00:02:16 | Sat 00:08:17 |
| access.etsu.edu | 151.141.99.22 | mail.etsu.edu | 151.141.8.105 | 1627 | 1494413 | Sat 00:00:06 | Sat 00:08:54 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 209-190-250-141.cos.com | 209.190.250.141 | mail.etsu.edu | 151.141.8.105 | 14 | 2870 | Sat 00:02:00 | Sat 00:02:02 |
| meac6st130b.etsu.edu | 151.141.51.138 | mail.etsu.edu | 151.141.8.105 | 36 | 4992 | Sat 00:01:08 | Sat 00:07:08 |
| jc-c-24-159-43-221.chartertn.net | 24.159.43.221 | mail.etsu.edu | 151.141.8.105 | 39 | 5823 | Sat 00:00:52 | Sat 00:07:24 |
| 184.knoxville-04rh16rt-ca.dial-access.att.net | 12.93.223.184 | mail.etsu.edu | 151.141.8.105 | 66 | 9664 | Sat 00:00:46 | Sat 00:01:43 |
| 24.158.138.118 | 24.158.138.118 | mail.etsu.edu | 151.141.8.105 | 52 | 8594 | Sat 00:01:37 | Sat 00:07:40 |
| etsuhfpwb.etsu.edu | 151.141.60.237 | mail.etsu.edu | 151.141.8.105 | 39 | 5842 | Sat 00:01:37 | Sat 00:07:37 |
| tafr82914 | 151.141.94.233 | mail.etsu.edu | 151.141.8.105 | 212 | 31112 | Sat 00:01:36 | Sat 00:07:53 |
| user6.net275.nc.sprint-hsd.net | 205.240.32.6 | mail.etsu.edu | 151.141.8.105 | 140 | 13165 | Sat 00:01:32 | Sat 00:07:34 |
| etsu88025.etsu.edu | 151.141.65.83 | mail.etsu.edu | 151.141.8.105 | 39 | 5653 | Sat 00:01:32 | Sat 00:07:33 |
| etsu82355.etsu.edu | 151.141.23.72 | mail.etsu.edu | 151.141.8.105 | 84 | 12694 | Sat 00:00:44 | Sat 00:08:45 |
| 66.191.248.247 | 66.191.248.247 | mail.etsu.edu | 151.141.8.105 | 31 | 5237 | Sat 00:00:36 | Sat 00:08:37 |
| etsu86343.etsu.edu | 151.141.8.69 | mail.etsu.edu | 151.141.8.105 | 51 | 8844 | Sat 00:01:26 | Sat 00:07:27 |
| pcp03218068pcs.grey01.tn.comcast.net | 68.54.96.97 | mail.etsu.edu | 151.141.8.105 | 52 | 7735 | Sat 00:00:29 | Sat 00:08:31 |
| holst.siteprotect.com | 64.26.0.34 | mail.etsu.edu | 151.141.8.105 | 12 | 2412 | Sat 00:00:26 | Sat 00:00:28 |
| user130.net550.nc.sprint-hsd.net | 65.40.235.130 | mail.etsu.edu | 151.141.8.105 | 55 | 9138 | Sat 00:00:05 | Sat 00:08:06 |
| etsu88565.etsu.edu | 151.141.12.206 | mail.etsu.edu | 151.141.8.105 | 10 | 964 | Sat 00:00:05 | Sat 00:00:05 |
| scabbers.ornl.gov | 160.91.76.162 | mail.etsu.edu | 151.141.8.105 | 48 | 7119 | Sat 00:00:04 | Sat 00:08:05 |
| 138.knoxville-06rh16rt-ca.dial-access.att.net | 12.93.227.138 | mail.etsu.edu | 151.141.8.105 | 308 | 33978 | Sat 00:00:04 | Sat 00:08:49 |
| out003.tpca.net | 66.180.244.23 | mail.etsu.edu | 151.141.8.105 | 26 | 7087 | Sat 00:02:47 | Sat 00:06:10 |
| netstat.etsu.edu | 151.141.8.57 | mail.etsu.edu | 151.141.8.105 | 410 | 36423 | Sat 00:00:04 | Sat 00:08:41 |
| mailserver3.iexpect.com | 216.35.70.233 | mail.etsu.edu | 151.141.8.105 | 14 | 5384 | Sat 00:02:44 | Sat 00:02:52 |
| jps-etsu | 151.141.48.180 | mail.etsu.edu | 151.141.8.105 | 16 | 1451 | Sat 00:03:27 | Sat 00:03:28 |
| members2.zippyclicks.com | 64.124.168.46 | mail.etsu.edu | 151.141.8.105 | 16 | 13568 | Sat 00:03:25 | Sat 00:03:38 |
| sccimhc01.insightbb.com | 63.240.76.163 | mail.etsu.edu | 151.141.8.105 | 12 | 2521 | Sat 00:03:46 | Sat 00:03:46 |
| etsu88505.etsu.edu | 151.141.12.204 | mail.etsu.edu | 151.141.8.105 | 10 | 963 | Sat 00:03:39 | Sat 00:03:40 |
| panther.mail.utk.edu | 160.36.178.33 | mail.etsu.edu | 151.141.8.105 | 29 | 9091 | Sat 00:04:25 | Sat 00:04:38 |
| imail.etsu.edu | 151.141.8.36 | mail.etsu.edu | 151.141.8.105 | 15 | 3665 | Sat 00:04:23 | Sat 00:04:23 |
| out009.tpca.net | 66.180.244.29 | mail.etsu.edu | 151.141.8.105 | 2 | 168 | Sat 00:05:07 | Sat 00:07:07 |
| lev+s g4.etsu.edu | 151.141.85.66 | mail.etsu.edu | 151.141.8.105 | 5 | 422 | Sat 00:05:59 | Sat 00:06:00 |
| out004.tpca.net | 66.180.244.24 | mail.etsu.edu | 151.141.8.105 | 51 | 12580 | Sat 00:06:25 | Sat 00:08:26 |
| ezproxy.etsu.edu | 151.141.112.214 | mail.etsu.edu | 151.141.8.105 | 18 | 3851 | Sat 00:06:48 | Sat 00:06:48 |
| 151.141.85.169 | 151.141.85.169 | mail.etsu.edu | 151.141.8.105 | 4 | 402 | Sat 00:07:22 | Sat 00:07:23 |
| e3000-1.ucg.com | 198.6.95.10 | mail.etsu.edu | 151.141.8.105 | 93 | 123042 | Sat 00:07:37 | Sat 00:09:00 |
| user229.net620.nc.sprint-hsd.net | 65.41.41.229 | mail.etsu.edu | 151.141.8.105 | 15 | 1369 | Sat 00:08:18 | Sat 00:08:21 |
| pcp03360819pcs.grey01.tn.comcast.net | 68.54.101.184 | mail.etsu.edu | 151.141.8.105 | 125 | 33749 | Sat 00:08:15 | Sat 00:08:38 |
| mta101.cheetahmail.com | 216.15.189.35 | mail.etsu.edu | 151.141.8.105 | 14 | 5636 | Sat 00:07:55 | Sat 00:07:57 |
| 216.98.74.17 | 216.98.74.17 | mail.etsu.edu | 151.141.8.105 | 13 | 3396 | Sat 00:08:37 | Sat 00:08:42 |
| cncfw.cn.edu | 12.38.254.2 | mail.etsu.edu | 151.141.8.105 | 1063 | 1389155 | Sat 00:08:35 | Sat 00:09:00 |
| imo-d05.mx.aol.com | 205.188.157.37 | mail.etsu.edu | 151.141.8.105 | 12 | 2240 | Sat 00:08:47 | Sat 00:08:48 |
| mdlv2.h-net.msu.edu | 35.8.2.252 | mail.etsu.edu | 151.141.8.105 | 49 | 59539 | Sat 00:08:47 | Sat 00:08:52 |

Again, conversations involving more than 10,000 bytes of data were identified and reconstructed traffic streams tested for the signature strings using Ethereal. The SMTP traffic stream from members2.zippyclicks.com (64.124.168.46) to mail.etsu.edu (151.141.8.105) produced a positive match for the strings “MOUT-MOUT Hybrid (c) Spanska”, “Happy99.exe”, “ \liste.ska”, “ \wsock32.”, and “ \Ska.dll” thereby indicating the probable presence of Happy99 Trojan in network traffic.

The screenshots indicating the signature strings as part of the SMTP traffic reconstructed using Ethereal are shown in figures 3.17 and 3.18. Figure 3.19 shows the entire reconstructed email message which contained the above mentioned signature strings indicating the presence of the Happy99 Trojan.

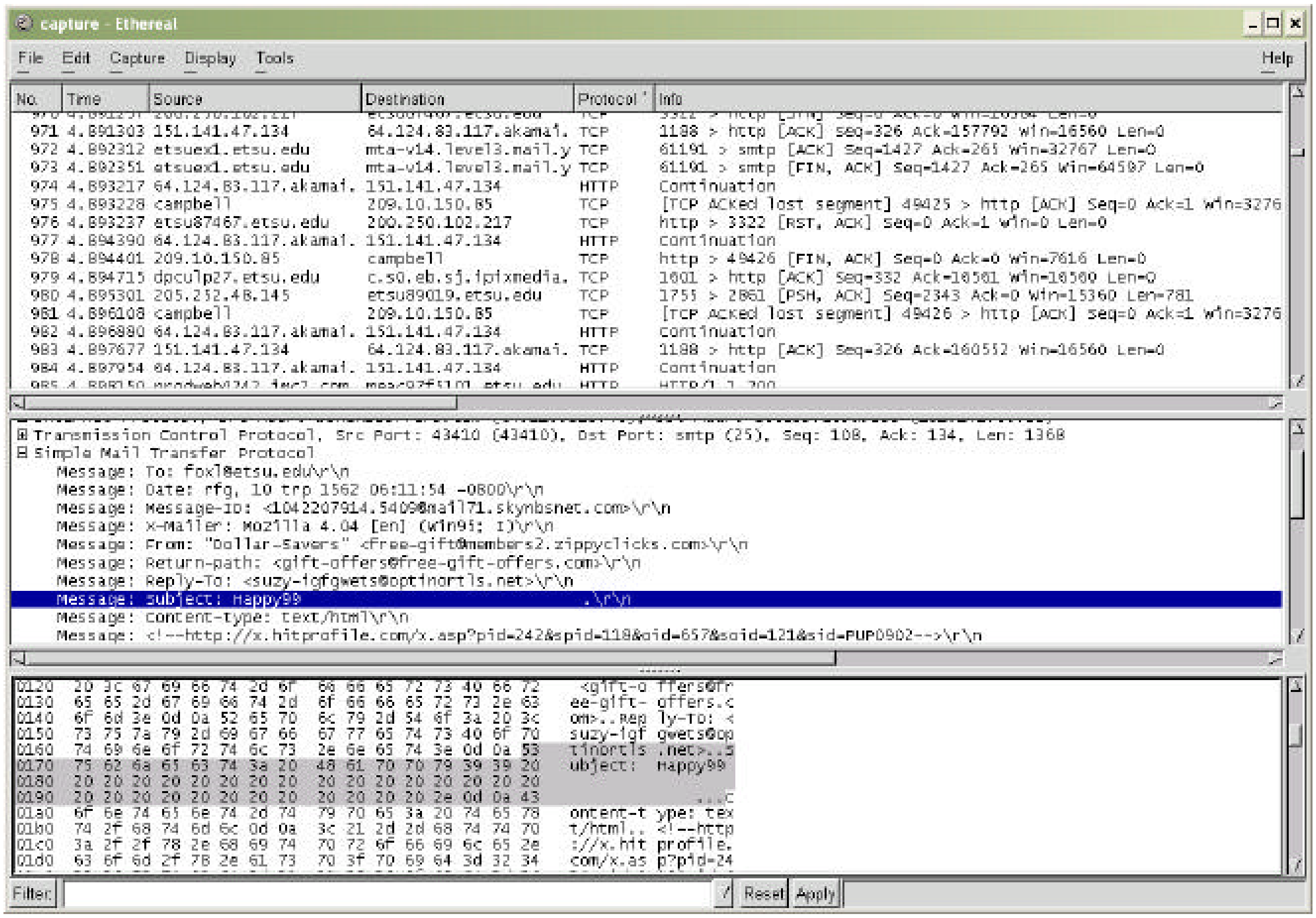


```
No.  Time     Source                  Destination             Protocol  Info
 549 4.492742 64.124.83.90.akamai.c   151.141.56.114          HTTP      Continuation
 550 4.493756 etsu85899.etsu.edu      exeter.wvi.com          TCP       1243 > http [ACK] Seq=341 Ack=6901 Win=16560 Len=0
 551 4.494150 64.124.83.90.akamai.c   151.141.56.114          HTTP      Continuation
 552 4.494551 151.141.56.114          64.124.83.90.akamai.c   TCP       1446 > http [ACK] Seq=241 Ack=11040 Win=16560 Len=0
 553 4.495789 64.124.83.90.akamai.c   151.141.56.114          HTTP      Continuation
 554 4.495799 195.195.244.122         webserv                 TCP       16708 > http [ACK] Seq=0 Ack=11840 Win=7300 Len=0
 555 4.496529 151.141.56.114          64.124.83.90.akamai.c   TCP       1446 > http [ACK] Seq=241 Ack=13800 Win=16560 Len=0
 556 4.497270 exeter.wvi.com          etsu85899.etsu.edu      HTTP      Continuation
 557 4.497279 lbcache1.sat.rackspac   jcdc2.etsu.edu          DNS       Standard query PTR 130.59.141.151.in-addr.arpa
 558 4.497293 ad.us.doubleclick.net   84513etsu.etsu.edu      TCP       http > 1242 [SYN, ACK] Seq=0 Ack=0 Win=16560 Len=0
 559 4.497427 prodweb4242.imc2.com    meac97f5101.etsu.edu    HTTP      HTTP/1.1 200
 560 4.497724 webserv                 195.195.244.122         HTTP      Continuation
 561 4.497836 webserv                 195.195.244.122         HTTP      Continuation
 562 4.498965 84513etsu.etsu.edu      ad.us.doubleclick.net   TCP       1242 > http [ACK] Seq=1 Ack=1 Win=1460 Len=0
 563 4.499127 exeter.wvi.com          etsu85899.etsu.edu      HTTP      Continuation
 564 4.499172 jcdc2.etsu.edu          lbcache1.sat.rackspac   DNS       Standard query response PTR atanu PTR qcomlab8.etsu.edu PTR etsu
```

```
You are receiving this email \r\n
 Dollar-Savers through \r\n
begin 644 Happy99.exe\ . MOUT-MOUT Hybrid (c) Spanska 1999.    ''   Happy New Year 1999 !!....\liste.ska .se follow the un\Ska.dll
```

```
03d0  71 68 29 2e 20 20 49 66  62 65 67 69 6e 20 36 34   qh).  If begin 64
03e0  34 20 48 61 70 70 79 39  39 2e 65 78 65 5c 20 2e   4 Happy9 9.exe\ .
03f0  20 4d 4f 55 54 2d 4d 4f  55 54 20 48 79 62 72 69    MOUT-MO UT Hybri
0400  64 20 28 63 29 20 53 70  61 6e 73 6b 61 20 31 39   d (c) Sp anska 19
0410  39 39 2e 20 20 20 20 27  27 20 20 48 61 70 70 79   99.    ' '  Happy
0420  20 4e 65 77 20 59 65 61  72 20 31 39 39 39 20 21    New Yea r 1999 !
0430  21 2e 2e 2e 2e 5c 6c 69  73 74 65 2e 73 6b 61 20   !....\li ste.ska 
0440  2e 73 65 20 66 6f 6c 6c  6f 77 20 74 68 65 20 75   .se foll ow the u
0450  6e 5c 53 6b 61 2e 64 6c  6c 20 20 0d 0a 69 6e 73   n\Ska.dl l  ..ins
0460  74 77 73 6f 63 6b 33 32  2e 20 20 20 20 2e 2e 2e   twsock32 .    ...
0470  20 3c 62 72 3e 3c 62 72  3e 20 3c 2f 66 6f 6e 74    <br><br > </font
0480  3e 0d 0a 3c 44 49 56 20  73 74 79 6c 65 3d 22 46   >..<DIV  style="F
0490  4f 4e 54 3a 20 31 30 70  74 20 61 72 69 61 6c 22   ONT: 10p t arial"
04a0  3e 0d 0a 3c 44 49 56 3e  26 6e 62 73 70 3b 3c 2f   >..<DIV> &nbsp;</
04b0  44 49 56 3e 3c 2f 44 49  56 3e 0d 0a 3c 44 49 56   DIV></DI V>..<DIV
```

Figure 3.17: Positive Signature Match for the Happy99 Trojan

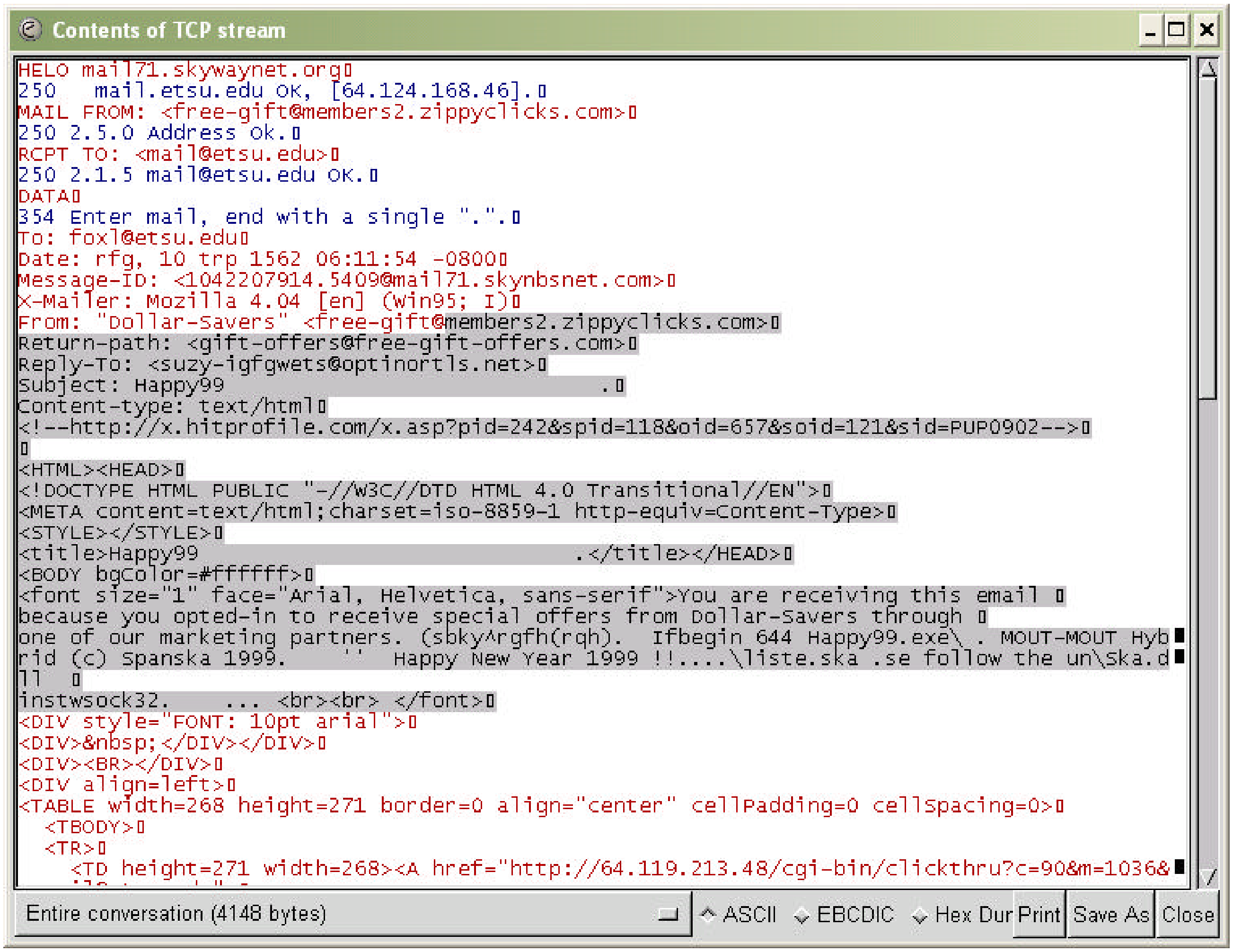


```
No.  Time     Source                  Destination             Protocol  Info
 971 4.891303 151.141.47.134          64.124.83.117.akamai.   TCP       1188 > http [ACK] Seq=326 Ack=157792 Win=16560 Len=0
 972 4.892312 etsuex1.etsu.edu        mta-v14.level3.mail.y   TCP       61191 > smtp [ACK] Seq=1427 Ack=265 Win=32767 Len=0
 973 4.892351 etsuex1.etsu.edu        mta-v14.level3.mail.y   TCP       61191 > smtp [FIN, ACK] Seq=1427 Ack=265 Win=64587 Len=0
 974 4.893217 64.124.83.117.akamai.   151.141.47.134          HTTP      Continuation
 975 4.893228 campbell                209.10.150.85           TCP       [TCP ACKed lost segment] 49425 > http [ACK] Seq=0 Ack=1 Win=3276
 976 4.893237 etsu87467.etsu.edu      200.250.102.217         TCP       http > 3322 [RST, ACK] Seq=0 Ack=1 Win=0 Len=0
 977 4.894390 64.124.83.117.akamai.   151.141.47.134          HTTP      Continuation
 978 4.894401 209.10.150.85           campbell                TCP       http > 49426 [FIN, ACK] Seq=0 Ack=0 Win=7616 Len=0
 979 4.894715 dpculp27.etsu.edu       c.50.eb.sj.ipixmedia.   TCP       1601 > http [ACK] Seq=332 Ack=10501 Win=10500 Len=0
 980 4.895301 205.252.48.145          etsu89019.etsu.edu      TCP       1755 > 2861 [PSH, ACK] Seq=2343 Ack=0 Win=15360 Len=781
 981 4.896108 campbell                209.10.150.85           TCP       [TCP ACKed lost segment] 49426 > http [ACK] Seq=0 Ack=1 Win=3276
 982 4.896880 64.124.83.117.akamai.   151.141.47.134          HTTP      Continuation
 983 4.897677 151.141.47.134          64.124.83.117.akamai.   TCP       1188 > http [ACK] Seq=326 Ack=160552 Win=16560 Len=0
 984 4.897954 64.124.83.117.akamai.   151.141.47.134          HTTP      Continuation
```

```
⊞ Transmission Control Protocol, Src Port: 43410 (43410), Dst Port: smtp (25), Seq: 108, Ack: 134, Len: 1368
⊟ Simple Mail Transfer Protocol
    Message: To: foxl@etsu.edu\r\n
    Message: Date: rfg, 10 trp 1562 06:11:54 -0800\r\n
    Message: Message-ID: <1042207914.5409@mail71.skynbsnet.com>\r\n
    Message: X-Mailer: Mozilla 4.04 [en] (Win95; I)\r\n
    Message: From: "Dollar-Savers" <Free-gift@members2.zippyclicks.com>\r\n
    Message: Return-path: <gift-offers@free-gift-offers.com>\r\n
    Message: Reply-To: <suzy-igfgwets@optinortls.net>\r\n
    Message: Subject: Happy99                             .\r\n
    Message: Content-type: text/html\r\n
    Message: <!--http://x.hitprofile.com/x.asp?pid=242&spid=118&oid=657&soid=121&sid=PUP0902-->\r\n
```

```
0120  20 3c 67 69 66 74 2d 6f  66 66 65 72 73 40 66 72    <gift-o ffers@fr
0130  65 65 2d 67 69 66 74 2d  6f 66 66 65 72 73 2e 63   ee-gift- offers.c
0140  6f 6d 3e 0d 0a 52 65 70  6c 79 2d 54 6f 3a 20 3c   om>..Rep ly-To: <
0150  73 75 7a 79 2d 69 67 66  67 77 65 74 73 40 6f 70   suzy-igf gwets@op
0160  74 69 6e 6f 72 74 6c 73  2e 6e 65 74 3e 0d 0a 53   tinortls .net>..S
0170  75 62 6a 65 63 74 3a 20  48 61 70 70 79 39 39 20   ubject:  Happy99
0180  20 20 20 20 20 20 20 20  20 20 20 20 20 20 20 20
0190  20 20 20 20 20 20 20 20  20 20 20 20 2e 0d 0a 43               ...C
01a0  6f 6e 74 65 6e 74 2d 74  79 70 65 3a 20 74 65 78   ontent-t ype: tex
01b0  74 2f 68 74 6d 6c 0d 0a  3c 21 2d 2d 68 74 74 70   t/html.. <!--http
01c0  3a 2f 2f 78 2e 68 69 74  70 72 6f 66 69 6c 65 2e   ://x.hit profile.
01d0  63 6f 6d 2f 78 2e 61 73  70 3f 70 69 64 3d 32 34   com/x.as p?pid=24
```

