

NetViewer: A Network Traffic Visualization and Analysis Tool

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ABSTRACT

The frequent and large-scale network attacks have led to an increased need for developing techniques for analyzing network traffic. If efficient analysis tools were available, it could become possible to detect the attacks, anomalies and to appropriately take action to contain the attacks before they have had time to propagate across the network. This paper describes NetViewer, a network monitoring tool that can simultaneously detect, identify and visualize attacks and anomalous traffic in real-time by passively monitoring packet headers. NetViewer represents the traffic data as images, enabling the application of image/video processing techniques for the analysis of network traffic.

NetViewer is released free to the general public. By employing a freely available visualization tool, the users of NetViewer can comprehend the characteristics of the network traffic observed in the aggregate. NetViewer can be employed to detect and identify network anomalies such as DoS/DDoS attacks, worms and flash crowds. NetViewer can also provide information on traffic distributions over IP address/port number domains, utilization of link capacity and effectiveness of Quality of Service policies.

Introduction

The frequent and increasing malicious attacks on network infrastructure, using various forms of denial of service attacks, have led to an increased need for developing techniques for analyzing network traffic. If efficient analysis tools were available, it could become possible (i) to detect the attacks, anomalies and (ii) to appropriately take action to mitigate the attacks before they have had time to propagate across the network or to cripple the infrastructure. These tools may be in turn useful for traffic engineering purpose since the network traffic analysis provided by these tools could lead to the identification of resource bottlenecks and peak usage.

A variety of tools for flow-based measurement have arisen from both the commercial and free software communities. To study and classify traffic on the network based on usage and protocols, a number of tools such as FlowScan [PLO00], Cisco's FlowAnalyzer, and AutoFocus [ESTsv03], are used as traffic analyzers. While flow-based features within the network infrastructures are convenient, such approaches may not be sufficient for reliable and fast application. Some of these tools provide real-time reporting capability, but much of the analysis is done off-line. These tools have been effectively utilized for traffic engineering and postmortem anomaly detection. However, rigorous real-time analysis is needed for detecting and identifying the anomalies so that

mitigation action can be taken as promptly as possible. Some of these tools are based on the volume of traffic such as byte counts and packet counts. When links are not sufficiently provisioned, normal traffic volumes may reach the capacity of the links most of the time. In such cases, attack traffic may not induce significant overshoot in traffic volume (merely replacing existing normal traffic) and hence may make traffic volume signal ineffective in detecting attacks. Sophisticated low-rate attacks [EUZk03] and replacement attacks, which don't give rise to noticeable variance in traffic volume, could go undetected when only traffic volume is considered. Furthermore, the tools which collect and process flow data may not scale to high-speed links as they focus on individual flow behavior. Our tool tries to look at aggregate packet header data in order to improve scalability.

Intrusion detection systems (IDS) such as Snort and Bro are an important part of network security architecture and signature database-based monitoring of network traffic for predefined suspicious activity or patterns. These tools are widely deployed by network administrators. This detection principle relies on the availability of established rules of the anomalous or suspicious network traffic activity. While the identification mechanism of the IDS tools provides fine-grain control of network flows, they however need to be updated continuously with the latest rules for coping with novel attacks. Our approach tries to

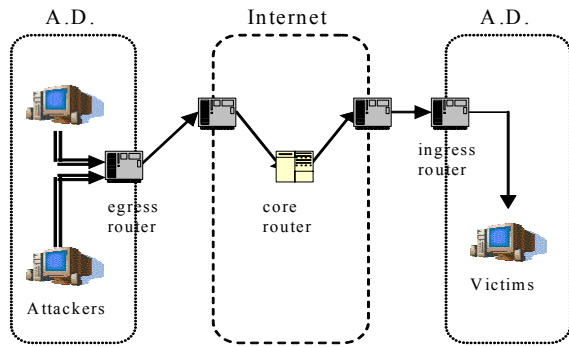


Figure 1. The installation locations of NetViewer. For ingress/egress filtering, it can be employed in a router or at the boundary of an administrative domain.

develop a generic mechanism independent of specific anomalies for improving adaptability.

In this paper, we describe a tool named NetViewer for traffic anomaly detection based on analyzing the distribution of traffic header data, in postmortem and in real-time. We adopt a network measurement-based approach that can simultaneously detect, identify and visualize attacks and anomalous traffic in real-time. We propose to represent samples of network packet header data as frames or images. With such a formulation, a series of samples can be seen as a sequence of frames or video. This enables techniques from image processing and video compression such as scene change analysis and motion prediction to be applied to the packet header data to reveal interesting properties of traffic. Our work here brings techniques from image processing and video analysis to visualization and real-time analysis of traffic patterns. We show that “scene change analysis” can reveal sudden changes in traffic behavior or anomalies [LELs03, ZHAKs93, LIEke97, SHEd95, GYAKc03]. We show that “motion prediction” techniques can be employed to understand the future patterns of some of the attacks. We show that it may be feasible to represent multiple pieces of data as different colors of an image enabling a uniform treatment of multidimensional packet header data. NetViewer can give an intuitive and descriptive illustration of network traffic, with visible features, to network operators.

