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Brooks Hickman
Spirent Communications
David Newman
Network Test
Saldju Tadjudin
Spirent Communications
Terry Martin
GVNW Consulting Inc

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Benchmarking Methodology for Firewall Performance
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Status of this Memo

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Abstract

This document discusses and defines a number of tests that may be used to describe the performance characteristics of firewalls. In addition to defining the tests this document also describes specific formats for reporting the results of the tests.

This document is a product of the Benchmarking Methodology Working Group (BMWG) of the Internet Engineering Task Force (IETF).

Table of Contents

1. Introduction

This document provides methodologies for the performance benchmarking of firewalls. It provides methodologies in four areas: forwarding, connection, latency and filtering. In addition to defining the tests, this document also describes specific formats for reporting the results of the tests.

A previous document, "Benchmarking Terminology for Firewall Performance" [1], defines many of the terms that are used in this document. The terminology document SHOULD be consulted before attempting to make use of this document.

2. Requirements

In this document, the words that are used to define the significance of each particular requirement are capitalized. These words are:

* "MUST" This word, or the words "REQUIRED" and "SHALL" mean that

the item is an absolute requirement of the specification.

* "SHOULD" This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this

item, but the full implications should be understood and the case carefully weighed before choosing a different course.

* "MAY" This word or the adjective "OPTIONAL" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

An implementation is not compliant if it fails to satisfy one or more of the MUST requirements for the protocols it implements. An implementation that satisfies all the MUST and all the SHOULD requirements for its protocols is said to be "unconditionally compliant"; one that satisfies all the MUST requirements but not all the SHOULD requirements for its protocols is said to be "conditionally compliant".

3. Scope

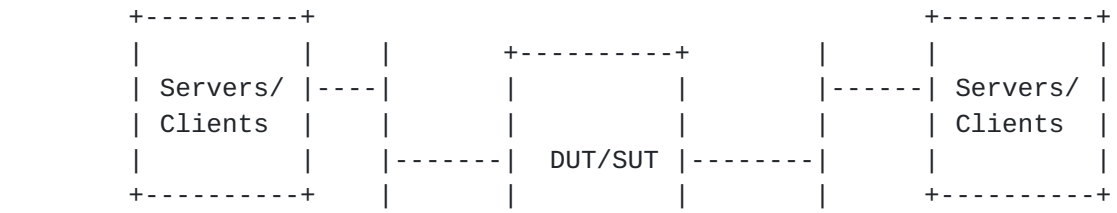
Firewalls can provide a single point of defense between networks. Usually, a firewall protects private networks from the public or shared networks to which it is connected. A firewall can be as simple as a device that filters different packets or as complex as a group of devices that combine packet filtering and application-level proxy or network translation services. This RFC will focus on developing benchmark testing of DUT/SUTs, wherever possible, independent of their implementation.

4. Test Setup

Test configurations defined in this document will be confined to dual-homed and tri-homed as shown in figure 1 and figure 2 respectively.

Firewalls employing dual-homed configurations connect two networks. One interface of the firewall is attached to the unprotected network, typically the public network(Internet). The other interface is connected to the protected network, typically the internal LAN.

In the case of dual-homed configurations, servers which are made accessible to the public(Unprotected) network are attached to the private(Protected) network.



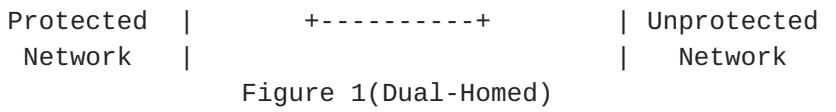


Figure 1(Dual-Homed)

Tri-homed[1] configurations employ a third segment called a Demilitarized Zone(DMZ). With tri-homed configurations, servers accessible to the public network are attached to the DMZ. Tri-Homed configurations offer additional security by separating server(s) accessible to the public network from internal hosts.