Figure 3.18: Positive Signature Match for the Happy99 Trojan—Expanded Tree



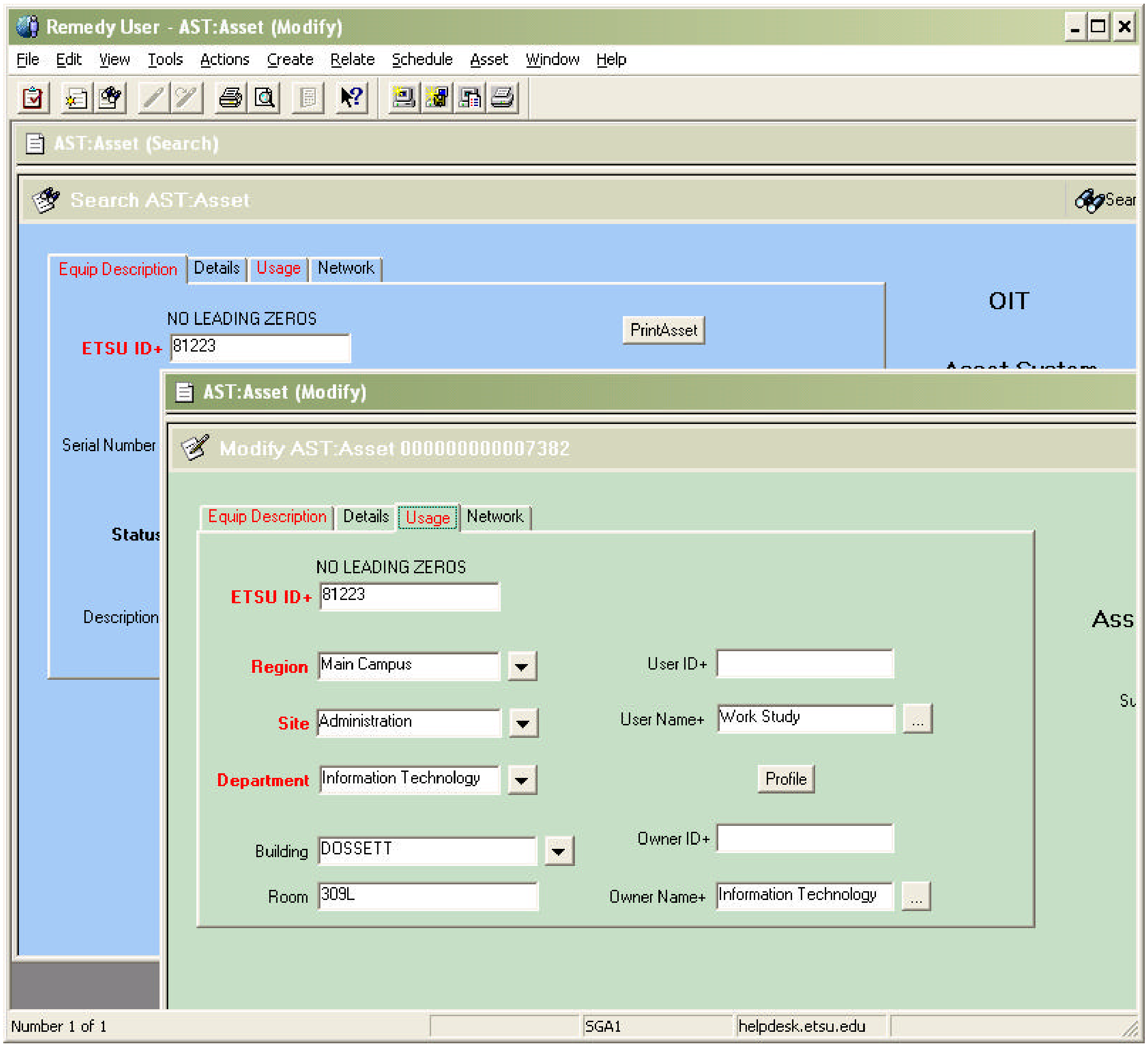
```
HELO mail71.skywaynet.org▯
250   mail.etsu.edu OK, [64.124.168.46].▯
MAIL FROM: <free-gift@members2.zippyclicks.com>▯
250 2.5.0 Address Ok.▯
RCPT TO: <mail@etsu.edu>▯
250 2.1.5 mail@etsu.edu OK.▯
DATA▯
354 Enter mail, end with a single ".".▯
To: foxl@etsu.edu▯
Date: rfg, 10 trp 1562 06:11:54 -0800▯
Message-ID: <1042207914.5409@mail71.skynbsnet.com>▯
X-Mailer: Mozilla 4.04 [en] (Win95; I)▯
From: "Dollar-Savers" <free-gift@members2.zippyclicks.com>▯
Return-path: <gift-offers@free-gift-offers.com>▯
Reply-To: <suzy-igfgwets@optinortls.net>▯
Subject: Happy99                                 .▯
Content-type: text/html▯
<!--http://x.hitprofile.com/x.asp?pid=242&spid=118&oid=657&soid=121&sid=PUP0902-->▯
▯
<HTML><HEAD>▯
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.0 Transitional//EN">▯
<META content=text/html;charset=iso-8859-1 http-equiv=Content-Type>▯
<STYLE></STYLE>▯
<title>Happy99                              .</title></HEAD>▯
<BODY bgColor=#ffffff>▯
<font size="1" face="Arial, Helvetica, sans-serif">You are receiving this email ▯
because you opted-in to receive special offers from Dollar-Savers through ▯
one of our marketing partners. (sbky^rgfh(rqh).  Ifbegin 644 Happy99.exe\ . MOUT-MOUT Hyb█
rid (c) Spanska 1999.     ''  Happy New Year 1999 !!....\liste.ska .se follow the un\Ska.d█
ll  ▯
instwsock32.     ...  <br><br> </font>▯
<DIV style="FONT: 10pt arial">▯
<DIV>&nbsp;</DIV></DIV>▯
<DIV><BR></DIV>▯
<DIV align=left>▯
<TABLE width=268 height=271 border=0 align="center" cellPadding=0 cellSpacing=0>▯
  <TBODY>▯
  <TR>▯
    <TD height=271 width=268><A href="http://64.119.213.48/cgi-bin/clickthru?c=90&m=1036&█
```

Figure 3.19: Reconstructed Email Message Containing the Happy99 Trojan Signature

On further investigation, the URL "members2.zippyclicks.com" appeared to be associated with a Lyris list manager being operated for a company called "ZippyClicks". The company on its website, www.zippyclicks.com, claims to be "*… the leading source for incredible discounts, sweepstakes and coupons chosen exclusively for our user base of millions!…*"

### 3.3.5.6 Step VI: Physical Identification of Target Machines

The presence of the worm was also detected by McAfee's GroupShield Exchange 5.0 enterprise-antivirus system. The GroupShield Exchange 5.0 antivirus tool is designed for use with Microsoft Exchange 2000 Server platform. The utility is installed on ETSU's exchange server 'etsuex1.etsu.edu' that is deployed further down the network. Had malicious code bypassed the antivirus system as well as the firewall and infected a network host, the target host would have been identified, and corrective action taken locally. The infected host's physical location could be ascertained using the Action Request System software from Remedy Corporation. A sample screenshot from the Remedy System is shown in Figure 3.20.



ETSU ID+ 81223

Modify AST:Asset 000000000007382

ETSU ID+ 81223

Region: Main Campus

Site: Administration

Department: Information Technology

Building: DOSSETT

Room: 309L

User ID+:

User Name+: Work Study

Owner ID+:

Owner Name+: Information Technology

Number 1 of 1 | SGA1 | helpdesk.etsu.edu

Figure 3.20: Remedy in Action

It is common knowledge that certain users get their personal laptops and connect them to the ETSU network. These 'unauthorized' machines would defy detection by the Remedy software. In such a situation, the target host identification would be based on the combination of the source IP address and the MAC address of the network card obtained from the network card conversation data for a particular session as illustrated below in table 3.13

Table 3.13: Network card conversation

| MAC Address | IP Address | Packets | Bytes | First Seen | Last Seen |
|---|---|---:|---:|---|---|
| 00:60:08:bf:29:b2 | 151.141.8.151 | 37 | 4162 | Sat 00:00:32 | Sat 00:25:32 |
| 00:04:4d:fc:e2:00 | unknown | 42 | 14952 | Sat 00:00:32 | Sat 00:25:52 |
| 00:06:5b:1a:57:6f | 151.141.8.101 | 17 | 1414 | Sat 00:00:29 | Sat 00:25:30 |
| 00:80:a3:56:0e:91 | unknown | 51 | 5967 | Sat 00:00:28 | Sat 00:25:40 |
| 00:00:81:39:eb:16 | 151.141.55.5 | 784 | 47040 | Sat 00:00:27 | Sat 00:26:06 |
| 00:b0:d0:b3:ae:0b | 151.141.8.197 | 13 | 1509 | Sat 00:00:27 | Sat 00:25:59 |
| 00:c0:4f:78:0e:11 | 151.141.8.214 | 12 | 1390 | Sat 00:06:49 | Sat 00:22:09 |
| 00:10:0d:3d:48:00 | 151.141.8.1 | 1023 | 484268 | Sat 00:00:25 | Sat 00:25:36 |
| 00:c0:4f:ae:0e:08 | 151.141.8.213 | 2 | 514 | Sat 00:06:17 | Sat 00:18:20 |
| 00:06:5b:3f:7e:90 | 151.141.8.106 | 33 | 3064 | Sat 00:00:25 | Sat 00:25:26 |
| 00:50:e4:1e:8e:2c | 151.141.8.57 | 16 | 1680 | Sat 00:05:32 | Sat 00:21:16 |
| 00:b0:d0:f3:82:fb | 151.141.8.103 | 38 | 3778 | Sat 00:00:24 | Sat 00:25:49 |
| 00:c0:4f:78:2e:8a | 151.141.8.216 | 6 | 754 | Sat 00:05:20 | Sat 00:25:20 |
| 00:10:18:02:34:cb | 151.141.8.50 | 70 | 4870 | Sat 00:00:23 | Sat 00:25:41 |
| 00:b0:d0:68:38:70 | 151.141.8.177 | 4 | 634 | Sat 00:05:18 | Sat 00:17:16 |
| 00:06:5b:39:4f:4f | 151.141.8.36 | 14 | 3605 | Sat 00:04:23 | Sat 00:04:23 |
| 00:50:04:a9:fe:bc | 151.141.8.40 | 17 | 2028 | Sat 00:04:10 | Sat 00:17:58 |
| 00:c0:4f:78:0c:3f | 151.141.8.212 | 6 | 892 | Sat 00:04:08 | Sat 00:16:08 |
| 00:90:27:84:b1:1b | 151.141.8.25 | 3 | 574 | Sat 00:04:08 | Sat 00:16:06 |
| 00:06:5b:3b:c9:e2 | 151.141.8.39 | 7 | 952 | Sat 00:03:59 | Sat 00:16:16 |
| 00:90:27:dc:f0:7d | 151.141.8.53 | 172 | 20620 | Sat 00:00:05 | Sat 00:25:38 |
| 00:b0:d0:f3:82:fb | 151.141.8.103 | 4394 | 1256652 | Sat 00:00:05 | Sat 00:26:07 |
| 00:06:5b:1a:57:6f | 151.141.8.101 | 1075 | 736715 | Sat 00:00:05 | Sat 00:26:07 |
| 00:06:28:a6:57:47 | unknown | 780 | 46800 | Sat 00:00:04 | Sat 00:26:06 |
| 02:01:97:8d:08:69 | 151.141.8.104 | 1671 | 2371893 | Sat 00:00:04 | Sat 00:26:06 |
| 00:10:0d:3d:48:00 | 151.141.8.1 | 17750 | 15103522 | Sat 00:00:04 | Sat 00:26:07 |
| 00:50:e4:1e:8e:2c | 151.141.8.57 | 1254 | 129861 | Sat 00:00:04 | Sat 00:26:04 |
| 00:b0:d0:d0:72:ac | 151.141.8.51 | 1476 | 89506 | Sat 00:00:03 | Sat 00:26:06 |
| 00:02:b3:35:a7:f6 | unknown | 1466 | 87960 | Sat 00:00:03 | Sat 00:26:06 |
| 00:a0:c9:3d:83:20 | unknown | 305 | 52168 | Sat 00:00:03 | Sat 00:25:59 |
| 00:06:5b:8d:1f:44 | 151.141.8.110 | 65 | 10791 | Sat 00:00:23 | Sat 00:16:28 |
| 00:08:74:19:22:48 | 151.141.8.219 | 26 | 2979 | Sat 00:00:23 | Sat 00:24:23 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 00:06:5b:0f:44:65 | 151.141.8.44 | 10 | 1270 | Sat 00:00:21 | Sat 00:15:27 |
| 00:06:28:a6:57:47 | unknown | 26 | 9438 | Sat 00:00:18 | Sat 00:25:18 |
| 00:90:27:de:59:c1 | 151.141.8.154 | 12 | 1114 | Sat 00:00:16 | Sat 00:25:24 |
| 00:c0:4f:0e:e2:35 | 151.141.8.150 | 390 | 30225 | Sat 00:00:15 | Sat 00:25:17 |
| 00:a0:c9:cf:dc:ca | 151.141.8.153 | 3 | 574 | Sat 00:03:58 | Sat 00:15:57 |
| 00:a0:c9:39:aa:3a | 151.141.8.15 | 81 | 9881 | Sat 00:00:15 | Sat 00:25:44 |
| 00:90:27:dc:ef:80 | 151.141.8.176 | 34 | 9410 | Sat 00:03:37 | Sat 00:25:19 |
| 00:c0:4f:0e:e2:35 | 151.141.8.150 | 249 | 15937 | Sat 00:00:14 | Sat 00:25:18 |
| 00:06:5b:39:4f:4f | 151.141.8.36 | 12 | 1390 | Sat 00:03:20 | Sat 00:23:23 |
| 00:06:5b:3d:8c:0d | 151.141.8.58 | 9 | 1210 | Sat 00:00:13 | Sat 00:18:01 |
| 00:90:27:dc:f1:31 | 151.141.8.155 | 7 | 814 | Sat 00:03:13 | Sat 00:23:56 |
| 00:b0:d0:f0:dc:a7 | 151.141.8.100 | 187 | 19034 | Sat 00:00:13 | Sat 00:25:49 |
| 00:06:5b:3c:d6:47 | 151.141.8.46 | 16 | 1630 | Sat 00:03:13 | Sat 00:25:13 |
| 00:06:5b:8c:c1:bb | 151.141.8.185 | 6 | 892 | Sat 00:03:09 | Sat 00:15:10 |
| 00:90:27:85:8f:30 | 151.141.8.22 | 10 | 1270 | Sat 00:03:07 | Sat 00:25:22 |
| 00:90:27:85:8f:dd | 151.141.8.62 | 9 | 1210 | Sat 00:02:58 | Sat 00:20:13 |
| 00:60:08:bf:6d:b7 | 151.141.8.162 | 12 | 1134 | Sat 00:02:48 | Sat 00:24:00 |
| 00:60:08:03:59:3b | 151.141.8.183 | 7 | 1248 | Sat 00:02:48 | Sat 00:22:02 |
| 00:40:95:75:1c:5d | unknown | 143 | 13156 | Sat 00:00:11 | Sat 00:26:06 |
| 00:60:08:bf:29:b2 | 151.141.8.151 | 118 | 7880 | Sat 00:00:11 | Sat 00:25:59 |
| 00:c0:4f:01:00:c1 | 151.141.8.29 | 95 | 6094 | Sat 00:00:10 | Sat 00:25:56 |
| 00:06:5b:8d:1f:44 | 151.141.8.110 | 82 | 5866 | Sat 00:00:07 | Sat 00:25:49 |
| 00:80:a3:56:0e:cc | 151.141.8.28 | 208 | 24674 | Sat 00:00:07 | Sat 00:25:19 |
| 00:b0:d0:f0:dc:a7 | 151.141.8.100 | 2986 | 2086258 | Sat 00:00:06 | Sat 00:26:07 |
| 00:c0:4f:ae:0e:13 | 151.141.8.206 | 5 | 694 | Sat 00:02:35 | Sat 00:22:26 |
| 00:06:5b:3f:7e:90 | 151.141.8.106 | 2883 | 1662425 | Sat 00:00:06 | Sat 00:26:06 |
| 00:10:0d:3d:48:00 | 151.141.8.1 | 338 | 29744 | Sat 00:00:06 | Sat 00:26:06 |
| 00:06:5b:1f:2d:f8 | 151.141.8.41 | 12 | 1390 | Sat 00:02:34 | Sat 00:19:24 |
| 00:e0:1e:42:8d:59 | unknown | 339 | 29832 | Sat 00:00:05 | Sat 00:26:03 |
| 00:b0:d0:cd:4c:e6 | 151.141.8.69 | 16 | 1630 | Sat 00:02:21 | Sat 00:24:55 |
| 00:40:95:75:1c:5d | unknown | 3533 | 1627432 | Sat 00:00:05 | Sat 00:25:51 |
| 00:90:27:dc:f0:09 | 151.141.8.54 | 6 | 892 | Sat 00:02:17 | Sat 00:14:19 |
| 00:60:97:ac:28:96 | 151.141.8.175 | 3 | 574 | Sat 00:02:17 | Sat 00:14:17 |
| 00:a0:c9:2d:fe:19 | 151.141.8.24 | 5 | 694 | Sat 00:02:15 | Sat 00:14:53 |
| 00:c0:4f:96:6d:69 | 151.141.8.225 | 5 | 694 | Sat 00:02:11 | Sat 00:20:35 |
| 00:c0:4f:96:6b:96 | 151.141.8.202 | 6 | 892 | Sat 00:02:07 | Sat 00:14:08 |
| 00:c0:4f:66:2f:b6 | unknown | 3 | 771 | Sat 00:02:06 | Sat 00:26:04 |
| 00:b0:d0:68:6b:e4 | 151.141.8.178 | 5 | 694 | Sat 00:01:57 | Sat 00:20:32 |

# CHAPTER 4

# RESULTS

## 4.1 Results

The inferences presented in this section are based on data collected from August 2002 to April 2003 using the tools described in section 3.2.2. Apart from these tools, data was also taken from the Cisco PIX 525 firewall log files which consisted of more than half a million entries (approximately 556,970 entries) for the time period under consideration.

Section 4.2 deals with the traffic tree subclasses while section 4.3 identifies the overall top ten protocols in terms of percentage of ETSU's total network traffic (inbound as well as outbound) based on the total number of bytes transmitted. Section 4.4 presents the percentage breakdown of the largest bandwidth–soaking protocol on the campus. Section 4.5 shows a detailed monthly breakdown of actual bandwidth utilization on the network while section 4.6 provides a breakdown of rogue traffic on legitimate ports. Finally, section 4.7 gives the percentage bandwidth abuse.

## 4.2 Bandwidth Traffic Tree

ETSU's campus bandwidth is currently managed by dividing inbound and outbound traffic into a hierarchical tree structure with various subclasses having different priority settings. The root class contains five subclasses, viz., 'Discovered Ports', 'High', 'Average', 'Low' and 'Discard'. Such a classification facilitates higher priority for mission critical applications and lower priority for uncritical ones. The traffic related to undesired applications and ports—and not already blocked by the firewall—is discarded by the PacketShaper. Pie charts that show the top 10 members of each class categorized by average flow rate are in Appendix H.

## 4.3 Top Ten Protocols

The top ten protocols in terms of percentage of ETSU's total network traffic (inbound as well as outbound) are tabulated below in tables 4.1 and 4.2 respectively.

Table 4.1: Inbound traffic—Top 10 Protocols

| Protocol / Application | Traffic Percentage |
|---|---|
| HTTP | 76% |
| WinMedia | 4% |
| FTP | 3% |
| SMTP | 3% |
| Real | 2% |
| SSL | 2% |
| UDP_Port_6970 | 2% |
| NNTP | 2% |
| Default | 1% |
| MPEG-Video | 1% |
| All other classes | 4% |

Table 4.2: Outbound traffic—Top 10 Protocols

| Protocol / Application | Traffic Percentage |
|---|---|
| HTTP | 70% |
| pcANYWHERE | 7% |
| SSL | 5% |
| FTP | 5% |
| SMTP | 5% |
| Default | 3% |
| Microsoft-ds | 2% |
| DNS | 1% |
| WinMedia | 1% |
| POP3 | 1% |
| All other classes | 2% |

HTTP, the predominant protocol, consumes roughly 3/4 of the total bandwidth. This data is consistent with Thompson et. al.'s finding that HTTP constituted 65-75% of backbone traffic flow.

## 4.4 Breakdown of HTTP Traffic

A classification of HTTP traffic by website topic, presented in Table 4.3 and depicted in Figure 4.1, shows a spectrum of user interest consistent with the diverse mission of ETSU.

Table 4.3: Breakdown of HTTP Traffic

| **Area of Interest** | **%** | | **Area of Interest** | **%** |
|---|---|---|---|---|
| | | | | |
| Email (web based) | 20 | | Discount / Bargain websites | 4 |
| Entertainment | 11 | | Women's support groups | 4 |
| News | 11 | | Health related | 3 |
| ETSU URLs | 10 | | Education / Tutorials related | 2 |
| Miscellaneous | 7 | | Hobby sites | 2 |
| Science and Technology related | 7 | | Foreign language sites | 1 |
| E-commerce (eg. eBAY) | 6 | | History | 1 |
| Business related | 5 | | Job hunting | 1 |
| Sports | 5 | | | |

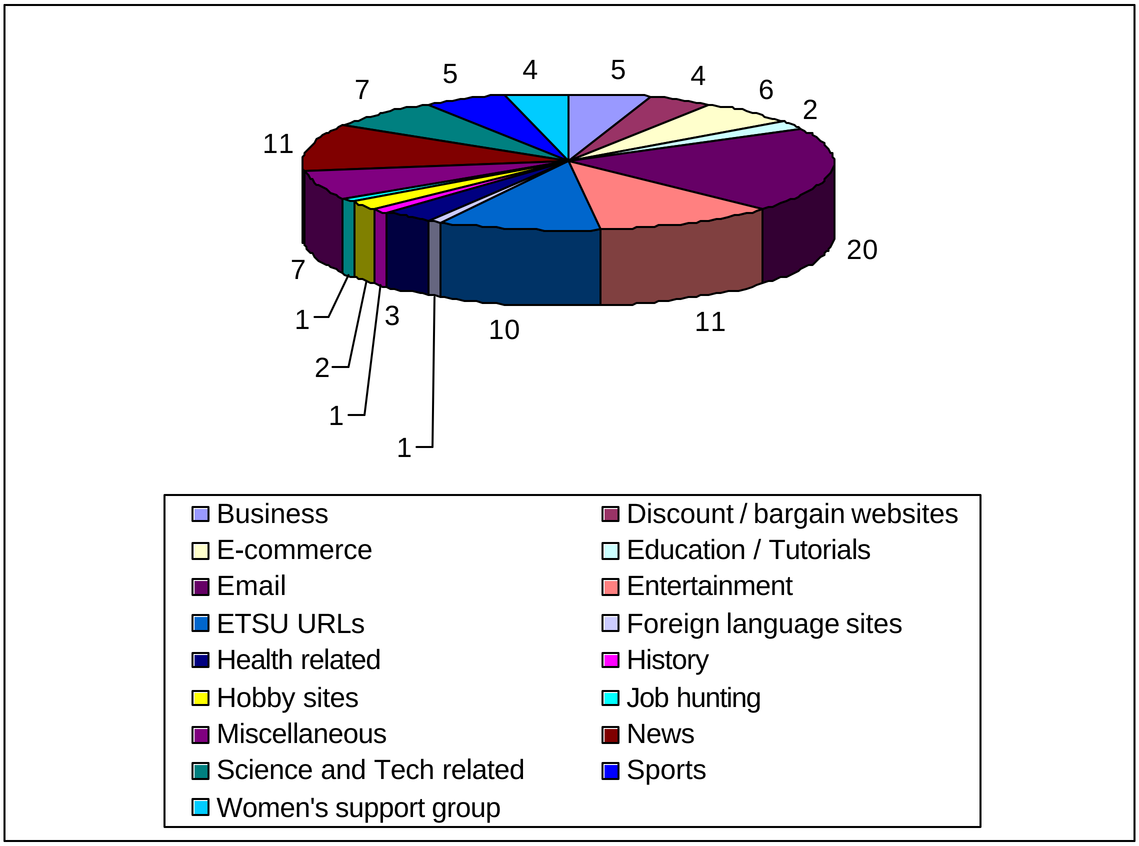


Figure 4.1: Breakdown of HTTP traffic: Percentage distribution

### 4.5 Bandwidth Utilization

The inbound and outbound breakdown of actual bandwidth utilization on the ETSU network is given in tables 4.4 and 4.5 respectively. Figures 4.2 and 4.3 depict the bandwidth distribution using bar charts.

