The CoralReef software suite as a tool for system and network administrators

David Moore, Ken Keys, Ryan Koga, Edouard Lagache, and k claflfy

Abstract— Until now, system administrators have lacked a flexible real-time network traffic monitoring package. Such a package must provide a wide range of services but remain flexible enough for rapid in-house customization. Existing passive data collection tools are typically narrow in scope, designed for specific tasks from packet capture (tcpdump [1]) to accounting (NeTraMet [2]). In response, CAIDA has created the CoralReef suite designed to provide network administrators and researchers with a consistent interface for a wide range of network analysis applications, from raw capture to flows analysis to real-time report generation. CoralReef provides a convenient set of passive data tools for a diverse audience.

CoralReef is a package of device drivers, libraries, classes, and applications. We briefly outline the architecture and provide relevant case studies and examples of CoralReef’s use as applied to real-world networking situations. We will show how CoralReef is a powerful, extensible, and convenient package for network monitoring and reporting.

I. INTRODUCTION

With the growth in traffic volume and increasing diversity of applications on the Internet, understanding and managing networks has become increasingly difficult and important. To this end we have created the CoralReef passive traffic monitoring suite, which allows network users, administrators, and researchers to measure and analyze network traffic. The CoralReef software suite is a comprehensive collection of tools developed by CAIDA to collect, store, and analyze traffic data. CoralReef can be deployed on a dedicated monitor host using data capture cards that tap a fiber optic link, or on virtually any UNIX system without special hardware using libpcap interfaces. CoralReef software handles everything from the low level details of cell and packet capture to the production of high level HTML reports in near real-time. Network and system administrators can use the CoralReef suite to monitor and interpret a wide range of observed network behavior.

CoralReef evolved from OCXmon monitors, developed jointly by MCI and NLANR [3][4]. The OCXmon monitors ran on MS-DOS, could only monitor ATM links, and provided only basic cell capture (in device-dependent format) and limited flow summary capability. CoralReef runs on UNIX, and supports device independent access to network data from OCXmon hardware, native OS network interfaces, and trace files; programming APIs; a variety of bundled analysis applications; and greater flexibility in remote access and administration. CoralReef is developed and tested under FreeBSD, Linux, and Solaris, although specialized hardware drivers are not available for all operating systems. CoralReef has two releases, a “public” non-commercial use version and a version available only to CAIDA members. Both versions implement the same set of libraries and APIs, but the members-only version incorporates performance and operational enhancements geared toward CAIDA members. What makes CoralReef unique is that it supports a large number of features at many layers, and provides APIs and hooks at every layer, making it easier for anyone to apply it in unanticipated ways and develop new applications with minimum duplicated effort.

Because commercial software tools lack sufficient flexibility, network administrators often develop their own network analysis tools, typically based on tcpdump [1]. A part of tcpdump is the library libpcap [5] which provides a standard way to access IP data and BPF (Berkeley Packet Filter) devices. The tcpdump tool also has a packet data file format (pcap) which has become a de facto industry standard. Several network analyzer tools are built on top of libpcap, such as the Ethereal [6] protocol analyzer and NetraNet (RFC 2722 [7] and RFC 2724 [8]), which are geared toward long term collection for metering and billing. Other network analysis tools include the MEHARI [9] ATM/IP analysis system; Narsus [10] for long-term workload and billing; the DGA ATM/POS capture cards and software [11] by the WANd group at the University of Waikato, New Zealand; Clevertool’s netboy [12]; Network Associates Sniffer Pro [13]; and NIKSUN’s NetVCR [14].

This paper describes version 3.5.0 of the CoralReef suite. Section II presents an overview of CoralReef libraries, applications, and their relationships. In section III we describe how to set up a CoralReef monitor. Section IV contains multiple examples of using CoralReef to answer realistic networking questions. Section V describes the continuous HTML report generation capabilities of CoralReef. Finally, we conclude the paper in section VI with a summary.

II. AN OVERVIEW OF THE CORALREEF SOFTWARE SUITE

CoralReef is a package of libraries, device drivers, classes, and applications written in, and for use with, several programming languages. The overall architecture and programming interfaces are described in a separate paper[15] and are not covered here. Figure 1 shows an overview of the relationships between CoralReef applications. Detailed descriptions of the software tools can be found at the CoralReef web site (http://www.caida.org/tools/measurement/coralreef/).