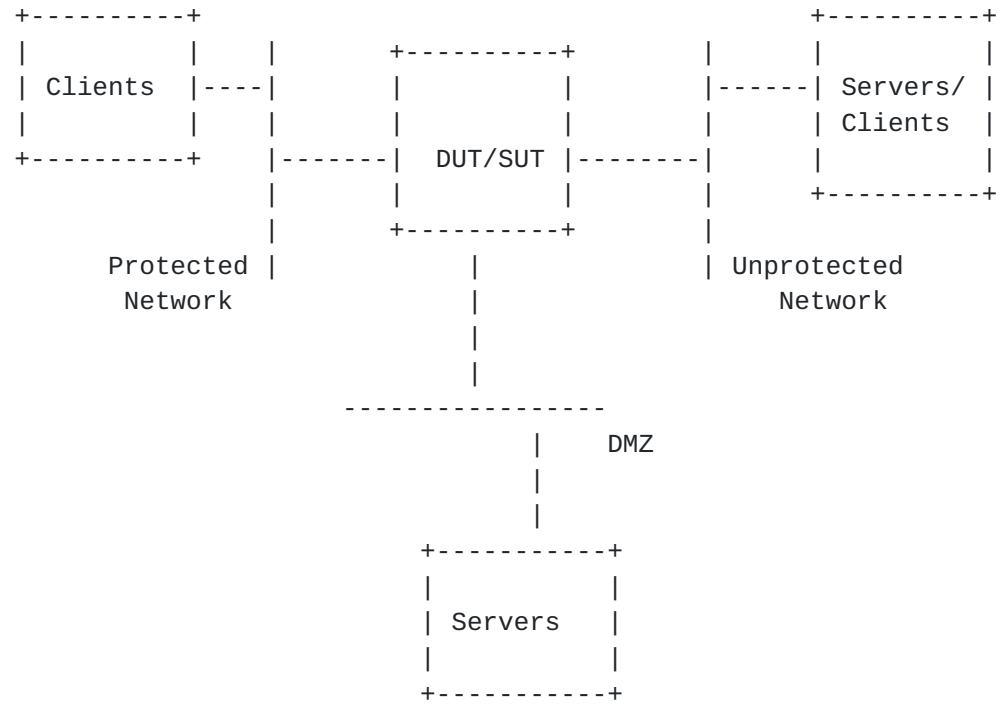


Figure 2(Tri-Homed)

4.1 Test Considerations

4.2 Virtual Clients/Servers

Since firewall testing may involve data sources which emulate multiple users or hosts, the methodology uses the terms virtual clients/servers. For these firewall tests, virtual clients/servers specify application layer entities which may not be associated with a unique physical interface. For example, four virtual clients may originate from the same data source[1]. The test report SHOULD indicate the number of virtual clients and virtual servers participating in the test.

Testers MUST synchronize all data sources participating in a test.

4.3 Test Traffic Requirements

While the function of a firewall is to enforce access control policies, the criteria by which those policies are defined vary depending on the implementation. Firewalls may use network layer,

transport layer or, in many cases, application-layer criteria to make access-control decisions.

For the purposes of benchmarking firewall performance this document references HTTP 1.1 or higher as the application layer entity, although the methodologies may be used as a template for benchmarking with other applications. Since testing may involve proxy based DUT/SUTs, HTTP version considerations are discussed in appendix A.

4.4 DUT/SUT Traffic Flows

Since the number of interfaces are not fixed, the traffic flows will be dependent upon the configuration used in benchmarking the DUT/SUT. Note that the term "traffic flows" is associated with client-to-server requests.

For Dual-Homed configurations, there are two unique traffic flows:

```
Client       Server
------         ------
Protected   -> Unprotected
Unprotected -> Protected
```

For Tri-Homed configurations, there are three unique traffic flows:

```
Client       Server
------         ------
Protected ->   Unprotected
Protected ->   DMZ
Unprotected -> DMZ
```

4.5 Multiple Client/Server Testing

One or more clients may target multiple servers for a given application. Each virtual client MUST initiate connections in a round-robin fashion. For example, if the test consisted of six virtual clients targeting three servers, the pattern would be as follows:

```
Client          Target Server(In order of request)
#1              1     2     3     1...
  #2              2     3     1     2...
  #3              3     1     2     3...
  #4              1     2     3     1...
  #5              2     3     1     2...
  #6              3     1     2     3...
```

4.6 Network Address Translation(NAT)

Many firewalls implement network address translation(NAT), a function which translates internal host IP addresses attached to the protected network to a virtual IP address for communicating

across the unprotected network(Internet). This involves additional processing on the part of the DUT/SUT and may impact performance. Therefore, tests SHOULD be ran with NAT disabled and NAT enabled

to determine the performance differentials. The test report MUST indicate whether NAT was enabled or disabled.

4.7 Rule Sets

Rule sets[1] are a collection of access control policies that determine which packets the DUT/SUT will forward and which it will reject[1]. Since criteria by which these access control policies may be defined will vary depending on the capabilities of the DUT/SUT, the following is limited to providing guidelines for configuring rule sets when benchmarking the performance of the DUT/SUT.

It is RECOMMENDED that a rule be entered for each host(Virtual client). In addition, testing SHOULD be performed using different size rule sets to determine its impact on the performance of the DUT/SUT. Rule sets MUST be configured in a manner, such that, rules associated with actual test traffic are configured at the end of the rule set and not the beginning.

The DUT/SUT SHOULD be configured to deny access to all traffic which was not previously defined in the rule set. The test report SHOULD include the DUT/SUT configured rule set(s).

4.7 Web Caching

Some firewalls include caching agents to reduce network load. When making a request through a caching agent, the caching agent attempts to service the response from its internal memory. The cache itself saves responses it receives, such as responses for HTTP GET requests. Testing SHOULD be performed with any caching agents on the DUT/SUT disabled.

4.8 Authentication

Access control may involve authentication processes such as user, client or session authentication. Authentication is usually performed by devices external to the firewall itself, such as an authentication server(s) and may add to the latency of the system. Any authentication processes MUST be included as part of connection setup process.

5. Benchmarking Tests

5.1 IP Throughput

5.1.1 Objective

To determine the throughput of network-layer data transversing the DUT/SUT, as defined in RFC1242[1]. Note that while RFC1242 uses the term frames, which is associated with the link layer, the

procedure uses the term packets, since it is referencing the network layer. This test is intended to baseline the ability of the DUT/SUT to forward packets at the network layer.

