Harpoon

A Flow-level Traffic Generator
User manual

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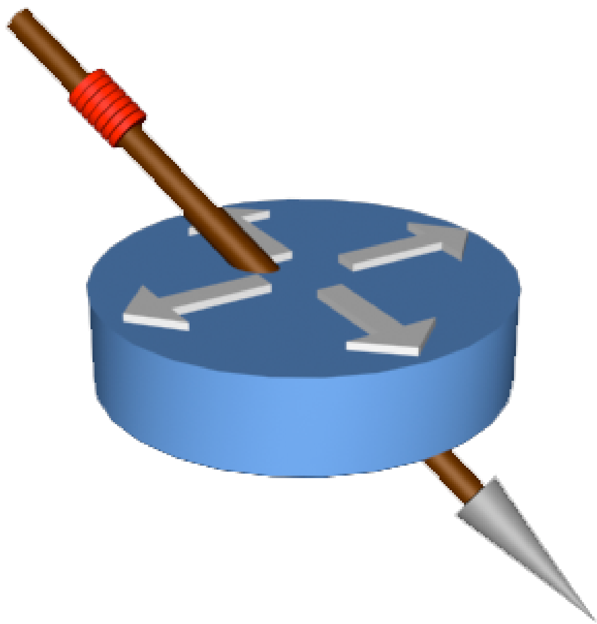

This manual is for the Harpoon Flow-level Traffic Generator. The following copyright notice covers the Harpoon source code, including all documentation, images, and ancillary files.

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1 Overview of Harpoon

Harpoon is a flow-level traffic generator. It uses a set of distributional parameters that can be automatically extracted from Netflow traces to generate flows that exhibit the same statistical qualities present in measured Internet traces, including temporal and spatial characteristics. Harpoon can be used to generate representative background traffic for application or protocol testing, or for testing network switching hardware. This manual begins by describing the architecture of Harpoon. Subsequent chapters describe how to effectively configure, run, and manage Harpoon.

A suggested roadmap for getting up and running with Harpoon is to read this chapter, Chapter 1 [Overview of Harpoon], page 1, followed by the next chapter, Chapter 2 [Basic Configuration], page 7, referring as needed to Chapter 4 [Running Harpoon], page 24 and Appendix A [More Examples], page 33 for command-line parameter, environment variable, and specific examples. Readers wanting to use the self-configuration tools or to deploy Harpoon in large testbeds should read the whole manual.

1.1 Architecture of Harpoon

The design objectives of Harpoon are (1) to scalably generate application-independent network traffic at the IP flow level, and (2) to be easily parameterized to create traffic that is statistically identical to traffic measured at a given vantage point in the Internet. Figure 1.1 [High-level data flow diagram of Harpoon] depicts a high-level process flow of these objectives. We start with the basic definition of an IP flow and use this to create a constructive model for network traffic generation which we describe below.

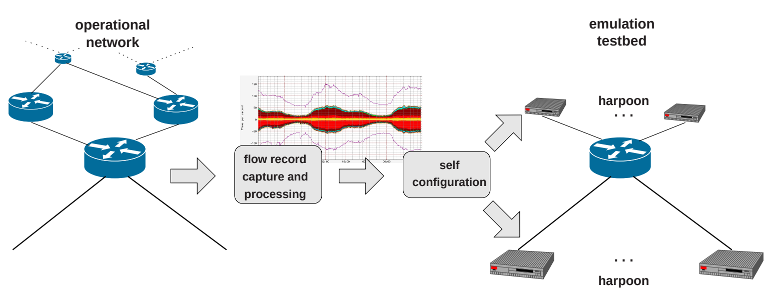

Figure 1.1: **High-level data flow diagram of Harpoon.** IP flow records are collected at a given vantage point in an operational network using standard software like `flow-tools`. Key aspects of the live flows are extracted during a self-configuration step. These parameters are used to generate traffic in a testbed that statistically matches the temporal (diurnal) volume characteristics as well as the spatial (source and destination IP address frequency) characteristics of the live flows.

An IP flow is typically defined as a unidirectional series of IP packets of a given protocol traveling between a source and a destination IP/port pair within a certain period of time. The final condition of this statement is somewhat ambiguous, so we pragmatically tie our definition to Cisco's implementation of Netflow and to the tools we use to gather and analyze network flow data. Netflow data includes source and destination AS/IP/port pairs, packet and byte counts, flow start and end times, protocol information, and a bitwise `OR` of TCP flags for all packets of a flow, in addition to other fields. This data is exported either on timer deadlines or when certain events occur (e.g., a TCP FIN or RST, or a cache becomes full), whichever comes first. While this would seem to pragmatically resolve ambiguity in the definition of a flow, specific expiration-related timing behaviors can vary (see *Cisco Netflow White Paper*[1]). The result is that flow start time stamps are accurate, while flow end time stamps are not. This inaccuracy does not impact a user of Harpoon, but it does make a difference to the self-configuration tools. For more details, see the Harpoon technical paper.

From this operational definition of a flow, Harpoon's architecture begins with the notion of unicast file transfers using either TCP or UDP. Harpoon does not address the packet level dynamics of TCP file transfers. Rather, it relies on the version(s) of TCP running on end hosts to transfer the requested file. Modeling UDP traffic is complicated by the fact that packet emission behaviors are largely application-specific. At present, Harpoon contains three models of UDP packet transfer: a simple parameterized constant packet rate, a fixed-interval periodic ping-pong, and an exponentially distributed ping-pong. The first source type is similar to some audio and video streams, while the latter two types are intended to mimic the standard Network Time Protocol (NTP) and Domain Name Service (DNS), respectively. UDP traffic in today's Internet is likely to be made up of a wider variety of application level traffic (including voice, SQL worms, etc.) whose behavior is not captured in our current three source-type model. Development of a model with a more diverse set of UDP traffic sources is left for future work.

The Harpoon flow model is a two level architecture and is depicted in Figure 1.2 [Harpoon's flow-based two level hierarchical traffic model]. We refer to the lower level of the Harpoon model as the *connection level*. It is made up of two components that have measurable distributional properties. The first component is the *size* of the file transferred, and the second component is the time interval between consecutive file transfer requests, the *inter-connection time*. Harpoon makes requests for files with sizes drawn from an empirical distribution $P_{FileSize}$. Connection initiations are separated by time intervals drawn from an empirical distribution $P_{InterConnection}$.

The upper level of the Harpoon model is referred to as the *session level*. Harpoon sessions are divided into either TCP or UDP types that conduct data transfers using the respective protocol during the time that they are

[1] http://www.cisco.com/univercd/cc/td/doc/cisintwk/intsolns/netflsol/nfwhite.htm.

active. The session level has two components: the number of *active sessions* and the *IP spatial distribution*. By modulating the number of sessions that are active at any point in time, Harpoon can match the byte, packet, and flow volumes from the original data and realize the temporal (diurnal) traffic volumes that are a common characteristic of the Internet[2]. The average number of sessions of each type (TCP/UDP) that are active at any point in a day is derived from a flow data time series for consecutive non-overlapping intervals of length $IntervalDuration$ seconds to create an empirical model for $P_{ActiveSessions}$. Scalability is naturally achieved by dividing the number of active sessions across any number of hosts comprising the testbed. For each session, Harpoon picks source and destination addresses from ranges of available addresses to make a series of file transfer requests. The address selection is made preferentially using weights drawn from empirical distributions $P_{IPRange_{src}}$ and $P_{IPRange_{dest}}$. A series of file transfer requests then takes place between the source and destination for $IntervalDuration$ seconds. When Harpoon is started, it begins with the average number of sessions in the first interval and proceeds through consecutive intervals for the duration of the test.

In summary, the Harpoon model is made up of a combination of five distributional models for TCP sessions: file size, inter-connection time, source and destination IP ranges, number of active sessions. There are three distributional models for UDP sessions: constant bit-rate, periodic and exponential ping-pong. Each of these distributions can be specified manually or, in the case of TCP traffic, extracted from packet traces or Netflow data collected at a live router. These models enable the workload generated by Harpoon to be application independent or to be tuned to a specific application. The models are combined in a constructive manner to create a series of file transfer requests that results in representative flow-level network traffic. The parameters for TCP sessions are summarized below:

Parameter	**Description**
$P_{FileSize}$	Empirical distribution of file sizes transferred.
$P_{InterConnection}$	Empirical distribution of time between consecutive TCP connections initiated by an IP source-destination pair.
$P_{IPRange_{src}}$ and $P_{IPRange_{dest}}$	Ranges of IP addresses with preferential weights set to match the empirical frequency distributions from the original data.
$P_{ActiveSessions}$	The distribution of the average number of sessions (IP source-destination pairs) active during consecutive intervals of the mea-

[2] See, for example, Vern Paxson's thesis (ftp://ftp.ee.lbl.gov/papers/vp-thesis/dis.ps.gz).

sured data. By modulating this distribution, Harpoon can match the temporal byte, packet and flow volumes from the original data.

IntervalDuration
: Time granularity over which Harpoon matches average byte, packet and flow volumes

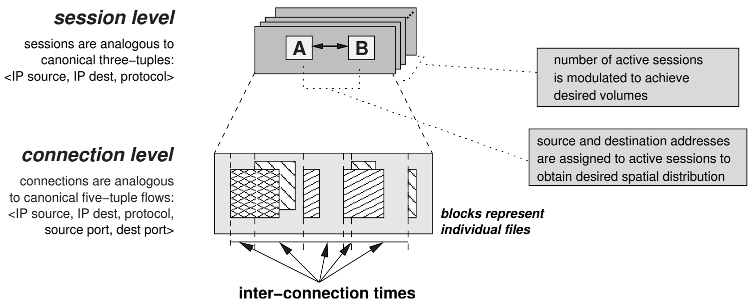

Figure 1.2: **Harpoon's flow-based two level hierarchical traffic model.** Sessions are comprised of a series of connections separated by durations drawn from the inter-connection time distribution. Source and destination IP address selection (A and B in the figure) is weighted to match the frequency distribution of the original flow data. The number of active sessions determines the overall average load offered by Harpoon. A heavy-tailed empirical file size distribution and an ON/OFF transfer model generate self-similar packet-level behavior.