Table 4.4: Inbound Bandwidth Utilization

| Time Period | | Mission Critical Traffic (Kbytes) | Desirable Traffic (Kbytes) | Traffic on well known ports associated with non-critical applications (Kbytes) | Rogue Traffic that evaded the Firewall (Kbytes) |
|---|---|---|---|---|---|
| 2002 | Aug | 2894643 | 440153723 | 3073573 | 194 |
| | Sep | 3105739 | 715618093 | 2874194 | 897 |
| | Oct | 2489764 | 645623146 | 2467839 | 521 |
| | Nov | 2738495 | 621723864 | 1200734 | 478 |
| | Dec | 2832599 | 501153611 | 2506453 | 167 |
| 2003 | Jan | 1962745 | 564207521 | 1894562 | 456 |
| | Feb | 1096018 | 477981245 | 9894594 | 58 |
| | Mar | 2147250 | 675905489 | 181467 | 114 |
| | Apr | 3003671 | 762369432 | 3742091 | 608 |
| **Total** | | **22270924** | **5404736124** | **27835507** | **3493** |

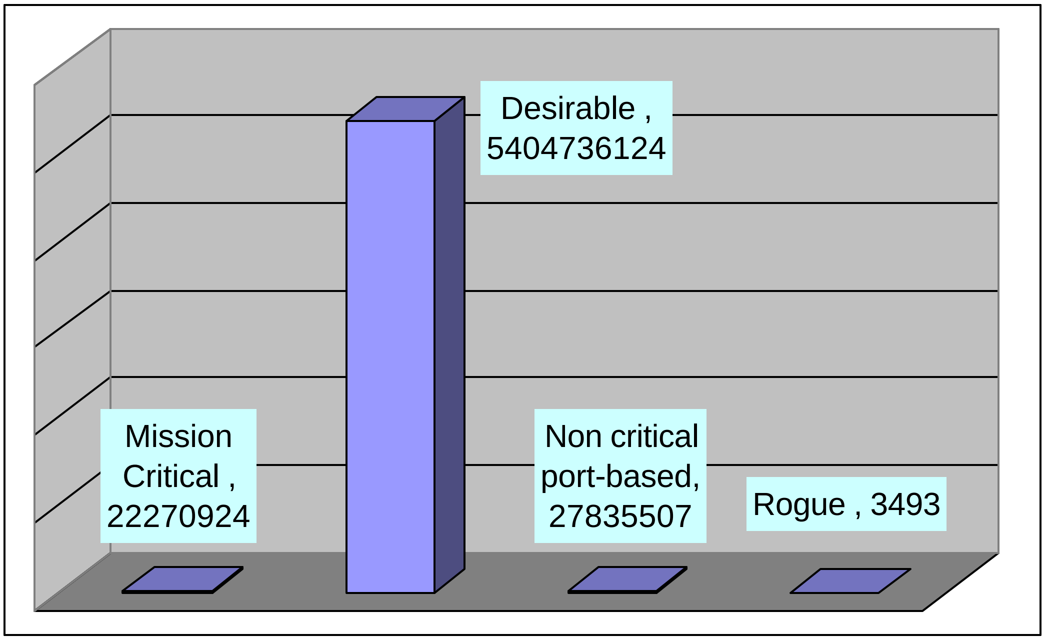


Figure 4.2: Inbound Bandwidth Distribution

The measurements indicate an almost uniform level of rogue data during the various months. A steep dip in the amount of rogue traffic in February seems to be an aberration to the trend without any seemingly justifiable reason.

Table 4.5: Outbound Bandwidth Utilization

| Time Period | | Mission Critical Traffic (Kbytes) | Desirable Traffic (Kbytes) | Traffic on well-known ports associated with non-critical applications (Kbytes) | Rogue Traffic that evaded the Firewall (Kbytes) |
|---|---|---|---|---|---|
| 2002 | Aug | 3284729 | 278794532 | 119348 | 237 |
| | Sep | 2503484 | 297154612 | 184737 | 693 |
| | Oct | 2798493 | 293261284 | 138918 | 168 |
| | Nov | 3105375 | 265245862 | 278492 | 127 |
| | Dec | 3093118 | 225556456 | 190774 | 91 |
| 2003 | Jan | 1483929 | 240184328 | 93483 | 458 |
| | Feb | 1259630 | 182290399 | 620385 | 651 |
| | Mar | 2313949 | 264214473 | 32310 | 150 |
| | Apr | 2979740 | 341132406 | 648645 | 151 |
| **Total** | | **22822447** | **2387834352** | **2307092** | **2726** |

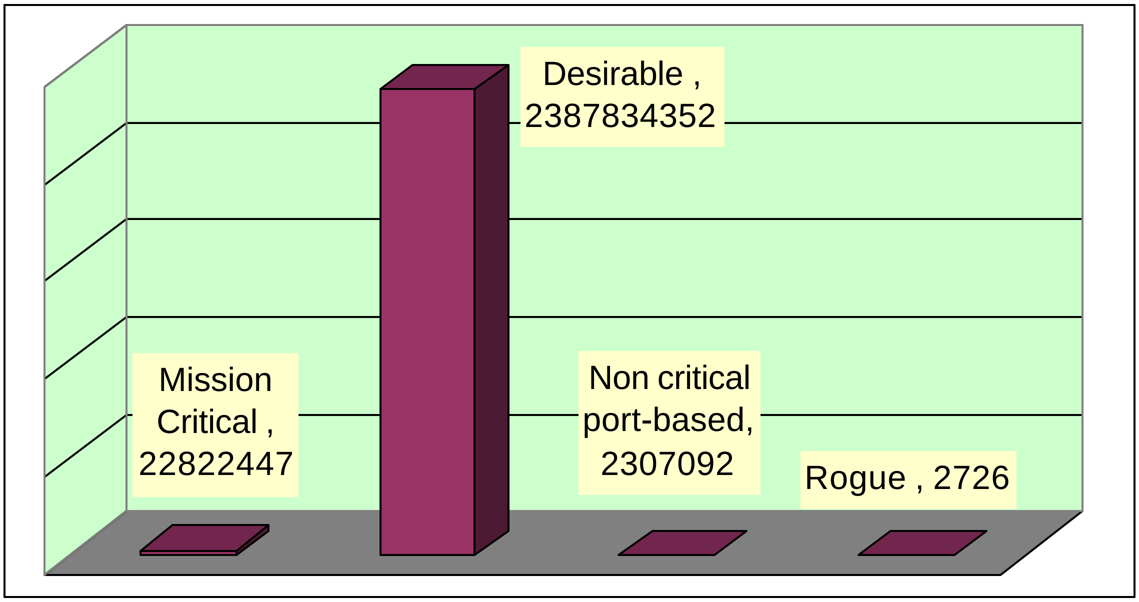


Figure 4.3: Outbound Bandwidth Distribution

The outbound traffic measurements also indicate an almost uniform level of rogue traffic with a steep dip in December. Since the total traffic levels are comparable to other months and the decline is only in the rogue traffic, it might suggest that the students may be the biggest source of outgoing rogue traffic (as most of the students were not using the campus network during the winter vacation).

## 4.6 Rogue Traffic on Legitimate Ports

Data from McAfee’s GroupShield Exchange 5.0 Enterprise Suite system indicates that approximately 2.5% of the traffic on the network constituted rogue traffic using legitimate channels of communication. A summary of the malicious data passing through legitimate ports classified on the basis of type and number of occurrences is tabulated below. The graphical distribution of this data is represented in figure 4.4. A detailed list showing the individual constituents of the various classes is placed in Appendix I.

Table 4.6: Malicious Data in Legitimate Traffic

| **Type of Malicious Data** | **Number of occurrences** |
|---|---:|
| Klez | 25591 |
| Known Exploits | 22569 |
| Sobig | 4707 |
| Yaha | 2133 |
| Trojans / Malicious Scripts | 861 |
| Win 32 Worms | 478 |
| Word Macro Viruses | 325 |
| Nimda | 116 |
| SirCam | 113 |
| Known Viruses | 84 |
| Rogue VB Script | 44 |

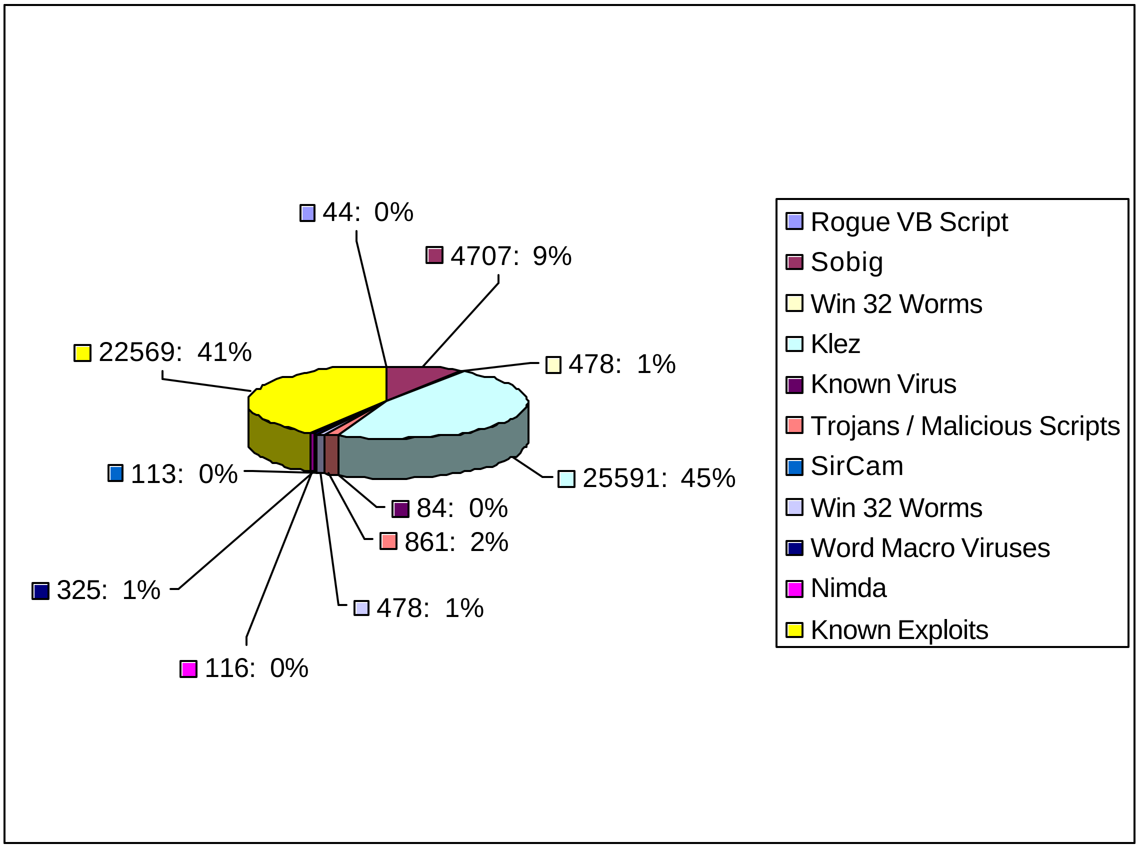


Figure 4.4: Rogue Traffic on Legitimate Ports

## 4.7 Bandwidth Abuse

This section deals with the bandwidth abuse calculations on the ETSU network. Tables 4.7 and 4.8 quantify the inbound and outbound total traffic as well as rogue traffic (in number of actual kilobytes transmitted) that evaded the firewall and was detected and finally discarded using the PacketShaper. Figure 4.5 uses a pie chart to highlight the difference between the total traffic and rogue traffic on the network.

Table 4.7: Inbound Total Traffic vs. Rogue Traffic

| **Time Period** | | **Total Traffic (Kbytes)** | **Rogue Traffic that evaded the firewall (Kbytes)** |
|---|---|---:|---:|
| 2002 | Aug | 500167483 | 194 |
| | Sep | 778214003 | 897 |
| | Oct | 694653132 | 521 |
| | Nov | 625795271 | 478 |
| | Dec | 506493793 | 167 |
| 2003 | Jan | 608367221 | 456 |
| | Feb | 781976592 | 58 |
| | Mar | 678255235 | 114 |
| | Apr | 769120652 | 608 |
| Total | | 5943043382 | 3493 |

Table 4.8: Outbound Total Traffic vs. Rogue Traffic

| **Time Period** | | **Total Traffic (Kbytes)** | **Rogue Traffic that evaded the firewall (Kbytes)** |
|---|---|---:|---:|
| 2002 | Aug | 283794532 | 237 |
| | Sep | 301148615 | 693 |
| | Oct | 297581263 | 168 |
| | Nov | 271253367 | 127 |
| | Dec | 228841638 | 91 |
| 2003 | Jan | 243184735 | 458 |
| | Feb | 293298565 | 651 |
| | Mar | 266568533 | 150 |
| | Apr | 344763543 | 151 |
| Total | | 2530434791 | 2726 |

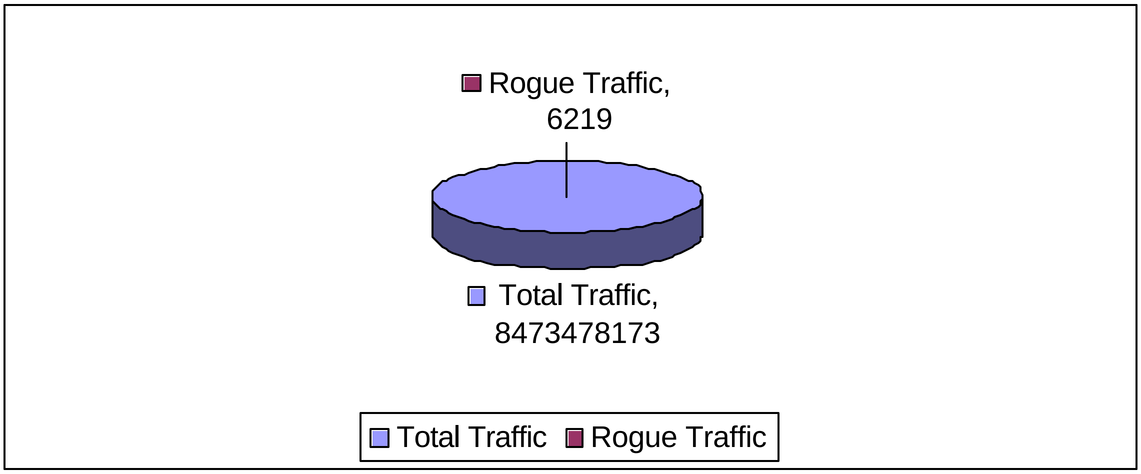


Figure 4.5: Bandwidth Abuse

Total (Inbound and Outbound) traffic: **8473478173 Kilo Bytes**

Total (Inbound and Outbound) rogue traffic: **6219 Kilo Bytes**

**% Bandwidth Abuse: 0.000073393% or 7.3393e-5**

### 4.7.1 Bandwidth Abuse Analysis

While bandwidth measurements as shown above indicate negligible bandwidth abuse on the campus network, the figures may be misleading for the following reasons:

**1.** These measurements are done using the PacketShaper. Since the PacketShaper is placed inside the firewall, these measurements reflect only the traffic permitted by the firewall. A substantial part of the undesirable traffic has been discarded before it reaches the PacketShaper.

**2.** HTTP traffic forms as much as 70-76% of the entire traffic. Even though the firewall logs facilitate traffic classification (as shown in figure 4.11 and table 4.19), it is difficult to classify traffic as “desirable” (official) or “undesirable” (personal) on any university network. While most commercial organizations have a clearly defined “area of professional interest”, universities like ETSU offer courses in almost all the categories as classified in table 4.19 and hence traffic in all these classes may be justified as “desirable”. This thesis regards the entire HTTP traffic as desirable traffic for the purpose of bandwidth measurement.

# CHAPTER 5

# CONCLUSION

## 5.1 Defense–In–Depth

Effective bandwidth management and secure network transactions can be achieved by using appropriate policies and tools. A secure network with assured bandwidth availability for mission critical applications is crucial for information assurance. However, the absence of a "silver bullet" mechanism to achieve meaningful security necessitates the adoption of the defense–in–depth strategy. This approach relies on multiple layers of security thereby eliminating a single point of failure. This helps in minimizing the overall damage to the network even if one of the layers of defense is compromised. An effective defense–in–depth strategy would include components such as firewalls, network as well as host intrusion detection and intrusion prevention systems, packet shapers, network management systems, protocol analyzers, vulnerability scanners, anti–virus and anti-Trojan programs, and cryptographic tools to encrypt sensitive data. Establishment of a DMZ and ensuring that unwanted ports remain closed at all times are also effective practices. Seamless integration of the various layers of security is crucial for achieving the key attributes of information assurance, viz., confidentiality, integrity, availability, and non-repudiation.

## 5.2 The 'KHYATI' Paradigm

To be totally effective, the defense–in–depth approach should be complemented by the KHYATI (Knowledge, Host hardening, Yauld monitoring, Analysis, Tools and Implementation) paradigm. The underlying concepts behind the different constituents of the KHYATI paradigm are outlined in sections 5.2.1 to 5.2.6.

### 5.2.1 Knowledge

Knowledge as a key for ensuring network security cannot be overemphasized. Knowledge of the various threats as well as the methods to deal with them remains one of the most important elements in any security policy. The success of security policies depends to a great extent on the level of knowledge and awareness of the people of any particular organization. Knowledge is a double-edged sword. While the black hats rely on intricate system knowledge to exploit vulnerabilities, the same knowledge can be used by system administrators to secure their networks form dedicated attacks. Knowledge about the workings of potentially dangerous tools like root-kits can protect against malicious attacks. A case in point is a comprehensive list prepared by "SnakeByte[51]" at http://www.snake-basket.de/e/AV.txt, which lists the files used by various anti-virus programs. While Trojans and other malicious code can use this information to disable the anti-virus programs, system administrators can use the same information to verify the integrity and efficacy of their anti-virus systems. An attempt was made throughout the study period to keep current with new vulnerabilities and exploits.

### 5.2.2 Host hardening

*"A chain is only as strong as its weakest link"*. No amount of network hardening and perimeter security measures undertaken by a system administrator can assure meaningful security as long as the individual hosts are not secure enough. An able attacker may use access to a single host to compromise the entire network. Host hardening involves using secure passwords, access policies and security-oriented practices aimed at improving the individual host's effective security. The prerequisite for this is requisite knowledge regarding the various threats and vulnerabilities and how to deal with them. If each host on the network is fully secure, the need

for aggressive centralized security—and the damage from its breach—may be reduced considerably.

### 5.2.3 Yauld monitoring

Nothing can replace the benefits achieved by yauld or aggressive monitoring. As shown in the preceding sections, active network monitoring helps in reducing bandwidth abuse effectively. Constant and aggressive monitoring facilitates preventive action not only against well-known vulnerabilities but also against 'zero-day exploits'.

### 5.2.4 Analysis

Aggressive monitoring in itself may not produce the required results unless it is complemented by a thorough and detailed analysis of the data. Computer forensics have shown the potential to prevent system damage when data generated by monitoring tools is analyzed correctly and in a timely way. Many hacking attempts are preceded by tell-tale signs like systematic and sustained port scanning. A timely and correct threat assessment based on analysis of firewall logs might go a long way in thwarting such attacks. Robert Graham[50] has compiled a list of common port scans and their implications at http://www.robertgraham.com/pubs/firewall-seen.html#1. This may be helpful in a meaningful analysis of various probes on a network and maybe be used to abort potential attacks.

### 5.2.5 Tools

The appropriate tools and applications necessary to thwart attacks must be available. In addition to preventive tools like vulnerability scanners and IDSs, the system administrator must be equipped with tools that minimize the damage in the aftermath of an attack. No amount of knowledge, monitoring and data-analysis can offset the lack of appropriate tools. The choice of tools depends on the organization's role as well as the criticality of the network data and resources that needs to be protected.

### 5.2.6 Implementation

Last but not the least, the actual implementation of the various security policies is of utmost importance. As the old adage goes, "*its not what technology can do, but what's important is what you can do with technology*". Despite the awareness and availability of the correct tools, the inability to properly implement the policies has resulted in a number of avoidable casualties. An effective implementation policy would be based on constant feedback, compliance checks, and regular vulnerability assessments.

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# APPENDICES

# APPENDIX A

## PROTOCOLS AND SERVICES SUPPORTED BY ETHEREAL

| | |
|---|---|
| A | AAL1, AAL3_4, AARP, AFP, AFS (RX), AH, AIM, AJP13, AODV, AODV6, ARCNET, ARP/RARP, ASAP, ASP, ATM, ATM LANE, ATP, AVS WLANCAP, Auto-RP |
| B | BACapp, BACnet, BEEP, BGP, BOFL, BOOTP/DHCP, BOOTPARAMS, BOSSVR, BROWSER, BVLC, Boardwalk |
| C | CDP, CDS_CLERK, CFLOW, CGMP, CHDLC, CLEARCASE, CLNP, CLTP, CONV, COPS, COTP, CPHA, CUPS, CoSine |
| D | DCCP, DCERPC, DCE_DFS, DDP, DDTP, DEC_STP, DFS, DHCPv6, DLSw, DNS, DNSSERVER, DSI, DTSPROVIDER, DTSSTIME_REQ, DVMRP, Data, Diameter |
| E | EAP, EAPOL, EIGRP, ENC, EPM, ESIS, ESP, ETHERIP, Ethernet, |
| F | FC, FC ELS, FC FZS, FC-FCS, FC-SWILS, FC-dNS, FCIP, FCP, FC_CT, FDDI, FIX, FLDB, FR, FTP, FTP-DATA, FTSERVER, FW-1, Frame |
| G | GIOP, GMRP, GNUTELLA, GRE, GSS-API, GTP, GTPv0, GTPv1, GVRP |
| H | H.261, H1, HCLNFSD, HPEXT, HSRP, HTTP, HyperSCSI |
| I | IAPP, IB, ICAP, ICMP, ICMPv6, ICP, ICQ, IEEE 802.11, IGMP, IGRP, ILMI, IMAP, IP, IPComp, IPFC, IPP, IPX, IPX MSG, IPX RIP, IPX SAP, IPv6, IRC, ISAKMP, ISDN, ISIS, ISL, ISUP, IUA |
| K | KLM, KRB5, KRB5RPC |
| L | L2TP, LACP, LANMAN, LAPB, LAPBETHER, LAPD, LDAP, LDP, LLAP, LLC, LMI, LMP, LPD, LSA, LSA_DS, Lucent/Ascend |
| M | M2PA, M2TP, M2UA, M3UA, MAPI, MGMT, MIPv6, MMSE, MOUNT, MPEG1, MPLS, MRDISC, MS Proxy, MSDP, MSNIP, MSNMS, MTP2, MTP3, MTP3MG, Mobile IP, Modbus/TCP, MySQL |
| N | NBDS, NBIPX, NBNS, NBP, NBSS, NCP, NDMP, NDPS, NETLOGON, NFS, NFSACL, NFSAUTH, NIS+, NIS+ CB, NLM, NMPI, NNTP, NSPI, NTLMSSP, NTP, NetBIOS, Null |
| O | OAM AAL, OSPF, OXID |
| P | PCNFSD, PFLOG, PGM, PIM, POP, PPP, PPP BACP, PPP BAP, PPP CBCP, PPP CCP, PPP CDPCP, PPP CHAP, PPP Comp, PPP IPCP, PPP IPV6CP, PPP LCP, PPP MP, PPP MPLSCP, PPP PAP, PPP PPPMux, PPP PPPMuxCP, PPP VJ, PPPoED, PPPoES, PPTP, Portmap, Prism |
| Q | Q.2931, Q.931, QLLC, QUAKE, QUAKE2, QUAKE3, QUAKEWORLD |
| R | RADIUS, RANAP, REMACT, REP_PROC, RIP, RIPng, RMI, RMP, RPC, RPC_BROWSER, RPC_NETLOGON, RPL, RQUOTA, RSH, RSTAT, RSVP, RSYNC, RS_ACCT, RS_ATTR, RS_PGO, RS_REPADM, RS_REPLIST, RS_UNIX, RTCP, RTMP, RTP, RTSP, RWALL, RX, Raw, Rlogin |
| S | SADMIND, SAMR, SAP, SCCP, SCCPMG, SCSI, SCTP, SDLC, SDP, SECIDMAP, SGI MOUNT, SIP, SKINNY, SLARP, SLL, SMB, SMB Mailslot, SMB Pipe, SMPP, SMTP, SMUX, SNA, SNA XID, SNAETH, SNMP, SPNEGO-KRB5, SPOOLSS, SPRAY, SPX, SRVLOC, SRVSVC, SSCOP, SSH, SSL, STAT, STAT-CB, STP, SUA, |

| | |
|---|---|
| | Serialization, SliMP3, Socks, Spnego, Syslog |
| T | TACACS, TACACS+, TAPI, TCP, TDS, TELNET, TFTP, TIME, TKN4Int, TNS, TPKT, TR MAC, TSP, TZSP, Token-Ring |
| U | UBIKDISK, UBIKVOTE, UCP, UDP |
| V | V.120, VLAN, VRRP, VTP, Vines, Vines FRP, Vines SPP |
| W | WBXML, WCCP, WCP, WHDLC, WHO, WINREG, WKSSVC, WSP, WTLS, WTP |
| X | X.25, X.29, X11, XDMCP, XOT, XYPLEX |
| Y | YHOO, YMSG, YPBIND, YPPASSWD, YPSERV, YPXFR |
| Z | ZEBRA, ZIP |
| Misc. | 802.11 MGT, cds_solicit, cprpc_server, dce_update, iSCSI, mdshdr, roverride, rpriv, rs_misc, rsec_login |