5.1.2 Setup Parameters

The following parameters MUST be defined:

Packet size - Number of bytes in the IP packet, exclusive of any link layer header or checksums.

Test Duration - Duration of the test, expressed in seconds.

5.1.3 Procedure

The tester will offer client/server traffic to the DUT/SUT, consisting of unicast IP packets. The tester MUST offer the packets at a constant rate. The test MAY consist of either bi-directional or unidirectional traffic, with the client offering a unicast stream of packets to the server for the latter.

The test MAY employ an iterative search algorithm. Each iteration will involve the tester varying the intended load until the maximum rate, at which no packet loss occurs, is found. Since backpressure mechanisms may be employed, resulting in the intended load and offered load being different, the test SHOULD be performed in either a packet based or time based manner as described in RFC2889[7]. As with RFC1242, the term packet is used in place of frame. The duration of the test portion of each trial MUST be at least 30 seconds.

When comparing DUT/SUTs with different MTUs, it is RECOMMENDED to limit the maximum IP size tested to the maximum MTU supported by all of the DUT/SUTs.

5.1.4 Measurement

5.1.4.1 Network Layer

Throughput - Maximum offered load, expressed in either bits per second or packets per second, at which no packet loss is detected.

Forwarding Rate - Forwarding rate, expressed in either bits per second or packets per second, the device is observed to successfully forward to the correct destination interface in response to a specified offered load.

5.1.4 Reporting Format

The test report MUST note the packet size(s), test duration, throughput and forwarding rate. If the test involved offering packets which target more than one segment(Protected, Unprotected or DMZ), the report MUST identify the results as an aggregate throughput measurement.

The throughput results SHOULD be reported in the format of a table with a row for each of the tested packet sizes. There SHOULD be

columns for the packet size, the intended load, the offered load, resultant throughput and forwarding rate for each test.

A log file MAY be generated which includes the packet size, test duration and for each iteration:

- Step Iteration
  - Pass/Fail Status
- Total packets offered
- Total packets forwarded
- Intended load
- Offered load(If applicable)
- Forwarding rate

5.2 Concurrent TCP Connection Capacity

5.2.1 Objective

To determine the maximum number of concurrent TCP connections supported through or with the DUT/SUT, as defined in RFC2647[1].

5.2.2 Setup Parameters

The following parameters MUST be defined for all tests:

5.2.2.1 Transport-Layer Setup Parameters

Connection Attempt Rate - The aggregate rate, expressed in connections per second, at which new TCP connection requests are attempted. The rate SHOULD be set at or lower than the maximum rate at which the DUT/SUT can accept connection requests.

Age Time - The time, expressed in seconds, the DUT/SUT will keep a connection in its connection table after receiving a TCP FIN or RST packet.

5.2.2.2 Application-Layer Setup Parameters

Validation Method - HTTP 1.1 or higher MUST be used for this test.

Object Size - Defines the number of bytes, excluding any bytes associated with the HTTP header, to be transferred in response to an HTTP 1.1 or higher GET request.

5.2.3 Procedure

An iterative search algorithm MAY be used to determine the maximum number of concurrent TCP connections supported through or with the DUT/SUT.

For each iteration, the aggregate number of concurrent TCP connections attempted by the virtual client(s) will be varied. The destination address will be that of the server or that of the NAT

proxy. The aggregate rate will be defined by connection attempt rate, and will be attempted in a round-robin fashion(See 4.5).

To validate all connections, the virtual client(s) MUST request an object using an HTTP 1.1 or higher GET request. The requests MUST be initiated on each connection after all of the TCP connections have been established.

When testing proxy-based DUT/SUTs, the virtual client(s) MUST request two objects using HTTP 1.1 or higher GET requests. The first GET request is required for connection time establishment measurements as specified in appendix B. The second request is used for validation as previously mentioned. When comparing proxy and non-proxy based DUT/SUTs, the test MUST be performed in the same manner.

Between each iteration, it is RECOMMENDED that the tester issue a TCP RST referencing all connections attempted for the previous iteration, regardless of whether or not the connection attempt was successful. The tester will wait for age time before continuing to the next iteration.

5.2.4 Measurements

5.2.4.1 Application-Layer measurements

Number of objects requested

Number of objects returned

5.2.4.2 Transport-Layer measurements

Maximum concurrent connections - Total number of TCP connections open for the last successful iteration performed in the search algorithm.

The following measurements SHOULD be performed on a per iteration basis:

Minimum connection establishment time - Lowest TCP connection establishment time measured as defined in appendix B.

Maximum connection establishment time - Highest TCP connection establishment time measured as defined in appendix B.

Average connection establishment time - The mean of all measurements of connection establishment times.

Aggregate connection establishment time - The total of all measurements of connection establishment times.

5.2.5 Reporting Format

5.2.5.1 Application-Layer Reporting:

The test report MUST note the object size, number of completed requests and number of completed responses.

The intermediate results of the search algorithm MAY be reported in a table format with a column for each iteration. There SHOULD be rows for the number of requests attempted, number of requests completed, number of responses attempted and number of responses completed. The table MAY be combined with the transport-layer reporting, provided that the table identify this as an application layer measurement.

Version information:

The test report MUST note the version of HTTP client(s) and server(s).