1.2 Harpoon Software Components

There are five programs and scripts included with Harpoon:

- `harpoon`, the main executable, along with *traffic generation plugins* for implementing Harpoon user-level behavior using OS-supplied protocol implementations (e.g. TCP) or another kind of packet emission processes,
- `config_validator`, a utility for validating the structure of a config file.
- `harpoon_flowproc`, a utility for pre-processing flow records (raw Netflow version 5 or `flow-tools` format) for self-configuration, and
- `harpoon_conf.py`, a utility for generating configuration files for `harpoon` (the self-configurator).
- `harpoon_reconf.py`, a utility for tuning existing configuration files to produce desired traffic volumes.

`harpoon`, `config_validator`, and `harpoon_flowproc` are C++ programs. Requirements for building Harpoon include a C++ compiler with a functional standard template library (recent versions of GCC easily satisfy this requirement), a POSIX threads implementation, and the eXpat XML parsing library[3]. The `flow-tools`[4] library is optionally used by `harpoon_flowproc`. If no installation of `flow-tools` is found, the `harpoon_flowproc` tool will still be built, but will only be able to process wire format Netflow 5 records.

The scripts `harpoon_conf.py` and `harpoon_reconf.py` require a Python interpreter, version 2.3 or greater[5]. If a suitable Python interpreter is not found, the other tools will be built, but a warning will appear when configuring the software.

The traffic generation plugins exist as dynamically loadable modules (aka shared libraries, dynamically linked libraries, bundles). For example, all logic specific to generating TCP flow traffic is confined to the `TCPPlugin` module and all logic specific for UDP constant bit-rate traffic generation is confined to the `UDPcbrPlugin` module. (Appendix C [Creating New Traffic Generation Modules], page 43 describes how to create modules to generate any type of desired traffic.) You do not have to know how these modules work to generate basic TCP or UDP-CBR traffic, but you should understand the basic roles of the distributions used by different Harpoon plugins in order to feed properly formatted configuration files to Harpoon.

Subsequent chapters describe how to use these tools to produce desired traffic. For basic configuration using sample configuration files supplied with the Harpoon software distribution, see Chapter 2 [Basic Configuration], page 7. For more extensive discussion of configuring Harpoon using the self-configuration tools, see Chapter 3 [Advanced Configuration], page 15. Command-line options, applicable environment variables, and signal handling for the above tools are covered in Chapter 4 [Running Harpoon], page 24. Finally, more examples on configuring, using, and managing Harpoon are given in Appendix A [More Examples], page 33. Note that this manual assumes a working knowledge of UNIX-ish systems and shell commands. If you need help on those basics, look elsewhere.

1.2.1 Building the Harpoon Software

Building Harpoon consists of the following steps:

1. Unpack the distribution. Using GNU `tar`, "`tar xzvf harpoon_distribution.tgz`" will do the trick, substituting the particular file name for "`harpoon_distribution.tgz`".
2. Run `./configure` in the top-level directory of the unpacked software. This step will build appropriate make files for your system. Optionally, you may use the `--prefix` flag to specify where the software is to be installed. The installation location defaults to `/usr/local/harpoon`.

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[3] http://expat.sourceforge.net

[4] http://www.splintered.net/sw/flow-tools

[5] http://www.python.org

3. Run `make`. By default, the main components of Harpoon, all plugins, and some (presently undocumented) miscellaneous tools are built. If available, use GNU make, since some make programs do not properly handle some of the constructs in Harpoon's makefiles.
4. (optional) `make selfconf`. Build the self configuration tool `harpoon_flowproc`.
5. (optional) `make doc`. You'll need the GNU texinfo tools and/or doxygen for this to work.
6. (optional) `make install`. Move the appropriate components to the installation target directory. By default, the install directory is `/usr/local/harpoon`.

Harpoon is known to build and run on FreeBSD 5.1-5.4, Linux 2.2-2.6, MacOS X 10.2-10.4, and Solaris 8-10. Harpoon does not build on Windows, though there is an intent to eventually make that possible.

If `configure` does not find certain required libraries, you might try the following syntax:

```
$ CPPFLAGS=-I/path-to-include-files LDFLAGS=-L/path-to-libs \
    ./configure
```

This syntax generally works to force `configure` to look in the right directories.

By default, harpoon is built with optimization level '`-O2`' and with debugging symbols '`-g`'. An easy way to change this is to use the above syntax recipe:

```
$ CXXFLAGS="-g" ./configure
```

The above example will build Harpoon with debugging symbols but no optimization. Building Harpoon without debugging symbols and a desired level of optimization can be accomplished in a similar way.

Finally, you'll very likely have to set `LD_LIBRARY_PATH` (Linux, FreeBSD and Solaris) or `DYLD_LIBRARY_PATH` (MacOS X) to the directory where plugin objects are installed. See Section 4.1.4 [Environment Variables], page 25 for further information.

2 Basic Configuration

This chapter discusses simple configurations of Harpoon using the supplied example config files (in the 'examples' subdirectory of the software distribution). Simple changes to the config files to accomodate local addressing and traffic volume requirements are also discussed. The next chapter discusses more complicated configurations of Harpoon using your own flow records. It is assumed here that you have successfully built Harpoon (See Section 1.2.1 [Building the Harpoon Software], page 5).

Example configurations are found in the 'examples' subdirectory. There are two TCP traffic configuration examples provided:

'tcp_client.xml' and 'tcp_server.xml'
: A very simple setup for illustrative purposes only.

'tcp_client_ex2.xml' and 'tcp_server_ex2.xml'
: A TCP client/server pair with inter-connection times generated from exponential distribution with mean 1 second and file sizes generated from Pareto distribution with alpha=1.2 shape=1500 (bytes).

2.1 Validating a Configuration

The first step toward running harpoon should be to make sure configuration files you intend to use are properly formed. A tool, config_validator exists for this purpose. The tool takes only one argument, the configuration file. Shown below is output of config_validator run on 'tcp_client_ex2.xml' and 'tcp_server_ex2.xml'.

```
$ ./config_validator ../examples/tcp_client_ex2.xml
loading ../examples/tcp_client_ex2.xml
bad address - no prefix len?
Checking load of TcpClient
name: TcpClient
objfile: tcp_plugin.dylib
maxthreads: 10
personality: client
client source pool:
address list:
        0.0.0.0 - 0.0.0.0 :0 (1)
client destination pool:
address list:
        127.0.0.1 - 127.0.0.1 :10000 (1)

dumping distributions (first 10):
active_sessions: 10
interconnection_times: 3.99391 0.293601 2.12709 1.21451 0.409159 0.1121
0.580837 0.101379 0.724933 0.224031
```

There are a number of items to note here:

- First, each plugin configuration has a name. The name of this plugin is TcpClient. The name must be unique for all plugins loaded and running in the same Harpoon process. (Note that you can have multiple configurations of TCP plugins running as both clients and servers within a single process, but they must each have different names.)
- The shared object file loaded for this plugin is '`tcp_plugin.dylib`'. The operating system loader finds this file by searching the directories specified by `LD_LIBRARY_PATH` environment variable. See Section 4.1.4 [Environment Variables], page 25 for more information.
- In Harpoon, sessions are mapped in a 1-1 fashion onto threads. The `maxthreads` plugin attribute specifies the maximum number of operating system threads to start in the plugin. To generate a specific level of traffic, a certain number of threads/sessions are made active over successive intervals of time. This number of active sessions is specified by the `active_sessions` distribution. Note that a specified number of active sessions can be greater than the value given for `maxthreads`. In this case, the `maxthreads` parameter acts as a limit; the actual number of active sessions is $min(\texttt{maxthreads}, ActiveSessions_i)$, where $ActiveSessions_i$ is the number of active sessions for interval i. See [distributional parameters], page 4 to review the role of sessions in Harpoon.
- `personality` specifies whether this plugin is acting in a server-side or client-side role.
- `client source pool` and `client destination pool` denote address pools used by this plugin. Since this is a client-side plugin, the `client source pool` is used to bind the local-side of TCP connections to a specific local address. In this example, the local address is `0.0.0.0`, meaning that the operating system will fill in a default local address. The `client destination pool` addresses specify remote addresses and ports where Harpoon TCP servers are listening.
- Finally, 10 random values from the distributions used by the particular endpoint (client or server) are printed. For TCP clients, there are two relevant distributions: `active_sessions` and `interconnection_times`. For TCP servers (example shown below), there are two relevant distributions: `active_sessions` and `file_sizes`.

Validation of the server-side configuration file is now shown below:

```
$ ./config_validator ../examples/tcp_server_ex2.xml
loading ../examples/tcp_server_ex2.xml
bad address - no prefix len?
Checking load of TcpServer
name: TcpServer
objfile: tcp_plugin.dylib
maxthreads: 37
personality: server
server address pool:
address list:
        0.0.0.0 - 0.0.0.0 :10000 (1)
```

```
dumping distributions (first 10):
active_sessions: 37
file_sizes: 18643900 15150 807481 157679 23465 4930 39188 4418 56341 10863
```

Now that the client-side configuration file has been validated and explained, there is little new to describe. Note that the name of the plugin has changed to `TcpServer` and the personality is `server`, but the plugin shared object file is still `tcp_plugin.dylib`. For servers, the `maxthreads` and `active_sessions` parameters specify the number of active threads waiting to service file requests. These numbers can be set to the same single value in most cases. (The problem of how many threads/sessions to keep active is similar to the problem of configuring a web server. Unlike modern web servers, Harpoon does not allocate server threads in a dynamic way, so this number must be statically set in the configuration files to a reasonable value.) Finally, note that the server address is set to a default address (`0.0.0.0`) and the port is set to 10000.

2.2 Modifying Configuration File Addresses

For the client-side configuration file shown above, the destination address pool is set to a single address of `127.0.0.1` – the loopback interface. This isn't particularly helpful, since we would like to generate traffic over a network, not just through some operating system layers. This address pool is easily changed.

Using your favorite text editor, open the file '`tcp_client_ex2.xml`'. Toward the end of the file the following lines are found:

```
...
<address_pool name="client_source_pool">
     <address ipv4="0.0.0.0" port="0" />
</address_pool>

<address_pool name="client_destination_pool">
     <address ipv4="127.0.0.1/32" port="10000" />
</address_pool>
...
```

To change the server address (`client_destination_pool`), change the address block `127.0.0.1/32` to be the desired address. For host prefixes (/32 masks) the mask is optional; specifying `127.0.0.1` has the same effect as specifying `127.0.0.1/32`. (`config_validator` warns about this lack of prefix, however. See the above examples for the warning: "bad address - no prefix len?".)