## APPENDIX B
PROTOCOLS AND SERVICES CLASSIFIED BY PACKETSHAPER

| Service | Description |
|---|---|
| ActiveX | Microsoft's object-oriented program technologies and tools |
| AFP | AppleTalk Filing Protocol (AppleShare IP) |
| AppleTalk | Apple's network protocol |
| AURP | AppleTalk Update-based Routing Protocol |
| Baan | Baan enterprise management system |
| BackWeb (Polite) | Push technology. Polite BackWeb has an agent on the client to prevent BackWeb background traffic from interfering with other IP network applications. |
| BGP | Border Gateway Protocol |
| Biff | UNIX new mail notification |
| CBT | Core-based Trees (Multicast Routing Protocol) |
| ccMail | cc:Mail email application |
| CiscoDiscovery | Cisco Router Discovery Protocol |
| Citrix | Connectivity application to access applications across any type of network connection. |
| Citrix-ICA | Citrix ICA |
| Citrix-SB | Citrix server browsing (UDP) |
| Clarent-CC | Clarent Voice over IP Command Center |
| Clarent-Complex | Clarent complex traffic |
| Clarent-Mgmt | Clarent management traffic |
| Clarent-Voice-S | Clarent voice traffic (simple) |
| Client | The client end of any connection (not auto-discovered) |
| CORBA | CORBA Internet Inter-ORB Protocol (IIOP) |
| CRS | Microsoft Content Replication Service and Distributed Password Authentication |
| CU-Dev | Fujitsu Device Control (CU-DEV on TCP/IP) |
| CUSeeMe | Internet telephone application service group |
| CUSeeMe-av | Internet telephone audio/video |
| CUSeeMe-ce | Internet telephone connection establishment |
| CUSeeMe-cl | Internet telephone connection listener |
| DCOM | Microsoft Distributed Component Object Model |
| DECnet | Digital Equipment Corporation's network protocol |
| DHCP | Dynamic Host Configuration Protocol |
| DHCP-C | DHCP or BootP Client |
| DHCP-S | DHCP or BootP Server |
| DLS | SNA and FNA over TCP transport—Service group classification of Data Link Switch traffic, both read and write port numbers |
| DLS-RPN | Data Link Switch Read Port Number |
| DLS-WPN | Data Link Switch Write Port Number |

| | |
|---|---|
| DNS | Domain Name Service |
| Doom | Doom, the game |
| DPA | Microsoft's Distributed Password Authentication |
| DRP | DECnet Routing Protocol |
| EGP | Network Routing Information (Exterior Gateway Protocol) |
| EIGRP | Enhanced Interior Gateway Routing Protocol |
| FileMaker Pro | Database Application |
| Finger | Finger User Information Protocol |
| FIX | Financial Information eXchange |
| FNA | Fujitsu Network Architecture (a variant of SNA) |
| FNAonTCP-1 | Transport Independent Convergence - FNA on TCP port 492 |
| FNAonTCP-2 | Transport Independent Convergence - FNA on TCP port 493 |
| FTP | File Transfer Protocol service group classification—both FTP commands and data |
| FTP-Cmd | File Transfer Protocol command channel |
| FTP-Data | File Transfer Protocol data transfer channel |
| Gopher | Search application |
| GRE | General Routing Encapsulation |
| Groupwise | Novell Groupwise messaging system |
| Groupwise-MTA | Novell Groupwise Message Transfer Agent |
| Groupwise-POA | Novell Groupwise Post Office Agent |
| H.323 | Internet telephony standard service group |
| H.323-GKD | H.323 Gatekeeper Discovery |
| H.323-H.245 | H.323 call control |
| H.323-Q.931 | H.323 call setup |
| H.323-RAS | H.323 Gatekeeper Control (Registration, Admission, and Status) |
| HTTP (Web) | Web traffic—Hypertext Transport Protocol |
| I-Phone | Phone service via the Internet |
| ICMP | Internet Control Message Protocol |
| Ident | Identification Protocol |
| IGMP | Internet Group Management Protocol |
| IMAP | Interactive Mail Access Protocol |
| IP | Internet Protocol (not auto-discovered) |
| IPSec | IP Security Encapsulation |
| IPSec-AH | IPSec Authentication Header |
| IPSec-ESP | IPSec Encapsulating Security Payload |
| IPv6 | Internet Protocol version 6 |
| IPX | Novell's networking protocol |
| IRC | Internet Relay Chat |
| IRC-194 | IRC on port 194 |
| IRC-6665 | IRC on port 6665 (server to server) |
| IRC-6667 | IRC on port 6667 (client to server) |

| | |
|---|---|
| ISAKMP | ISAKMP/IKE key exchange |
| Kali | Gaming Protocol |
| Kerberos | Network Authentication Service (ticket granting and checking) |
| L2TP | Level 2 Tunneling Protocol for VPN connections (UDP encapsulation) |
| LAT | DEC Printer Support (Local Area Transport) |
| LDAP | Lightweight Directory Access Protocol |
| Lockd | Lock Daemon |
| LotusNotes | Groupware for collaborative communication |
| Marimba | Marimba’s Castanet push technology |
| Micom-VIP | Micom Voice over IP (V/IP) |
| MPEG-Audio | Moving Picture Experts Group - Audio Streams |
| MPEG-Video | Moving Picture Experts Group - Video Streams |
| MSSQ | Microsoft Message Queue Traffic |
| MSSQ-CQ | MSSQ Client Queue |
| MSSQ-IS | MSSQ Information Store |
| MSSQ-Ping | MSSQ Ping Mechanism |
| MSSQ-QMT | MSSQ Queue Manager Traffic |
| MSSQ-SQ | MSSQ Server Queue |
| MS-SQL | Service group for both Microsoft SQL Mon and Server traffic |
| MS-SQL-Mon | Microsoft SQL Monitor |
| MS-SQL-Server | Microsoft Structured Query Language (SQL) Server |
| NetBEUI | Service group for NetBEUI—Network protocol for PCs |
| NetBIOS-IP | NetBIOS over IP |
| NetBIOS-IP-NS | NetBIOS Name Service |
| NetBIOS-IP-SSN | NetBIOS Session Service |
| NFS | Network File System (both TCP and UDP) |
| NNTP (News) | Network News Transfer Protocol |
| NTP | Network Time Protocol |
| NW5-CMD | Netware 5 - Compatibility Mode Drivers service group |
| NW5-CMD-TCP | Netware 5 - Compatibility Mode Drivers over TCP |
| NW5-CMD-UDP | Netware 5 - Compatibility Mode Drivers over UDP |
| NW5-NCP | Netware 5 Core Protocol |
| OpenConnect-JCP | Browser-based access to host applications |
| Oracle | Database application |
| OracleClient | Oracle Java client (Webforms) |
| Oracle-netv1 | Oracle SQL*Net v1 |
| Oracle-netv2 | Oracle SQL*Net v2 |
| Oracle 8i | Oracle 8i by database name |
| OSI | OSI over TCP (RFC2126), e.g., Microsoft Exchange X.400 |
| OSPF | Network Routing Information (Open Shortest-Path First) |
| pcAnywhere | Remote management collaboration tool |

| | |
|---|---|
| pcAnywhere-D | pcAnywhere data |
| pcAnywhere-OD | pcAnywhere data (old port) |
| pcAnywhere-OS | pcAnywhere status (old port) |
| pcAnywhere-S | pcAnywhere status |
| PIM | Protocol-Independent Multicast Routing Protocol |
| PointCast | Push technology application |
| POP3 (Mail) | Post office protocol for email POP3 (Mail) |
| PPTP | Point-to-Point Tunneling Protocol |
| Printer | UNIX line printer spooler (LPR) |
| Quake | Quake, the game |
| Quake-A | Quake 1 |
| Quake-B | Quake 2 |
| Quake-II-TCP | Quake over TCP |
| Quake-II-UDP | Quake over UDP |
| RADIUS | Service group for Remote Authentication Dial-in Service |
| RADIUS-Acct | RADIUS accounting service |
| RADIUS-Auth | RADIUS authentication service |
| RARP | Reverse Address Resolution Protocol |
| RC5DES | DES (data encryption standard) encryption-cracking application |
| RDP | Remote Desktop Protocol—Microsoft’s Windows Terminal Server |
| RealAudio | Service group for RealAudio streaming audio/video application—both TCP and UDP |
| RealAudio-TCP | Streaming audio/video application TCP channel |
| RealAudio-UDP | Streaming audio/video application UDP channel |
| REXEC | UNIX remote execution protocol |
| RIP | Routing Information Protocol (UDP) |
| RTCP-B | Real-time control protocol (broadcast) |
| RTCP-I | Real-time control protocol (interactive) |
| RTP-B | Real-time protocol (broadcast) |
| RTP-I | Real-time protocol (interactive) |
| RTSP | Real-time Streaming Protocol |
| rwho | Reports current users for all hosts on the local network |
| SHOUTcast | Streaming audio |
| SLP | Service Location Protocol |
| SMS | Microsoft SMS (Systems Management Server) Help Desk |
| SMS-Auth | Microsoft SMS authentication |
| SMS-Chat | Microsoft SMS remote chat |
| SMS-File | Microsoft SMS file transfer |
| SMS-RC | Microsoft SMS remote control |
| SMTP (Mail) | Simple Mail Transfer Protocol |
| SNA | IBM’s Systems Network Architecture protocol |
| SNMP | Service group for both Simple Network Management Protocol monitor and traps |

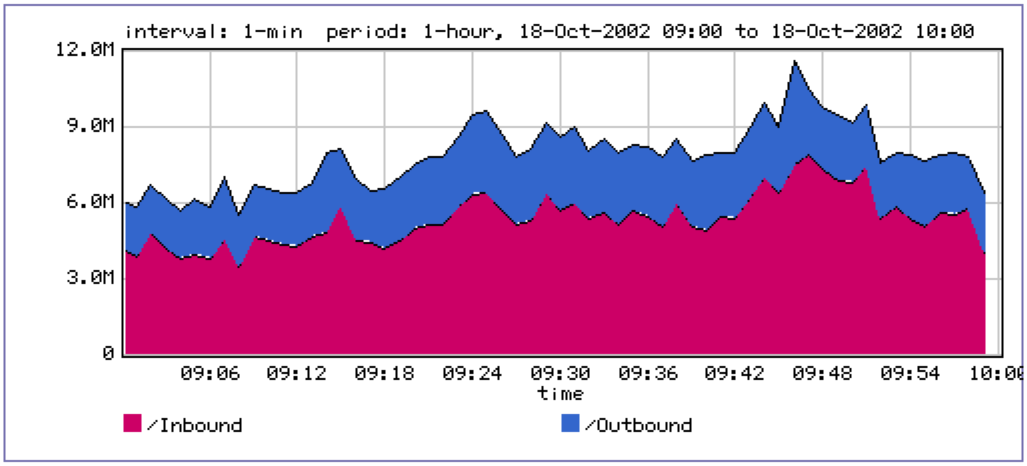
| | |
|---|---|
| SNMP Mon | Simple Network Management Protocol monitor |
| SNMP Trap | Simple Network Management Protocol traps |
| SOCKS | SOCKS Proxy Protocol |
| Spanning Tree | IEEE802.1 Bridge Spanning Tree |
| SSH | Secure shell remote login protocol |
| SSL | Secure Sockets Layer protocol |
| ST2 | Internet Stream Protocol, version 2 |
| StreamWorks | StreamWorks Audio and Video |
| SunRPC | Sun's Remote Procedure Calls (UDP) |
| Syslog | UNIX System Logging |
| T.120 | Collaboration application |
| TACACS | Login host protocol |
| TCP | Transmission Control Protocol—all Internet TCP traffic (not auto-discovered) |
| Telnet | Network terminal protocol |
| TFTP | Trivial File Transfer Protocol |
| Timbuktu | Timbuktu Pro service group; networked remote control application |
| Timbuktu-ctl | Timbuktu Control Channel |
| Timbuktu-hs | Timbuktu Handshaking |
| Timbuktu-obs | Timbuktu Observe Channel |
| Timbuktu-snd | Timbuktu Send Channel |
| Timbuktu-xch | Timbuktu Exchange Channel |
| TN3270 | Telnet for IBM 3270 terminals and 3270 emulation |
| TN3287 | IBM 3270 print traffic (TN3287 extensions) |
| TN5250 | IBM 5250 terminal traffic over Telnet |
| TN5250p | IBM 5250 print traffic over Telnet |
| UDP | User Datagram Protocol—all Internet UDP traffic (not auto-discovered) |
| UUCP | Unix-to-Unix Copy Protocol |
| VDOPhone | Service group for Internet telephone application (not auto-discovered) |
| VDOPhone-a | Internet telephone application—TCP port 1 (not auto-discovered) |
| VDOPhone-b | Internet telephone application—TCP port 2 (not auto-discovered) |
| VDOPhone-UDP | VDOPhone real-time media (not auto-discovered) |
| Whois | Application that identifies the owner of a domain name |
| WindowsMedia | Microsoft Windows Media Player |
| WindowsMedia-T | Windows Media Streaming over TCP |
| WindowsMedia-U | Windows Media Streaming over UDP |
| WINS | Windows Internet Name Service |
| XWindows | X11 Windowing agent (UDP) |
| XWindows-DM | XWindows Display Manager (XDMCP) |
| XWindows-S | XWindows Server |
| YahooMsg | Yahoo! Messenger |

Source: PacketShaper Reference Guide version 4.1

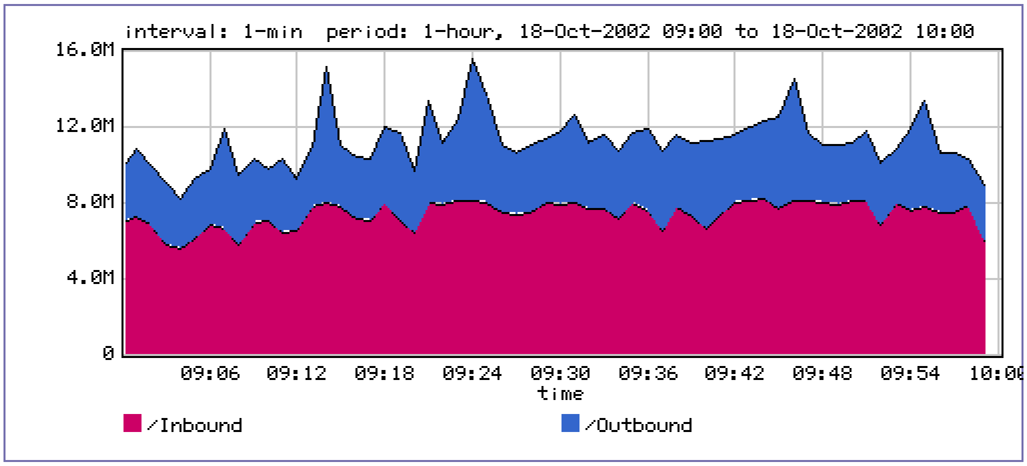
APPENDIX C

SAMPLE AVERAGE AND PEAK FLOW RATES

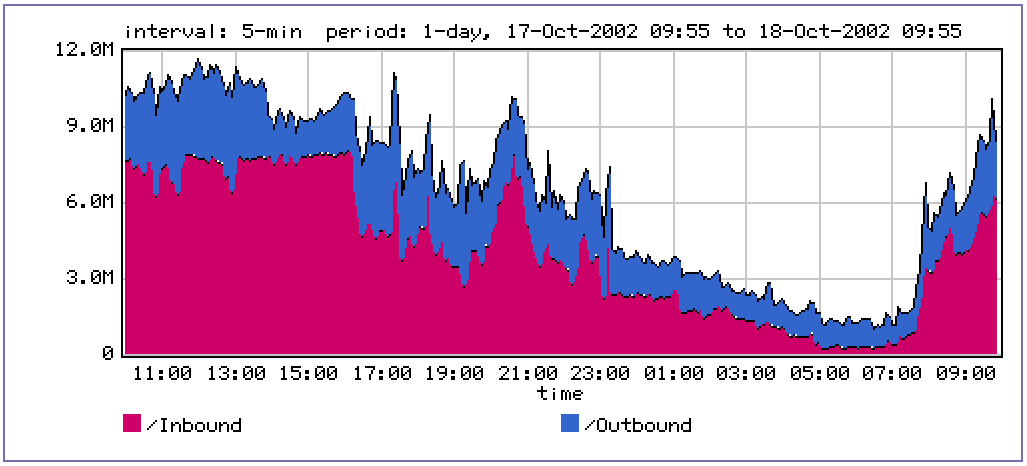
## Hourly Average Rate (18 Oct 2002: 09:00 to 10:00)



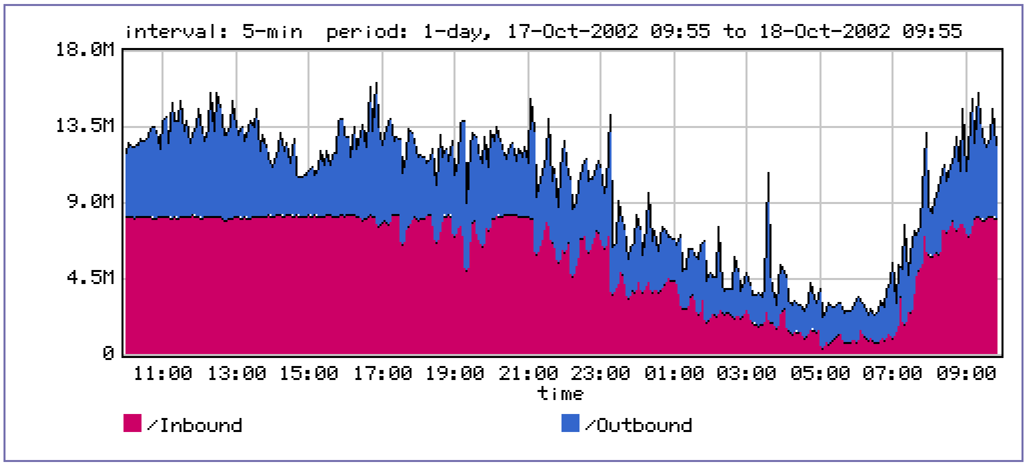
## Hourly Peak Rate (18 Oct 2002: 09:00 to 10:00)



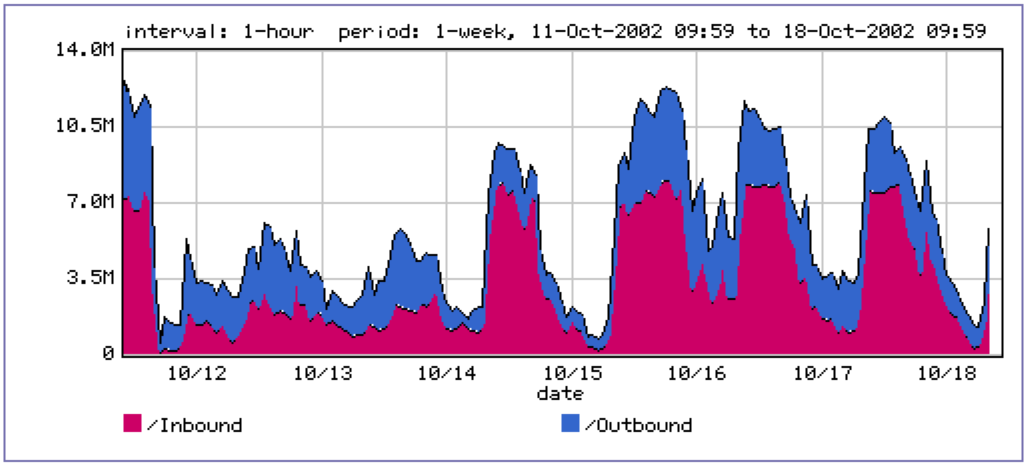
## Daily Average Rate (17 Oct to 18 Oct 2002)



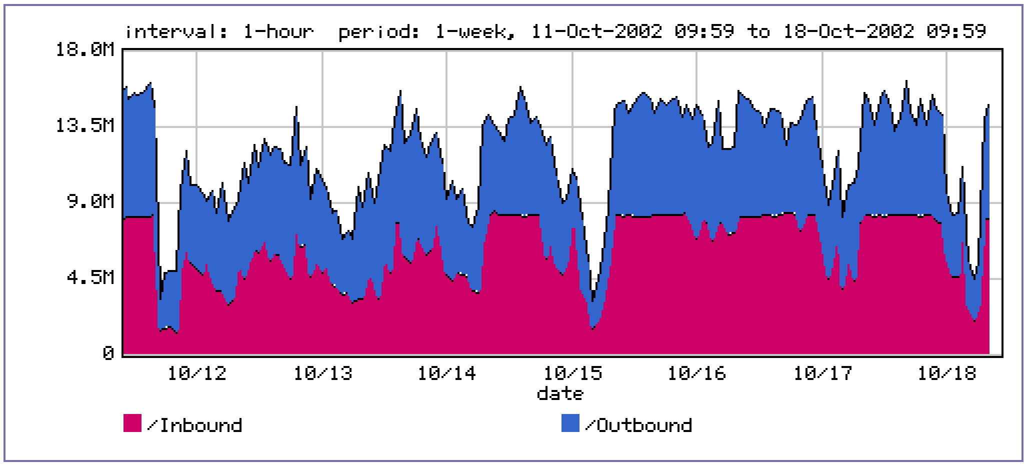
## Daily Peak Rate (17 Oct to 18 Oct 2002)



## Weekly Average Rate (11 Oct to 18 Oct 2002)



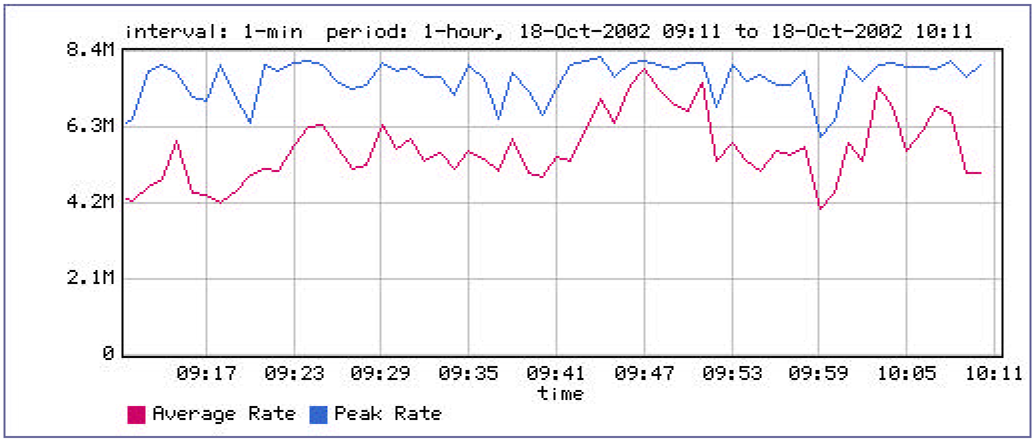
## Weekly Peak Rate (11 Oct to 18 Oct 2002)