Environment

The visibility of fields in the network packets may be impacted by the location where traffic is observed. NetViewer can be applied for analyzing inbound/outbound traffic at administrative domain (AD) edge router as shown in Fig. 1. The AD

represents the access link, ISP (Internet Service Provider) and intra-domain IP-based networks such as enterprise networks and campus networks.

Employing ingress filtering with NetViewer monitors the flow of traffic as it enters a network under administrative control. NetViewer can be combined with a Quality of Service (QoS) policy framework to rate limit high-bandwidth flows identified by NetViewer.

Egress filtering with NetViewer inspects the flow of traffic as it leaves a network under administrative control. There are typically policy regulations for inner machines initiating outgoing connections to the Internet. Outbound filtering has been advocated for limiting the possibility of address spoofing i.e., to make sure that source addresses correspond to the designated addresses for the AD. Traffic monitoring at a source network enables a detector to detect attacks early, to control hijacking of AD machines, and to limit the liability from such attacks and the squandering of resources. NetViewer can help prevent compromised systems on a network from attacking systems elsewhere through egress filtering.

Our traffic attack/anomaly filtering efforts have been targeted at the edge environment due to resource utilization issues and source address spoofing concerns.

Goals

NetViewer’s goal is not to detect and eliminate the anomalies eradicatedly, but to bring the anomalous traffic under control in real-time so that the mitigation mechanisms could be deployed fast to counter the threats of the anomalies. We also want NetViewer to not contain any legitimate traffic in the process of containing attack traffic. Our goal is to detect and contain 99.7% of the attack and anomalous traffic at a false alarm rate of 0.3%. Given the current and growing network link speeds, anything we implement needs to be fast and efficient enough to not excessively burden existing network infrastructure.

As an operational goal, we want that the containment is centrally processed at a router level, rather than something that the end users would have to deal with. Netviewer can work with packets on the fly at a router in real-time mode and packet traces in libpcap or NetFlow format in post-mortem mode.

Architecture

NetViewer’s architecture is mainly focused on performance, simplicity, and versatility. NetViewer system’s architecture consists of five major software

components: the packet parser, the signal computing engine, the detection engine, the visualization engine and the alerting engine, which are programmed in ANSI C and Matlab language [MAT01].

The Packet Parser

The packet parser engine is responsible for collecting and processing raw packets and traffic data exported from routers. NetViewer can work with traffic records in postmortem or work with more aggregate data upon packet arrival in real-time. It can parse packets on the fly and parse network packet header traces with libpcap (packet capture library) [PCAP94], Cisco's NetFlow [NETF] and NLANR formats [NLA02] such as DAG, Coral, and TSH (time sequenced headers).

Traffic volume, such as packet counts, byte counts and the number of flows, can be used as a signal, and fields in the packet header, such as addresses, port numbers and protocols, can be employed as an observed domain. According to operator's concern, NetViewer then generates images of the distribution of traffic intensity in the chosen domain. Based on the kinds of traffic data and the header domain, we categorize the image-based signals into address-based, flow-based and port-based signals. Address-based signal employs packet count distribution over address domain (either source address alone, or destination address alone, or a 2-dimensional source and destination address domain). Flow-based signal employs the flow number distribution over address domain(s). Port-based signal employs packet count distribution over port number domain.

Traffic headers such as addresses and port numbers have larger spaces over which data is distributed, that is, 2^{32} IPv4 addresses and 2^{16} port numbers. Any developed technique should be simple enough to be deployable, i.e., should not be expensive in terms of memory and processing resources. In order to address the problem of large domain spaces, we have employed a concise data structure for reducing the domain space [KIMrv04]. We explain this data structure using address-based signal as an example. This data structure $count[i][j][t]$ represents the data sample at time t . The data structure consists of 4 arrays $count[4]$ for the 4 bytes of the IP address. Within each array, we have 256 locations, for a total of 4×256 locations = 1024 locations. By default, the size of one location is set to 16 bits. A location $count[i][j][t]$ is used to record the packet count for the address j in i^{th} field of the IP address in time interval t . This provides a concise description of the address instead of 2^{32} locations that would be required to store the address

occurrence uniquely. Upon packet arrival, the corresponding four positions of the data structure are updated through scaling.

The Signal Computing Engine

Each sampling period, the packet counts of the entire traffic are recoded to the corresponding positions of each IP address byte-segment, and the normalized packet count is quantized and represented using equation (1). Each resultant normalized packet count then represents the intensity of the corresponding pixel in the image representation of the traffic as shown in Fig. 2.

$$p_{ijt} = \frac{count[i][j][t]}{\sum_{j=0}^{255} count[i][j][t]}, \quad i=0,1,2,3 \quad (1)$$

In order to quantitatively analyze the network traffic anomalies, we compute correlation and deltas based on normalized packet counts. Consider two adjacent sampling instants. We can define correlation signal at sampling point t by (2-1), which measures correlation of traffic intensity at a particular address. Delta is defined as the difference of normalized packet counts by (2-2), which is a useful signal at the beginning and ending of attacks.

$$C_{ijt} = p_{ijt} * p_{ijt-1} \quad (2-1)$$

$$\Delta p_{ijt} = p_{ijt} - p_{ijt-1} \quad (2-2)$$

We employ the variance of pixel intensities in the image as traffic signal for scene change analysis, which is denoted by S_σ . Using the variance of these image signals for deriving thresholds, we can obtain an approximation of the energy distribution of the normalized packet counts within the observation domain as follows.

$$S_\sigma = \left[\frac{1}{1024} \sum_{i=0}^3 \sum_{j=0}^{255} (p_{ijt} - \overline{p_{ijt}})^2 \right]^{\frac{1}{2}} \quad (3)$$

, where p_{ijt} are pixel intensities, and $\overline{p_{ijt}} = \frac{1}{1024} \sum_{i=0}^3 \sum_{j=0}^{255} p_{ijt}$

Upon each sampling instant, the aggregate traffic signal is instantaneously calculated based on accumulated data structure for real-time analysis.