5.2.5.2 Transport-Layer Reporting:

The test report MUST note the connection attempt rate, age time and maximum concurrent connections measured.

The intermediate results of the search algorithm MAY be reported in the format of a table with a column for each iteration. There SHOULD be rows for the total number of TCP connections attempted, total number of TCP connections completed, minimum TCP connection establishment time, maximum TCP connection establishment time, average connection establishment time and the aggregate connection establishment time.

5.3 Maximum TCP Connection Establishment Rate

5.3.1 Objective

To determine the maximum TCP connection establishment rate through or with the DUT/SUT, as defined by RFC2647[1].

5.3.2 Setup Parameters

The following parameters MUST be defined for all tests:

5.3.2.1 Transport-Layer Setup Parameters

Number of Connections - Defines the aggregate number of TCP connections that must be established.

Age Time - The time, expressed in seconds, the DUT/SUT will keep a

connection in it's state table after receiving a TCP FIN or RST packet.

5.3.2.2 Application-Layer Setup Parameters

Validation Method - HTTP 1.1 or higher MUST be used for this test.

Object Size - Defines the number of bytes, excluding any bytes associated with the HTTP header, to be transferred in response to an HTTP 1.1 or higher GET request.

5.3.3 Procedure

An iterative search algorithm MAY be used to determine the maximum rate at which the DUT/SUT can accept TCP connection requests.

For each iteration, the aggregate rate at which TCP connection requests are attempted by the virtual client(s) will be varied. The destination address will be that of the server or that of the NAT proxy. The aggregate number of connections, defined by number of connections, will be attempted in a round-robin fashion(See 4.5).

The same application-layer object transfers required for validation and establishment time measurements as described in the concurrent TCP connection capacity test MUST be performed.

Between each iteration, it is RECOMMENDED that the tester issue a TCP RST referencing all connections attempted for the previous iteration, regardless of whether or not the connection attempt was successful. The tester will wait for age time before continuing to the next iteration.

5.3.4 Measurements

5.3.4.1 Application-Layer measurements

Number of objects requested

Number of objects returned

5.3.4.2 Transport-Layer measurements

Highest connection rate - Highest rate, in connections per second, for which for the search algorithm passed.

The following measurements SHOULD performed on a per iteration basis:

Minimum connection establishment time - Lowest TCP connection establishment time measured as defined in appendix B.

Maximum connection establishment time - Highest TCP connection establishment time measured as defined in appendix B.

Average connection establishment time - The mean of all measurements of connection establishment times.

Aggregate connection establishment time - The total of all measurements of connection establishment times.

5.3.5 Reporting Format

5.3.5.1 Application-Layer Reporting:

The test report MUST note object size(s), number of completed requests and number of completed responses.

The intermediate results of the search algorithm MAY be reported in a table format with a column for each iteration. There SHOULD be rows for the number of requests and responses completed. The table MAY be combined with the transport-layer reporting, provided that the table identify this as an application layer measurement.

Version information:

The test report MUST note the version of HTTP client(s) and server(s).

5.3.5.2 Transport-Layer Reporting:

The test report MUST note the number of connections, age time and highest connection rate measured.

The intermediate results of the search algorithm MAY be reported in the format of a table with a column for each iteration. There SHOULD be rows for the connection attempt rate, total number of

TCP connections attempted, total number of TCP connections completed, minimum TCP connection establishment time, maximum TCP connection establishment time, average connection establishment time and the aggregate connection establishment time.

5.4 Maximum TCP Connection Tear Down Rate

5.4.1 Objective

To determine the maximum TCP connection tear down rate through or with the DUT/SUT, as defined by RFC2647[1].

5.4.2 Setup Parameters

Number of Connections - Defines the number of TCP connections that the tester will attempt to tear down.

Age Time - The time, expressed in seconds, the DUT/SUT will keep a connection in it's state table after receiving a TCP FIN or RST packet.

5.4.3 Procedure

An iterative search algorithm MAY be used to determine the maximum TCP connection tear down rate. The test iterates through different

5.4.3 Procedure

An iterative search algorithm MAY be used to determine the maximum TCP connection tear down rate. The test iterates through different TCP connection tear down rates with a fixed number of TCP connections.

The virtual client(s) will initialize the test by establishing TCP connections defined by number of connections. The virtual client(s) will then attempt to tear down all of TCP connections, at a rate defined by tear down attempt rate. For benchmarking purposes, the tester MUST use a TCP FIN when initiating the connection tear down.

In the case of proxy based DUT/SUTs, the DUT/SUT will itself receive the final ACK in the three-way handshake when a connection is being torn down. For validation purposes, the virtual client(s) MAY verify that the DUT/SUT received the final ACK in the connection tear down exchange for all connections by transmitting a TCP datagram referencing the previously town down connection. A TCP RST should be received in response to the TCP datagram.

5.4.4 Measurements

Highest connection tear down rate - Highest rate, in connections per second, for which all TCP connections were successfully torn down.

The following measurements SHOULD performed on a per iteration basis. The tester MUST only include such measurements for which both sides of the connection were successfully torn down. For example, tear down times for connections which are left in a FINWAIT-2[8] state should not be included:

Minimum connection tear down time - Lowest TCP connection tear down time measured as defined in appendix C.