Most CoralReef applications fall into one of two categories: those with names beginning with “crl,” which operate on raw packet data; and those with names beginning with “t2,” which operate on aggregated flow data. We will refer to these groups of applications as cr1_ and t2_*, respectively. Sources of raw data include custom Coral drivers for special collection cards, the libpcap library for commodity network interfaces, and trace files generated by cr1.trace, tcpdump, or other software.

A. Raw traffic applications

All of the cr1_* applications take a common set of command line and configuration options. These options include stopping after a specified number of packets or ATM cells or after a specified time duration; link specific parameters; filtering by ATM virtual channels; number of bytes to capture on each packet; and debugging level. Applications that operate on packets can filter their input with BPF (tcpdump) filter expressions. Applications that operate at regular time intervals have a common syntax for
specifying the interval size.

Pure utilities:
- `crl_trace` — captures network traffic to a `.crl` trace file
- `crl_info` — reports hardware and link configuration details of a trace file
- `crl_time` — outputs timestamps and inter-arrival time information for packets or ATM cells
- `crl_encode` — encodes the IP addresses in a `.crl` file to protect privacy
- `crl_to_*` — captures network traffic or converts trace files to other file formats

Simple tools:
- `crl_print` — prints headers and payloads of ATM cells
- `crl_print_pkt` — prints multiple layers of protocol headers and payloads of packets
- `crl_rate_layer2` — at regular time intervals, outputs cell count and bit rate for each ATM channel
- `crl_rate` — at regular time intervals, outputs IPv4 and IPv6 packet and byte counts, and counts of non-IP packets

Static Reports:
- `crl_hist` — reports packet and byte counts by IP length and protocol, port summary matrices for TCP and UDP, fragment counts by protocol, packet length histograms for the entire trace and for a list of applications, and the top 10 source and destination port numbers seen for TCP and UDP traffic
- `crl_bycountry` — reports the amount of traffic flowing to and from networks, and between networks, ASes, and countries

Specialized Utilities:
- `crl_portmap` — captures all packets from any hosts that connect to another host's portmap port
- `crl_flow` — at regular time intervals, aggregates packet data into flows by source and destination IP addresses, protocol, and source and destination ports

B. Traffic flow applications

The `t2_*` applications operate on tables generated by `crl_flow` or other `t2_*` applications, with the same time intervals.
- `t2_report` — generates HTML summary reports (described in Section V)
- `t2_ASmatrix` — with a routing table (described in Section V), aggregates by source and destination Autonomous System numbers and source and destination ports
- `t2_top` — sorts a table by packets, bytes, or flows, and displays the top N entries
- `t2_rate` — outputs counts of IP packets, bytes, and flows
- `t2_convert` — aggregates a table by specified keys

C. Other applications
- `crl_to_pcap` — converts Coral traces or live data to pcap format for use with existing `libpcap` tools
- `parse_bgp_dum` — converts output from a router "show ip bgp" output to the routing table format used by `t2_ASmatrix`, `t2_report`, and `crl_bycountry`
- `parse_bgp_mrt` — converts MRTd[16] output to the routing table format used by `t2_ASmatrix`, `t2_report`, and `crl_bycountry`

D. Libraries
- `libcoral` — reads trace files and live network interfaces, and provides common functionality for all `crl_*` applications
- `Coral.pm` — perl interface to `libcoral`
- `ASFinder` — maps IP addresses to AS numbers and network prefixes
- `AppPorts` — maps protocols and port numbers to application names
- `NetGeolClient` — maps IP addresses and AS numbers to geographic locations
- `Tables` — manipulating and processing the tables used by the `t2_*` applications

III. Using CoralReef in an Operational Setting

CoralReef can only monitor traffic that is visible to a network interface. If the network you want to monitor is a shared medium such as non-switched Ethernet or FDDI, any interface on that network is sufficient. Monitoring a link between routers or on a switched network requires directing traffic into additional dedicated interfaces, which may be either standard interfaces read via `libpcap`, or special hardware accessed through Coral drivers. A link can be tapped either with a physical splitter (Figure 2a) or by configuring a span or mirror port on the appropriate switch or router (Figure 2b). Note that tapping both directions of a link with splitters requires a dedicated interface for each direction.