If there are two servers running on separate machines and without contiguous addresses, simply add another `<address ... />` line with the second address.

Note that for servers, the address pool definition follows the same structure, but there is a current limitation in that only one address is used for binding. That is, specifying two addresses for a server to listen on will not have the desired effect; only one address will be used. For now, using the default address specifier, `0.0.0.0`, is the best option.

2.3 Starting Harpoon

We now have two configuration files with addresses set appropriately. The examples below show how to start harpoon with these configuration files. We assume here that the environment variable `LD_LIBRARY_PATH` has been set properly (see Section 4.1.4 [Environment Variables], page 25). Alternatively, a shell script `run_harpoon.sh` is installed when `make install` is run that sets the environment variable to the correct directory and then executes `harpoon`. The examples below use this script, which has been installed in the default location of '`/usr/local/harpoon`'.

On the server machine:

```
$ /usr/local/harpoon/run_harpoon.sh -v10 -w300 -c \
  -f examples/tcp_server.xml
...
10:02:16 sev(07) stopping plugin TcpServer
10:02:16 sev(00) TcpServer: plugin stopped - threads killed and reaped
10:02:16 sev(07) starting plugin TcpServer
10:02:16 sev(02) TcpServer: no plugin state existed on start - created
10:02:16 sev(01) TcpServer: started plugin with 1 threads.
10:02:16 sev(01) <stopping plugins: TcpServer:ok ><starting plugins: \
  TcpServer:ok >
10:02:16 sev(09) harpoon started. verbosity<10>warp_factor<60> \
  autoincr?<1>continuousrun?<1>
10:02:16 sev(05) 00:00 - emulation time tick
...
```

And on the client machine:

```
$/usr/local/harpoon/run_harpoon.sh -v10 -w300 -f examples/tcp_client.xml
...
10:02:40 sev(07) stopping plugin TcpClient
10:02:40 sev(00) TcpClient: plugin stopped - threads killed and reaped
10:02:40 sev(07) starting plugin TcpClient
10:02:40 sev(02) TcpClient: no plugin state existed on start - created
10:02:40 sev(01) TcpClient: started plugin with 1 threads.
10:02:40 sev(01) <stopping plugins: TcpClient:ok ><starting plugins: \
  TcpClient:ok >
10:02:40 sev(09) harpoon started. verbosity<10>warp_factor<300>\
  autoincr?<1>continuousrun?<0>
10:02:40 sev(05) 00:00 - emulation time tick
...
```

The command-line options used above require explanation:

'`-v10`'
: Turn on verbose messages. You should use this setting (level 10) of verbosity, especially when first getting started with Harpoon.

'`-w300`'
: Set interval duration length to 300 seconds (also referred to as "warp factor"). Given a specification of `<active_sessions>` in a configuration file, Harpoon will iterate through this list, setting

the number of active sessions to each value for durations of 300 seconds. If the original intervals were one hour in length (*i.e.*, the average number of sessions was calculated over successive intervals of one hour) and the '-w' flag is set to 600 seconds, a 24 hour period could be emulated in 14,400 seconds (four hours). It should be clear from this explanation where the term "warp factor" comes from.

'-f [examples/tcp_client.xml, examples/tcp_server.xml]'
: Specify the configuration file to load. Multiple '-f' flags may be used to tell Harpoon to load more than one configuration file.

'-c'
: While the first three options were used for each side (client and server) of Harpoon, the '-c' parameter is only used for the server-side. This option tells Harpoon to continuously cycle over its list of active sessions, specified in <active_sessions>. Normally, Harpoon will iterate only **once** through this list, then cease activity. For experiments of fixed duration, this is often the desired behavior. However, for servers this behavior is generally to be avoided. The reason is that servers (at least for the plugins provided with the Harpoon software distribution) do not produce traffic without some request or provocation from clients. It is therefore much easier to simply leave servers running, cycling over a list of active sessions (typically set to a single value anyway), much like a continuously running web server.

More information on command-line parameters is given in [harpoon command-line parameters], page 24.

Now that the client and server are started, we can get information from these processes via XML-RPC. Using the `stats.py` script in the 'cli' subdirectory (and a Python interpreter of version 2.2 or greater):

```
$ python ./stats.py -u http://servermachine:8180/ \
  -u http://clientmachine:8180/
stats for  <ServerProxy for servermachine:8180/>
server-wide information:
        emulation_interval   1
----
plugin-specific information:

        TcpServer is running - up for  81  seconds
                target threads = 1  active threads = 1
                num_transfer = 36
                send_bandwidth_total_bps = 35555.6
                send_bandwidth_recent_bps = 35555.6
                bytes_sent_total = 360000.0
                bytes_sent_recent = 360000.0
                personality = server
stats for  <ServerProxy for clientmachine:8180/>

server-wide information:
```

```
        emulation_interval   0
----
plugin-specific information:

        TcpClient is running - up for  21  seconds
                target threads = 1  active threads = 1
                num_requests = 10
                personality = client
```

Note that the statistics gathered using the `stats.py` tool are approximate and only reflect an application point of view. You should not use them in any "real" measurements (like for paper submissions!). They are there to simply help with diagnosing and monitoring currently running Harpoon processes. Other XML-RPC tools are provided in the '`cli`' subdirectory. More information on them is provided in Chapter 5 [Managing Harpoon], page 29.

2.4 Modifying a Configuration to Produce Different Traffic Volumes

A common requirement is for harpoon to generate a specific average load. A tool, `harpoon_reconf.py` is provided to assist in determining the appropriate number of sessions to configure at a client to produce the desired level of traffic.

If we wish to set the number of sessions so that the traffic rate (bandwidth) produced by Harpoon is 5 Mbps averaged over a 10 minute interval, we can use the `harpoon_reconf.py` tool as follows (from the top-level Harpoon source directory):

```
$ python selfconf/harpoon_reconf.py -d -c examples/tcp_client_ex2.xml
  -s examples/tcp_server_ex2.xml -i 600 -r 5000000
...
targetbytes 375000000.0 simbytes 378522468 median 4 mean 3 \
  stdev 0.771722460186 max 5 flows 4085
number of sessions should be 3 to achieve volume of  375000000 bytes \
  (5000000.0 bits/sec)
$
```

The tool reports that the number of active sessions should be set to 3 (the mean).

The options used for `harpoon_reconf.py` are as follows:

'`-d`' Turn on verbose (debugging) information.

'`-c examples/tcp_client_ex2.xml`'
: Specify the client-side configuration file. This is a required parameter.

'`-s examples/tcp_server_ex2.xml`'
: Specify the server-side configuration file. This is a required parameter.

'-i 600' Specify the interval duration. The value used for this parameter should be the same as the '-w' parameter passed to `harpoon`. See [harpoon command-line parameters], page 24 and Section 2.3 [Starting Harpoon], page 10 for more information. This is a required parameter.

'-r 5000000'
Specify the target traffic rate, in bits per second. Alternatively, you may use the '-b' parameter to specify the total volume (in bytes) that should be generated over the specified interval duration (given by '-i'). One of '-r' or '-b' is required.

Note that the '-d' flag was used, producing verbose output. The target byte volume to produce over the requested interval of 600 seconds is 375000000 ($5000000/8 \times 600 = 375000000$). The mean and standard deviation of the sessions needed to produce 5 Mbps are 3 and 0.772, respectively. The output value `simbytes` is the average amount of traffic (in bytes) estimated to be produced for three sessions. This value will always be greater than the target (but generally not too much), since the self configuration tools aim to produce at least as much traffic as was originally sent.

After restarting the server and client, we use `stats.py` one minute later to check the server status and see that Harpoon is producing roughly 5Mbps. This tool takes only one option, '-u', to specify the URL of the harpoon XML-RPC listener. By default, port 8180 is used.

```
$ python cli/stats.py -u http://servermachine:8180/
...
        TcpServer is running - up for  60  seconds
                target threads = 3  active threads = 3
                num_transfer = 397
                send_bandwidth_total_bps = 4334040.0
                send_bandwidth_recent_bps = 6360550.0
                bytes_sent_total = 32505300.0
                bytes_sent_recent = 13516200.0
                personality = server
...
```

Near the end of the test, we run `stats.py` again to check progress:

```
$ python cli/stats.py -u http://servermachine:8180/
...
        TcpServer is running - up for  557  seconds
                target threads = 3  active threads = 3
                num_transfer = 4217
                send_bandwidth_total_bps = 6247000.0
                send_bandwidth_recent_bps = 5237350.0
                bytes_sent_total = 434947000.0
                bytes_sent_recent = 75286800.0
                personality = server
...
```

We see that Harpoon is making a pretty good match to 5 Mbps and is quite close to the average `match_rate` calculated above.

Recall that the matching is done based on some interval of time (see [Harpoon's flow-based two level hierarchical traffic model]). Note also that this matching is approximate, and depends on many factors. The nature of the underlying distributions (file sizes and interconnection times) have a great impact on the goodness of the match, but selection of the interval duration also has a significant effect. Generally, longer intervals (*i.e.* five or ten minutes) are best. Very often the match between what you expect and what you get is quite good, but it can be "less good" if you pick a short interval and have distributions with extreme variability.

3 Advanced Configuration

In the previous chapter, basic configuration of Harpoon was discussed, including configuration file validation, setting desired endpoint addresses, and tuning Harpoon to produce the desired traffic volume. This chapter fills in gaps from the previous chapter by discussing, in more detail, the structure of Harpoon configuration files (using the TCP traffic generator plugins as the basis for discussion), and the use of the self-configuration tools.

Harpoon uses XML documents for its config files. As described in [validation of config files], page 26, an XML schema is distributed with Harpoon that defines the structure of config files for the supplied TCP traffic plugin. Tools are provided to automatically generate configuration files from raw flow records. There is also a tool, `config_validator`, which is a simple validator of config files. The validator can't catch all logical errors, but it will catch all syntactical errors.

While the self-configuration tool `harpoon_conf.py` can generate valid config files for Harpoon, it is often useful to manually tweak the files produced by this script depending on testbed requirements. For this reason, description of how to use the self-configuration tools is followed by a discussion of the detailed structure of configuration files.