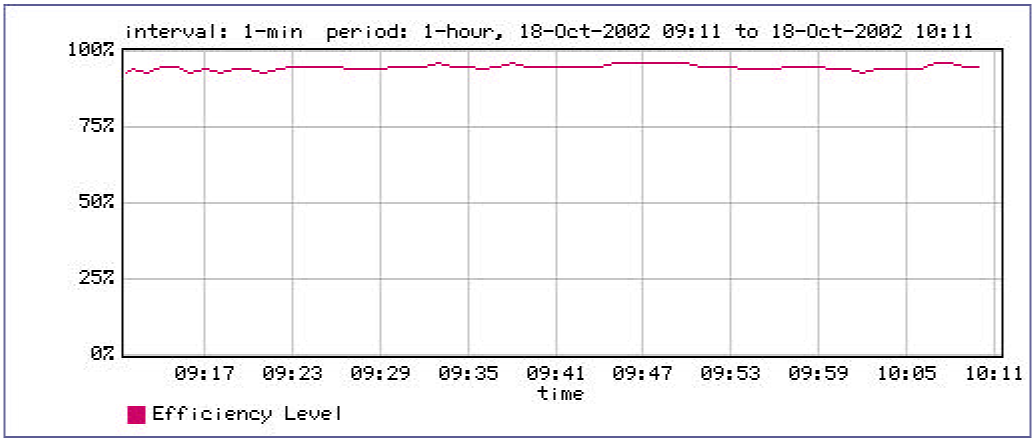
APPENDIX D

NETWORK PERFORMANCE SUMMARY

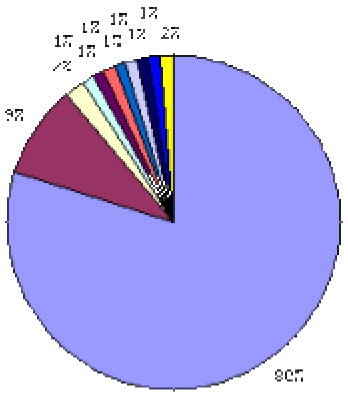
## Hourly Inbound Utilization

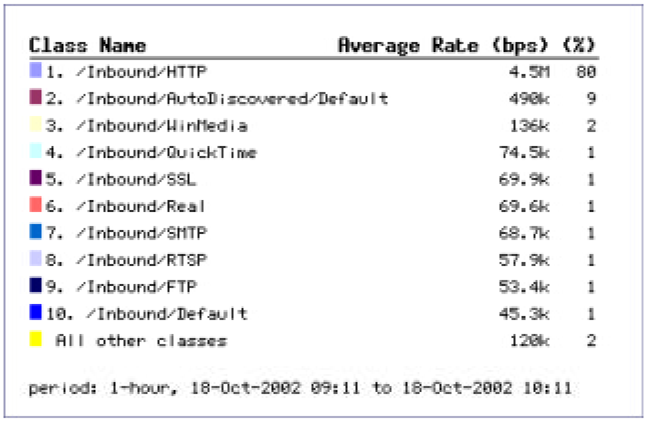


## Hourly Inbound Network Efficiency



## Hourly Inbound Top 10 Classes

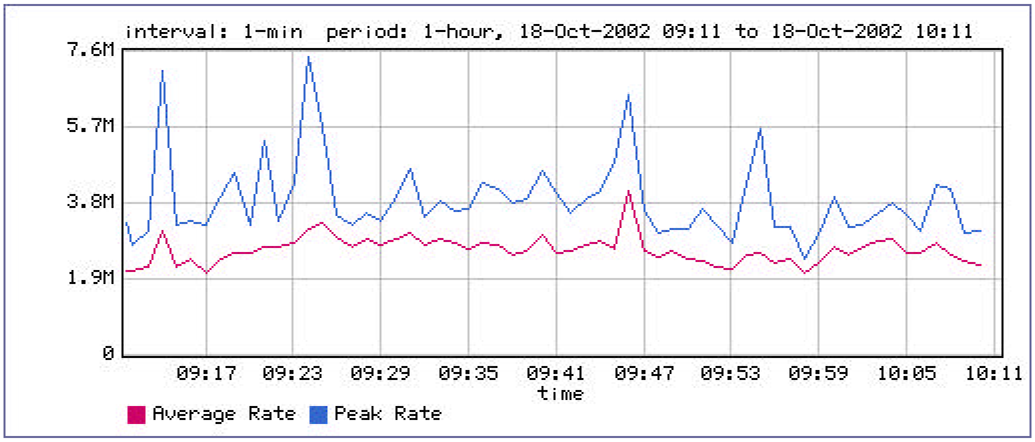




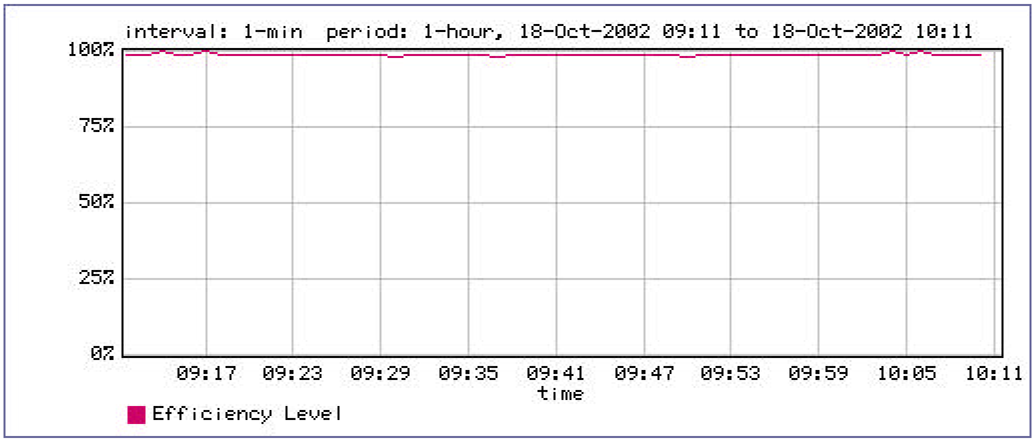
| Class Name | | Average Rate (bps) | (%) |
|---|---|---|---|
| ▨ | 1. /Inbound/HTTP | 4.5M | 80 |
| ▨ | 2. /Inbound/AutoDiscovered/Default | 490k | 9 |
| ▨ | 3. /Inbound/WinMedia | 136k | 2 |
| ▨ | 4. /Inbound/QuickTime | 74.5k | 1 |
| ▨ | 5. /Inbound/SSL | 69.9k | 1 |
| ▨ | 6. /Inbound/Real | 69.6k | 1 |
| ▨ | 7. /Inbound/SMTP | 68.7k | 1 |
| ▨ | 8. /Inbound/RTSP | 57.9k | 1 |
| ▨ | 9. /Inbound/FTP | 53.4k | 1 |
| ▨ | 10. /Inbound/Default | 45.3k | 1 |
| ▨ | All other classes | 120k | 2 |

period: 1-hour, 18-Oct-2002 09:11 to 18-Oct-2002 10:11

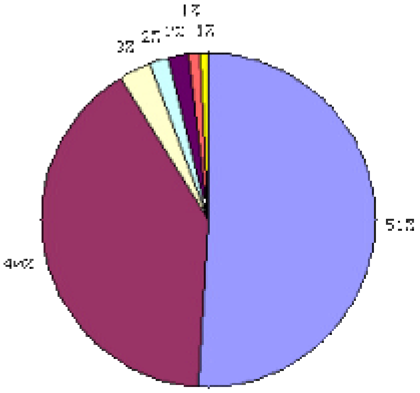
## Hourly Outbound Utilization

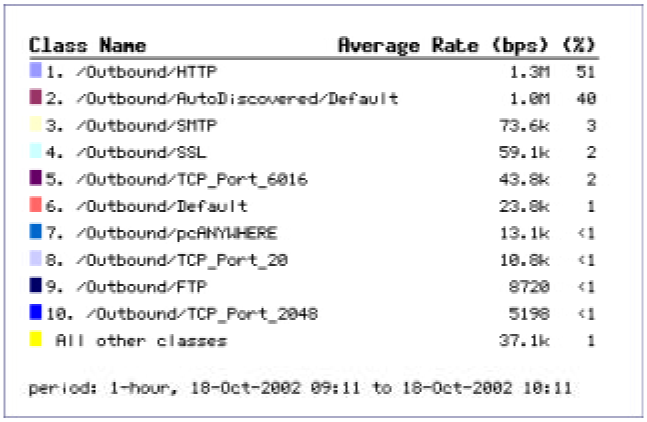


## Hourly Outbound Network Efficiency



## Hourly Outbound Top 10 Classes

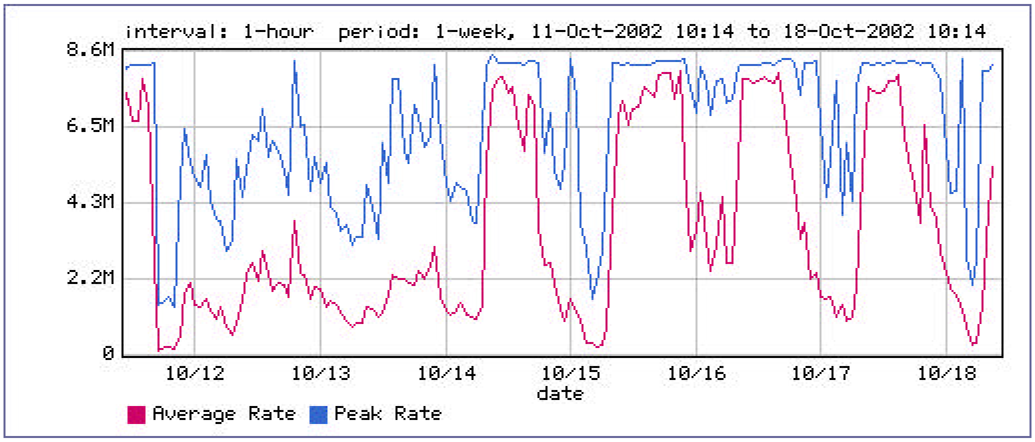




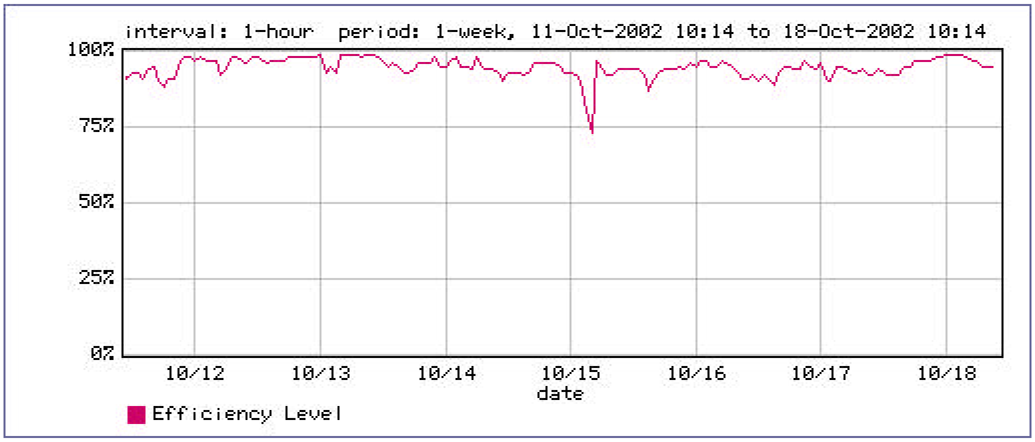
| Class Name | Average Rate (bps) | (%) |
|---|---|---|
| ■ 1. /Outbound/HTTP | 1.3M | 51 |
| ■ 2. /Outbound/AutoDiscovered/Default | 1.0M | 40 |
| ■ 3. /Outbound/SMTP | 73.6k | 3 |
| ■ 4. /Outbound/SSL | 59.1k | 2 |
| ■ 5. /Outbound/TCP_Port_6016 | 43.8k | 2 |
| ■ 6. /Outbound/Default | 23.8k | 1 |
| ■ 7. /Outbound/pcANYWHERE | 13.1k | <1 |
| ■ 8. /Outbound/TCP_Port_20 | 10.8k | <1 |
| ■ 9. /Outbound/FTP | 8720 | <1 |
| ■ 10. /Outbound/TCP_Port_2048 | 5198 | <1 |
| ■ All other classes | 37.1k | 1 |

period: 1-hour, 18-Oct-2002 09:11 to 18-Oct-2002 10:11

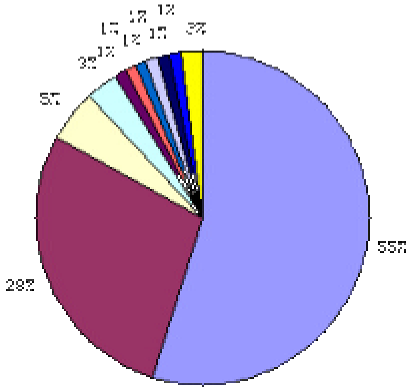
## Weekly Inbound Utilization

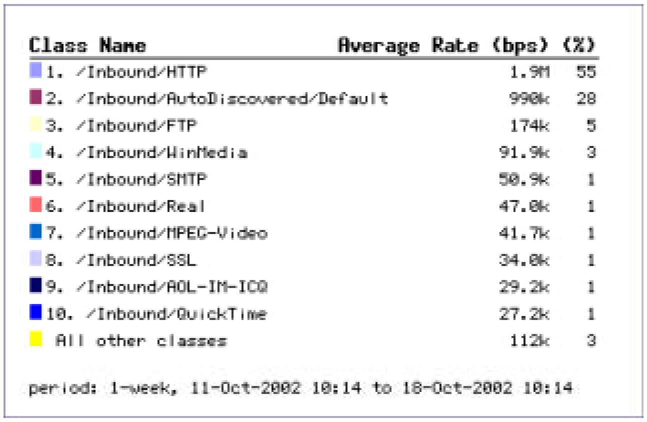


## Weekly Inbound Network Efficiency



## Weekly Inbound Top 10 Classes

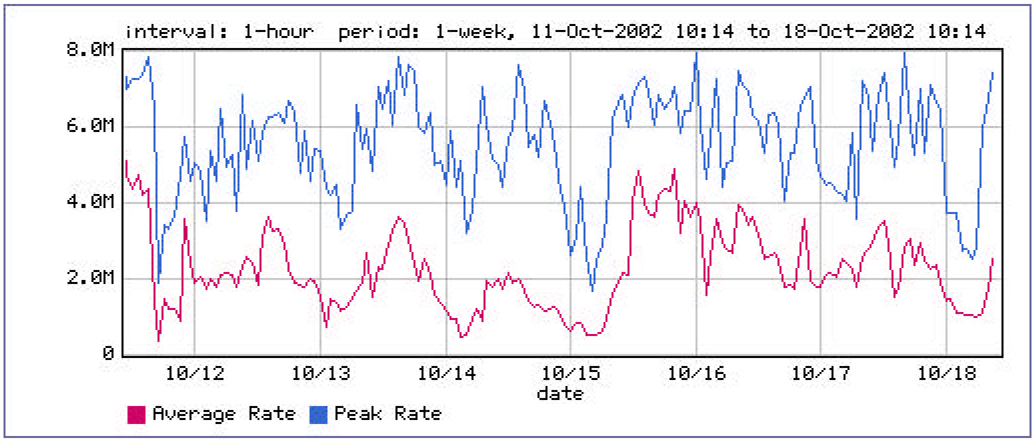




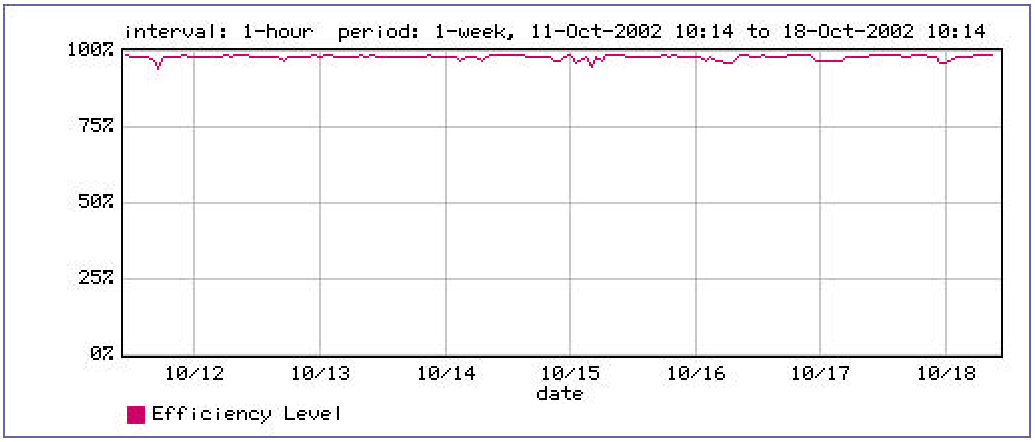
| Class Name | Average Rate (bps) | (%) |
|---|---|---|
| ■ 1. /Inbound/HTTP | 1.9M | 55 |
| ■ 2. /Inbound/AutoDiscovered/Default | 990k | 28 |
| ■ 3. /Inbound/FTP | 174k | 5 |
| ■ 4. /Inbound/WinMedia | 91.9k | 3 |
| ■ 5. /Inbound/SMTP | 50.9k | 1 |
| ■ 6. /Inbound/Real | 47.0k | 1 |
| ■ 7. /Inbound/MPEG-Video | 41.7k | 1 |
| ■ 8. /Inbound/SSL | 34.0k | 1 |
| ■ 9. /Inbound/AOL-IM-ICQ | 29.2k | 1 |
| ■ 10. /Inbound/QuickTime | 27.2k | 1 |
| ■ All other classes | 112k | 3 |

period: 1-week, 11-Oct-2002 10:14 to 18-Oct-2002 10:14

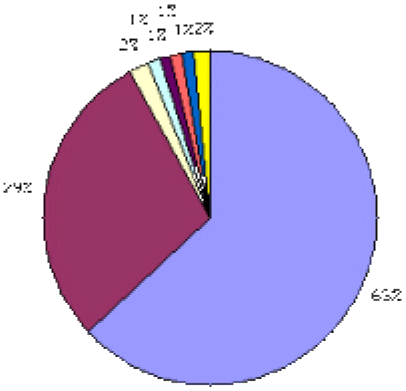
## Weekly Outbound Utilization

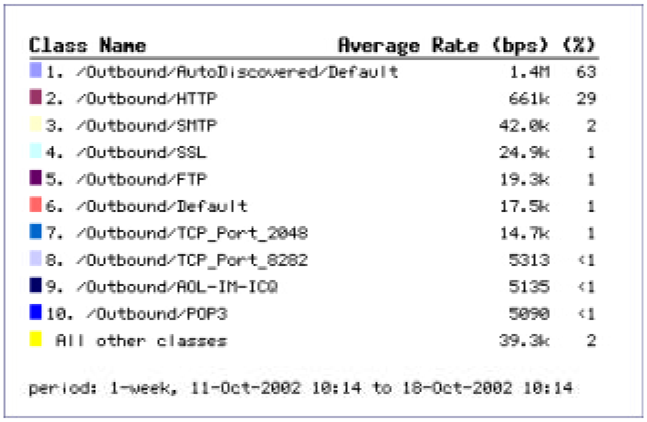


## Weekly Outbound Network Efficiency



## Weekly Outbound Top 10 Classes

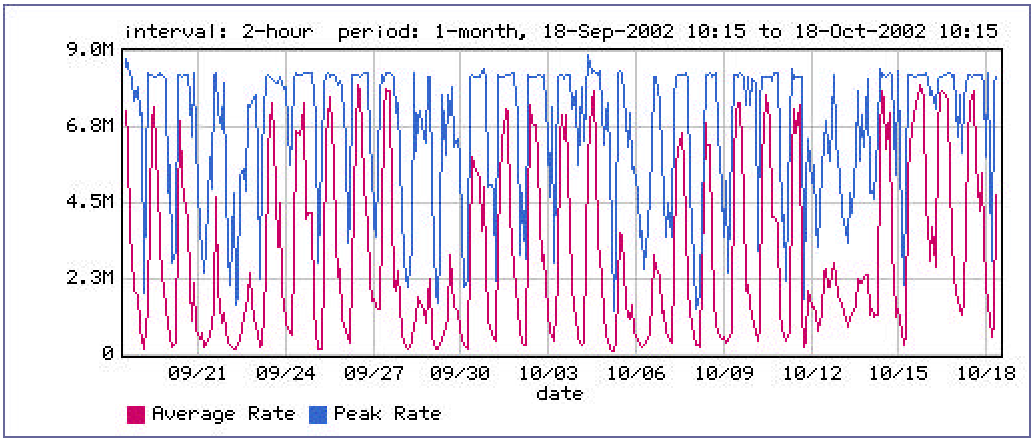




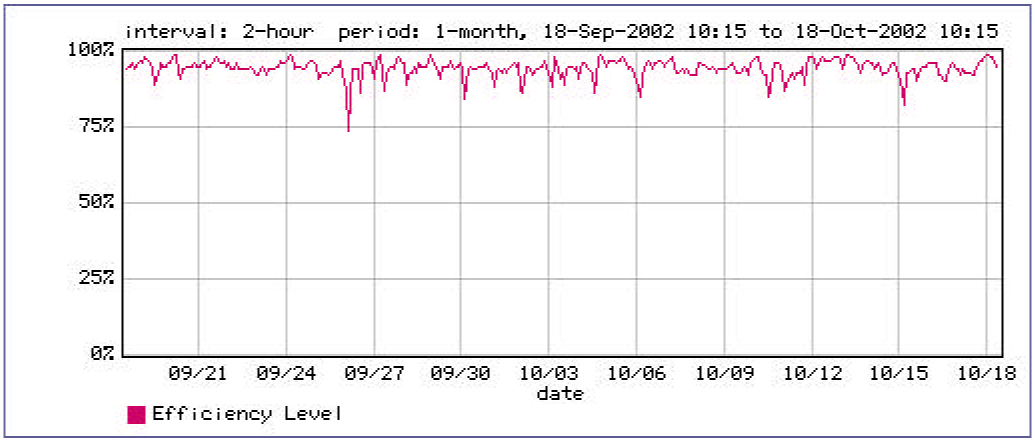
| | Class Name | Average Rate (bps) | (%) |
|---|---|---|---|
| ■ | 1. /Outbound/AutoDiscovered/Default | 1.4M | 63 |
| ■ | 2. /Outbound/HTTP | 661k | 29 |
| ■ | 3. /Outbound/SMTP | 42.0k | 2 |
| ■ | 4. /Outbound/SSL | 24.9k | 1 |
| ■ | 5. /Outbound/FTP | 19.3k | 1 |
| ■ | 6. /Outbound/Default | 17.5k | 1 |
| ■ | 7. /Outbound/TCP_Port_2048 | 14.7k | 1 |
| ■ | 8. /Outbound/TCP_Port_8282 | 5313 | <1 |
| ■ | 9. /Outbound/AOL-IM-ICQ | 5135 | <1 |
| ■ | 10. /Outbound/POP3 | 5090 | <1 |
| ■ | All other classes | 39.3k | 2 |

period: 1-week, 11-Oct-2002 10:14 to 18-Oct-2002 10:14

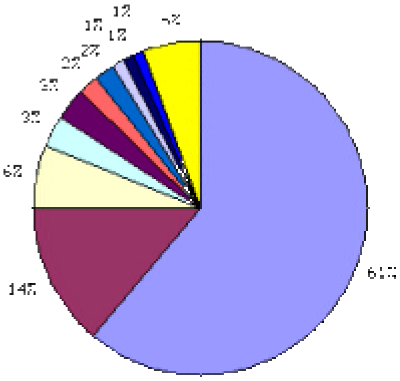
## Monthly Inbound Utilization

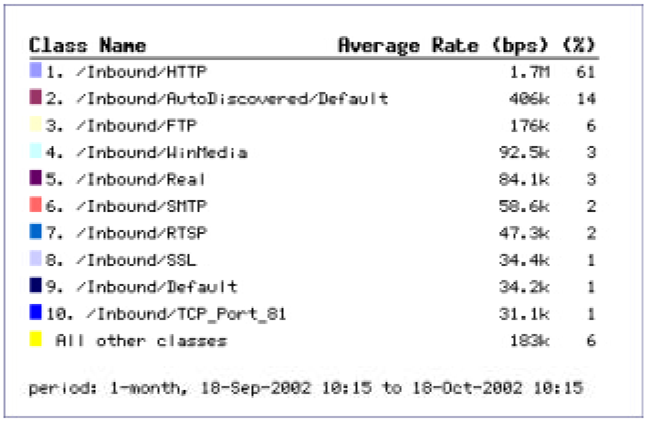


## Monthly Inbound Network Efficiency



## Monthly Inbound Top 10 Classes

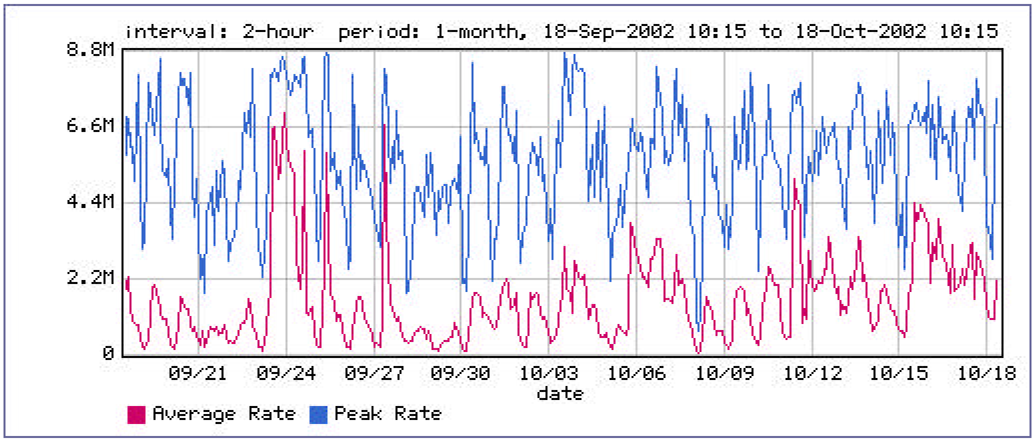




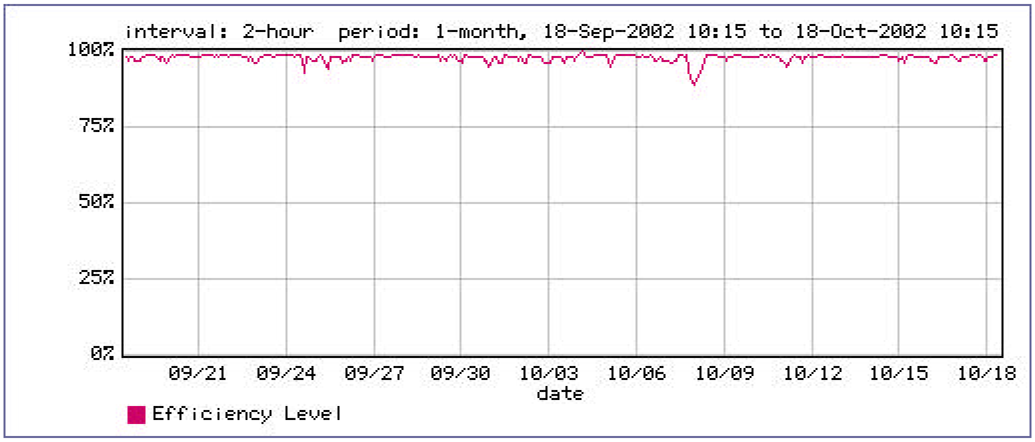
| Class Name | Average Rate (bps) | (%) |
|---|---|---|
| ■ 1. /Inbound/HTTP | 1.7M | 61 |
| ■ 2. /Inbound/AutoDiscovered/Default | 406k | 14 |
| ■ 3. /Inbound/FTP | 176k | 6 |
| ■ 4. /Inbound/WinMedia | 92.5k | 3 |
| ■ 5. /Inbound/Real | 84.1k | 3 |
| ■ 6. /Inbound/SMTP | 58.6k | 2 |
| ■ 7. /Inbound/RTSP | 47.3k | 2 |
| ■ 8. /Inbound/SSL | 34.4k | 1 |
| ■ 9. /Inbound/Default | 34.2k | 1 |
| ■ 10. /Inbound/TCP_Port_81 | 31.1k | 1 |
| ■ All other classes | 183k | 6 |