Maximum connection tear down time - Highest TCP connection tear down time measured as defined in appendix C.

Average connection tear down time - The mean of all measurements of connection tear down times.

Aggregate connection tear down time - The total of all measurements of connection tear down times.

5.4.5 Reporting Format

The test report MUST note the number of connections, age time and highest connection tear down rate measured.

The intermediate results of the search algorithm SHOULD be reported in the format of a table with a column for each iteration. There SHOULD be rows for the number of TCP tear downs attempted, number of TCP connection tear downs completed, minimum TCP connection tear down time, maximum TCP connection tear down time, average TCP connection tear down time and the aggregate TCP connection tear down time.

5.5 Denial Of Service Handling

5.5.1 Objective

To determine the effect of a denial of service attack on a DUT/SUT TCP connection establishment and/or HTTP transfer rates. The denial of service handling test MUST be run after obtaining baseline measurements from sections 5.3 and/or 5.6.

The TCP SYN flood attack exploits TCP's three-way handshake mechanism by having an attacking source host generate TCP SYN packets with random source addresses towards a victim host, thereby consuming that host's resources.

5.5.2 Setup Parameters

Use the same setup parameters as defined in section 5.3.2 or 5.6.2, depending on whether testing against the baseline TCP connection establishment rate test or HTTP transfer rate test, respectfully.

In addition, the following setup parameters MUST be defined.

SYN attack rate - Rate, expressed in packets per second, at which the server(s) or NAT proxy address is targeted with TCP SYN packets.

5.5.3 Procedure

Use the same procedure as defined in section 5.3.3 or 5.6.3, depending on whether testing against the baseline TCP connection establishment rate or HTTP transfer rate test, respectfully. In addition, the tester will generate TCP SYN packets targeting the server(s) IP address or NAT proxy address at a rate defined by SYN attack rate.

The tester originating the TCP SYN attack MUST be attached to the unprotected network. In addition, the tester MUST not respond to the SYN/ACK packets sent by target server or NAT proxy in response to the SYN packet.

Some firewalls employ mechanisms to guard against SYN attacks. If such mechanisms exist on the DUT/SUT, tests SHOULD be run with these mechanisms enabled to determine how well the DUT/SUT can maintain,

under such attacks, the baseline connection establishment rates and HTTP transfer rates determined in section 5.3 and section 5.6, respectively.

5.5.4 Measurements

Perform the same measurements as defined in section 5.3.4 or 5.6.4, depending on whether testing against the baseline TCP connection establishment rate test or HTTP transfer rate, respectfully.

In addition, the tester SHOULD track TCP SYN packets associated with the SYN attack which the DUT/SUT forwards on the protected or DMZ interface(s).

5.5.5 Reporting Format

The test SHOULD use the same reporting format as described in section 5.3.5 or 5.6.5, depending on whether testing against the baseline TCP connection establishment rate test or HTTP transfer rate, respectfully.

In addition, the report MUST indicate a denial of service handling test, SYN attack rate, number TCP SYN attack packets transmitted and the number of TCP SYN attack packets forwarded by the DUT/SUT. The report MUST indicate whether or not the DUT has any SYN attack mechanisms enabled.

5.6 HTTP Transfer Rate

5.6.1 Objective

To determine the transfer rate of HTTP requested object transversing the DUT/SUT.

5.6.2 Setup Parameters

The following parameters MUST be defined for all tests:

5.6.2.1 Transport-Layer Setup Parameters

Number of connections - Defines the aggregate number of connections attempted. The number SHOULD be a multiple of the number of virtual clients participating in the test

5.6.2.2 Application-Layer Setup Parameters

Session type - The virtual clients/servers MUST use HTTP 1.1 or higher.

GET requests per connection - Defines the number of HTTP 1.1 or higher GET requests attempted per connection.

Object Size - Defines the number of bytes, excluding any bytes associated with the HTTP header, to be transferred in response to an

HTTP 1.1 or higher GET request.

5.6.3 Procedure

Each HTTP 1.1 or higher client will request one or more objects from an HTTP 1.1 or higher server using one or more HTTP GET requests. The aggregate number of connections attempted, defined by number of connections, MUST be evenly divided among all of the participating virtual clients.

If the virtual client(s) make multiple HTTP GET requests per connection, it MUST request the same object size for each GET request. Multiple iterations of this test SHOULD be ran using different object sizes.

5.6.4 Measurements

5.6.4.1 Application-Layer measurements

Average Transfer Rate - The average transfer rate of the DUT/SUT MUST be measured and shall be referenced to the requested object(s). The measurement will start on transmission of the first bit of the first requested object and end on transmission of the last bit of the last requested object. The average transfer rate, in bits per second, will be calculated using the following formula:

$$\text{TRANSFER RATE(bit/s)} = \frac{\text{OBJECTS} * \text{OBJECTSIZE} * 8}{\text{DURATION}}$$

OBJECTS - Total number of objects successfully transferred across all connections.

OBJECTSIZE - Object size in bytes

DURATION - Aggregate transfer time based on aforementioned time references.