The Detection Engine

The detection engine employs a theoretical basis for deriving thresholds for analyzing traffic signals and anomaly detection. For 3σ -based statistical analysis, we

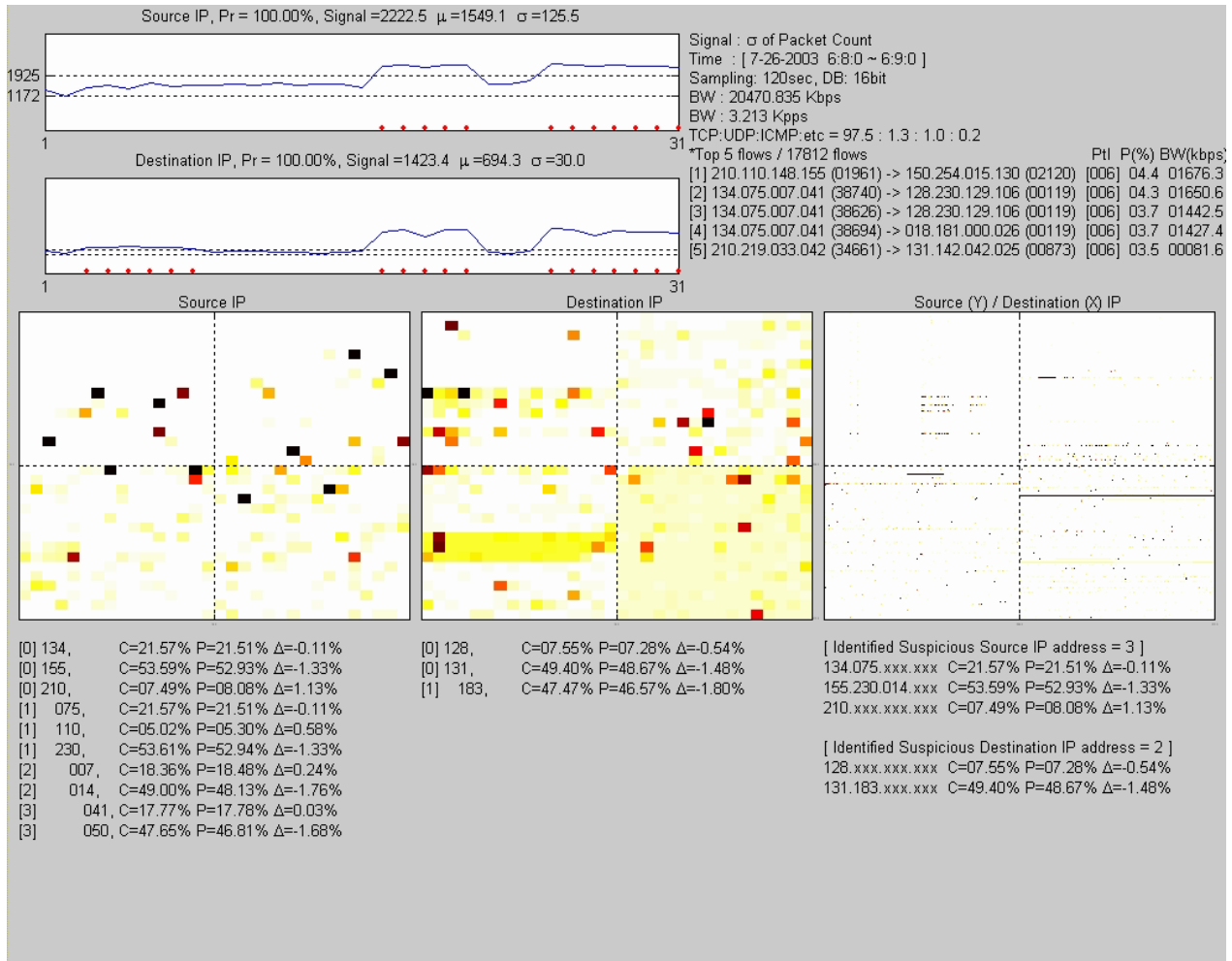


Figure 2. A running example of NetViewer.

set 2 kinds of thresholds, a high threshold T_H and a low threshold T_L . When we respectively set the T_H and T_L thresholds to $\pm 3.0\sigma$ of aforementioned traffic signal distributions in ambient traffic, attacks can be detected with an error rate of 0.3% (if the signal is normally distributed) which can be expected as target false alarm rate as (4-1) [NIS05]. For deriving initial thresholds from background traffic, a tune-up procedure is necessary just after powering up. By default, it is set to 120 samples; that is 2 hours in case of 1 minute samples. To analyze the statistical properties of normal traffic dynamically, we employed an exponential weighted moving average (EWMA) of normal traffic free of attacks. The dynamic average of the traffic is updated at every sampling point excluding attack periods.