3.1 Self-Configuration Tools

For self-configuration, there are two required steps, and one optional step.

1. Process flow records using the `harpoon_flowproc` tool. The flow records can be in Netflow version 5 wire format or in `flow-tools` format. The output of this step is an intermediate flow representation.
2. Process the intermediate format produced in the previous step using the `harpoon_conf.py` tool to produce Harpoon config files.
3. Optionally, the configuration files produced in step 2 can be processed to produce a bit rate different from the original flow trace. The `harpoon_reconf.py` tool takes two Harpoon configuration files as input to perform this task.

3.2 The `harpoon_flowproc` tool

The `harpoon_flowproc` tool takes raw flow records in either Netflow version 5 wire format, or in `flow-tools` format. If your system does not have `flow-tools` installed, you'll only be able to use the raw Netflow capability. The tool takes the flow records as standard input and produces an intermediate format on standard output. This intermediate format is used by the tool `harpoon_conf.py` (see Section 3.3 [advanced harpoon_conf.py], page 16, below) to produce configuration files for Harpoon.

By default, `harpoon_flowproc` uses an *IntervalDuration* value of 60 seconds, expects TCP flags in the flow records, and expects the input format to be `flow-tools`. See Section 4.3.1 [running harpoon_flowproc], page 26 for more information on command line options. The example below shows an hour's worth of flow records being piped into `harpoon_flowproc`, with the output written to '`flowproc.out`'. It shows that there were over 4 million flows over that hour, with about 1.8 million TCP flows. However, only 1.2 million TCP flows had SYN and FIN or RST flags (i.e., were "well-formed"). Finally, flow surgery did not have to be performed on any of the flows. (Note that it isn't abnormal that surgery is minimal or not required, at least on flow record traces I've looked at.)

```
$ flow-cat ft-v05.2002-07-31.13* | ./harpoon_flowproc -i 60 > flowproc.out
sorting tcp flow records...  took 25 sec.
total flows: 4071060
total TCP flows: 1867860
total well-formed TCP flows: 1216691
surgery performed: 0
$
```

3.3 The `harpoon_conf.py` tool

The Python script `harpoon_conf.py` uses the output from the tool `harpoon_conf` to produce configuration files for Harpoon. In the example below, an interval duration of 600 seconds is specified ('`-i`' 600), source and destination address pools are specified ('`-S`' and '`-D`' options), and output config files have a prefix of "testoutput". See Section 4.3.2 [running harpoon_conf.py], page 27 for more information on command line parameters.

```
$ ./harpoon_conf.py -i 600 -S '10.54.1.0/24' -D '10.54.42.1/32' \
  -p testoutput flowproc.out
got starting time from file header:  1028138318.2
progress (10k lines):  . . . . . . . . . .   100000
. . . . . . . . . . .   200000
. . . . done ( 232645 lines)
$
```

The configuration files resulting from this script may still need to be tweaked. In particular, the number of active sessions set in the client configuration file may exceed the maximum number of threads per process on the operating system where Harpoon will be run. Either that, or you may wish to set up a multi-host configuration, splitting the load generation over some number of machines. For these situations, you will have to manually edit the configuration files, changing the number of active sessions to an appropriate value, and setting client source and destination addresses to appropriate values.

3.4 The `harpoon_reconf.py` tool

The `harpoon_reconf.py` is used to tune existing client and server configuration files to produce a specified bit rate. The configuration files that this script uses can be produced by the `harpoon_conf.py` tool or can be made using configuration files based on distributions from known distributions. In the example below, the target rate is specified as 5 Mbps and the script reports that 314 sessions should be configured to produce this volume. The script itself does not modify the configuration files, so this value must be set in the client configuration file. See also Section 2.4 [Modifying a Configuration to Produce Different Traffic Volumes], page 12, and Section 4.3.3 [running harpoon_reconf.py], page 28.

```
$ ./harpoon_reconf.py -d -c testoutput_tcpclient.xml \
  -s testoutput_tcpserver.xml -i 300 -r 5000000
target volume:  187500000.0
interval duration:  300
client conf file:  testoutput_tcpclient.xml
server conf file:  testoutput_tcpserver.xml
target: 187500000.0 carry: 0
targetbytes 187500000.0 simbytes 187720505 median 320 mean 314 \
  stdev 55.02035895 max 415 flows 16174
number of sessions should be 314 to achieve volume of  187500000 bytes \
  (5000000.0 bits/sec)
$
```

3.5 Configuration File Structure

The best way to describe the structure of Harpoon config files is through an example:

```
<?xml version="1.0"?>
<harpoon_plugins>
        <plugin name="Example" objfile="example.so"
                maxthreads="42", personality="server">

             ...

        </plugin>
</harpoon_plugins>
```

The top-level tag in any config file must be `<harpoon_plugins>`. Within that element, any number of traffic generation `<plugin>`s may be defined. Every Harpoon configuration file **must** be structured this way - the XML parser that Harpoon uses (`expat` — `http://expat.sourceforge.net/`) enforces this requirement.

3.5.1 <plugin> Definitions

For the `<plugin>` element, there are three require attributes, and one optional attribute:

name An identifier for this plugin. It must be unique for all incarnations of a traffic generator module running under the control of a single `harpoon` executable. That is, you must have separate `<plugin>` tags defined for client and server portions of the same traffic generator if they are running in the same `harpoon` process. For example, for the client-side of a TCP plugin you might use the name “TCPClient” and for the server-side you might use “TCPServer”.

objfile The object file into which traffic generation code is compiled. For most UNIX-like operating systems, this file will end in the extension `.so`. For MacOS X, this extension is normally `.dylib`.

maxthreads
An integer defining the maximum number of threads to create for this plugin. One thread represents one Harpoon session. Note that different operating systems impose limits on the maximum number of threads per process. Harpoon will happily attempt to create one million threads if you ask it to — it is up to you to make sure this number makes sense. If Harpoon is unable to create the number of threads you ask for it will croak, leaving both you and the formerly running `harpoon` quite miserable.

personality
This attribute should contain the value ‘`server`’ or ‘`client`’. Harpoon is organized as a client-server application. This attribute specifies how the traffic generator named in the configuration file should behave, either as a client or as a server. More specifically, each plugin module has two code entrypoints: `server_session` and `client_session`. The entrypoint taken depends on this attribute. See Appendix C [Creating New Traffic Generation Modules], page 43 for more details.

3.5.2 Configuring Distributions

Within a `<plugin>` element, you define the distribution data used by the plugin. Depending on the “personality” of the plugin and on the particular traffic generator, different distributions may be required. For example, for the TCP client, file sizes are irrelevant since it is the server that generates files. Note that the `config_validator` tool does not assume that *all* distributions are required and checks only for the existence of distributions that make sense based on the configured personality.

As described in Chapter 1 [Overview of Harpoon], page 1 and summarized in [distributional parameters], page 4, there are five distributions comprising Harpoon’s architectural model for TCP flows. Configuration of three of those parameters is described here. Addressing is described in the following section.

Each of the parameters $P_{FileSize}$, $P_{InterConnection}$, $P_{ActiveSessions}$, $P_{IPRange_{src}}$, and $P_{IPRange_{dest}}$ are configured using XML tags `<file_sizes>`, `<interconnection_times>`, `<active_sessions>`, and `<address_pool>`, respectively, also shown in the example below. Whitespace-separated values for each distribution should be written between start and end tags for the respective element. There is no required order among these tags. For the TCP plugin, servers expect `<file_sizes>` and `<active_sessions>`. File sizes values are given in bytes. Clients expect <interconnection_times> and <active_sessions>. Interconnection times are given in (floating point) seconds. Both endpoints require <address_pool> tags, as described below.

The <active_sessions> tag identifies the number of Harpoon sessions (threads) that should be active for a given interval. By default, this interval is assumed to be an 60 seconds, though it need not be so. By adjusting the "warp factor" ('-w' option, [harpoon command-line parameters], page 24) on the **harpoon** command-line, any mapping between emulation time and wall-clock time may be made. The Harpoon plugin controller will adjust the number of active threads per interval according to the distribution given in <active_sessions>. By default, Harpoon will iterate **once** through the list of <active_sessions>, then plugin activity will cease (*i.e.*, number of active sessions will be set to 0). For clients, this is often the desired behavior. For servers, however, this is very often not desirable. The '-c' flag can be given to Harpoon so that it cycles continuously over its list of <active_sessions>.

The `maxthreads` attribute described above serves as a cap to the number of threads to be created for a plugin. If values given for <active_sessions> exceeds maxthreads, no threads beyond **maxthreads** will be created. For the client-side, the relationship between the values given for <active_sessions> and load generated by Harpoon should be straightforward. For servers, it is often best to simply supply one value (which should usually be the same as the value given for `maxthreads`) so that enough server handlers are running at all times. Choosing this value is akin to provisioning a web server, and the default values set by the Harpoon configuration tools may or may not need tuning in different environments.

The next two examples show how the three distributions described above appear in configuration files. For these examples, the plugin headers (attributes) are not specified, only the applicable distributions.

For a TCP server, only the <active_sessions> and <file_sizes> elements are required:

```
<plugin ... >
        <!-- for a TCP server configuration -->
        <active_sessions>
             47
        </active_sessions>

        <file_sizes>
             200 42000 300 1200 5400 ...
        </file_sizes>

        ...
</plugin>
```

For a TCP client, only the <active_sessions> and <interconnection_times> elements are required:

```
<plugin ... >
        <!-- for a TCP client configuration -->
```

```
            <active_sessions>
                 50 58 60 61 70 75 ...
            </active_sessions>

            <interconnection_times>
                 1.2 0.3 4.95 1.5 0.1 0.9  ...
            </interconnection_times>

            ...
    </plugin>
```

3.5.3 Configuring Addresses

This section introduces the XML tags for configuring client source and destinations addresses, and server addresses. The basic ideas are:

- when clients make requests to servers, they bind to local *source addresses* and ports, and connect to remote *destination addresses* and ports;
- servers bind to a server address and port, waiting for client requests; client source addresses can be specified, or can be set to allow the operating system to assign a default local address (the same goes for servers).