period: 1-month, 18-Sep-2002 10:15 to 18-Oct-2002 10:15

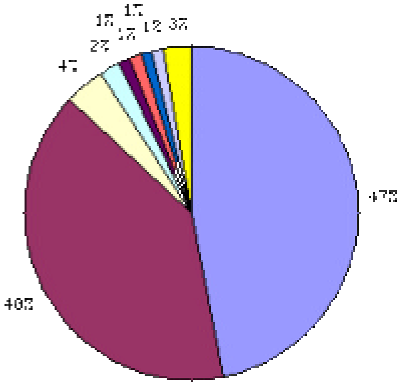
## Monthly Outbound Utilization

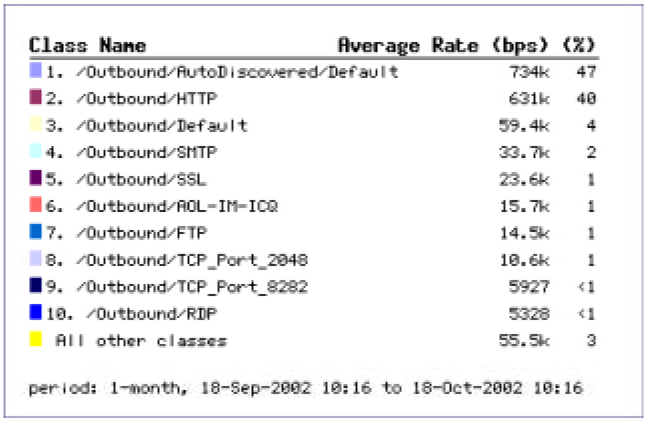


## Monthly Outbound Network Efficiency



# Monthly Outbound Top 10 Classes





| Class Name | Average Rate (bps) | (%) |
|---|---|---|
| ■ 1. /Outbound/AutoDiscovered/Default | 734k | 47 |
| ■ 2. /Outbound/HTTP | 631k | 40 |
| ■ 3. /Outbound/Default | 59.4k | 4 |
| ■ 4. /Outbound/SMTP | 33.7k | 2 |
| ■ 5. /Outbound/SSL | 23.6k | 1 |
| ■ 6. /Outbound/AOL-IM-ICQ | 15.7k | 1 |
| ■ 7. /Outbound/FTP | 14.5k | 1 |
| ■ 8. /Outbound/TCP_Port_2048 | 10.6k | 1 |
| ■ 9. /Outbound/TCP_Port_8282 | 5927 | <1 |
| ■ 10. /Outbound/RDP | 5328 | <1 |
| ■ All other classes | 55.5k | 3 |

period: 1-month, 18-Sep-2002 10:16 to 18-Oct-2002 10:16

| | Total Kbytes Received | Total Kbytes Sent |
|---|---|---|
| **Hourly** | 2490145 | 1152978 |
| **Daily** | 44917399 | 21853781 |
| **Weekly** | 259153192 | 166159166 |
| **Monthly** | 905631746 | 497226101 |

# APPENDIX E

## ETSU NETWORK TRAFFIC TREE AS ON APRIL 01 2003

| Class name | Type | Class | Policy | Cur | 1 Min | Peak |
|---|---|---|---|---|---|---|
| | | hits | hits | rate | avg | rate |
| | | | | | | |
| /Inbound | + | | n/a | 5.3M | 5.0M | 8.9M |
| Localhost | PE | 131 | 131 | 0 | 0 | 4 |
| Discard | E | | n/a | 0 | 0 | 22 |
| TCP_Port_4242 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_6669 | P | 0 | 0 | 0 | 0 | 0 |
| Audiogalaxy | P | 0 | 0 | 0 | 0 | 0 |
| CUSeeMe | P | 0 | 0 | 0 | 0 | 0 |
| Doom | P | 0 | 0 | 0 | 0 | 0 |
| eDonkey | P | 0 | 0 | 0 | 0 | 0 |
| Gnutella | P | 26 | 26 | 0 | 0 | 0 |
| Half-Life | P | 0 | 0 | 0 | 0 | 0 |
| IRC | P | 0 | 0 | 0 | 0 | 0 |
| KaZaA | P | 2827 | 2827 | 0 | 0 | 0 |
| Napster | P | 4 | 4 | 0 | 0 | 0 |
| Net2Phone | P | 0 | 0 | 0 | 0 | 0 |
| Quake | P | 0 | 0 | 0 | 0 | 0 |
| SHARESUDP | P | 0 | 0 | 0 | 0 | 0 |
| TFTP | P | 0 | 0 | 0 | 0 | 0 |
| Unreal | P | 0 | 0 | 0 | 0 | 0 |
| Webshots | P | 3 | 3 | 0 | 0 | 10 |
| YahooGames | P | 6 | 6 | 0 | 0 | 0 |
| Battle.net | P | 0 | 0 | 0 | 0 | 0 |
| Blubster | P | 0 | 0 | 0 | 0 | 0 |
| CU-DEV | P | 0 | 0 | 0 | 0 | 0 |
| Echo | P | 0 | 0 | 0 | 0 | 0 |
| Mythic | P | 0 | 0 | 0 | 0 | 0 |
| SonyOnline | P | 0 | 0 | 0 | 0 | 0 |
| High | E | | n/a | 8580 | 11.4k | 123k |
| Kerberos | P | 38 | 38 | 0 | 0 | 9906 |
| LDAP | P | 12 | 12 | 0 | 0 | 10 |
| NTP | P | 3468 | 3468 | 0 | 14 | 954 |
| OracleEM | P | 0 | 0 | 0 | 0 | 0 |
| RADIUS | P | 0 | 0 | 0 | 0 | 0 |
| SNMP | P | 5774 | 5774 | 0 | 577 | 10.9k |
| Day-Time | P | 21 | 21 | 70 | 36 | 7921 |
| DNS | P | 158820 | 158820 | 8439 | 10.4k | 122k |
| INFOC-RTMS | P | 0 | 0 | 0 | 0 | 0 |
| SLP | P | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SMS | P | 126 | 126 | 442 | 324 | 6427 |
| TimeServer | P | 36 | 36 | 2 | 2 | 397 |
| WINS | P | 0 | 0 | 0 | 0 | 0 |
| Low | E | | n/a | 703k | 714k | 8.9M |
| TCP_Port_10110 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_10120 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_1026 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_2011 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_5001 | P | 2 | 2 | 0 | 5 | 25.9k |
| TCP_Port_5010 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_6009 | P | 42 | 42 | 493 | 272 | 3358 |
| TCP_Port_6016 | P | 220 | 220 | 0 | 68 | 10.8k |
| TCP_Port_7226 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_80 | P | 788 | 785 | 413 | 124 | 62.9k |
| TCP_Port_85 | P | 0 | 1 | 0 | 0 | 0 |
| UDP_Port_6970 | P | 141 | 138 | 173k | 197k | 1.3M |
| AFS | P | 0 | 0 | 0 | 0 | 0 |
| BackWeb | P | 4 | 4 | 0 | 0 | 21.5k |
| Chaincast | P | 0 | 0 | 0 | 0 | 0 |
| CIFS-TCP | P | 0 | 0 | 0 | 0 | 0 |
| CVSpserver | P | 0 | 0 | 0 | 0 | 0 |
| Finger | P | 0 | 0 | 0 | 0 | 0 |
| FTP | P | 5312 | 5306 | 28.4k | 18.3k | 1.4M |
| Gopher | P | 3 | 3 | 0 | 0 | 168 |
| lockd | P | 1 | 1 | 0 | 0 | 0 |
| Marimba | P | 2 | 2 | 18 | 18 | 18 |
| MPEG-Audio | P | 25 | 25 | 1 | 1 | 2.5M |
| MPEG-Video | P | 161 | 161 | 2 | 2 | 2.9M |
| MSN-Messenger | P | 191 | 190 | 149 | 67 | 52.7k |
| QuickTime | P | 7 | 7 | 0 | 1805 | 1.0M |
| RC5DES | P | 9 | 9 | 0 | 0 | 362 |
| Real | P | 257 | 257 | 80.5k | 92.5k | 2.2M |
| rsync | P | 0 | 0 | 0 | 0 | 0 |
| Shoutcast | P | 0 | 0 | 0 | 0 | 0 |
| SMTP | P | 31994 | 31983 | 133k | 112k | 1.2M |
| WHOIS | P | 1 | 1 | 0 | 0 | 3 |
| WinMedia | P | 294 | 292 | 258k | 257k | 1.3M |
| YahooMsg | P | 30 | 30 | 64 | 76 | 4112 |
| AOL-IM-ICQ | P | 137 | 137 | 605 | 421 | 26.7k |
| ISAKMP | P | 1 | 1 | 0 | 0 | 2776 |
| Kontiki | P | 16 | 16 | 0 | 0 | 292 |
| Microsoft-ds | P | 119 | 119 | 6 | 6 | 8.8M |
| NetBIOS-IP | P | 131 | 131 | 0 | 0 | 568 |
| NFS | P | 0 | 0 | 0 | 0 | 0 |
| RTSP | P | 26 | 24 | 14 | 20 | 1230 |
| Average | E | | n/a | 4.6M | 4.4M | 7.2M |

| | | | | | | |
|---|---|---|---|---|---|---|
| GRE | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_8080 | P | 226 | 226 | 0 | 2 | 2851 |
| ATSTCP | P | 0 | 0 | 0 | 0 | 0 |
| ccMail | P | 0 | 0 | 0 | 0 | 0 |
| Citrix | | | n/a | 0 | 0 | 1 |
| Default | P | 1 | 1 | 0 | 0 | 1 |
| CitrixIMA | P | 0 | 0 | 0 | 0 | 0 |
| DLS | P | 0 | 0 | 0 | 0 | 0 |
| FileMaker | P | 1 | 1 | 0 | 5 | 3196 |
| Groupwise | P | 22 | 22 | 10.8k | 5983 | 123k |
| HTTP | P | 594372 | 593910 | 4.1M | 4.2M | 7.1M |
| Ident | P | 7 | 7 | 0 | 0 | 213 |
| IMAP | P | 224 | 253 | 0 | 26 | 87.6k |
| LotusNotes | P | 0 | 0 | 0 | 0 | 0 |
| MATIP | P | 0 | 0 | 0 | 0 | 0 |
| MCK-Signaling | P | 0 | 0 | 0 | 0 | 0 |
| MSSQL | P | 1 | 1 | 0 | 0 | 0 |
| NNTP | P | 0 | 0 | 0 | 0 | 0 |
| NW5-CMD | P | 1 | 1 | 0 | 0 | 0 |
| Oracle | P | 84 | 84 | 0 | 3 | 29.9k |
| Persona | P | 0 | 0 | 0 | 0 | 0 |
| POP3 | P | 5598 | 5588 | 1127 | 1067 | 279k |
| PPTP | P | 1 | 1 | 0 | 0 | 0 |
| RDP | P | 1 | 1 | 0 | 0 | 0 |
| RTCP-I | P | 0 | 0 | 0 | 0 | 0 |
| RTP-I | P | 0 | 0 | 0 | 0 | 0 |
| SMTBF | P | 1 | 1 | 3 | 3 | 3 |
| SSH | P | 14 | 14 | 0 | 4609 | 215k |
| SSL | P | 10176 | 10168 | 363k | 248k | 1.1M |
| T.120 | P | 0 | 0 | 0 | 0 | 0 |
| Telnet | P | 43 | 43 | 0 | 452 | 26.4k |
| Timbuktu | P | 1 | 1 | 0 | 0 | 189 |
| VNC | P | 1 | 1 | 0 | 22 | 475k |
| WebEx | P | 0 | 0 | 0 | 0 | 0 |
| XWindows | P | 0 | 0 | 0 | 0 | 0 |
| DCOM | P | 22 | 22 | 32 | 9 | 15.2k |
| H.323 | P | 1 | 1 | 0 | 4 | 2327 |
| pcANYWHERE | P | 972 | 972 | 0 | 8 | 31.6k |
| ICMP | #NAME? | 15395 | 15395 | 284 | 171 | 17.2k |
| rsh | | 0 | n/a | 0 | 1 | 636 |
| MeetingMaker | | 0 | n/a | 0 | 0 | 0 |
| NW5-NCP | | 9 | n/a | 0 | 0 | 0 |
| StreamWorks | | 1 | n/a | 0 | 0 | 0 |
| DiscoveredPorts | | | n/a | 156 | 142 | 41.9k |
| TCP_Port_12968 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_13311 | | 0 | n/a | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TCP_Port_17037 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_17202 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_17801 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_18511 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_19397 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_2048 | | 287 | n/a | 100 | 83 | 24.3k |
| TCP_Port_21153 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_2443 | | 107 | n/a | 0 | 22 | 13.5k |
| TCP_Port_26161 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_27423 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_32110 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_34277 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_36935 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_3899 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_4000 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_40376 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_41320 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_4170 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_42783 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_444 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_45581 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_46481 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_46801 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_5100 | | 4 | n/a | 0 | 0 | 26.2k |
| TCP_Port_5190 | | 34 | n/a | 101 | 73 | 15.4k |
| TCP_Port_5730 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_59560 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_63005 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_7152 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_7755 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_8016 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_8200 | | 0 | n/a | 36 | 27 | 90 |
| TCP_Port_8282 | | 2137 | n/a | 56 | 79 | 31.7k |
| TCP_Port_8384 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_88 | | 14 | n/a | 0 | 0 | 11.5k |
| TCP_Port_8999 | | 10 | n/a | 0 | 0 | 20.4k |
| TCP_Port_9217 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_9991 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_8197 | | 0 | n/a | 0 | 0 | 0 |
| Default | P I | 18817 | 21420 | 1974 | 1869 | 286k |
| | | | | | | |
| /Outbound | + | | n/a | 970k | 1.1M | 9.1M |
| Localhost | PE | 131 | 131 | 0 | 0 | 3 |
| SameSide | PE | 0 | 0 | 0 | 0 | 0 |
| Discard | E | | n/a | 0 | 0 | 0 |
| TCP_Port_4242 | P | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TCP_Port_6669 | P | 0 | 0 | 0 | 0 | 0 |
| Audiogalaxy | P | 0 | 0 | 0 | 0 | 0 |
| CUSeeMe | P | 0 | 0 | 0 | 0 | 0 |
| Doom | P | 0 | 0 | 0 | 0 | 0 |
| eDonkey | P | 0 | 0 | 0 | 0 | 0 |
| Gnutella | P | 30 | 30 | 0 | 0 | 0 |
| Half-Life | P | 0 | 0 | 0 | 0 | 0 |
| IRC | P | 0 | 0 | 0 | 0 | 0 |
| KaZaA | P | 4151 | 4151 | 0 | 0 | 0 |
| MATIP | P | 0 | 0 | 0 | 0 | 0 |
| Napster | P | 4 | 4 | 0 | 0 | 0 |
| Net2Phone | P | 0 | 0 | 0 | 0 | 0 |
| Quake | P | 0 | 0 | 0 | 0 | 0 |
| Unreal | P | 0 | 0 | 0 | 0 | 0 |
| Webshots | P | 1 | 1 | 0 | 0 | 0 |
| YahooGames | P | 6 | 6 | 0 | 0 | 0 |
| Battle.net | P | 0 | 0 | 0 | 0 | 0 |
| Blubster | P | 0 | 0 | 0 | 0 | 0 |
| Mythic | P | 0 | 0 | 0 | 0 | 0 |
| SonyOnline | P | 0 | 0 | 0 | 0 | 0 |
| Average | E | | n/a | 888k | 956k | 6.3M |
| GRE | P | 0 | 0 | 0 | 0 | 0 |
| ATSTCP | P | 0 | 0 | 0 | 0 | 0 |
| ccMail | P | 0 | 0 | 0 | 0 | 0 |
| Citrix | | | n/a | 0 | 0 | 0 |
| Default | P | 1 | 1 | 0 | 0 | 0 |
| CitrixIMA | P | 0 | 0 | 0 | 0 | 0 |
| DLS | P | 0 | 0 | 0 | 0 | 0 |
| FileMaker | P | 1 | 1 | 0 | 9 | 1222 |
| Groupwise | P | 22 | 22 | 1694 | 1463 | 34.2k |
| HTTP | P | 567265 | 566811 | 800k | 884k | 5.9M |
| Ident | P | 7 | 7 | 0 | 0 | 317 |
| IMAP | P | 224 | 248 | 0 | 82 | 99.0k |
| LotusNotes | P | 0 | 0 | 0 | 0 | 0 |
| MCK-Signaling | P | 0 | 0 | 0 | 0 | 0 |
| MSSQL | P | 1 | 1 | 0 | 0 | 66 |
| NW5-CMD | P | 1 | 1 | 0 | 0 | 0 |
| Oracle | P | 84 | 84 | 0 | 1 | 42.7k |
| Persona | P | 0 | 0 | 0 | 0 | 0 |
| POP3 | P | 5597 | 5587 | 2905 | 3019 | 636k |
| PPTP | P | 1 | 1 | 0 | 0 | 107 |
| RDP | P | 1 | 1 | 0 | 0 | 65 |
| RTCP-I | P | 0 | 0 | 0 | 0 | 0 |
| RTP-I | P | 0 | 0 | 0 | 0 | 0 |
| SMTBF | P | 1 | 1 | 0 | 0 | 0 |
| SSH | P | 14 | 14 | 0 | 520 | 51.6k |

| | | | | | | |
|---|---|---|---|---|---|---|
| SSL | P | 10174 | 10166 | 55.4k | 75.9k | 1.5M |
| T.120 | P | 0 | 0 | 0 | 0 | 0 |
| Telnet | P | 43 | 43 | 0 | 526 | 236k |
| Timbuktu | P | 1 | 1 | 0 | 0 | 97 |
| VNC | P | 1 | 1 | 0 | 39 | 20.5k |
| WebEx | P | 0 | 0 | 0 | 0 | 0 |
| XWindows | P | 0 | 0 | 0 | 0 | 0 |
| DCOM | P | 22 | 22 | 31 | 9 | 14.3k |
| H.323 | P | 897 | 897 | 55 | 38 | 362 |
| pcANYWHERE | P | 971 | 971 | 0 | 0 | 66.6k |
| ICMP | #NAME? | 35648 | 35648 | 253 | 428 | 112k |
| High | E | | n/a | 6589 | 6624 | 844k |
| DHCP | P | 0 | 0 | 0 | 0 | 0 |
| Kerberos | P | 38 | 38 | 0 | 0 | 13.2k |
| LDAP | P | 12 | 12 | 0 | 0 | 6 |
| NTP | P | 8391 | 8391 | 0 | 42 | 1606 |
| OracleEM | P | 0 | 0 | 0 | 0 | 0 |
| RADIUS | P | 0 | 0 | 0 | 0 | 0 |
| SNMP | P | 12281 | 12281 | 334 | 511 | 24.4k |
| Syslog | P | 0 | 0 | 0 | 0 | 0 |
| Day-Time | P | 21 | 21 | 69 | 12 | 4572 |
| DNS | P | 184894 | 184894 | 6219 | 4360 | 843k |
| INFOC-RTMS | P | 0 | 0 | 0 | 0 | 0 |
| RIP | P | 1 | 1 | 0 | 0 | 0 |
| SLP | P | 0 | 0 | 0 | 0 | 0 |
| SMS | P | 126 | 126 | 460 | 124 | 219k |
| TimeServer | P | 36 | 36 | 2 | 2 | 416 |
| WINS | P | 0 | 0 | 0 | 0 | 0 |
| RSVP | P | 0 | 0 | 0 | 0 | 0 |
| Low | E | | n/a | 95.2k | 80.7k | 9.1M |
| TCP_Port_10110 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_10130 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_17811 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_2011 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_5001 | P | 2 | 2 | 0 | 9 | 622 |
| TCP_Port_5010 | P | 0 | 0 | 0 | 0 | 0 |
| TCP_Port_85 | P | 0 | 0 | 0 | 0 | 0 |
| UDP_Port_1235 | P | 0 | 0 | 0 | 0 | 0 |
| UDP_Port_192 | P | 355 | 355 | 76 | 149 | 152 |
| UDP_Port_5190 | P | 0 | 0 | 0 | 0 | 0 |
| UDP_Port_6970 | P | 141 | 138 | 4854 | 4531 | 17.0k |
| AFS | P | 0 | 0 | 0 | 0 | 0 |
| BackWeb | P | 4 | 4 | 0 | 0 | 3115 |
| Chaincast | P | 0 | 0 | 0 | 0 | 0 |
| CIFS-TCP | P | 0 | 0 | 0 | 0 | 0 |
| CVSpserver | P | 0 | 0 | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| FTP | P | 5300 | 5294 | 53.1k | 31.7k | 500k |
| Gopher | P | 3 | 3 | 0 | 0 | 175 |
| lockd | P | 1 | 1 | 0 | 0 | 0 |
| Marimba | P | 2 | 2 | 26 | 26 | 26 |
| MPEG-Audio | P | 25 | 25 | 1 | 1 | 589k |
| MPEG-Video | P | 161 | 161 | 0 | 5 | 47.6k |
| MSN-Messenger | P | 191 | 190 | 202 | 73 | 7858 |
| NNTP | P | 0 | 0 | 0 | 0 | 0 |
| QuickTime | P | 6 | 6 | 0 | 70 | 14.4k |
| RC5DES | P | 9 | 9 | 0 | 0 | 379 |
| Real | P | 254 | 254 | 2691 | 4880 | 34.7k |
| rsync | P | 0 | 0 | 0 | 0 | 0 |
| Shoutcast | P | 0 | 0 | 0 | 0 | 0 |
| SMTP | P | 31992 | 31981 | 29.3k | 25.9k | 6.0M |
| SSDP | P | 0 | 0 | 0 | 0 | 0 |
| TFTP | P | 960 | 960 | 0 | 45 | 8161 |
| WHOIS | P | 1 | 1 | 0 | 0 | 1 |
| WinMedia | P | 301 | 299 | 9153 | 9672 | 26.3k |
| YahooMsg | P | 30 | 30 | 196 | 115 | 1287 |
| AOL-IM-ICQ | P | 137 | 137 | 551 | 245 | 14.0k |
| Echo | P | 0 | 0 | 0 | 0 | 0 |
| ISAKMP | P | 1 | 1 | 0 | 0 | 4882 |
| Kontiki | P | 16 | 16 | 0 | 0 | 283 |
| Microsoft-ds | P | 119 | 119 | 0 | 5 | 9.0M |
| NetBIOS-IP | P | 1507 | 1505 | 244 | 305 | 5794 |
| NFS | P | 1 | 1 | 0 | 0 | 0 |
| RTSP | P | 195 | 193 | 28 | 41 | 4109 |
| SunRPC | P | 31 | 31 | 0 | 0 | 4 |
| Protocol_41 | P | 1 | 1 | 0 | 0 | 1 |
| Protocol_54 | P | 54 | 54 | 0 | 0 | 577 |
| Finger | | 0 | n/a | 0 | 0 | 0 |
| rsh | | 0 | n/a | 0 | 3 | 1367 |
| SHARESUDP | | 0 | n/a | 0 | 0 | 0 |
| CU-DEV | | 0 | n/a | 0 | 0 | 0 |
| MeetingMaker | | 0 | n/a | 0 | 0 | 0 |
| NW5-NCP | | 9 | n/a | 0 | 0 | 220 |
| StreamWorks | | 2 | n/a | 0 | 0 | 0 |
| IPSec | | 1 | n/a | 0 | 0 | 1801 |
| Protocol_255 | | 0 | n/a | 0 | 0 | 0 |
| DiscoveredPorts | | | n/a | 939 | 795 | 429k |
| TCP_Port_10230 | | 1 | n/a | 0 | 916 | 52.6k |
| TCP_Port_15126 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_15533 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_18429 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_19052 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_20169 | | 0 | n/a | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| TCP_Port_2048 | | 287 | n/a | 51 | 42 | 147k |
| TCP_Port_2443 | | 107 | n/a | 0 | 20 | 19.4k |
| TCP_Port_26161 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_29798 | | 3 | n/a | 0 | 1 | 6461 |
| TCP_Port_3000 | | 4 | n/a | 1 | 1 | 104 |
| TCP_Port_34277 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_36931 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_37258 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_3899 | | 0 | n/a | 3 | 3 | 3 |
| TCP_Port_42783 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_46481 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_46781 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_47067 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_50000 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_5100 | | 4 | n/a | 0 | 0 | 1468 |
| TCP_Port_5190 | | 34 | n/a | 97 | 78 | 2950 |
| TCP_Port_6009 | | 42 | n/a | 437 | 177 | 1578 |
| TCP_Port_60090 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_60132 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_6016 | | 220 | n/a | 360 | 101 | 13.9k |
| TCP_Port_6099 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_63006 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_7755 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_8200 | | 0 | n/a | 74 | 57 | 184 |
| TCP_Port_8282 | | 2137 | n/a | 28 | 40 | 429k |
| TCP_Port_8999 | | 10 | n/a | 0 | 0 | 22.8k |
| TCP_Port_9324 | | 0 | n/a | 0 | 0 | 0 |
| TCP_Port_9909 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_10615 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_1130 | P | 0 | 0 | 0 | 0 | 0 |
| UDP_Port_1138 | P | 0 | 0 | 0 | 0 | 0 |
| UDP_Port_1320 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_1622 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_1678 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_1920 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2174 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2312 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_25 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2760 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2767 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2785 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_2944 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3049 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3059 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3283 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3403 | | 0 | n/a | 0 | 0 | 0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| UDP_Port_3568 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3594 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_3918 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_4015 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_4473 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_6971 | | 0 | n/a | 0 | 0 | 0 |
| UDP_Port_7001 | | 19 | n/a | 0 | 1 | 479 |
| UDP_Port_9 | | 1 | n/a | 0 | 0 | 0 |
| Default | P I | 20286 | 23167 | 13.9k | 6377 | 2.9M |