The detection engine can judge the current traffic status by calculating the standard intensity deviation of signals in each sampling instant by (4-2). The analyzed

information will be compared with historical thresholds of traffic to see whether the traffic's characteristics are out of regular norms. Sudden changes over 3σ in the analyzed signal are expected to indicate anomalies.

$$X \sim N(\mu, \sigma^2) \rightarrow \Pr(\mu - 3.0\sigma < X \leq \mu + 3.0\sigma) \approx 99.7\% \quad (4-1)$$

$$\text{traffic status} \begin{cases} \text{normal,} & \text{if } T_L < S_\sigma < T_H \\ \text{attack,} & \text{if } S_\sigma \leq T_L \text{ or } T_H \leq S_\sigma \end{cases} \quad (4-2)$$

Also, with mean, standard deviation and signal value at every sampling point, the detection engine would compute the probability of anomaly assuming the normal distribution [KILn02, NIS05].

The Visualization Engine

The visualization engine employs graphic library of Matlab (in this implementation) for displaying traffic signals and images. The visualization engine produces user-friendly, images of network traffic. As shown in

Fig. 2, the visual parts of NetViewer’s main screen make up four primary components: the general traffic profile, traffic distribution signals, traffic images and anomaly reports. While the profiling and reporting components are expressed in text, the traffic signals and images are visualized in graphs. The visualization engine enables NetViewer to offer these visual measurements as a real-time motion picture. It could help the network operators recognize the trends and transitions in network traffic.

The visualization engine plots the standard deviation of traffic intensity computed by (3) versus the sampling instant in source and destination domains respectively as network traffic signals. If the anomaly is detected, a red dot is marked on the bottom and calls the network operator’s attention. NetViewer’s viewing window is controllable for short-term and long-term analysis purposes. By default, the window is 60 sampling points, which is the latest 1 hour with 1 minute samples.

Each element of the data structure computed by (1) corresponds to a rectangular area (or pixel) in the traffic image. The values of the elements of the data structure are indexed into the current color-table that determines the color of each pixel. The color of each pixel shows the intensity of traffic at the source or destination or (source, destination) pair in 2-dimensions. The descending order of intensity is black, red, orange, yellow and white. Each quadrant corresponds to each byte in IP address structure. In 1-dimensional source or destination domain, each quadrant consists of 16-by-16 pixels for mapping 256 elements of one byte of IP address as shown in Fig. 3(a). Each quadrant maps the

0 to 255 values of one byte of IP address in a row-major order. Thus four quadrants consist of the entire 4-byte IP address. The four bytes 0 to 3 of IP address are also organized as quadrants in a row-major order. In 2-dimensional image, the x-axis in each quadrant corresponds to the distribution of the destination IP addresses, and y-axis that of the source addresses as shown in Fig. 3(b). In each quadrant, source and destination addresses consist of 256-by-256 pixels.

The Alerting Engine

Once anomalies are detected through scene change analysis, the alerting engine scrutinizes the above quantities by (1) and (2) for identification purposes. From the predefined correlation and delta thresholds, the alerting engine can identify the IP addresses of suspicious attackers and victims. Based on the revealed IP addresses, we closely investigate each address on the basis of statistical measurements. This inspection will lead to some form of a detection signal that could be used to alert the network administrator of the potential anomalies in the network traffic. The alerting engine generates the detection reports in online image as well as in an offline file.

NetViewer’s Functionality

NetViewer and its component engines are responsible for profiling and monitoring raw packets or trace data exported from routers. NetViewer monitors each packet and maintains data structures based on the observed domain (address, port numbers etc.). When anomalies are detected, NetViewer reports its detection results and may optionally take containment actions. It may be configured to either archive for postmortem analysis or discard the counter contents after processing.

Controllable parameters, such as window size for determining the amount of retained data and thresholds, can be configured before or after the packet parser engine takes an action. By default, a sampling interval is set to 60 seconds for deriving most stable traffic images, and a sampling duration ratio is 1:1. That is to say, we sampled for 30 seconds and paused for 30 seconds for reducing the processing requirements. Our techniques are light-weight enough for traffic to be continuously sampled without any pause periods.

Fig. 2 is a sample NetViewer graph of real traffic with attack at an access link.

Traffic Profiling Function

The above right text in Fig. 2 shows the general information of current network traffic. The profile includes the selected signal type, the local time, the

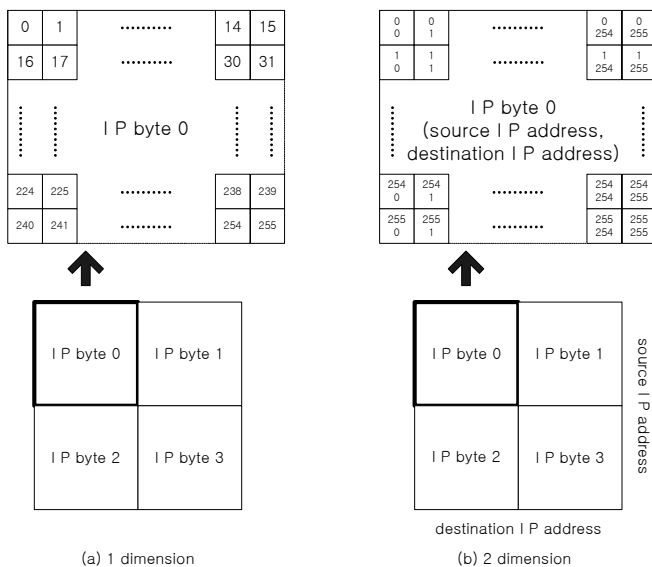


Figure 3. The visualization of network traffic signal in IP address domain.

selected sampling period, number of bits used to represent traffic intensity of individual pixels in the data structure, and the bandwidth in Kbps (bits per second) and Kpps (packets per second).