The hardware needed depends on the utilization of the links being monitored and the amount of aggregation desired. For straightforward packet traces, the main constraint is usually disk performance and capacity; we recommend ultra-wide SCSI rather than an IDE drive. For flow collection and analysis, memory and CPU speed are more important. Individual applications in a CoralReef pipeline can run

![Fig. 1. Overview of CoralReef Applications](image-url)
IV. EXAMPLES

In this section, we briefly present examples of using CoralReef in an operational setting. A more complete outline of uses can be found in the CoralReef documentation or the user community mailing list.

Several `-C` options are common to all `crl_*` applications. In the following examples, we use `-Ci=time` to specify the repeated interval at which the application processes data and outputs results, and `-C'filter expression'` to specify a BPF filter expression that selects the packets to be measured. To stop the applications after a specific duration, you would use the `-Cd=time` option. The `crl_*` applications can read traffic from a variety of sources; in these examples, the data source is “if:fxp0”, a native Ethernet interface (fxp0) read via libpcap.

IP addresses in the sample outputs have been encoded for privacy. Some output has been edited to better fit the page and for illustrative value.

Timestamps in application output are printed in UNIX timestamp format.

A. Using `crl_rate` to check utilization of subinterfaces

The `crl_rate` application counts packets and bytes on interfaces and subinterfaces at regular intervals. On Ethernet interfaces, subinterfaces are IEEE 802.1Q VLANs. On ATM interfaces, virtual channels are reported as subinterfaces. Other types of interfaces do not have subinterfaces.

A.1 Goal: continuously measure traffic on a link, in packets and bytes.

Command line:
```
crl_rate -Ci=10 if:fxp0
```

Sample output: See listing 1.
Explanation: This output shows that there was traffic on 7 VLANs on Ethernet interface fpx0 in a 10 second period. A similar table would be printed every 10 seconds. The “non_ip” column counts packets of protocols like ARP, AppleTalk, and IPX. The total IPv4 traffic on this link in 10 seconds was about 99.5 Megabytes, or 79.6 Megabits per second. Note that the bytes counted are those in layer 3 and above; bytes in lower layer encapsulations like Ethernet and ATM are not counted.

This simple example is a good way to test your CoralReef monitor and software setup to verify that the output matches your expectations.

There was only one interface in this example, labeled 0 in the output, but it is possible to monitor multiple interfaces simultaneously.

A.2 Goal: find out how much KaZaA traffic is on your link.

Command line:
```
crl_rate -s -Ci=300 -C'filter port 1214' if:fxp0
```

Sample output: See listing 2.
Explanation: In this example, we were not interested in subinterfaces (VLANs), so we used the `-s` option to omit them. Because of high variability in these kinds of measurements, larger intervals are usually more useful. In this example, we used a 5 minute interval. To limit the measured traffic to KaZaA[17], we used a BPF filter to match only traffic to or from KaZaA’s well-known port (1214). In the first of the two intervals shown, there were about 1.33 Gigabytes of KaZaA traffic, or 35.5 Megabits per second.

B. Using `crl_flow` to collect flow data

The `crl_flow` application summarizes data by IP flows. In this context, a flow is identified by the 5-tuple of source address (src), destination address (dst), protocol (proto), source port (sport), and destination port (dport). A flow is unidirectional, so there will be one flow for each of the two directions of a network connection, with sources and destinations swapped.

The definition of flow termination can be chosen by a command line option. The `-t` option specifies that flows terminate at the end of each interval, which is the most useful definition for this kind of continuous monitoring. Other definitions are typically more useful in offline analysis of historic data, as is often needed in research situations.

A table of these 5-tuples, along with counts of packets, bytes, and flows for each, is called a `Tuple_Table`. The “ok” column contains a 1 if sport and dport are meaningful for the protocol and were not truncated by capturing too few header bytes. Ports are meaningful for TCP, UDP, and ICMP (for ICMP, the sport and dport columns actually contain ICMP type and code, respectively).