# APPENDIX F

## PROTOCOLS AND SERVICES RECOGNIZED BY PACKETPUP

| Category | Specific Instances |
|---|---|
| FTP | FTPActive<br>FTPControl<br>FTPPassive |
| HTTP | HTTP<br>HTTP-ACTIVEX<br>HTTP-CodeRed<br>HTTP-CodeRedII<br>HTTP-EXE<br>HTTP-IDA<br>HTTP-RAR<br>HTTPS<br>HTTP-Zip<br>DoubleClick |
| A/V Stream | HTTP-AVI<br>HTTP-Audio-MPEG<br>HTTP-Video-MPEG<br>HTTP-QuickTime<br>HTTP-ShockWave-Flash<br>RealMedia 1 and 2<br>ShoutCast<br>WebRadio<br>WindowsMedia |
| Peer-to-Peer | Aimster<br>AudioGalaxyLogin<br>AudioGalaxySearch<br>AudioGalaxyDownloadReq<br>AudioGalaxyXfer<br>Blubster<br>DirectConnect<br>Gnutella<br>Gnutella Web<br>GnutellaXfer<br>KaZaA<br>KaZaAXfer<br>Microsoft-DS<br>NapsterXfer<br>NetBIOX-SSN<br>ScourExchange<br>ScourExchangeXfer<br>SongSpy |

| | |
|---|---|
| | SpinFrenzy |
| Remote Shell | Rlogin<br>REXEC<br>RSH<br>SSH<br>Telnet<br>XWindows<br>VNC |
| Other TCP | |
| Non-IP | |
| Other IP | Finger<br>Gopher |
| Messaging | AIMLogin<br>AIMXfer<br>AIMMsg<br>ICQLogin<br>ICQMsg<br>MSNMessengerLogin<br>MSNMessengerXfer<br>E-mail/Newsgroups<br>IMAP<br>IMAPS<br>NNTP<br>POP<br>POP3S<br>SMTP<br>Hotmail<br>YahooMail |

# APPENDIX G

## SAMPLE DATA FROM PACKETPUP LOGFILE

| | | | | |
|---|---|---|---|---|
| Feb | 21 | 9:26:58 | packetpup[1188]: | Parsed rule HTTP on line 66 |
| Feb | 21 | 9:26:58 | packetpup[1188]: | Finished reading rule file |
| Feb | 21 | 9:26:58 | packetpup[1188]: | listening on network device \Device\NPF_{6F35C19A-8365-4E2F-8ACB-DFD263669DE4} |
| Feb | 21 | 9:26:58 | packetpup[1188]: | Allocated 1048576 bytes for PCAP buffer. |
| Feb | 21 | 9:26:58 | packetpup[1188]: | listening |
| Feb | 21 | 9:26:58 | packetpup[1188]: | Packet matched rule SMTP: 206.46.170.98.34317 -> 151.141.8.105.25 |
| Feb | 21 | 9:26:58 | packetpup[1188]: | M SMTP,206.46.170.98,34317,151.141.8.105,25 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | Packet matched rule POP3S: 151.141.12.204.2866 -> 151.141.8.105.995 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | M POP3S,151.141.12.204,2866,151.141.8.105,995 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6042 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6042 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.48.22.1569 -> 151.141.8.105.443 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | M HTTPS,151.141.48.22,1569,151.141.8.105,443 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | Packet matched rule SMTP: 64.124.168.46.8766 -> 151.141.8.105.25 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | M SMTP,64.124.168.46,8766,151.141.8.105,25 |
| Feb | 21 | 9:26:59 | packetpup[1188]: | Email/News Connection 64.124.168.46.8766->151.141.8.105.25 terminated 5.08 Packets/sec |
| Feb | 21 | 9:26:59 | packetpup[1188]: | F Email/News,64.124.168.46,8766,151.141.8.105,25,12,2,0.15,25.08 |
| Feb | 21 | 9:27:00 | packetpup[1188]: | Packet matched rule SMTP: 151.141.99.22.1464 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:00 | packetpup[1188]: | M SMTP,151.141.99.22,1464,151.141.8.105,25 |
| Feb | 21 | 9:27:00 | packetpup[1188]: | 151.141.47.44.1215 151.141.8.105.80 mail.etsu.edu /exchange |
| Feb | 21 | 9:27:00 | packetpup[1188]: | Packet matched rule POP3S: 151.141.31.77.4205 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:00 | packetpup[1188]: | M POP3S,151.141.31.77,4205,151.141.8.105,995 |
| Feb | 21 | 9:27:01 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.103.25 -> 151.141.8.104.6044 |
| Feb | 21 | 9:27:01 | packetpup[1188]: | M SMTP,151.141.8.103,25,151.141.8.104,6044 |
| Feb | 21 | 9:27:01 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6047 |
| Feb | 21 | 9:27:01 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6047 |
| Feb | 21 | 9:27:02 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.47.44.1216 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:02 | packetpup[1188]: | M HTTPS,151.141.47.44,1216,151.141.8.105,443 |
| Feb | 21 | 9:27:02 | packetpup[1188]: | Packet matched rule HTTPS: 206.105.206.72.4710 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:02 | packetpup[1188]: | M HTTPS,206.105.206.72,4710,151.141.8.105,443 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | Packet matched rule SMTP: 151.141.99.22.1465 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | M SMTP,151.141.99.22,1465,151.141.8.105,25 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | Packet matched rule SMTP: 151.141.99.22.1466 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | M SMTP,151.141.99.22,1466,151.141.8.105,25 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.76.248.1044 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:03 | packetpup[1188]: | M HTTPS,151.141.76.248,1044,151.141.8.105,443 |
| Feb | 21 | 9:27:04 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.103.25 -> 151.141.8.104.6049 |
| Feb | 21 | 9:27:04 | packetpup[1188]: | M SMTP,151.141.8.103,25,151.141.8.104,6049 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule SMTP: 206.106.119.10.4648 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M SMTP,206.106.119.10,4648,151.141.8.105,25 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule SMTP: 24.106.95.18.2175 -> 151.141.8.105.25 |

| | | | | |
|---|---|---|---|---|
| Feb | 21 | 9:27:06 | packetpup[1188]: | M SMTP,24.106.95.18,2175,151.141.8.105,25 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule POP3S: 151.141.41.212.2644 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M POP3S,151.141.41.212,2644,151.141.8.105,995 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6053 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6053 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule IMAPS: 160.36.210.70.1073 -> 151.141.8.105.993 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M IMAPS,160.36.210.70,1073,151.141.8.105,993 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule IMAP: 151.141.8.103.143 -> 151.141.8.104.5373 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M IMAP,151.141.8.103,143,151.141.8.104,5373 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.46.106.1347 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:06 | packetpup[1188]: | M HTTPS,151.141.46.106,1347,151.141.8.105,443 |
| Feb | 21 | 9:27:07 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.59.188.1107 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:07 | packetpup[1188]: | M HTTPS,151.141.59.188,1107,151.141.8.105,443 |
| Feb | 21 | 9:27:08 | packetpup[1188]: | Packet matched rule SMTP: 216.39.115.52.4430 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:08 | packetpup[1188]: | M SMTP,216.39.115.52,4430,151.141.8.105,25 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.47.44.1217 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | M HTTPS,151.141.47.44,1217,151.141.8.105,443 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | Packet matched rule HTTPS: 68.54.96.36.2081 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | M HTTPS,68.54.96.36,2081,151.141.8.105,443 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.47.44.1218 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:11 | packetpup[1188]: | M HTTPS,151.141.47.44,1218,151.141.8.105,443 |
| Feb | 21 | 9:27:12 | packetpup[1188]: | 151.141.62.167.2010 151.141.8.105.80 mail.etsu.edu /default.asp |
| Feb | 21 | 9:27:12 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.76.248.1045 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:12 | packetpup[1188]: | M HTTPS,151.141.76.248,1045,151.141.8.105,443 |
| Feb | 21 | 9:27:12 | packetpup[1188]: | Packet matched rule POP3S: 151.141.55.192.3319 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:12 | packetpup[1188]: | M POP3S,151.141.55.192,3319,151.141.8.105,995 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6054 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6054 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | Packet matched rule IMAPS: 151.141.8.57.63778 -> 151.141.8.105.993 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | M IMAPS,151.141.8.57,63778,151.141.8.105,993 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.57.63777 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | M SMTP,151.141.8.57,63777,151.141.8.105,25 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | Packet matched rule HTTPS: 24.159.43.221.4966 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:13 | packetpup[1188]: | M HTTPS,24.159.43.221,4966,151.141.8.105,443 |
| Feb | 21 | 9:27:14 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.68.167.2315 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:14 | packetpup[1188]: | M HTTPS,151.141.68.167,2315,151.141.8.105,443 |
| Feb | 21 | 9:27:14 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.62.167.2011 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:14 | packetpup[1188]: | M HTTPS,151.141.62.167,2011,151.141.8.105,443 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | Packet matched rule POP3S: 151.141.59.124.1132 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | M POP3S,151.141.59.124,1132,151.141.8.105,995 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6055 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6055 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | Packet matched rule POP3S: 63.162.206.106.2865 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:16 | packetpup[1188]: | M POP3S,63.162.206.106,2865,151.141.8.105,995 |
| Feb | 21 | 9:27:17 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6056 |
| Feb | 21 | 9:27:17 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6056 |

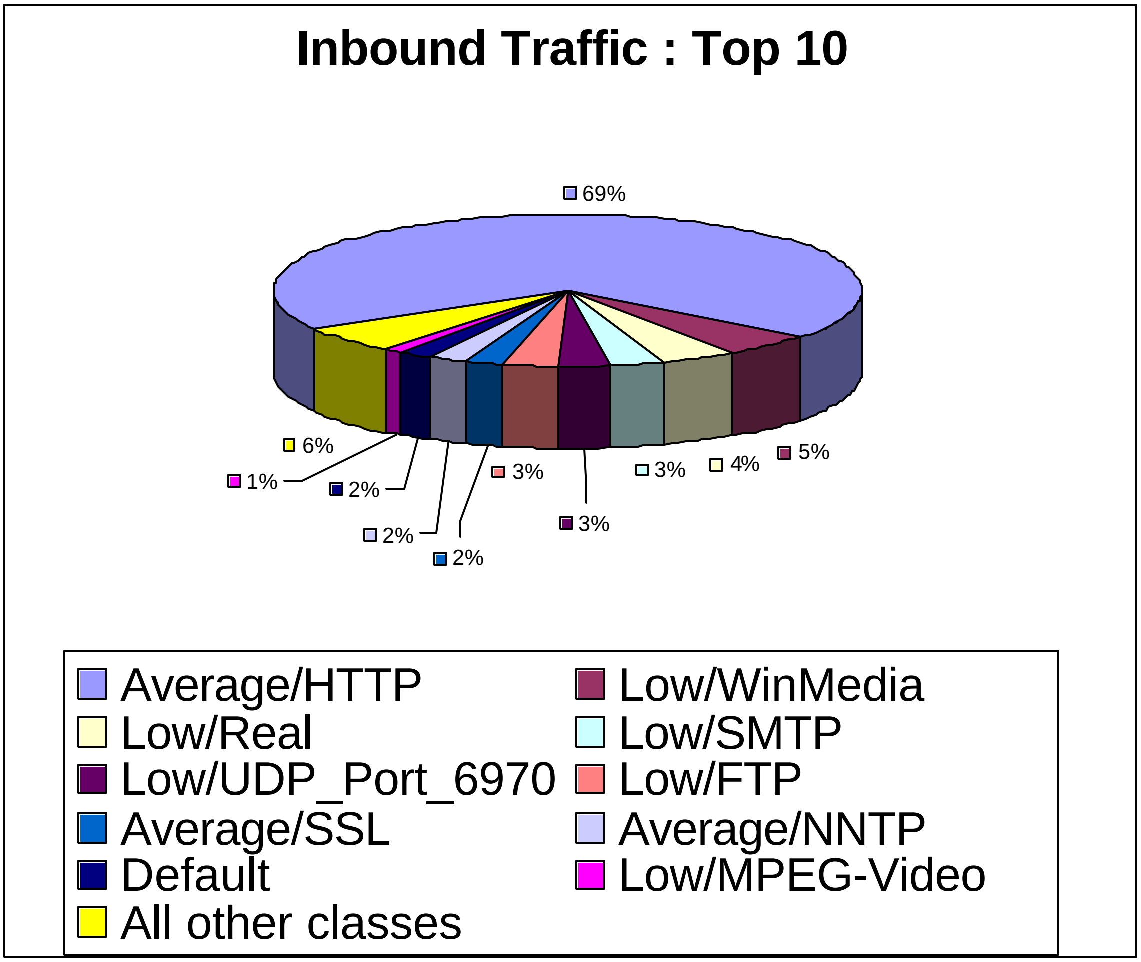
|  |  |  |  |  |
|---|---|---|---|---|
| Feb | 21 | 9:27:17 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.47.44.1219 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:17 | packetpup[1188]: | M HTTPS,151.141.47.44,1219,151.141.8.105,443 |
| Feb | 21 | 9:27:17 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.46.106.1346 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:17 | packetpup[1188]: | M HTTPS,151.141.46.106,1346,151.141.8.105,443 |
| Feb | 21 | 9:27:18 | packetpup[1188]: | WWW Connection 151.141.68.167.2315->151.141.8.105.443 terminated.63 Packets/sec |
| Feb | 21 | 9:27:18 | packetpup[1188]: | F WWW,151.141.68.167,2315,151.141.8.105,443,1138,7,0.26,1.63 |
| Feb | 21 | 9:27:18 | packetpup[1188]: | Packet matched rule SMTP: 151.141.99.22.1469 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:18 | packetpup[1188]: | M SMTP,151.141.99.22,1469,151.141.8.105,25 |
| Feb | 21 | 9:27:19 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.68.167.2316 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:19 | packetpup[1188]: | M HTTPS,151.141.68.167,2316,151.141.8.105,443 |
| Feb | 21 | 9:27:19 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.103.25 -> 151.141.8.104.6058 |
| Feb | 21 | 9:27:19 | packetpup[1188]: | M SMTP,151.141.8.103,25,151.141.8.104,6058 |
| Feb | 21 | 9:27:20 | packetpup[1188]: | Packet matched rule NNTP: 151.141.8.57.63796 -> 151.141.8.105.119 |
| Feb | 21 | 9:27:20 | packetpup[1188]: | M NNTP,151.141.8.57,63796,151.141.8.105,119 |
| Feb | 21 | 9:27:20 | packetpup[1188]: | Packet matched rule SMTP: 216.33.97.76.39843 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:20 | packetpup[1188]: | M SMTP,216.33.97.76,39843,151.141.8.105,25 |
| Feb | 21 | 9:27:21 | packetpup[1188]: | Packet matched rule SMTP: 151.141.99.22.1470 -> 151.141.8.105.25 |
| Feb | 21 | 9:27:21 | packetpup[1188]: | M SMTP,151.141.99.22,1470,151.141.8.105,25 |
| Feb | 21 | 9:27:21 | packetpup[1188]: | Packet matched rule HTTPS: 65.162.104.178.1410 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:21 | packetpup[1188]: | M HTTPS,65.162.104.178,1410,151.141.8.105,443 |
| Feb | 21 | 9:27:22 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.106.25 -> 151.141.8.104.6062 |
| Feb | 21 | 9:27:22 | packetpup[1188]: | M SMTP,151.141.8.106,25,151.141.8.104,6062 |
| Feb | 21 | 9:27:22 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.62.167.2012 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:22 | packetpup[1188]: | M HTTPS,151.141.62.167,2012,151.141.8.105,443 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.62.167.2013 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | M HTTPS,151.141.62.167,2013,151.141.8.105,443 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | WWW Connection 151.141.76.248.1044->151.141.8.105.443 terminated 30 Packets/sec |
| Feb | 21 | 9:27:23 | packetpup[1188]: | F WWW,151.141.76.248,1044,151.141.8.105,443,714,6,0.04,0.30 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | WWW Connection 151.141.76.248.1045->151.141.8.105.443 terminated.69 Packets/sec |
| Feb | 21 | 9:27:23 | packetpup[1188]: | F WWW,151.141.76.248,1045,151.141.8.105,443,1113,8,0.09,0.69 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | Packet matched rule POP3S: 24.158.97.34.21850 -> 151.141.8.105.995 |
| Feb | 21 | 9:27:23 | packetpup[1188]: | M POP3S,24.158.97.34,21850,151.141.8.105,995 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | Packet matched rule POP: 151.141.8.103.110 -> 151.141.8.104.6065 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | M POP,151.141.8.103,110,151.141.8.104,6065 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | Packet matched rule HTTPS: 151.141.85.199.1171 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | M HTTPS,151.141.85.199,1171,151.141.8.105,443 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | Packet matched rule HTTPS: 24.158.137.162.1378 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | M HTTPS,24.158.137.162,1378,151.141.8.105,443 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | Packet matched rule SMTP: 151.141.8.106.25 -> 151.141.8.104.6067 |
| Feb | 21 | 9:27:24 | packetpup[1188]: | M SMTP,151.141.8.106,25,151.141.8.104,6067 |
| Feb | 21 | 9:27:25 | packetpup[1188]: | WWW Connection 24.158.137.162.1378->151.141.8.105.443 terminated 66 Packets/sec |
| Feb | 21 | 9:27:25 | packetpup[1188]: | F WWW,24.158.137.162,1378,151.141.8.105,443,741,5,0.82,5.66 |
| Feb | 21 | 9:27:25 | packetpup[1188]: | Packet matched rule HTTPS: 24.158.137.162.1380 -> 151.141.8.105.443 |
| Feb | 21 | 9:27:25 | packetpup[1188]: | M HTTPS,24.158.137.162,1380,151.141.8.105,443 |
| Feb | 21 | 9:27:27 | packetpup[1188]: | WWW Connection 151.141.62.167.2012->151.141.8.105.443 terminated 5.80 Packets/sec |
| Feb | 21 | 9:27:27 | packetpup[1188]: | F WWW,151.141.62.167,2012,151.141.8.105,443,2350,27,0.49,5.80 |

# APPENDIX H

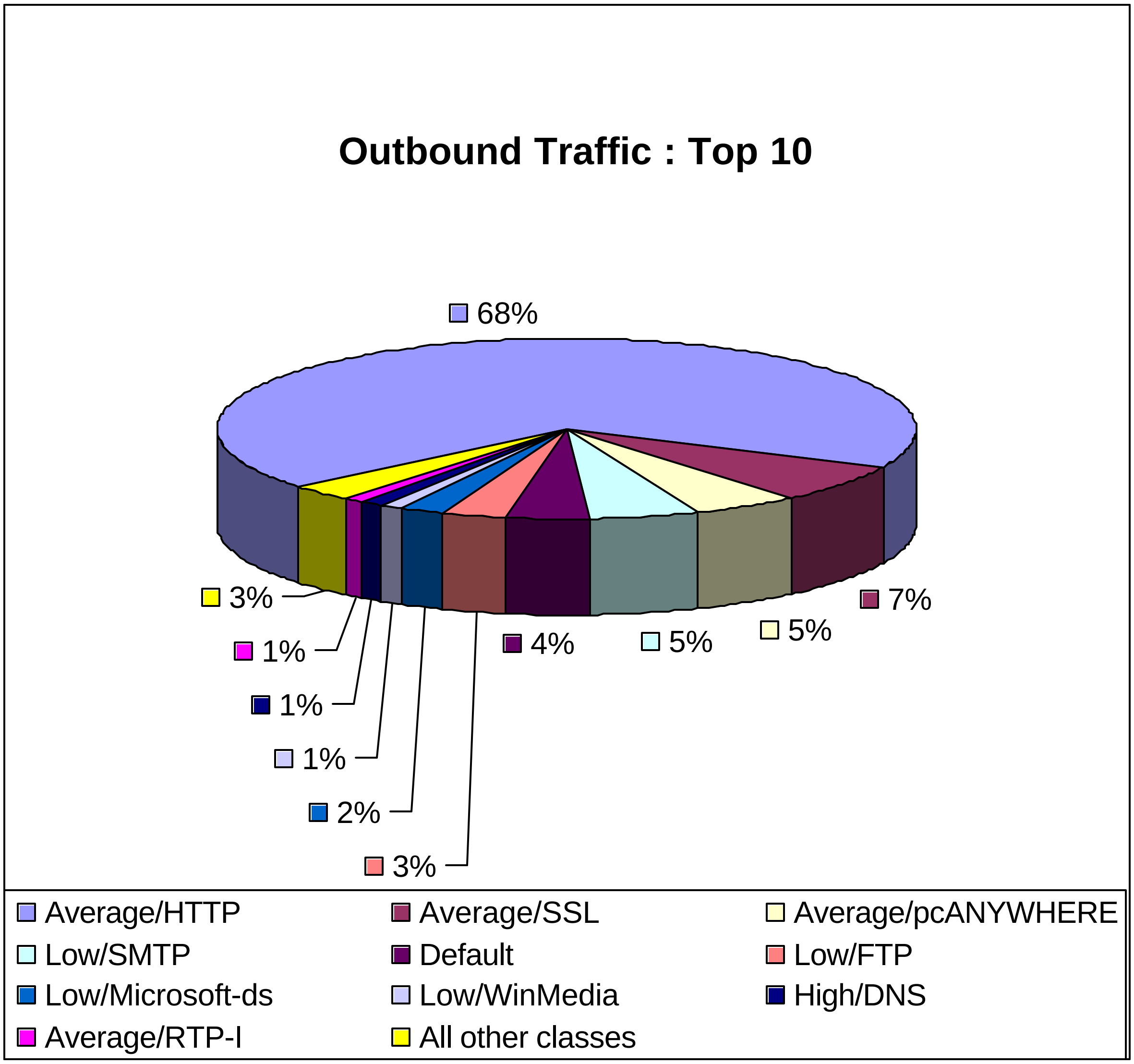
## TOP TEN CLASS MEMBERS

Pie charts indicating the top 10 members of the different subclasses of the traffic tree categorized on the basis of the average flow rate are shown below.