All addresses (client source addresses, client destination addresses, and server addresses) are defined using the XML tag <address_pool>, but with different values for the required attribute `name`. Within each address pool, there may be any number of <address> elements. Each <address> element must contain exactly two attributes: `ipv4` and `port`. The address element must be in a CIDR-style format[1]. The port value of 0 is a special value which indicates that the operating system should automatically choose a local ephemeral port for the connection. Likewise, the address "0.0.0.0" means that the client should bind to the default local address, and the server should bind to "*". For server addresses, only one address and port should be defined: multihoming in this way is not implemented yet.

Note that these addresses say nothing about protocol. Protocol-specific items are defined within plugin code.

The address attribute name "ipv4" suggests that other kinds of addresses are possible. At present, only IPv4 addresses are supported but it is conceivable that IPv6 will be supported in the future. Using any attribute for an address except "ipv4" will generate a configuration file parse error.

Continuing with the examples from above, the server address pool might defined as:

```
    <plugin ... >
            <!-- for a TCP server configuration -->
            <active_sessions>
```

[1] A current limitation with this scheme is that all four bytes of an IPv4 address must be given even for short prefixes. Instead of writing `10.5/16`, you should write `10.5.0.0/16`.

```
                47
           </active_sessions>

           <file_sizes>
                200 42000 300 1200 5400 ...
           </file_sizes>

           <address_pool name="server_address">
                   <address ipv4='0.0.0.0' port='10000'/>
           </address_pool>
   </plugin>
```

In this case, the server binds to “*.10000”. That is, port 10000 for any local address on the server. For the client configuration, we define a source address pool of 64 address (actually, 62 usable addresses, not including the host and broadcast addresses) and for destination addresses we define two separate class C networks (254 usable addresses):

```
   <plugin ... >
           <!-- for a TCP client configuration -->
           <active_sessions>
                50 58 60 61 70 75 ...
           </active_sessions>

           <interconnection_times>
                1.2 0.3 4.95 1.5 0.1 0.9  ...
           </interconnection_times>

           <address_pool name="client_source_addresses">
                   <address ipv4='192.168.1.0/26' port='0' />
           </address_pool>

           <address_pool name="client_destination_addresses">
                   <address ipv4='192.168.47.0/24' port='10000'/>
                   <address ipv4='192.168.46.0/24' port='9900'/>
                   ...
           </address_pool>
   </plugin>
```

3.5.4 Putting It All Together

To wrap up the examples in this section, we fill in the main plugin attributes to complete the configuration files. For the server:

```
   <plugin name="ServerExample" objfile="tcp_plugin.so"
           maxthreads="47", personality="server">

           <!-- for a TCP server configuration -->

           <active_sessions>
                47
           </active_sessions>

           <file_sizes>
```

```
          200 42000 300 1200 5400 ...
     </file_sizes>

     <address_pool name="server_address">
             <address ipv4='0.0.0.0' port='10000'/>
     </address_pool>
</plugin>
```

And for the client:

```
<plugin name="ClientExample" objfile="tcp_plugin.so"
        maxthreads="75", personality="client">

        <!-- for a TCP client configuration -->

        <active_sessions>
             50 58 60 61 70 75 ...
        </active_sessions>

        <interconnection_times>
             1.2 0.3 4.95 1.5 0.1 0.9  ...
        </interconnection_times>

        <address_pool name="client_source_addresses">
                <address ipv4='192.168.1.0/26' port='0' />
        </address_pool>

        <address_pool name="client_destination_addresses">
                <address ipv4='192.168.47.0/24' port='10000'/>
                <address ipv4='192.168.46.0/24' port='9900'/>
                ...
        </address_pool>
</plugin>
```

3.5.5 Nesting Configuration Files

A feature of Harpoon configuration files is that one file may include another, allowing a user of Harpoon to nest configuration files and reuse identical distribution data in more than one plugin without duplicating the data itself.

Using the tag `<config_file>` as in the example below causes the named file to be substituted in place:

```
<plugin ... >
...
<config_file> file_sizes.xml </config_file>
...
</plugin>
```

Assume the file `file_sizes.xml` contains:

```
<file_sizes> 500 23423 837 7735 </file_sizes>
```

The resulting configuration would “behave” as if you had written:

```
<plugin ... >
...
<file_sizes> 500 23423 837 7735 </file_sizes>
```

```
    ...
    </plugin>
```

A very important thing to note is that each configuration file used by Harpoon (whether it is a “top-level” configuration file or one that is included by another) must be a well-formed XML document. One consequence is that files can contain only one top-level element. Essentially, this means that a file containing exactly the following:

```
<active_users> 55 67 79 80 100 140 142 130 110 </active_users>
<file_sizes> 500 23423 837 7735 </file_sizes>
```

is **illegal** — the XML parser that Harpoon uses will complain loudly. You must structure your config files to accomodate this restriction.

Another point to note (which will be described again below) is that while you may use file names that include full or relative paths, any relative paths will be relative to the working directory of the `harpoon` executable. Any plugin object files referenced in configuration files will also be referred to relative to the working directory of `harpoon`.

4 Running Harpoon

4.1 The harpoon executable

`harpoon` is the executable used to load modules for traffic generation. Traffic generation is not implemented directly in `harpoon`, it is rather a manager of traffic generation plugins. Using command line parameters and an external management interface (XML-RPC) you can load, unload, start, stop, and query traffic generation modules.

4.1.1 harpoon command-line parameters

Most configuration is done through the external management interface, but there are a few command line parameters for initial loading and configuration of `harpoon`. These parameters are:

'`-f filename`'
: With the '`-f`' switch you specify Harpoon config files to be initially loaded. You may specify multiple '`-f`' parameters in order to load more than one config file.

'`-l logfile`'
: The argument to the '`-l`' switch is a file name to which log messages will be appended. By default, log messages are written to `STDERR`.

'`-p port`'
: The '`-p`' flag sets the port that Harpoon's internal HTTP server listens on. By default, this port is 8180.

'`-s seed`'
: The '`-s`' option sets a specific seed for random number generation. If this option is not set, the random number generator is seeded using a combination of the current time and Harpoon's process ID.

'`-v verbiage_level`'
: The '`-v`' option sets the level of verbosity for log messages spewed by Harpoon. The argument to '`-v`' should be an integer from 0 to 10, with 0 meaning minimal log messages are emitted, and 10 meaning lots of program chatter is logged.

'`-w warp_factor`'
: With the '`-w`' switch, you may set the number of seconds that comprise an $IntervalDuration$. By default, this value is 60 seconds, so if the values given in $P_{ActiveUsers}$ represent the number of active users per hour, it will take 24 minutes to emulate a full day. See the full Harpoon paper for some of the issues in setting this parameter.

'`-c`'
: Use the '`-c`' flag to tell Harpoon to continuously cycle over its values of $P_{ActiveSessions}$. The default behavior is for Harpoon to

spend $InvalDuration$ time on each value of $P_{ActiveSessions}$, successively stepping through the series of number of active sessions and stopping after the final value. With the '`-c`' flag, Harpoon will cycle indefinitely over these $P_{ActiveUsers}$ values.

'`-a`' Use the '`-a`' switch to cause Harpoon to not automatically cycle through the values in $P_{ActiveUsers}$. Using this flag, it is possible to manually (through the XML-RPC interface) cycle through intervals. Harpoon will ignore the '`-w`' switch if '`-a`' is set.

'`-?`' This option dumps usage information on the above command-line parameters. Unrecognized options given to `harpoon` also have this effect.

In addition to `harpoon` command-line parameters described in [harpoon command-line parameters], page 24, two run-time features to be aware of are signal handlers implemented by Harpoon, and event logging capability of Harpoon.

4.1.2 Signals Handled by Harpoon

The following table describes signals handled by Harpoon. All other signals are blocked.

`SIGINT`
`SIGTERM` Sending an interrupt signal to Harpoon has the effect of shutting Harpoon down. First, all user-level threads running plugin code are shut down, then the HTTP/XML-RPC listener is stopped. Finally, Harpoon crumples in a heap.

`SIGUSR1` Sending the USR1 signal has the effect of shutting down all user-level plugin threads. All plugins are returned to the idle state. Harpoon itself continues to process remote-interface method calls.

`SIGUSR2` Sending the USR2 signal to Harpoon causes all plugins to be reset (analogous to the `resetAll()` XML-RPC method described below.) First, all plugin threads are stopped, second, the emulated hour is reset to 0, finally, plugin threads are restarted for all loaded plugins.

4.1.3 Harpoon Event Logging

Logging capability within Harpoon is currently quite limited. Using the '`-v`' option to the `harpoon` executable causes different levels of log messages to be written or suppressed. All log messages are currently written to `STDERR` by default, unless an '`-l`' switch is given to `harpoon`.

4.1.4 Environment Variables

While there are no environment variables required specifically by Harpoon, many operating systems will require setting the variable `LD_LIBRARY_PATH` (or a similar variable, *e.g*, `DYLD_LIBRARY_PATH` on MacOS X) in order to make dynamic loading of plugins work properly. Before starting Harpoon, this variable should be set to include the directory where plugin modules are installed (often the same directory as Harpoon, but not necessarily.) You are advised to consult the relevant manual pages for reference (e.g., `ldconfig` and `ld.so` for Linux, `ld` and `ld.so.1` for Solaris, and `dyld` for MacOS X.)

A script, `run_harpoon.sh`, is supplied with the software distribution to automatically set the above environment variable and then invoke the harpoon executable. If you perform a `make install` when building Harpoon, this script will get installed and have the correct paths. If you do not install Harpoon, the script won't work (because of default installation path settings). If you want to use the script, simply edit it to suit your needs.

4.2 Validating a configuration file with `config_validator`

`config_validator` takes only one argument, the config file to be checked. It parses the given config file and prints diagnostics on what was parsed. Examples of config file validation are given in see Section A.2 [Validation of Configuration Files], page 34. The `config_validator` uses the same code internally as Harpoon (and can be quite picky!) so it really is a good idea to validate your config files using this tool.

Another way to validate your config files is to use a general-purpose XML schema validation tool. One such tool on the Web is at `http://apps.gotdotnet.com/xmltools/xsdvalidator/Default.aspx`. The file `harpoon_plugins.xsd` (see [XML Configuration Schema], page 39), in the documentation directory of the Harpoon distribution, is an XML schema defining the structure of Harpoon configuration files for the TCP plugin. (Note that this file *only* defines the structure for TCP plugins, therefore its use is limited. It is kept with the software distribution mainly for historical reasons.) For reference on XML schemas, see `http://www.w3.org/XML/Schema`. Note that schemas serve a similar purpose as SGML DTDs, but are written entirely in XML.