B.1 Goal: continuously collect data on link use, summarized by hosts, protocols, and ports.

Command line:
```
crl_flow -l -h -Ci=10 if:fxp0
```

Sample output: See listing 3.
Explanation:

The `-h` option tells `crl_flow` to print in human-readable format. With no formatting option, `crl_flow` prints a tab-separated format more suitable for input to other scripts. Additionally, `crl_flow -b` outputs a binary format that is readable by the `t2_*` applications, more efficiently than either of the text formats.

The output shown here has been edited to fit the page. Real output would have a `Tuple_Table` for each interface and
Listing 1

crl_rate output: traffic on a link.

Listing 2

crl_rate output: KaZaA traffic.

Listing 3

crl_flow output: Continuous data collection.
subinterface, repeated every 10 seconds; an interface or
subinterface summary preceding each table; and two addi-
tional columns in each table showing the first and last packet
timestamp observed within each flow. Remember that IP
addresses have been encoded for privacy.

The sample output shows one UDP DNS flow (protocol
17, port 53), one HTTP flow from a web server to a client,
several HTTP flows from clients to web servers, and one
large flow on TCP port 1214 (KaZaA).

C. Using t2.* to monitor utilization and flows

Although crl_flow does some aggregation, its output is
still typically too voluminous to be directly useful. The t2.*
applications further aggregate or filter the output of crl_flow
for more specific needs. In particular, t2_rate -s outputs a
single line per interval summarizing the packets, bytes, and
flows observed. t2_top sorts table entries by packets, bytes,
or flows, and prints only the top N.

Most t2.* applications accept different table types as in-
put, and can identify the table type of their input automati-
cally. crl_flow outputs a TupleTable; we will introduce other
table types in later examples.

C.1 Goal: continuously measure traffic on a link, in packets, bytes,
and flows.

Command line:
crl_flow -I -b -Ci=10 if:fxp0 | t2_rate -s
Sample output: See listing 4.

Explanation: In this example, t2_rate prints a line for every
10 second interval, the beginning of which is indicated in the
first column (time). The next three columns show the total
number of packets, bytes, and flows observed during the
interval. The “entries” column shows the number of table
tables, which, in the case of a TupleTable, is equal to the
number of flows. The last three columns show the average
number of packets, bytes, and flows per second during the
interval.

The -b option to crl_flow tells it to output in efficient bi-
ary format readable by t2.* applications. The use of this
option can drastically improve performance, and is recom-
meded when the intermediate output does not need to be
read by a human.

C.2 Goal: continuously find flows consuming the most bandwidth on
a link.

Command line:
crl_flow -I -b -Ci=10 if:fxp0 | t2_top -Sb -n5
Sample output: See listing 5.

Explanation: The “KEYS” columns are the same as the keys
in the input table, which in this example is a TupleTable
from crl_flow. The -Sp, -Sb, or -Sf option tells t2_top to sort
by packets, bytes, or flows, and the -n option specifies how
many entries to print.

D. Using t2.* to find hosts generating the most traffic

Often we want to aggregate the flows of a TupleTable by
a subset of its keys. For example, we may want to count
the bytes sent between pairs of hosts, regardless of their
protocols and ports; or, all the packets sent from a particular
TCP port, no matter what host sent or received them.

In addition to the TupleTable, CoralReef has other table
types defined by different sets of keys. For example, the
keys of an IP Matrix are source and destination IP addresses,
and the key of an IP_Table is a single IP address. Table 1
shows all tables and their keys.

The t2_convert application converts one table type to an-
other by aggregating entries with common keys. A conver-
sion operator determines which subset of input table keys
to use as the keys of the output table. For example, ap-
plying the src_IP_Table operator to a TupleTable generates
an IP_Table whose keys are the source addresses of the in-
put table. The pkts, bytes, and flows counts of each entry
in the new table are the sums of the corresponding counts
of the TupleTable entries with the same source IP address.

Figure 3 shows all the operators that can be applied to the
various table types.