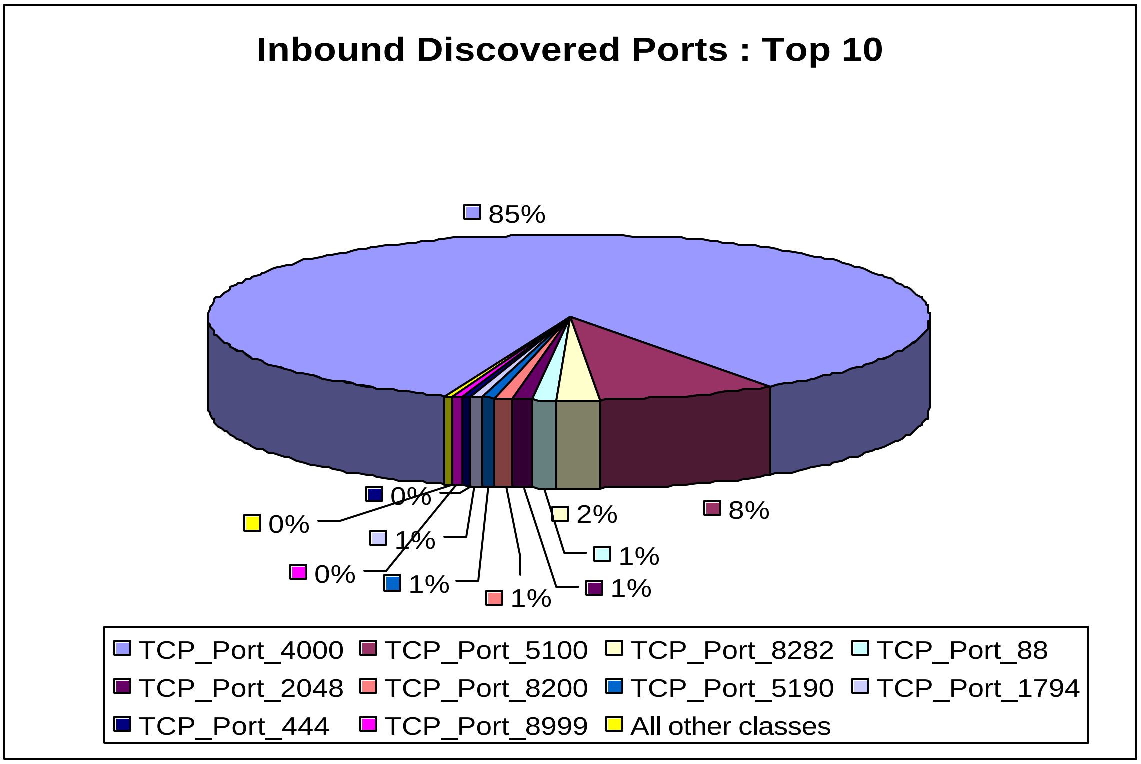
**Inbound Traffic**



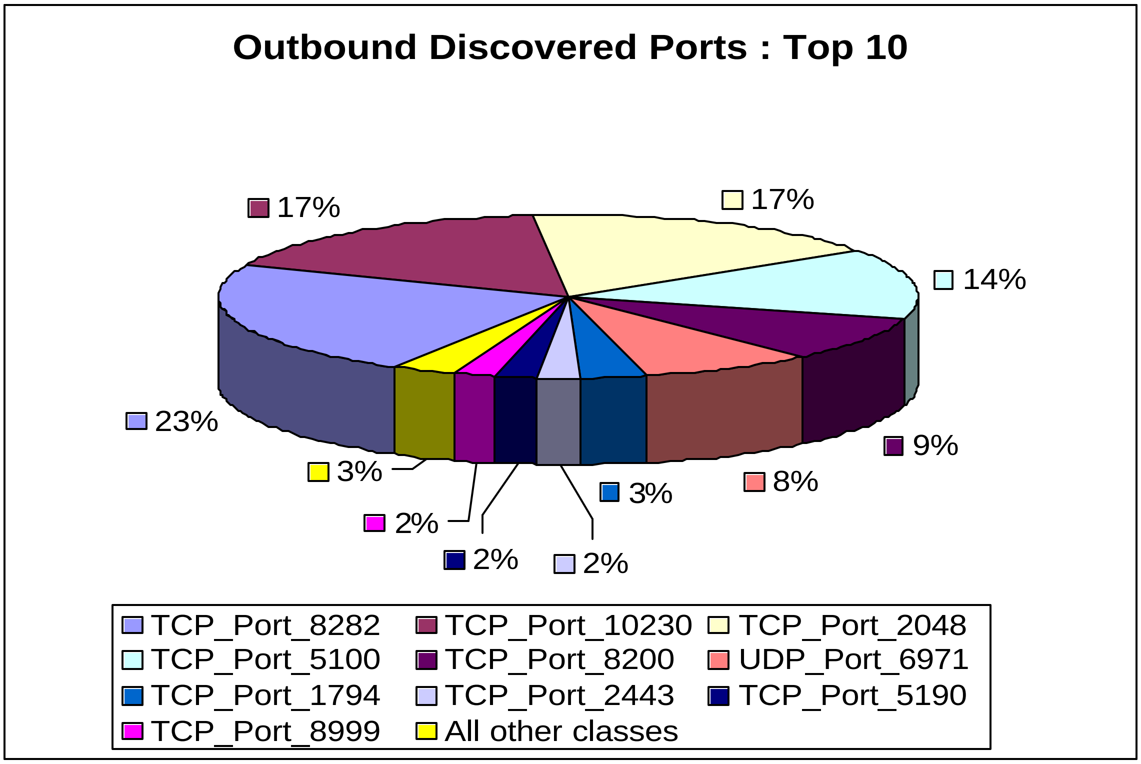
**Outbound Traffic**



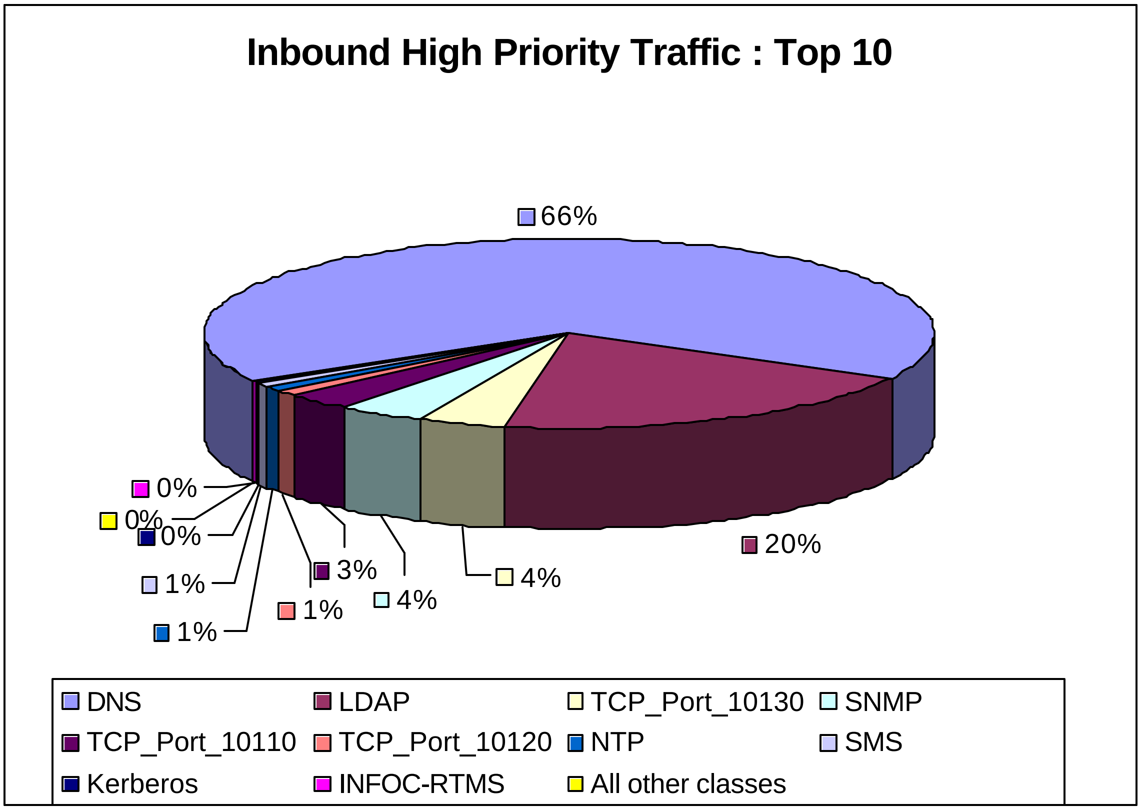
### Inbound/Discovered Ports



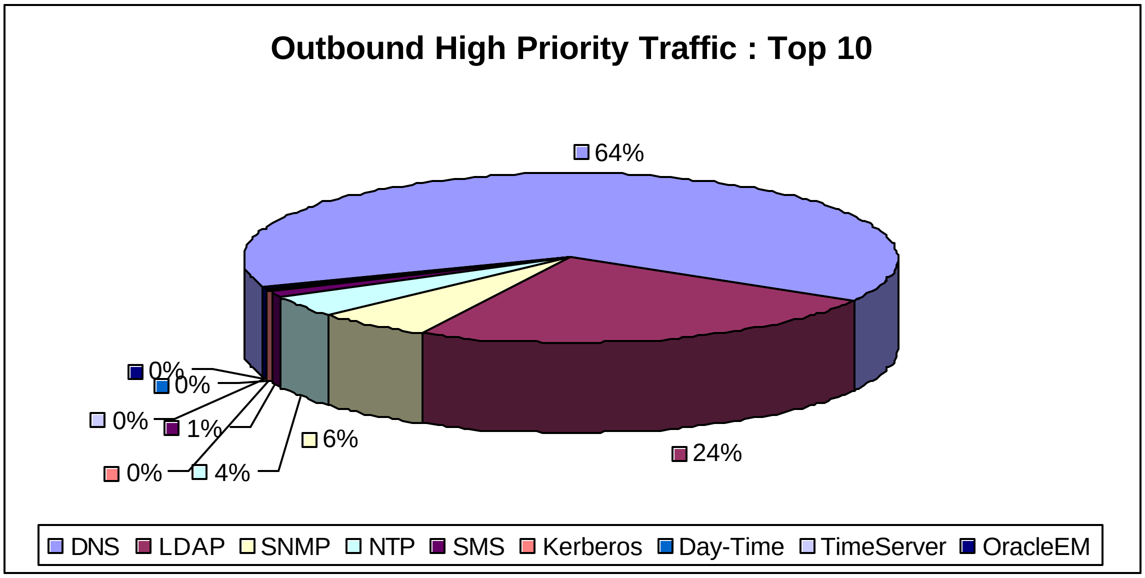
### Outbound/Discovered Ports



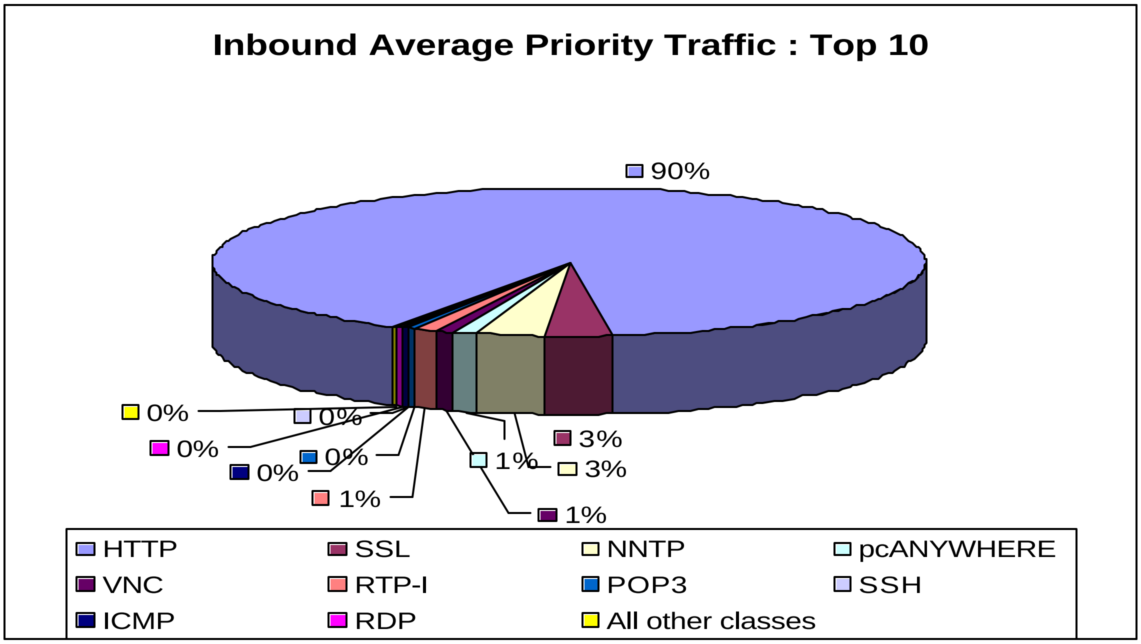
## Inbound / High



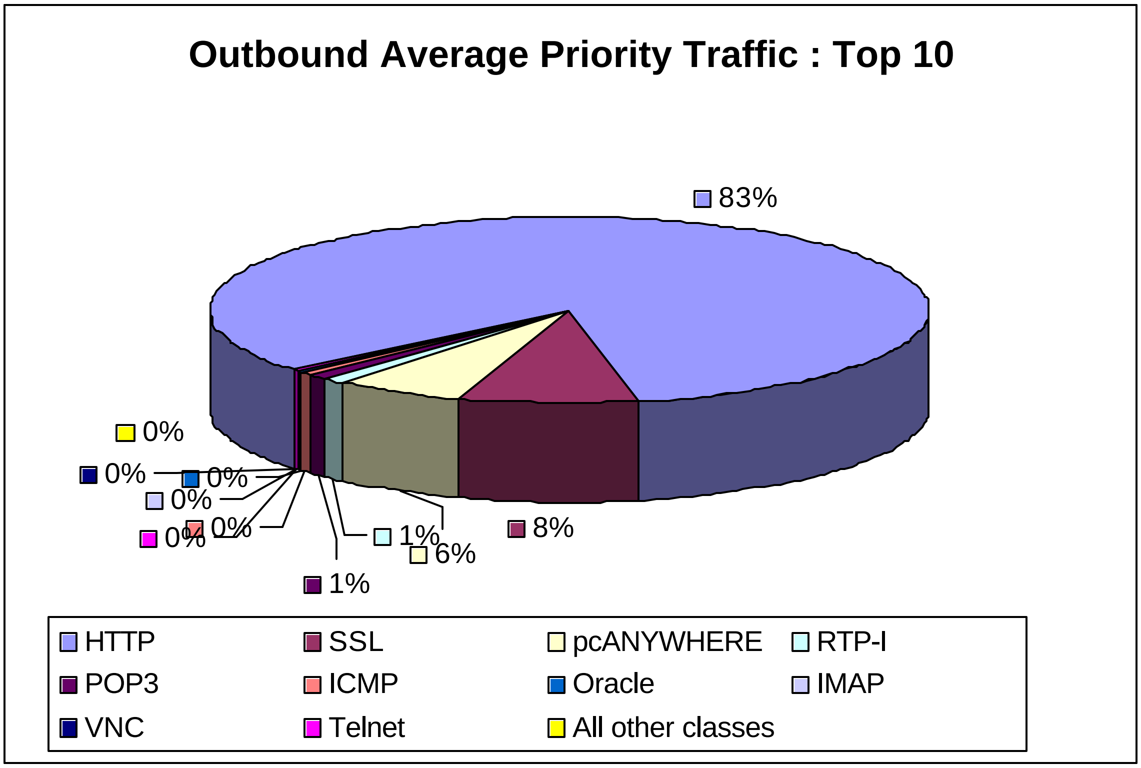
## Outbound / High



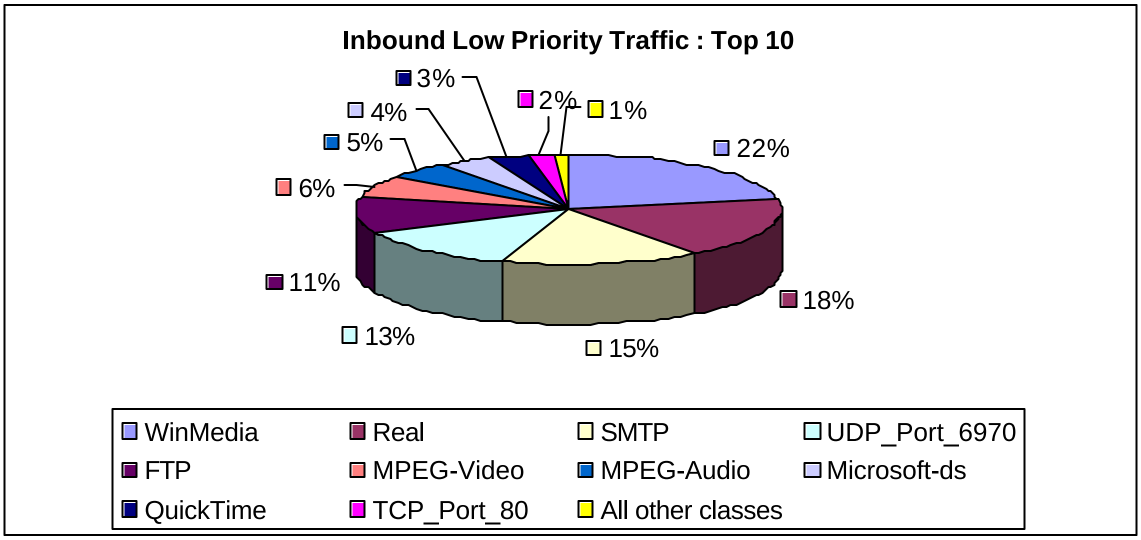
### Inbound / Average



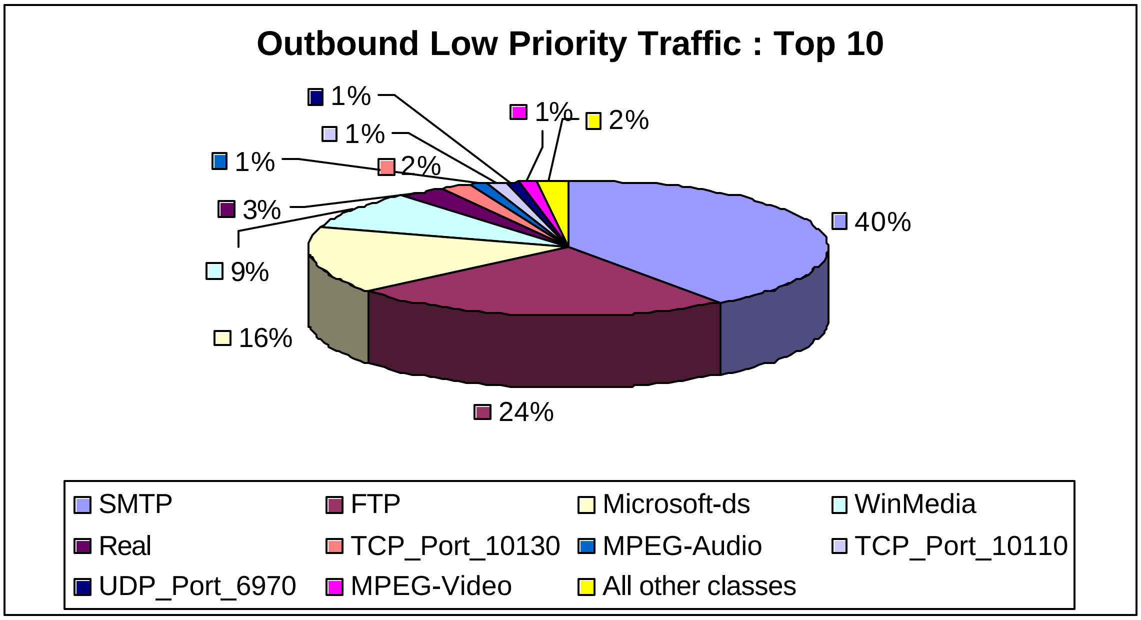
### Outbound / Average



**Inbound / Low**



**Outbound / Low**



# APPENDIX I

## MALICIOUS DATA ON LEGITIMATE PORTS

| Name | Occurrences |
|---|---:|
| AddRem joke | 1 |
| Anticmos | 1 |
| Antiexe | 3 |
| AX/Frame-Exploit | 1 |
| Backdoor-RQ | 1 |
| Bonus joke | 1 |
| Downloader-W | 2 |
| EICAR | 1 |
| Exploit-MIME.gen | 9 |
| Exploit-MIME.gen.b | 22495 |
| Exploit-MIME.gen.exe | 65 |
| Flipped joke | 2 |
| Form | 3 |
| Geschenk joke | 2 |
| Happy99 | 4 |
| IRC-Sdbot | 1 |
| JS/CardStealer | 1 |
| JS/Cisp | 2 |
| JS/Downloader-W | 1 |
| JS/Exploit | 2 |
| JS/Fortnight.b@M | 2 |
| JS/Fortnight@M | 2 |
| JS/IEStart.gen.c | 126 |
| JS/Kak@M | 24 |
| JS/NoClose | 143 |
| JS/Seeker.gen.e | 512 |
| JS/Seeker.gen.f | 7 |
| JS/Seeker.i | 7 |
| JS/Seeker.p | 1 |
| JS/Seeker.t | 12 |
| JS/Seeker.u | 6 |
| Linux/Exploit-SendMail | 1 |
| MessageMate joke | 8 |
| MP3Search | 2 |
| MP3Search.ldr | 2 |
| MultiDropper-AC | 2 |
| New UNIX | 1 |
| New Worm | 1 |
| One-Half.mp.3544a | 1 |
| Only joke | 1 |
| Salary joke | 3 |
| ServU-Daemon | 7 |

| | |
|---|---|
| Snowman joke | 1 |
| Socoten | 1 |
| Splash joke | 1 |
| StealthBoot | 13 |
| StressRelief joke | 1 |
| Suspicious IFrame.a | 17 |
| Unsafe JS | 8 |
| VBA/Generic | 2 |
| VBS/LoveLetter@MM | 2 |
| VBS/Redlof.dam | 1 |
| VBS/Redlof@M | 39 |
| W32/Aplore.htm | 1 |
| W32/BadTrans@MM | 5 |
| W32/BleBla.b@MM | 2 |
| W32/Braid.a@MM | 3 |
| W32/Bugbear@MM | 118 |
| W32/Elkern.cav.c | 44 |
| W32/Gibe.b@MM | 7 |
| W32/Gibe.gen@MM | 1 |
| W32/HLLP.Hantaner | 3 |
| W32/Hybris.gen@MM | 18 |
| W32/Klez.dam | 6 |
| W32/Klez.e@MM | 1 |
| W32/Klez.eml | 18 |
| W32/Klez.gen@MM | 10 |
| W32/Klez.h@MM | 25515 |
| W32/Klez.rar | 41 |
| W32/Korvar | 4 |
| W32/Lirva | 7 |
| W32/Lirva.a@MM | 33 |
| W32/Lirva.c@MM | 10 |
| W32/Lirva.dam | 1 |
| W32/Magistr.a@MM | 89 |
| W32/Magistr.b.dam1 | 2 |
| W32/Magistr.b@MM | 106 |
| W32/Magistr.dam3 | 6 |
| W32/Myparty.a@MM | 12 |
| W32/Navidad.e@M | 1 |
| W32/Nimda.eml | 9 |
| W32/Nimda.gen@MM | 39 |
| W32/Nimda.htm | 5 |
| W32/Nimda.q@MM | 2 |
| W32/Nimda@MM | 61 |
| W32/ProLin@MM | 1 |
| W32/SirCam@MM | 113 |
| W32/Ska@M | 2 |
| W32/Sobig@MM | 4707 |
| W32/SQLSpida | 1 |

| | |
|---|---|
| W32/Supova.worm | 1 |
| W32/Yaha.e@MM | 3 |
| W32/Yaha.g.dam | 1 |
| W32/Yaha.g@MM | 1838 |
| W32/Yaha.gen | 2 |
| W32/Yaha.k | 145 |
| W32/Yaha.k@MM | 135 |
| W32/Yaha.l | 2 |
| W32/Yaha.l@MM | 7 |
| W95/Kuang.gen | 2 |
| W97M/Assilem.c.gen | 2 |
| W97M/Class | 36 |
| W97M/ColdApe.gen | 13 |
| W97M/Ded.gen | 1 |
| W97M/Ethan.a | 7 |
| W97M/Groov.gen | 2 |
| W97M/Jerk.gen | 1 |
| W97M/Locale.gen | 33 |
| W97M/Marker.gen | 87 |
| W97M/Marker.o | 3 |
| W97M/Melissa.a@MM | 21 |
| W97M/Melissa.gen@MM | 1 |
| W97M/Nsi.e.gen | 3 |
| W97M/Proverb.gen | 8 |
| W97M/Replog.gen | 2 |
| W97M/Thus.gen | 9 |
| W97M/Titch.d.gen | 88 |
| W97M/Tristate.gen | 2 |
| WM/Cap | 4 |
| Wyx | 1 |
| X97M/Tristate.gen | 2 |

## VITA

# AMIT GROVER

| | |
|---|---|
| Personal Data: | Date of Birth: January 28, 1971 |
| | Place of Birth: New Delhi, India |
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| Education: | Delhi Public School, New Delhi, India; 1989 |
| | Jawaharlal Nehru University, India; Mechanical Engineering, 1994 |
| | IAT, India; Marine Propulsion Control Technology Course, 1995 |
| | INS Shivaji, India; Marine Engineering Specialization course, 1996 |
| | East Tennessee State University, Johnson City, TN, USA; Computer Science, Master of Science, 2003 |
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