4.3 Self-configuration Tools

This section describes the command-line options for the three self-configuration tools, `harpoon_flowproc`, `harpoon_conf.py`, and `harpoon_reconf.py`.

4.3.1 `harpoon_flowproc`

The flow record processor tool takes the flow records as standard input and produces a reformatted series of records (in ASCII) on standard output. There are a number of limitations to this program, making it unsuitable for very large flow record traces.

'-i' One of the main tasks of `harpoon_flowproc` is to organize flow records into a series of "sessions", which are connections between the same IP host pair initiated within some duration of time. The '-i' option allows the user to specify this duration of time in seconds. By default, a value of 60 seconds is used. This value should also match the value used for the '-i' to the `harpoon_conf.py` script.

'-n' `harpoon_flowproc`, by default, expects to use `flow-tools` format flow records (unless the `flow-tools` library is not found). To use Netflow 5 wire format records, use the '-n' flag.

'-w' `harpoon_flowproc` performs "flow surgery" to coalesce flow records adjacent in time that are very likely referencing the same flow. By default, only records containing `SYN` and `FIN` or `RST` flags will be used ("well-formed" flows). To relax this requirement, use the '-w' flag. Using this option, no flow records will be ignored based on lack of TCP flags. Note that flow surgery will not be performed if there are no TCP flags present, regardless whether the '-w' option is set.

4.3.2 harpoon_conf.py

The `harpoon_conf.py` Python script takes the output of `harpoon_flowproc` and produces XML configuration files that can be used by Harpoon. While the configuration files may need some manual tweaking for a particular environment, they can often be used right away. `harpoon_conf.py` has one required argument, the file produced from running `harpoon_flowproc`. All options listed below are not required.

'-s' Specify the point in time (floating point seconds) after which items from the input file should be used. This is an absolute time (i.e., not relative to the beginning of the trace). You might use this flag if you want to restrict `harpoon_conf.py` to only process output records for a particular time interval.

'-e' Specify the point in time (floating point seconds) before which items from the input file should be used. This is an absolute time (i.e., not relative to the beginning of the trace). You'd probably use this flag in conjunction with '-e' to only process output records for a particular time interval.

'-i' Specify the value of *IntervalDuration* to use. By default, a value of 300 seconds is used. Generally, a longer value such as 300 or 600 seconds is best.

'-m' Specify the maximum number of lines to process from the input file. This option is probably less useful unless you're doing some debugging. Normally, using the '-s' and '-e' options are what you should really use if you want to only process records over a particular time interval.

'-p' Specify a string to use as a prefix for output files. If the string '`testprefix`' is used, for example, the XML configuration files '`testprefix_tcpclient.xml`' and '`testprefix_tcpserver.xml`' will be produced. The default prefix is `harpoonconf`.

'-d' Turn on some debugging chatter. Multiple '`-d`' options cause more chatter.

'-D' Specify a client destination address pool as a CIDR prefix. For example, `-D '192.168.1.0/24'`. The '`-D`' option may be specified multiple times.

'-S' Specify a client source address pool as a CIDR prefix. For example, `-S '192.168.2.0/24'`. The '`-D`' option may be specified multiple times. Note that the server address defaults to `0.0.0.0` with port 10000.

4.3.3 harpoon_reconf.py

The `harpoon_reconf.py` Python script reads existing client and server config files and retunes them to produce specific traffic volumes. Only bitrates can be specified at this time.

'-c' Use this option to specify the client config file. This is a required option.

'-s' Use this option to specify the server config file. This is a required option.

'-i' Specify the value of *IntervalDuration* with the '`-i`' option. Default value is 300 seconds.

'-r' Specify the target rate in bits per second using this option. This is a required option.

'-d' Turn on debugging chatter.

5 Managing harpoon

In addition to using XML for its config files, Harpoon includes a restricted HTTP daemon which understands POST commands for XML-RPC, and PUT commands for upload of configuration and plugin files. These interfaces can be used to remotely manage Harpoon daemons. This chapter describes a usage of a PHP script for web-based Harpoon management. We also give details on the XML-RPC / HTTP interfaces to Harpoon.

5.1 Web-based Management

A PHP (`http://www.php.net`) script (`manage_harpoon.php`) and some Javascript and CSS support files are included with Harpoon to facilitate large-scale management of Harpoon. This section describes usage and design of this feature.

Sorry - this script is not documented yet (and not fully tested anyway).

5.1.1 Using `manage_harpoon.php`

FIXME

5.1.2 Setting up Apache and PHP

FIXME

5.2 Lower-level Management Interfaces

A restricted HTTP server is embedded in Harpoon which allows remote management using XML-RPC. The HTTP PUT method is also understood, allowing upload of XML configuration files and plugin binaries to remote Harpoon daemons. This section describes these low-level details of managing Harpoon. Normally, you do not need to be concerned with these details unless the supplied web interface is insufficient for your needs.

5.2.1 Supported XML-RPC Methods

The following table lists all XML-RPC methods recognized by Harpoon. The `harpoon` executable listens to port 8180 by default for requests. This can be changed with the '`-p`' switch, described in See [harpoon command-line parameters], page 24. There are simple Python scripts supplied with the Harpoon distribution that demonstrate the basics of making management RPCs. For further reference, see `http://www.xmlrpc.org/` (there is a very useful tutorial available at this site) and the Python documentation, available at `http://www.python.org/`.

A restriction to be aware of with the XML-RPC interface of Harpoon is that it is **single-threaded**. That is, it can only handle one request at a time. This implementation has the side-effect that any call that blocks for some amount of time will prevent any subsequent calls from executing until the blocked call finishes. (The primary reason for implementing the listener as a single thread is to limit the number of threads used by `harpoon` itself, leaving as many resources available as possible for user-level traffic generation threads.)

Simple scripts using each of the interfaces described below are provided in the '`cli`' subdirectory. You may also wish to look briefly the [stats.py tool example], page 13 for a concrete reference using one of these interfaces.

`system.listMethods`
: List all methods recognized by the server. Other standard `system` interfaces, such as `system.methodSignature` and `system.methodHelp` are not (yet) available.

`system.null`
: Ping the server. Returns the string `null`. No parameters are expected.

`loadConfig`
: Load an XML configuration file. The file name is given as a parameter to this method. The file name may include a relative path from the working directory of `harpoon`. Note that any configuration files nested in the one currently being loaded (named by this method) must also be named with paths relative to the working directory of `harpoon`. A boolean value is returned indicating success or failure.

`unloadConfig`
: Unload a plugin configuration. The plugin name is supplied as a parameter to this method. Any plugin state is destroyed (a la unloadPlugin() — see below), and configuration data for the plugin is also destroyed. The plugin must be idle for this method to succeed. A boolean value is returned indicating success or failure.

`queryPlugins`
: Returns a list of structures describing all plugin configurations that have been loaded. No parameters are expected.

`unloadPlugin`
: Unload the shared object implementing a plugin, leaving the configuration in-tact. One parameter is expected, the name of the plugin. The plugin must have been previously stopped for this call to succeed. Returns a string indicating success or failure. This call can be useful to destroy any static state retained by the plugin across calls to `startPlugin` and `stopPlugin`. That is, any statistics held in static variables of the class implementing the plugin are wiped clean as a side-effect. A boolean value is returned to indicate success or failure.

`loadPlugin`
: One parameter is required, the plugin name. Load the shared object for the plugin named in the parameter. The plugin configuration must already have been loaded for this call to succeed. A boolean value is returned indicating success or failure.

`stopPlugin`
: One parameter is required, the plugin name. Stop all threads running for the named plugin. Returns a boolean indicating success or failure. Note that this call may take non-negligible time because of delay in gracefully stopping traffic generation threads. Be patient.

`startPlugin`
: One parameter is required, the plugin name. Starts user-level threads for the named plugin. If the shared object for the plugin has not already been loaded, this loading is done as a side-effect of this call. The plugin must be idle and/or unloaded for this call to succeed. A boolean value is returned indicating success or failure.

`getStats`
: No parameters are expected. Returns an array of structures indicating status and statistics of Harpoon and all loaded plugins.

`resetAll`
: No parameters are expected. Stops all running plugins, resets the emulated hour to 0 (zero) and restarts all plugins. A boolean value indicating success or failure is returned.

`suicide`
: No parameters are expected. Initiates a shutdown of all threads inside Harpoon, including Harpoon itself. A meaningless string is returned.

5.2.2 Uploading Files with HTTP `PUT`

In addition to processing XML-RPC methods using the HTTP POST command over port 8180, Harpoon also recognizes HTTP PUT commands. Using PUT can be useful in distributing configuration and plugin files across a number of Harpoon processes. No tools are distributed with Harpoon for distributing files. You are advised to use existing free tool such as `curl` or `wget` for this task. The destination file name is given as the URI, and may include a relative path. Any preceeding forward slashes are discarded.

Examples of uploading configuration files and plugins using `curl` are given below:

```
$ curl --upload-file dummy_plugin.xml \
  http://10.2.0.2:8180/dummy_plugin.xml
 % Total % Recvd % Xferd Average Speed          Time             Curr.
                          Dload  Upload Total    Current  Left     Speed
100 961  0    0  100  961     0    961   0:00:01  0:00:00  0:00:01   961
100 963  0    2  100  961     2    961   0:00:01  0:00:00  0:00:01     0
$
```

```
$ curl --upload-file dummy_plugin.so \
  http://10.2.0.2:8180/test/dummy_plugin.so
 % Total % Recvd % Xferd Average Speed            Time            Curr.
                           Dload  Upload Total    Current  Left    Speed
 54 37563 0  0   54 20480   0     20480 0:00:01   0:00:00  0:00:01 20480
100 37565 0  2  100 37563   2     37563 0:00:01   0:00:00  0:00:01 2780k
$
```

In the first example, an XML configuration file (`dummy_plugin.xml`) is written to the working directory of Harpoon. In the second example, a shared object plugin `dummy_plugin.so` is written to the `test` subdirectory under the working directory of `harpoon`.

Note that there are clear security consequences of the PUT command. At present there is **no** support for authentication or encryption of transactions using SSL. There is also at present no way disable the XML-RPC interface. These features may be added at a later date.