D.1 Goal: find the top 5 hosts by bytes of traffic generated

Command line:
crl_flow -I -b -Ci=10 if:fxp0 | t2_convert src_IP_Table | t2_top -Sb -n5

Sample output:

```
<table>
<thead>
<tr>
<th>#KEYS</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td># (top 5 sorted by bytes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4.0.27</td>
<td>16035</td>
<td>22534236</td>
<td>1</td>
</tr>
<tr>
<td>0.4.0.21</td>
<td>12202</td>
<td>13665357</td>
<td>46</td>
</tr>
<tr>
<td>0.4.0.30</td>
<td>2965</td>
<td>42230700</td>
<td>1</td>
</tr>
<tr>
<td>0.4.0.44</td>
<td>3647</td>
<td>3919348</td>
<td>1</td>
</tr>
<tr>
<td>0.4.0.4</td>
<td>1831</td>
<td>2702668</td>
<td>1</td>
</tr>
</tbody>
</table>
```

Explanation: The output of crl_flow is a TupleTable, with
keys src, dst, proto, ok, sport, and dport. To aggregate those
flows by source IP address, we apply the src_IP_Table opera-
tor with t2_convert. Since the flows column in a TupleTable
is always 1, the flows column in the resulting IP_Table is the
number of flows with that source IP address. Sorting this
IP_Table by bytes and taking the top 5 entries shows the
hosts sending the most bytes.

D.2 Goal: find the top 5 web servers by HTTP flows

Command line:
crl_flow -I -b -Ci=10 -C'filter tcp src port 80' if:fxp0 | t2_convert src_IP_Table | t2_top -Sf -n5

Sample output:

```
<table>
<thead>
<tr>
<th>#KEYS</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td># (top 5 sorted by bytes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4.0.27</td>
<td>18409</td>
<td>25864829</td>
<td>3</td>
</tr>
<tr>
<td>0.4.0.21</td>
<td>13900</td>
<td>15115873</td>
<td>46</td>
</tr>
<tr>
<td>0.4.0.30</td>
<td>3097</td>
<td>4417620</td>
<td>1</td>
</tr>
<tr>
<td>0.4.0.44</td>
<td>3185</td>
<td>3350880</td>
<td>1</td>
</tr>
<tr>
<td>0.4.0.64</td>
<td>1347</td>
<td>1948443</td>
<td>7</td>
</tr>
</tbody>
</table>
```

Explanation: This is similar to the previous example, except
we limit the traffic to web servers by using a filter option to
crl_flow and sort by flows (-Sf) instead of bytes. Aggregating
this TupleTable by source IP address and then sorting the
resulting IP_Table by flows shows the web servers with the
most HTTP connections during each 10 second interval.
# start pkts bytes flows entries pkts/s bits/s flows/s
1001982746 143315 97458948 6624 6624 14.33k 77.97M 662.40
1001982756 143985 98792491 6465 6465 14.40k 79.03M 646.50
...

Listing 4
t2_rate output: Utilization and flows.

<table>
<thead>
<tr>
<th>src</th>
<th>dst</th>
<th>proto</th>
<th>ok</th>
<th>sport</th>
<th>dport</th>
</tr>
</thead>
<tbody>
<tr>
<td>#KEYS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.4.0.27</td>
<td>0.98.0.1</td>
<td>6</td>
<td>1</td>
<td>46978</td>
<td>64671</td>
</tr>
<tr>
<td>0.4.0.30</td>
<td>0.19.0.2</td>
<td>6</td>
<td>1</td>
<td>22</td>
<td>64156</td>
</tr>
<tr>
<td>0.4.0.44</td>
<td>0.158.0.1</td>
<td>6</td>
<td>1</td>
<td>22</td>
<td>33222</td>
</tr>
<tr>
<td>0.4.0.4</td>
<td>0.17.0.1</td>
<td>6</td>
<td>1</td>
<td>80</td>
<td>58013</td>
</tr>
<tr>
<td>0.4.0.3</td>
<td>0.15.0.1</td>
<td>6</td>
<td>1</td>
<td>45925</td>
<td>20</td>
</tr>
<tr>
<td># end of text table</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Listing 5
t2_top output: High bandwidth consumers.