The next line illustrates the proportion occupied by each traffic protocol. It is possible to determine whether the current traffic is behaving normally through correlating it to that of previous states of traffic from a protocol viewpoint. This is based on the observation that during the attacks, the protocol employed by the attack traffic should see considerably more traffic than during normal traffic.

The Top 5 flows term shows the topmost 5 flows out of total flows in selected traffic volume, which can be packet count, byte number or the number of flows. It is expressed as a quintuple of source IP address/port number and destination IP address/port number, exploited protocol, occupied proportion in percentage, and bandwidth in Kbps. It is implemented using LRU (Least Recently Used) policy with partial state for identifying long-term high-rate flows [SMIkr01].

The profiling information presented by NetViewer assists in understanding the general nature of the traffic at the monitoring point.

Monitoring Function

The above left two sub-pictures in Fig. 2 illustrate traffic distribution signal over the latest predefined (and adjustable) time-window. The two pictures map to source domain and destination domain respectively. The captions above each picture explain the current traffic distribution. The Source IP term means that this signal is originated from packet counts in the source IP address domain. Based on the operator's selection, this term can be changed to Source FLOW which analyzes the number of flows over the source IP address domain, or to Source PORT which analyzes packet counts in the source port domain, or to Source MULTIDIMENSIONAL which analyzes multiple components of different distributions in the source IP address domain.

The Pr term estimates the anomalous probability of current traffic distribution assuming Gaussian distribution. The probability is computed from the normal distribution table based on the traffic signal, its μ and σ [NIS05]. We can be informed the possibility of anomalous traffic quantitatively. The Signal term is computed by (3). The " μ " and " σ " terms mean the mean value and the standard deviation of distribution signal using EWMA. The left two figures in y-axis and dotted vertical lines illustrate the $\pm 3.0\sigma$ levels respectively. The above statistical measurements are

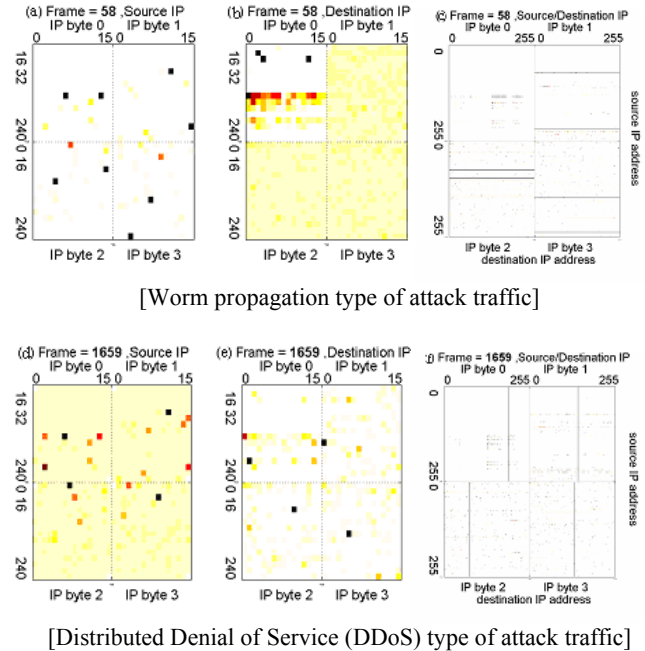


Figure 4. Various attack images reported by NetViewer.

dynamically updated at every sampling point excluding attack periods.

The red dots located on the bottom of the each sub-picture are marked when 3σ -based statistical analysis detects anomalies. The detection signal automatically triggers to identify the IP addresses of sources and destinations and can be used to alert traffic anomalies to the network operator.

Anomaly Reporting Function

The center three sub-pictures in Fig. 2 illustrate image-based traffic in the source/destination IP address domain and the 2-dimensional domain.

The color and darkness of each pixel indicate the intensity of traffic of corresponding IP address. In case of normal traffic, the aggregate traffic does not form any regular shape due to dispersibility of traffic of various and numerous flows in time and space. In the case of abnormal traffic, however, the traffic pattern of network may change and these changes could be exhibited in the visual images. From destination IP address in Fig. 2, a specific area of IP byte2 is shown in a darker yellow shade. It illustrates that the current traffic is concentrated on a (aggregated) single destination or a subnet. NetViewer also shows that a specific source, i.e., an attacker, monopolizes network traffic, shown in the form of a line in the 2-dimensional domain.

The exposed images can show various kinds of patterns according to the nature of attacks. Fig. 4 shows the visual expression of a worm and a DDoS attack respectively. While the horizontal lines imply that the same source targets multiple destinations in a worm attack, the vertical lines reveal that several machines (in a subnet) are targeting a single server in a DDoS attack.