5.6.4.2 Measurements at or below the Transport-Layer

The tester SHOULD make goodput[1] measurements for connection-oriented protocols at or below the transport layer. Goodput measurements MUST only reference the protocols payload, excluding any of the protocols header. In addition, the tester MUST exclude any bits associated with the connection establishment, connection tear down, security associations or connection maintenance.

Since connection-oriented protocols require that data be acknowledged, the offered load[6] will vary over the duration of the test. When performing forwarding rate measurements, the tester should measure the average forwarding rate over the duration of the test.

5.6.5 Reporting Format

5.6.5.1 Application-Layer reporting

The test report MUST note number of GET requests per connection and object size.

The transfer rate results SHOULD be reported in tabular form with a row for each of the object sizes. There SHOULD be a column for the object size, the number of completed requests, the number of completed responses, and the transfer rate results for each test.

Failure analysis:

The test report SHOULD indicate the number and percentage of HTTP GET request or responses that failed to complete.

Version information:

The test report MUST note the version of HTTP client(s) and server(s).

5.6.5.2 Transport-Layer and below reporting

The test report MUST note the aggregate number of connections. In addition, the report MUST identify the protocol for which the measurement was made.

The results SHOULD be in tabular form with a column for each iteration of the test. There should be columns for transmitted bits, retransmitted bits and the measured goodput.

Failure analysis:

The test report SHOULD indicate the number and percentage of connections that failed to complete.

5.7 HTTP Concurrent Transaction Capacity

5.7.1 Objective

Determine the maximum number of concurrent or simultaneous HTTP transactions the DUT/SUT can support. This test is intended to find the maximum number of users that can simultaneously access web objects.

5.7.2 Setup Parameters

GET request rate - The aggregate rate, expressed in request per second, at which HTTP 1.1 or higher GET requests are offered by the

virtual client(s).

Session type - The virtual clients/servers MUST use HTTP 1.1 or higher.

5.7.3 Procedure

An iterative search algorithm MAY be used to determine the maximum HTTP concurrent transaction capacity.

For each iteration, the virtual client(s) will vary the number of concurrent or simultaneous HTTP transactions - that is, on-going GET requests. The HTTP 1.1 or higher virtual client(s) will request one object, across each connection, from an HTTP 1.1 or higher server using one HTTP GET request. The aggregate rate at which the virtual client(s) will offer the requests will be defined by GET request rate.

The object size requested MUST be large enough, such that, the transaction - that is, the request/response cycle -- will exist for the duration of the test. At the end of each iteration, the tester MUST validate that all transactions are still active. After all of the transactions are checked, the transactions MAY be aborted.

5.7.4 Measurements

Maximum concurrent transactions - Total number of concurrent HTTP transactions active for the last successful iteration performed in the search algorithm.

5.7.5 Reporting Format

5.7.5.1 Application-Layer reporting

The test report MUST note the GET request rate and the maximum concurrent transactions measured.

The intermediate results of the search algorithm MAY be reported in a table format with a column for each iteration. There SHOULD be rows for the number of concurrent transactions attempted, GET request rate, number of aborted transactions and number of transactions active at the end of the test iteration.

Version information:

The test report MUST note the version of HTTP client(s) and server(s).

5.8 Maximum HTTP Transaction Rate

5.8.1 Objective

Determine the maximum HTTP transaction rate that a DUT/SUT can sustain.

5.8.2 Setup Parameters

Session Type - HTTP 1.1 or higher MUST be used for this test.

Test Duration - Time, expressed in seconds, for which the virtual client(s) will sustain the attempted GET request rate. It is RECOMMENDED that the duration be at least 30 seconds.

Requests per connection - Number of object requests per connection.

Object Size - Defines the number of bytes, excluding any bytes associated with the HTTP header, to be transferred in response to an HTTP 1.1 or higher GET request.

5.8.3 Procedure

An iterative search algorithm MAY be used to determine the maximum transaction rate that the DUT/SUT can sustain.

For each iteration, HTTP 1.1 or higher virtual client(s) will vary the aggregate GET request rate offered to HTTP 1.1 or higher server(s). The virtual client(s) will maintain the offered request rate for the defined test duration.

If the tester makes multiple HTTP GET requests per connection, it MUST request the same object size for each GET request rate. Multiple iterations of this test MAY be performed with objects of different sizes.

5.8.4 Measurements

Maximum Transaction Rate - The maximum rate at which all transactions -- that is all requests/responses cycles -- are completed.

Transaction Time - The tester SHOULD measure minimum, maximum and average transaction times. The transaction time will start when the virtual client issues the GET request and end when the requesting virtual client receives the last bit of the requested object.

5.8.5 Reporting Format

The test report MUST note the test duration, object size, requests per connection and the measured minimum, maximum and average transaction rate.

The intermediate results of the search algorithm MAY be reported in a table format with a column for each iteration. There SHOULD be rows for the GET request attempt rate, number of requests attempted, number and percentage of requests completed, number of responses

attempted, number and percentage of responses completed, minimum transaction time, average transaction time and maximum transaction time.

Version information:

The test report MUST note the version of HTTP client(s) and server(s).

5.9 Illegal Traffic Handling

5.9.1 Objective

To determine the behavior of the DUT/SUT when presented with a combination of both legal and Illegal traffic. Note that Illegal traffic does not refer to an attack, but traffic which has been explicitly defined by a rule(s) to drop.