<table>
<thead>
<tr>
<th>Table Type</th>
<th>Keys</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuple_Table</td>
<td>source IP, destination IP, IP protocol, ports ok, source port, destination port</td>
</tr>
<tr>
<td>IP_Table</td>
<td>IP</td>
</tr>
<tr>
<td>IP_Matrix</td>
<td>source IP, destination IP</td>
</tr>
<tr>
<td>Proto Ports Table</td>
<td>IP protocol, ports ok, source port, destination port</td>
</tr>
<tr>
<td>Port Table</td>
<td>port</td>
</tr>
<tr>
<td>Port Matrix</td>
<td>source port, destination port</td>
</tr>
<tr>
<td>Proto Table</td>
<td>IP protocol</td>
</tr>
<tr>
<td>AS Table</td>
<td>AS</td>
</tr>
<tr>
<td>AS Matrix</td>
<td>source AS, destination AS</td>
</tr>
<tr>
<td>Country Table</td>
<td>country</td>
</tr>
<tr>
<td>Country Matrix</td>
<td>source country, destination country</td>
</tr>
<tr>
<td>App Table</td>
<td>application</td>
</tr>
<tr>
<td>VPVC Table</td>
<td>vp/vc pair</td>
</tr>
<tr>
<td>Prefix Table</td>
<td>prefix/masklength</td>
</tr>
<tr>
<td>Prefix Matrix</td>
<td>source prefix/masklength, destination prefix/masklength</td>
</tr>
<tr>
<td>Length Table</td>
<td>length</td>
</tr>
</tbody>
</table>

TABLE 1
CoralReef table types.
E. Using t2_* to find hosts talking to the most hosts

Normally, the flows column in each entry of the output table of t2_convert is the sum of the flows column of the input table entries with the same output keys. But with the -F option of t2_convert, the flows column in each output entry will be the number of input entries with the same output keys. For example, given this IP_matrix table:

<table>
<thead>
<tr>
<th>src</th>
<th>dst</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0.0.1</td>
<td>0.0.0.2</td>
<td>3</td>
<td>120</td>
<td>3</td>
</tr>
<tr>
<td>0.0.0.1</td>
<td>0.0.0.3</td>
<td>1</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>0.0.0.1</td>
<td>0.0.0.4</td>
<td>10</td>
<td>400</td>
<td>5</td>
</tr>
</tbody>
</table>

The command “t2_convert src_IP_Table” yields an IP_Table in which the flows column shows the number of 5-tuple flows with the given source address:

<table>
<thead>
<tr>
<th>src</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0.0.1</td>
<td>14</td>
<td>560</td>
<td>9</td>
</tr>
</tbody>
</table>

but “t2_convert -F src_IP_Table” yields an IP_Table in which the flows column shows the number of IP pairs with the given source address:

<table>
<thead>
<tr>
<th>src</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0.0.1</td>
<td>14</td>
<td>560</td>
<td>3</td>
</tr>
</tbody>
</table>

E.1 Goal: find the number of unique destination hosts for each source host

Command line:

crl_flow -I -b -Ci=10 if:fxp0 | t2_convert IP_Matrix | t2_convert -F src_IP_Table | t2_top -Sf -n5

Sample output:

<table>
<thead>
<tr>
<th>src</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1.0.120</td>
<td>1159</td>
<td>93601</td>
<td>167</td>
</tr>
<tr>
<td>0.1.0.5</td>
<td>1553</td>
<td>119823</td>
<td>157</td>
</tr>
<tr>
<td>0.4.0.7</td>
<td>1042</td>
<td>109109</td>
<td>79</td>
</tr>
<tr>
<td>0.1.0.1</td>
<td>884</td>
<td>75684</td>
<td>71</td>
</tr>
<tr>
<td>0.1.0.65</td>
<td>941</td>
<td>106510</td>
<td>65</td>
</tr>
</tbody>
</table>

E.2 Goal: find the top 5 web servers by number of clients

Command line:

crl_flow -I -b -Ci=10 -C'filter tcp src port 80' if:fxp0 | t2_convert IP_Matrix | t2_convert -F src_IP_Table | t2_top -Sf -n5

Sample output:

<table>
<thead>
<tr>
<th>src</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1.0.52</td>
<td>180</td>
<td>78166</td>
<td>11</td>
</tr>
<tr>
<td>0.1.0.108</td>
<td>102</td>
<td>52397</td>
<td>6</td>
</tr>
<tr>
<td>0.1.0.62</td>
<td>33</td>
<td>33203</td>
<td>4</td>
</tr>
<tr>
<td>0.1.0.182</td>
<td>24</td>
<td>1713</td>
<td>4</td>
</tr>
<tr>
<td>0.1.0.231</td>
<td>40</td>
<td>33100</td>
<td>3</td>
</tr>
</tbody>
</table>

Explanation: Remember, since the -F option was used on the second t2_convert, the flows column is actually the number of corresponding entries in the IP_matrix input table, i.e. the number of IP pairs with the given source address. So, in the first 10 second interval, host 0.1.0.120 sent traffic to 159 different destination hosts, totaling 135597 bytes.

E.3 Goal: find the top 5 web servers by number of clients

Command line:

crl_flow -I -b -Ci=10 -C'filter tcp src port 80' if:fxp0 | t2_convert IP_Matrix | t2_convert -F src_IP_Table | t2_top -Sf -n5

Sample output:

<table>
<thead>
<tr>
<th>src</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1.0.120</td>
<td>1159</td>
<td>93601</td>
<td>167</td>
</tr>
<tr>
<td>0.1.0.5</td>
<td>1553</td>
<td>119823</td>
<td>157</td>
</tr>
<tr>
<td>0.4.0.7</td>
<td>1042</td>
<td>109109</td>
<td>79</td>
</tr>
<tr>
<td>0.1.0.1</td>
<td>884</td>
<td>75684</td>
<td>71</td>
</tr>
<tr>
<td>0.1.0.65</td>
<td>941</td>
<td>106510</td>
<td>65</td>
</tr>
</tbody>
</table>

#end of text table
Explanation: This example is similar to the previous one, except that we first filter the traffic to measure only packets sent by HTTP servers. So, in the first 10 second interval, host 0.1.0.52 sent HTTP traffic to 11 different destination hosts, totaling 78166 bytes.

E.3 Goal: find hosts on your internal network trying to spread the CodeRed worm

Command line:

crl_flow -I -b -Ci=60 -Csource=if:fxp0 \ -C”filter tcp dst port 80 and src net 10.0.0.0/8” | t2_convert IP_Matrix | t2_convert -F src_IP_Table | t2_top -Sf -n5

Sample output:

<table>
<thead>
<tr>
<th>#KEYS</th>
<th>pkts</th>
<th>bytes</th>
<th>flows</th>
</tr>
</thead>
<tbody>
<tr>
<td># (top 5 sorted by flows)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.0.39.61</td>
<td>7760</td>
<td>460800</td>
<td>7680</td>
</tr>
<tr>
<td>10.0.198.103</td>
<td>8960</td>
<td>358400</td>
<td>6144</td>
</tr>
<tr>
<td>10.0.39.60</td>
<td>6144</td>
<td>386840</td>
<td>6144</td>
</tr>
<tr>
<td>10.0.190</td>
<td>7168</td>
<td>299008</td>
<td>4864</td>
</tr>
<tr>
<td>10.0.19.1</td>
<td>12544</td>
<td>602112</td>
<td>4608</td>
</tr>
</tbody>
</table>

Explanation: Hosts infected with the CodeRed worm try to infect large numbers of other hosts by attempting to open an HTTP connection to random IP addresses (which may or may not actually exist or be running a web server)[18]. With the exception of web caches, most hosts do not open HTTP connections to more than a few different servers per second, so we should be suspicious of any host that tries to connect to significantly more servers. In particular, hosts infected with CodeRed attempt to open HTTP connections to many tens or hundreds of hosts per second. By using a filter that selects only packets from the internal network (10.0.0.0/8 in this example) to HTTP servers, and by seeing which of the hosts sending those packets are attempting to communicate with the most servers, we produce a list of internal hosts that are behaving suspiciously.