Once anomalies are detected, the identified IP addresses of sources and destinations are revealed in byte-segment level and 4-byte whole structure simultaneously as shown in the lower text of Fig. 2. These identified IP addresses are quantitatively investigated on the basis of statistical measurements using the correlation (C), the possession ratio (P), the delta (Δ) between consecutive frames and the black list (S) computed by the signal computing engine. S recorded in the last column indicates black listing which is successively identified and refined over recent sampling instances. It could help network operators make a final decision.

Additionally the detection report is optionally generated in a file format. The upper part of Fig. 5 shows the identified addresses responsible for the anomalies over the four byte-segment levels and the lower part of Fig. 5 illustrates source and destination addresses of attacks.

```
*****
[ Time : Sat 07-26-2003 05:12:00 ]
-----
```

Source IP[0]	134.	correlation = 17.48%	possession = 18.77%	delta = 2.50%	S
Source IP[0]	141.	correlation = 4.33%	possession = 3.94%	delta = 0.79%	S
Source IP[0]	155.	correlation = 58.20%	possession = 56.80%	delta = 2.84%	S
Source IP[0]	210.	correlation = 5.66%	possession = 6.51%	delta = 1.60%	S
Source IP[1]	75.	correlation = 17.47%	possession = 18.77%	delta = 2.51%	S
Source IP[1]	110.	correlation = 4.62%	possession = 5.25%	delta = 1.21%	S
Source IP[1]	223.	correlation = 4.31%	possession = 3.94%	delta = 0.78%	S
Source IP[1]	230.	correlation = 58.21%	possession = 56.84%	delta = 2.76%	S
Source IP[2]	7.	correlation = 15.59%	possession = 17.02%	delta = 2.74%	S
Source IP[2]	14.	correlation = 53.99%	possession = 52.31%	delta = 3.41%	S
Source IP[3]	41	correlation = 15.16%	possession = 16.36%	delta = 2.30%	S
Source IP[3]	50	correlation = 52.58%	possession = 50.83%	delta = 3.54%	S

```
-----
Identified No. 1st = 4, 2nd = 4, 3rd = 2, 4th = 2
=====
```

Destination IP[0]	128.	correlation = 4.37%	possession = 3.88%	delta = 1.01%	S
Destination IP[0]	128.	correlation = 6.08%	possession = 7.01%	delta = 1.75%	S
Destination IP[0]	131.	correlation = 53.65%	possession = 52.33%	delta = 2.67%	S
Destination IP[1]	181.	correlation = 56.03%	possession = 54.00%	delta = 4.15%	S
Destination IP[3]	26	correlation = 3.89%	possession = 3.58%	delta = 0.65%	S

```
-----
Identified No. 1st = 3, 2nd = 1, 3rd = 0, 4th = 1
=====
* Identified Suspicious Source IP address(es)
134. 75. 7. 41 correlation = 17.48% possession = 18.77% delta = 2.50% S
141.223.xxx.xxx correlation = 4.33% possession = 3.94% delta = 0.79% S
155.230.14.50 correlation = 58.20% possession = 56.80% delta = 2.84% S
210.xxx.xxx.xxx correlation = 5.66% possession = 6.51% delta = 1.60% S
-----
* Identified Suspicious Destination IP address(es)
18.xxx.xxx.xxx correlation = 4.37% possession = 3.88% delta = 1.01%
128.xxx.xxx.xxx correlation = 6.08% possession = 7.01% delta = 1.75% S
131.181.xxx.xxx correlation = 53.65% possession = 52.33% delta = 2.67% S
*****
```

Figure 5. The detection report of anomaly identification.¹

¹ For privacy, the IP addresses in Fig. 5 are appropriately sanitized.

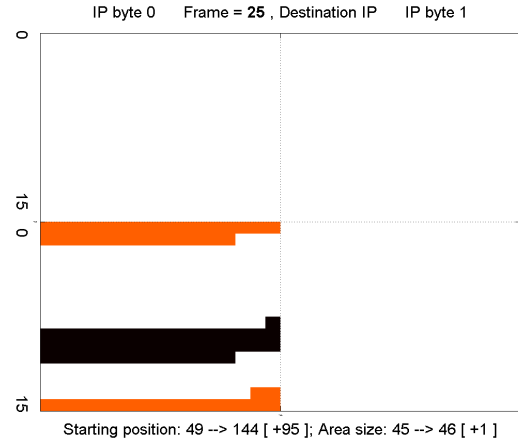


Figure 6. Potential attack estimation in red using motion prediction.

Auxiliary Function

NetViewer could support various auxiliary functions. The video/frame representation of network traffic enables motion estimation based techniques for attack prediction. Unassigned address ranges can be clearly marked in the generated images to identify address spoofing. We describe some of these functions here.

Multidimensional Image

Up to now, we have focused on address-based image on which normalized packet counts are visualized in the address domain. By the operator's selection, NetViewer's main screen can be changed to flow-based image which visualizes the number of flows over the address domain, or to port-based image which displays packet counts in the port domain, or to multidimensional image which simultaneously exhibits multiple components of different images in the address domain.

In multidimensional image, individual component, such as packet counts, the number of flows and the correlation of the packet counts, can be represented as different components (for example, Y, U, V) of an image or different primary colors (R, G, B). With the three distinct traffic components, NetViewer can comprehensively analyze the traffic properties of each IP address from diverse viewpoints.