5.9.2 Setup Parameters

Setup parameters will use the same parameters as specified in the HTTP transfer rate test(Section 5.6.2). In addition, the following setup parameters MUST be defined:

Illegal traffic percentage - Percentage of HTTP 1.1 or higher connections which have been explicitly defined in a rule(s) to drop.

5.9.3 Procedure

Each HTTP 1.1 or higher client will request one or more objects from an HTTP 1.1 or higher server using one or more HTTP GET requests. The aggregate number of connections attempted, defined by number of connections, MUST be evenly divided among all of the participating virtual clients.

The virtual client(s) MUST offer the connection requests, both legal and illegal, in an evenly distributed manner. Many firewalls have the capability to filter on different traffic criteria(IP addresses, Port numbers, etc). Testers may run multiple iterations of this test with the DUT/SUT configured to filter on different traffic criteria.

5.9.4 Measurements

Tester SHOULD perform the same measurements as defined in HTTP transfer rate test(Section 5.6.4). Unlike the HTTP transfer rate test, the tester MUST not include any bits which are associated with illegal traffic in its forwarding rate measurements.

5.9.5 Reporting Format

Test report SHOULD be the same as specified in the HTTP test(Section 5.6.5).

In addition, the report MUST note the percentage of illegal HTTP connections.

Failure analysis:

Test report MUST note the number and percentage of illegal connections that were allowed by the DUT/SUT.

5.10 IP Fragmentation Handling

5.10.1 Objective

To determine the performance impact when the DUT/SUT is presented with IP fragmented[5] traffic. IP packets which have been fragmented, due to crossing a network that supports a smaller MTU(Maximum Transmission Unit) than the actual IP packet, may require the firewall to perform re-assembly prior to the rule set being applied.

While IP fragmentation is a common form of attack, either on the firewall itself or on internal hosts, this test will focus on determining how the additional processing associated with the re-assembly of the packets have on the forwarding rate of the DUT/SUT. RFC 1858 addresses some fragmentation attacks that get around IP filtering processes used in routers and hosts.

5.10.2 Setup Parameters

The following parameters MUST be defined.

5.10.2.1 Non-Fragmented Traffic Parameters

Setup parameters will be the same as defined in the HTTP transfer rate test(Sections 5.6.2.1 and 5.6.2.2).

5.10.2.2 Fragmented Traffic Parameters

Packet size - Number of bytes in the IP/UDP packet, exclusive of link-layer headers and checksums, prior to fragmentation.

MTU - Maximum transmission unit, expressed in bytes. For testing purposes, this MAY be configured to values smaller than the MTU supported by the link layer.

Intended Load - Intended load, expressed as percentage of media utilization.

5.10.3 Procedure

Each HTTP 1.1 or higher client will request one or more objects from an HTTP 1.1 or higher server using one or more HTTP GET requests. The aggregate number of connections attempted, defined by number of connections, MUST be evenly divided among all of the participating

virtual clients. If the virtual client(s) make multiple HTTP GET requests per connection, it MUST request the same object size for each GET request.

A tester attached to the unprotected side of the network, will offer a unidirectional stream of unicast fragmented IP/UDP traffic, targeting a server attached to either the protected or DMZ segment. The tester MUST offer the unidirectional stream over the duration of the test -- that is, duration over which the HTTP traffic is being offered.

Baseline measurements SHOULD be performed with IP filtering deny rule(s) to filter fragmented traffic. If the DUT/SUT has logging capability, the log SHOULD be checked to determine if it contains the correct information regarding the fragmented traffic.

The test SHOULD be repeated with the DUT/SUT rule set changed to allow the fragmented traffic through. When running multiple iterations of the test, it is RECOMMENDED to vary the MTU while keeping all other parameters constant.

Then setup the DUT/SUT to the policy or rule set the manufacturer required to be defined to protect against fragmentation attacks and repeat the measurements outlined in the baseline procedures.

5.10.4 Measurements

Tester SHOULD perform the same measurements as defined in HTTP test(Section 5.6.4).

Transmitted UDP/IP Packets - Number of UDP packets transmitted by client.

Received UDP/IP Packets - Number of UDP/IP Packets received by server.

5.10.5 Reporting Format

5.10.1 Non-Fragmented Traffic

The test report SHOULD be the same as described in section 5.6.5. Note that any forwarding rate measurements for the HTTP traffic excludes any bits associated with the fragmented traffic which may be forward by the DUT/SUT.

5.10.2 Fragmented Traffic

The test report MUST note the packet size, MTU size, intended load, number of UDP/IP packets transmitted and number of UDP/IP packets forwarded. The test report SHOULD also note whether or not the DUT/SUT forwarded the offered UDP/IP traffic fragmented.

5.11 Latency

5.11.1 Objective

To determine the latency of network-layer or application-layer data traversing the DUT/SUT. RFC 1242 [3] defines latency.

5.11.2 Setup Parameters

The following parameters MUST be defined:

5.11.2.1 Network-layer Measurements

Packet size, expressed as the number of bytes in the IP packet, exclusive of link-layer headers and checksums.

Intended load, expressed as percentage of media utilization.

Test duration, expressed in seconds.