V. REPORT GENERATOR

The CoralReef report generator provides a web interface to continuously updated link usage reports. The report generator (t2-report) is a Perl application, using C backends for speed, which receives (via a pipe) either live data or traces taken from crl_flow. t2-report collects and displays timeseries information by using RDDtool[19].

The report generator utilizes many of the features of the CoralReef suite and thus illustrates some of the capabilities of the suite. At configurable intervals (e.g. every 5 minutes), t2-report produces pie charts and tables of traffic data from the most recent sample interval, and timeseries graphs of data over the last hour, day, week, month, and year. All three report forms present data as bytes, packets, and flows. The pie charts and tables show protocol breakdown, applications, flows, source/destination hosts, unknown TCP and UDP, and source/destination ASes and countries. The timeseries graphs show absolute counts and percentages for protocol breakdown and applications. There are two sets of application timeseries graphs. One shows only the applications specified in the t2_report configuration file, and the other shows the applications with the most traffic in each interval.

To report traffic by AS number, countries, and application names, t2-report must use external data not present in the packets themselves. t2-report uses a library called ASFinder and a routing table, as output by parse_lkp*, to map IP addresses to AS numbers. To get countries and AS names from AS numbers, t2-report uses NetGeo[20]. Application names are found by the AppPorts library, which uses a prioritized ruleset to map protocol and port numbers to applications. Users can add or modify application rules by editing a simple text file.

Figure 4 shows an example of a timeseries plot of application breakdown by bytes. Figure 5 shows an example of the top source ASes by bytes in a 5 minute period. The CoralReef web site has a live demonstration of the report generator monitoring the commodity traffic link for the U. C. San Diego.

VI. CONCLUSION

CoralReef provides a suite of tools to aid network administrators in monitoring and diagnosing changes in network behavior. CoralReef provides a unified platform to a wide range of capture devices and a collection of tools that can be applied at multiple levels of the network. Its components provide measures on a wide range of real-world network traffic flow applications, including validation and monitoring of hardware performance for saturation and diagnosis of network flow constraints. CoralReef can be used to produce standalone results or produce data for analysis by other programs. CoralReef reporting applications can output in text formats that can be easily manipulated with common UNIX data-reduction utilities (e.g. grep), providing enormous flexibility for customization in an operational setting.

CoralReef provides a balanced collection of features for network administrators seeking to monitor their network and diagnose trouble spots. It serves as a useful bridge between higher level monitoring tools which only work at a coarse level of aggregation and “dump” utilities which may overwhelm the administrator with detail. By covering the range from raw packet capture to real-time HTML report generation, CoralReef provides a viable toolkit for wide range of network administration needs.

VII. ACKNOWLEDGMENTS

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VIII. AVAILABILITY

The CoralReef software package is available for non-commercial use from http://www.caida.org/tools/measurement/coralreef/. Questions about CoralReef can be e-mailed to coral-info@caida.org.

REFERENCES

Fig. 4. Example of a timeseries plot of application breakdown by bytes

Fig. 5. Example of top source ASes by bytes in a 5 minute period

David Moore is the Co-Director and a PI of CAIDA (the Cooperative Association for Internet Data Analysis). David’s research interests are high speed network monitoring, denial-of-service attacks and infrastructure security, and Internet traffic characterization. His current research includes using the backscatter analysis technique to track and quantify global DoS attacks and Internet worms.

Ken Keys is lead developer of CAIDA’s CoralReef project. He has been involved with network research for 3 years and programming UNIX networking code for over 12 years. Ken is known to many for his years of work on TinyFugue, a popular MUD client.

Ryan Koga is CAIDA’s resident expert at integrating C and C++ with Perl. He spends most of his time developing libraries for CoralReef and writing assorted programs for other CAIDA projects.

Edouard Lagache is a Researcher and Perl developer with CAIDA. He received his Ph.D. from the University of California, Berkeley in 1995. He has done research on human/computer interaction and social aspects of learning.

kc claffy is Co-Director and a PI of CAIDA, and a resident research scientist based at the University of California’s San Diego Supercomputer Center. kc’s research interests include Internet workload/performance data collection, analysis and visualization, particularly with respect to commercial ISP collaboration/cooperation and sharing of analysis resources. kc received her Ph.D. in Computer Science from UCSD in 1994.