Attack Tracking

During some attacks, a concentrated attack is circulated on the address space. Using motion prediction, it is possible to expect or anticipate the next set of target addresses in such attacks. NetViewer estimates the locations of the next attack using

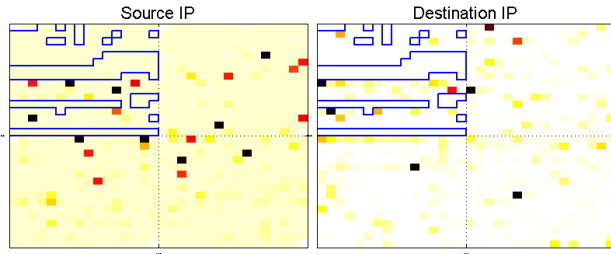


Figure 7. Spoofed source IP addresses.

modified motion prediction scheme. The results from such an analysis on a predictable attack are shown in Fig. 6. Fig. 6 shows the ongoing attacked parts in black and the result of motion prediction (in red pixels) indicating the next set of addresses that may be a target of this attack. The next potential attack ranges are estimated based on the starting positions of current attack and the motion vector length. The attack tracking would be displayed on NetViewer's subsidiary screen.

Automatic Spoofed Address Masking

In bandwidth consumption attacks such as traditional flood-based attacks, the source IP address of the packet could be usually spoofed through the abuse of raw sockets function or the like. The deliberate falsification is often forged in random order or in a dictionary order. Random destination addresses may also be employed during probing for possible infiltration. SQL Slammer was the representative random propagation worm [CER03]. And the portscan-based attacks heavily exploit the destination port numbers in random or sequential order.

Global address allocations are organized by types, which are classified according to prefixes. Currently, many portions of the IP address space are still unassigned by IANA (Internet Assigned Numbers Authority) [IPV04]. Especially, the unallocated address space can be clearly identified in the 1st byte image in NetViewer. Moreover, if NetViewer is located at the boundary of the AD, the system administrator can make sure that addresses correspond to the locally designated addresses for the AD. The packets coming into and going out of the AD should have the destination address and the source address assigned to the AD, respectively. The masking can be also applied to unavailable port services against portscan attacks if the network operator selects the NetViewer's port-based functions.

Fig. 7 shows the portion of NetViewer, where the blue-colored polygons indicate the reserved IP address space by IANA at the time of this writing. In legitimate traffic, there should be no pixels matching the unassigned space as shown in the destination IP image.

Since packets can not be allowed to originate from or be destined to these spaces, the (colored) pixels matching the unallocated space have to be from spoofed IP addresses as shown in the source IP image. This attack is an instantaneous attack with (randomly) spoofed source addresses which aimed at a specific machine with 160 byte-sized packets.

The spoofed address masking can be expanded to IP bytes 1, 2 and 3 as well because the system operator knows the AD's internal usable address range (for stub networks). This also enables detection of sequential portscan attacks through the identification of addresses that do not provide service at the designated ports.

How Is NetViewer Different From IDS?

Network intrusion detection system (NIDS) is an important part of network security area and signature-based detection approach is being widely employed by network operators. The rule-based matching mechanism requires that the completed analysis of attack patterns and the availability of established remedies be available beforehand. To cope with new attacks, IDS tools are continuously required to be updated with the latest rules. Currently there are a few available freeware/shareware and commercial IDS tools.

We review Snort as representative IDS [ROE99], [SNO], and compare the properties of Snort and NetViewer. We perform this comparison by running the systems on a live, production network. We report results from a time period which contained a large number of anomalous traffic transactions.

For our experiments, we installed Snort in Texas A&M University network environment, and gathered the detection results of Snort. We evaluate NetViewer on a trace of network traffic analyzed by the Snort system. Our experiment is carried out by capturing 24 hours of data on April 28th and 29th, 2004. After the basic configuration is performed, we turn on the IDS rules, and begin to monitor the Analysis Console for Intrusion Databases (ACID) [ACI].

Snort

Snort system reported 13,257 alerts distributed over the experiment time period. We compare it with results from NetViewer based on address-based signal. In the trace, it is apparent that there are continuous anomalies over almost the entire time period. NetViewer's detection result generally agrees with the results of Snort. Both Snort and NetViewer detect suspicious anomalies throughout the course of the trace capture. The detection performance could be considered at a similar level.

However, Snort's identification mechanism is superior in granularity. When coupled with a mechanism such as ACID, Snort can more readily identify the source of malicious activity, and what exactly that activity consists of. Snort provides an easily managed display of IP addresses and port numbers of any suspicious activity. On the other hand, when NetViewer performs the analysis, it reports the suspicious IP addresses and the pattern of abnormality in an aggregated fashion.

While Snort employs a qualitative analysis, NetViewer employs a quantitative analysis. During our evaluation, Snort missed the identification of many heavy traffic sources. Some flows, using the BitTorrent system run by one of the users of the network, accounted for about 30% to 60% traffic over certain time periods. However, without the operational rule, Snort did not detect these flows. However, NetViewer identified this flow as an anomalous event. This demonstrates the utility of measurement-based approaches in detecting previously unknown or undocumented anomalous behavior.