Appendix A More Examples

A.1 XML Configuration Files

The following examples show portions of the configurations 'tcp_client_ex2.xml' and 'tcp_server_ex2.xml' provided in the 'examples' subdirectory of the Harpoon software distribution. Not all distribution data is printed (noted by the ellipses in the examples).

First, the client configuration:

```
<harpoon_plugins>

  <plugin name="TcpClient" objfile="tcp_plugin.dylib"
          maxthreads="10" personality="client">

       <active_sessions> 10 </active_sessions>

       <interconnection_times>
       ...
       3.993905 0.293601 2.127093 0.174206 0.391431
       2.579116 0.273442 0.358623 0.173357 1.454077
       ...
       </interconnection_times>

       <address_pool name="client_source_pool">
            <address ipv4="10.54.40.2/32" port="0" />
       </address_pool>

       <address_pool name="client_destination_pool">
            <address ipv4="10.54.40.1/32" port="10000" />
       </address_pool>
  </plugin>
</harpoon_plugins>
```

Now, for the server configuration:

```
<harpoon_plugins>
  <plugin name="TcpServer" objfile="tcp_plugin.dylib"
          maxthreads="37" personality="server">

      <file_sizes>
      ...
      1034 9710 559390 52641 2122 2643 16167 22667 23660 20271790 14009
      ...
      </file_sizes>

      <active_sessions> 37 </active_sessions>

      <address_pool name="server_pool">
          <address ipv4="0.0.0.0" port="10000" />
      </address_pool>

  </plugin>
```

```
</harpoon_plugins>
```

If you wish to use these files to produce a specific traffic volume (bit rate), see Section 3.4 [[tuning traffic volume with harpoon_reconf.py]], page 16, Section 4.3.3 [[harpoon_reconf.py command-line parameters]], page 28, or Section 2.4 [[basic use of harpoon_reconf.py]], page 12. You may also wish to change the addresses to match your environment. See Section 2.2 [[modifying configuration file addresses]], page 9 or Section 3.5.3 [[address configuration]], page 20 for that information.

A.2 Validation of Configuration Files

We now validate the above configuration files and show the output of `config_validator` for each. (Note that there are slight local modifications to these config files so the output will not exactly match running `config_validator` on these same files in the Harpoon software distribution.)

```
$ config_validator tcp_client_ex2.xml
loading ../examples/tcp_client_ex2.xml
bad address - no prefix len?
Checking load of TcpClient
name: TcpClient
objfile: tcp_plugin.dylib
maxthreads: 50
personality: client
client source pool:
address list:
        10.54.0.22 - 10.54.0.22 :0 (1)
client destination pool:
address list:
        10.54.46.0 - 10.54.46.255 :10000 (256)

dumping distributions (first 10):
active_sessions: 12 27 40 41 36 48 50 50 49 25
interconnection_times: 3.99391 0.293601 2.12709 1.21451 0.409159 0.1121
    0.580837 0.101379 0.724933 0.224031
$
```

```
$ config_validator tcp_server_ex2.xml
loading ../examples/tcp_server_ex2.xml
bad address - no prefix len?
Checking load of TcpServer
name: TcpServer
objfile: tcp_plugin.dylib
maxthreads: 37
personality: server
server address pool:
address list:
        0.0.0.0 - 0.0.0.0 :10000 (1)

dumping distributions (first 10):
active_sessions: 37
file_sizes: 18643900 15150 807481 157679 23465 4930 39188 4418 56341 10863
```

A.3 Example Using Two Hosts, Unidirectional Traffic

For the above client and server configuration files, assuming that the client source and destination addresses are set up correctly, we're ready to start up Harpoon and generate traffic.

For the server, you should see something like this:

```
$ export LD_LIBRARY_PATH=\
      $LD_LIBRARY_PATH:/home/jsommers/harpoon/src/plugins
$ ./harpoon -f ../examples/tcp_server_ex2.xml -v10 -w300 -c
loading ../examples/tcp_server_ex2.xml... bad address - no prefix len?
 finished.
Checking load of TcpServer
name: TcpServer
objfile: tcp_plugin.so
maxthreads: 37
personality: server
server address pool:
address list:
        0.0.0.0 - 0.0.0.0 :10000 (1)

dumping distributions (first 10):
active_sessions: 37
file_sizes: 15150 807481 157679 23465 4930 39188 4418 56341 10863
11:06:04 sev(07) stopping plugin TcpServer
11:06:04 sev(00) TcpServer: plugin stopped - threads killed and reaped
11:06:04 sev(07) starting plugin TcpServer
11:06:04 sev(02) TcpServer: no plugin state existed on start - created
11:06:04 sev(01) TcpServer: started plugin with 37 threads.
11:06:04 sev(01) <stopping plugins: TcpServer:ok >\
   <starting plugins: TcpServer:ok >
11:06:04 sev(09) harpoon started.  verbosity<10>warp_factor<300>\
    autoincr?<1>continuousrun?<0>
11:06:04 sev(05) 000.00 - emulation time tick

...

⟨CTRL-c⟩
going down in a ball of flames...
$
```

Note that:

1. the variable `LD_LIBRARY_PATH` was set prior to starting Harpoon, and was specified using Bourne shell syntax;
2. the start up script was not used, so the above variable had to be set;
3. the '`-c`' flag was used so that Harpoon will continuously cycle over its list of active sessions—this is typically what is desired for a server;
4. the sixth log line (starting "`11:06:04 sev(01) <stopping plugins: TcpServer:ok >`" indicated that initial starting of the plugin was suc-

cessful (note that the plugin is first stopped and then started—this is normal);

5. each log line has the wall-clock time (hour:minute:second), a severity indication (ranging from 0, most important, to 10, debug jabber), Harpoon emulation time (epoch.fractional epoch), and the actual log message (note that the severity levels are currently rather inconsistent—sorry);
6. the process was stopped by hitting ⟨CTRL-c⟩.

The client side startup looks very similar, so it is not shown. Using either your own monitoring tools or the XML-RPC scripts (e.g., `stats.py`), you should be able to see evidence of traffic flowing.

A.4 Example Using Two Hosts, Bidirectional Traffic at Different Rates

Taking the previous example, we now want to do the following:

1. move the installation to two different hosts;
2. generate traffic in two directions;
3. set up traffic so 10 Mbps is generated in one direction and 20 Mbps is generated in the other direction.

Assume that host A has an IP address of `10.0.1.1`, and host B has an address of `10.0.1.2`. Assume also that we want the volume to be relatively steady over 300 second intervals. It's easiest if we work backwards based on the requirements above. First, we want to find out how many active sessions we need for generating 10Mbps, and how many sessions for 20 Mbps. To accomplish this, we need to use the `harpoon_reconf.py` script:

```
$ harpoon_reconf.py -c tcp_client_ex2.xml -s tcp_server_ex2.xml -i 300 \
   -r 10000000 -d
target volume:  375000000.0
interval duration:  300
client conf file:  ../examples/tcp_client_ex2.xml
server conf file:  ../examples/tcp_server_ex2.xml
target: 375000000.0 carry: 0
targetbytes 375000000.0 simbytes 407692953 median 7 mean 6 \
   stdev 1.50339682726 max 9 flows 3758
number of sessions should be 6 to achieve volume of  375000000 bytes \
   (10000000.0 bits/sec)
```

As arguments to `harpoon_reconf.py`, we supply the two existing configuration files ('`tcp_client_ex2.xml`' and '`tcp_server_ex2.xml`'), the interval duration (300 seconds), and the desired rate (10000000 bits per second). (We also supplied the '`-d`' flag to get a little more verbose output.) We see that there should be 6 sessions configured to produce 10 Mbps. In a similar way, we find that there should be 11 sessions configured to produce 20 Mbps.

Next, we need to create some new configuration files based on our existing files. Since the source and destination addresses for our clients are different, we need two separate client configuration files. We'll use default addresses for the server, so we only need one server config file for both machines.

The steps should be:

1. copy '`tcp_client_ex2.xml`' to '`clientA.xml`' and '`clientB.xml`';
2. edit '`clientA.xml`' to have source address of `10.0.1.1`, destination address of `10.0.1.2`, and number of active sessions as the single value 6 (also make sure that `maxthreads` attribute is set to at least 6);
3. edit '`clientB.xml`' to have source address of `10.0.1.2`, destination address of `10.0.1.1`, and number of active sessions as the single value 11 (also make sure that `maxthreads` attribute is set to at least 11);
4. move '`clientA.xml`' and a copy of '`tcp_server_ex2.xml`' to host A, and '`clientB.xml`' and a copy of '`tcp_server_ex2.xml`' to host B;
5. start up servers;
6. start up clients.

Once we start things up, we see that the 10 second averages over one 50 second period (in the 10Mbps direction) are: 15212977, 10309469, 9073456, 9846232, 14869665, which gives an average of about 11.8Mbps. Over a longer period, the average comes closer to 10Mbps, though generally will never be exactly 10Mbps. It should, however, be close over the range of an interval duration. Again, the quality of the match depends on a number of things, including the interval duration, the maximum inter-connection time (specified when using the self-configuration tools), and the nature of the inter-connection and file size distributions (heavy-tailed distributions need to be sampled over a long duration for the sample mean to come close to the distributional mean).

For the 20Mbps direction, we also take 10 second averages using SNMP. Over a 160 second duration, the samples are: 14028319, 23009625, 19027488, 20827397, 31798955, 32786164, 13115353, 15678779, 13945478, 11020225, 14158496, 10773346, 15449599, 18931181, 24803243, 26993437 which gives an average of 19.1Mbps—pretty close to 20Mbps, even over a shorter interval and the specified 300 seconds.

A.5 Example with Three Hosts

Finally, we want to do the following:

1. set up two client machines (A and B) to make requests to a single server;
2. generate 10 Mbps on reverse path to client A, and 5 Mbps on reverse path to client B;
3. set up two server processes to handle the load, so that one process serves client A, and the other process serves client B.

To our network of hosts A and B, we add a new machine, host C, with IP address `10.0.1.3`. We'll use host C as our server.

The easiest thing is to set up the server config files. Since we want to set up two processes to handle the server load, we'll need two configuration files:

1. copy the original server config file '`tcp_server_ex2.xml`' to '`serverA.xml`' and '`serverB.xml`';
2. edit '`serverA.xml`' to listen on port 10001 for client connections from host A (find the address pool toward the end of the file);
3. edit '`serverB.xml`' to listen on port 10002 for client connections from host B (find the address pool toward the end of the file);
4. move these two config files to host C.