Regarding the computational complexity, Snort looks at the payload of packet as well as the packet header. And currently over 2,400 filter rules are established [SNO]. NetViewer works on aggregated information from traffic samples. Snort would require more computing resources to be able to match NetViewer performance against heavy traffic.

From these above observations, we feel the two methods could be combined to provide a more complete detection system capable of detecting a wide array of different network security violations.

Availability

Information and source code of NetViewer may be acquired directly from the following web site at <http://dropzone.tamu.edu/~skim/netviewer.html>.

Conclusion

In this paper, we have presented an approach which represents traffic data as images or frames at each sampling point. Such an approach enabled us to view traffic data as a sequence of frames or video and allowed us to apply various image processing and video analysis techniques for studying traffic patterns. We have demonstrated our approach through an analysis of real traffic traces obtained at various major networks. Our results show that our approach leads to useful traffic visualization and analysis. We have studied detection and identification approaches along multiple

dimensions of IP packet header data such as addresses, port numbers, and the number of flows.

We compared our approach with a signature-based IDS system. Our results indicate that measurement based statistical approaches can be simple and effective and could be combined with IDS approaches to enable more effective monitoring of network traffic.

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Appendix A

The ANSI C codes below are what we used to record packet count into data structure in the packet parser.

```
for ( ip_field=0; ip_field<4; ip_field++ ) {
#ifdef SOURCE_IP_BASED                                /* which domain is observed */
    ip_addr = packet->src_ip;
#endif
#ifdef DEST_IP_BASED
    ip_addr = packet->dest_ip;
#endif

/* From byte0 to byte3 */
    if( !ip_field )
        addr_field = (unsigned char)(((ip_addr)&0xff000000)>>24);
    else if ( ip_field == 1 )
        addr_field = (unsigned char)(((ip_addr)&0x00ff0000)>>16);
    else if ( ip_field == 2 )
        addr_field = (unsigned char)(((ip_addr)&0x0000ff00)>>8);
    else
        addr_field = (unsigned char) ((ip_addr)&0x000000ff);

    DS[ip_field][addr_field] ++;                       /* updating counters in Data Structure */
}
}
```

Appendix B

The following ANSI C scripts are used for computing the statistical measurements in the signal computing engine.

```
typedef unsigned int    uint;                          /* 32 bit */
typedef unsigned short DS_Size;                        /* Data Structure resolution is 16 bit */

for( ip_field=0; ip_field<4; ip_field++ ) {
    window = (DS_Size *) DS;
    for( addr=0; addr<256; addr++ ) {
        if( *(window+addr) > 0 )
            t_count += *(window+addr);                 /* t_count = sum(count[i][j][t]) */
    }

    for( addr=0; addr<256; addr++ ) {
        pkt_ratio = (double)DS[ip_field][addr]/(double)t_count; /* p(i,j,t) */
        current_pkt_cnt = pkt_ratio * (double)Entry_Limit;      /* count[i][j][t] / sum(count[i][j][t]) */
        norm_DS[ip_field][addr] = (DS_Size)floor(current_pkt_cnt); /* Entry_Limit is 65,536 in 16-bit */
        /* normalized packet count */
    }

    for( addr=0; addr<256; addr++ ) {
        scaled_pkt_cnt = (uint) norm_DS[ip_field][addr] * (uint) norm_DS_old[ip_field][addr]; /* C(i,j,t) */
        current_pkt_cnt = (double)scaled_pkt_cnt / (double)Entry_Limit;
        scaled_pkt_cnt = (uint)ceil(current_pkt_cnt);
        norm_DS_C[ip_field][addr] = (DS_Size)scaled_pkt_cnt;

        signed_scaled_pkt_cnt = (int) norm_DS[ip_field][addr] - (int) norm_DS_old[ip_field][addr]; /* Delta(p(i,j,t)) */
        DS_D[ip_field][addr] = (signed_DS_Size)signed_scaled_pkt_cnt;
    }
}
}
```

Appendix C

The Matlab codes below are what we used to create our visualization engine.

```
block(1) = load(sprintf(norm_DS_Src), '-ascii'); % reading a normalized packet count file in source domain
block(2) = load(sprintf(norm_DS_Dst), '-ascii'); % in destination domain
block_2D = load(sprintf(norm_DS_2D), '-ascii'); % in 2-dimensional domain

Sig_stddev = std(block(1,:)); % standard deviation of image in source domain
Sig_stddev_M = mean(Sig_stddev( : )); % average of normal traffic free of attack
dev = abs(Sig_stddev_M - Sig_stddev); % deviation = abs(mean - signal value)
% Calculate the probability between (mean-dev) and (mean+dev)
pr = normcdf([Sig_stddev_M-dev Sig_stddev_M+dev], Sig_stddev_M, Sig_stddev_S);

% visualizing traffic signal
plot(Sig_stddev(1, :),'-b','LineWidth',1); hold on; % source domain
plot(Sig_stddev(2, :),'-b','LineWidth',1); hold on; % destination domain

% traffic image in 1-dimension
range = [0,pow2(DS_Resolution) - 1]; % Data Structure resolution is 16
for io = 1: 2 % source to destination domain
    imagesc(block(io), range); hold on;
    colormap(hot);
end

% traffic image in 2-dimension
imagesc(block_2D, range); hold on;
colormap(hot);
```