The server processes can now be started. You may wish to start them in the background, writing to separate log files. The other item you should be aware of is that the XML-RPC ports should be set differently from the default, otherwise these servers will clash. Assuming we've already set `LD_LIBRARY_PATH`, the start up lines should be something like:

```
$ harpoon -f serverA.xml -p 8181 -l serverA.log -w300 -c -v10 &
$ harpoon -f serverB.xml -p 8182 -l serverB.log -w300 -c -v10 &
```

Now, we need to set up the client config files. Since we already set the client source address in the previous example (see see Section A.4 [Example Using Two Hosts], page 36), we just need to set the destination addresses and ports correctly, and set the number of active sessions to produce the desired volumes.

First, we need to find out how many sessions should be active to produce 5Mbps:

```
$ harpoon_reconf.py -c clientB.xml -s serverB.xml -i 300 -r 5000000 -d
target volume:  187500000.0
interval duration:  300
client conf file:  ../examples/tcp_client_ex2.xml
server conf file:  ../examples/tcp_server_ex2.xml
target: 187500000.0 carry: 0
targetbytes 187500000.0 simbytes 209525866 median 4 mean 3 \
   stdev 0.891882585016 max 5 flows 2050
number of sessions should be 3 to achieve volume of  187500000 bytes \
   (5000000.0 bits/sec)
```

`harpoon_reconf.py` shows that there should be three sessions active to produce 5Mbps.

Now, we can edit the client config files and start the clients up:

1. edit '`clientA.xml`' to have host C (`10.0.1.3`) as the destination address and 10001 for the destination port (note that we already have the number of active sessions set to produce 10Mbps);
2. edit '`clientB.xml`' to have host C (`10.0.1.3`) as the destination address and 10002 for the destination port;
3. also in '`clientB.xml`', set the number of active sessions to three.

Now, start up the clients:

```
hostA$ harpoon -f clientA.xml -w300 -v10
...
hostB$ harpoon -f clientB.xml -w300 -v10
```

After a while, we check the server A process to see how much traffic is being generated using the `stats.py` script:

```
$ stats.py -u http://hostC:8181/
stats for  <ServerProxy for hostC:8181/>
server-wide information:
        emulation_interval   0
----
plugin-specific information:

        TcpServer is running - up for  117  seconds
                target threads = 37  active threads = 37
                num_transfer = 639
                send_bandwidth_total_bps = 4588290.0
                send_bandwidth_recent_bps = 5593370.0
                bytes_sent_total = 67103700.0
                bytes_sent_recent = 53137000.0
                personality = server
```

We see that about 5Mbps is being generated, which is what we wanted.

Note that for all these examples, we have not specified any physical connections, any emulated round-trip times, routes, or the like. These configuration settings are outside the domain of Harpoon. You should set these parameters based on requirements for your tests. You should also be aware that changing these network parameters (as opposed to application layer parameters in Harpoon) can make very significant differences in the nature of the generated traffic. Refer to the Harpoon technical paper for examples of such differences.

Appendix B XML Configuration Schema

The schema defining TCP plugin configuration files is given below for reference. (This file lives in the documentation subdirectory of the Harpoon software distribution.) Someday maybe there will be a nice parser generator to justify this file's existence. (But then I'll have to fix the logical bugs in the file...)

```
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema">

<xsd:annotation>
   <xsd:documentation xml:lang="en">

   this is an xml schema for harpoon configuration files.
   copyright 2004 joel sommers.

   an xml schema is a way to define the structure of xml documents using
   xml itself.  note that dtd (document type definitions) have a similar
   function, yet are written using sgml rather than xml.  for more
   info, see: http://www.w3.org/TR/xmlschema-1/.  a useful validator
   on the web is at:
   http://apps.gotdotnet.com/xmltools/xsdvalidator/Default.aspx.

   <!--
        $Id: appendices.texi,v 1.12 2005/08/05 19:36:35 jsommers Exp $
     -->

   </xsd:documentation>
</xsd:annotation>


<xsd:element name="harpoon_plugins" type="pluginList" />

<xsd:complexType name="pluginList">
  <xsd:sequence>
    <xsd:element name="plugin"
                 minOccurs="1" maxOccurs="unbounded"
                 type="pluginSpecifier" />
  </xsd:sequence>
</xsd:complexType>


<xsd:complexType name="pluginSpecifier">
   <xsd:sequence>
      <xsd:element name="config_file" type="xsd:string"
                   minOccurs="0" maxOccurs="unbounded" />

      <!--
        NB: these element are only required for implementation of TCP
        sources, and there are different specific requirements at
        a server or client (which are not specified in this schema).
```

```
        also, there are different elements required for different
        sources.  refer to the manual...

        NB: also, defining the sub-elements of the plugin as a sequence
        is overly restrictive, since they must appear in the same order
        as below.  in the actual code, we don't make that restriction;
        elements can appear in any order.
        -->

      <xsd:element name="interconnection_times" type="float_list"
                   minOccurs="0" maxOccurs="unbounded" />

      <xsd:element name="active_sessions" type="int_list"
                   minOccurs="0"  maxOccurs="unbounded" />

      <xsd:element name="file_sizes" type="int_list"
                   minOccurs="0"  maxOccurs="unbounded" />

      <xsd:element name="address_pool" type="addressList"
                   minOccurs="0" maxOccurs="unbounded" />

    </xsd:sequence>

    <xsd:attribute name="name" type="xsd:string" use="required"/>
    <xsd:attribute name="objfile" type="xsd:string" use="required"/>
    <xsd:attribute name="maxthreads" type="xsd:int" use="required"/>
    <xsd:attribute name="personality" type="personalityType"
                   use="optional"/>

  </xsd:complexType>


  <xsd:simpleType name="int_list">
    <xsd:list itemType="xsd:unsignedLong"/>
  </xsd:simpleType>

  <xsd:simpleType name="float_list">
    <xsd:list itemType="xsd:float"/>
  </xsd:simpleType>

  <xsd:simpleType name="personalityType">
    <xsd:restriction base="xsd:string">
      <xsd:enumeration value="client"/>
      <xsd:enumeration value="server"/>
      <xsd:enumeration value="unknown"/>
    </xsd:restriction>
  </xsd:simpleType>

  <xsd:simpleType name="addressPoolType">
    <xsd:restriction base="xsd:string">
      <xsd:enumeration value="client_source_pool"/>
      <xsd:enumeration value="client_destination_pool"/>
```

```
    <xsd:enumeration value="server_pool"/>
  </xsd:restriction>
</xsd:simpleType>

<xsd:complexType name="addressList">
   <xsd:sequence>
      <xsd:element name="address"
                   minOccurs="1" maxOccurs="unbounded"
                   type="addressSpecifier"/>
   </xsd:sequence>
   <xsd:attribute name="name" type="addressPoolType" use="required"/>
</xsd:complexType>

<xsd:complexType name="addressSpecifier">
  <xsd:attribute name="ipv4" type="ipv4Type" use="required"/>

  <!-- NB: not restrictive enough -->
  <xsd:attribute name="port" type="xsd:nonNegativeInteger"
                 use="required"/>
</xsd:complexType>

<xsd:simpleType name="ipv4Type">
  <xsd:restriction base="xsd:string">
     <!-- NB: not completely accurate, but sufficient for now -->
     <xsd:pattern value="\d{1,3}(\.\d{1,3}){0,3}(\/(\d+)){0,1}" />
  </xsd:restriction>
</xsd:simpleType>

</xsd:schema>
```

Appendix C Creating New Traffic Generation Modules

Creating a new traffic generation module can be as simple as subclassing the `HarpoonPlugin` class. There are five pure virtual methods that must be overwritten to accomplish this:

- `bool init(HarpoonPluginConfig*)`
- `void client_session(void)`
- `void server_session(void)`
- `void stats(std::ostream&)`
- `void shutdown(void)`

A toy example is given below. It is a good idea to review the documentation and code for the `TCPPlugin` before attempting to write your own plugin.

Note in the example below that the C symbol `factory_generator` is the symbol for which `harpoon` searches. This function returns just returns a new traffic generator object that implements the five specific entrypoints named above.

There are some tricks to maintaining common data structures for a plugin. See the `TCPPlugin` for documentation and an example of this behavior.

```
class DummyPlugin : public HarpoonPlugin
{
public:
   DummyPlugin() : HarpoonPlugin() {}
   virtual ~DummyPlugin() {}

   // plugin general, and thread specific configuration.  this method
   // is called for every thread, so you must be careful not to
   // re-initialize anything.
   virtual bool init(HarpoonPluginConfig *hpc)
   {
       HarpoonPlugin::init(hpc);
       return true;
   }

   // if plugin personality is client, this method is called
   virtual void client_session()
   {
       std::cerr << "dummy client session begin" << std::endl;
       sleep(10);
       std::cerr << "dummy client session end" << std::endl;
   }

   // if plugin personality is server, this method is called
   virtual void server_session()
   {
       std::cerr << "dummy server session begin" << std::endl;
```

```
            sleep(10);
            std::cerr << "dummy server session end" << std::endl;
        }

        // called for all threads when the plugin is being shut down.
        virtual void shutdown()
        {
            std::cerr << "dummy shutdown" << std::endl;
            return;
        }

        // best to check your own personality here to decide what stats
        // to return.
        virtual void stats(std::ostream &os)
        {
            XmlRpcUtil::encode_struct_value(os, "dummystats", "no stats!");
        }
    };

    /*
     * factory function.  "factory_generator" is the C symbol we look for
     * when loading harpoon plugins.  (We use a C factory function to get
     * around C++ name mangling issues.)
     */
    extern "C"
    {
      Harpoon::DummyPlugin *factory_generator(void)
      {
         return (new Harpoon::DummyPlugin());
      }
    }
```

Postscript

The full technical paper describing Harpoon appeared in the Internet Measurement Conference, Taormina, Sicily, Italy, in October 2004 (http://www.cs.wisc.edu/~jsommers/pubs/p173-sommers.pdf).
Harpoon first appeared as an extended poster at the SIGMETRICS conference, New York, New York, USA, in June 2004 (http://portal.acm.org/citation.cfm?doid=1005686.1005733).

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