Test instruments MUST generate packets with unique timestamp signatures.

5.11.2.2 Application-layer Measurements

Object Size - Defines the number of bytes, excluding any bytes associated with the HTTP header, to be transferred in response to an HTTP 1.1 or higher GET request. Testers SHOULD use the minimum object size supported by the media, but MAY use other object sizes as well.

Connection type. The tester MUST use one HTTP 1.1 or higher connection for latency measurements.

Number of objects requested.

Number of objects transferred.

Test duration, expressed in seconds.

Test instruments MUST generate packets with unique timestamp signatures.

5.11.3 Network-layer procedure

A client will offer a unidirectional stream of unicast packets to a server. The packets MUST use a connectionless protocol like IP or UDP/IP.

The tester MUST offer packets in a steady state. As noted in the

latency discussion in RFC 2544 [4], latency measurements MUST be taken at the throughput level -- that is, at the highest offered load with zero packet loss. Measurements taken at the throughput

level are the only ones that can legitimately be termed latency.

It is RECOMMENDED that implementers use offered loads not only at the throughput level, but also at load levels that are less than or greater than the throughput level. To avoid confusion with existing terminology, measurements from such tests MUST be labeled as delay rather than latency.

If desired, the tester MAY use a step test in which offered loads increment or decrement through a range of load levels.

The duration of the test portion of each trial MUST be at least 30 seconds.

5.11.4 Application layer procedure

An HTTP 1.1 or higher client will request one or more objects from an HTTP or higher 1.1 server using one or more HTTP GET requests. If the tester makes multiple HTTP GET requests, it MUST request the same-sized object each time. Testers may run multiple iterations of this test with objects of different sizes.

Implementers MAY configure the tester to run for a fixed duration. In this case, the tester MUST report the number of objects requested and returned for the duration of the test. For fixed-duration tests it is RECOMMENDED that the duration be at least 30 seconds.

5.11.5 Measurements

Minimum delay - The smallest delay incurred by data traversing the DUT/SUT at the network layer or application layer, as appropriate.

Maximum delay - The largest delay incurred by data traversing the DUT/SUT at the network layer or application layer, as appropriate.

Average delay - The mean of all measurements of delay incurred by data traversing the DUT/SUT at the network layer or application layer, as appropriate.

Delay distribution - A set of histograms of all delay measurements observed for data traversing the DUT/SUT at the network layer or application layer, as appropriate.

5.11.6 Network-layer reporting format

The test report MUST note the packet size(s), offered load(s) and test duration used.

The latency results SHOULD be reported in the format of a table with a row for each of the tested packet sizes. There SHOULD be columns

for the packet size, the intended rate, the offered rate, and the resultant latency or delay values for each test.

5.11.7 Application-layer reporting format

The test report MUST note the object size(s) and number of requests and responses completed. If applicable, the report MUST note the test duration if a fixed duration was used.

The latency results SHOULD be reported in the format of a table with a row for each of the object sizes. There SHOULD be columns for the object size, the number of completed requests, the number of completed responses, and the resultant latency or delay values for each test.

Failure analysis:

The test report SHOULD indicate the number and percentage of HTTP GET request or responses that failed to complete within the test duration.

Version information:

The test report MUST note the version of HTTP client and server.

6. References

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[5] David C. Clark, "IP Datagram Reassembly Algorithm", RFC 815 , July 1982.

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[7] Mandeville, R., Perser,J., "Benchmarking Methodology for LAN Switching Devices", RFC 2889, August 2000.

[8] Postel, J. (ed.), "Internet Protocol - DARPA Internet Program Protocol Specification", RFC 793, USC/Information Sciences Institute, September 1981.

7. Security Considerations

The primary goal of this document is to provide methodologies in benchmarking firewall performance. While there is some overlap between performance and security issues, assessment of firewall security is outside the scope of this document.

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9. Authors' Addresses

Brooks Hickman
Spirent Communications
26750 Agoura Road
Calabasas, CA 91302
USA

Phone: + 1 818 676 2412
Email: brooks.hickman@spirentcom.com

David Newman
Network Test Inc.
31324 Via Colinas, Suite 113
Westlake Village, CA 91362-6761
USA

Phone: + 1 818 889-0011
Email: dnewman@networktest.com

Saldju Tadjudin
Spirent Communications
26750 Agoura Road
Calabasas, CA 91302
USA

Phone: + 1 818 676 2468
Email: saldju.Tadjudin@spirentcom.com

Terry Martin
GVNW Consulting Inc.
8050 SW Warm Springs Road
Tualatin Or. 97062
USA

Phone: + 1 503 612 4422
Email: tmartin@gvnw.com

APPENDIX A: HTTP(HyperText Transfer Protocol)

The most common versions of HTTP in use today are HTTP/1.0 and HTTP/1.1 with the main difference being in regard to persistent connections. HTTP 1.0, by default, does not support persistent connections. A separate TCP connection is opened up for each GET request the client wants to initiate and closed after the requested object transfer is completed. While some implementations HTTP/1.0 supports persistence through the use of a keep-alive, there is no official specification for how the keep-alive operates. In addition, HTTP 1.0 proxies do support persistent connection as they do not recognize the connection header.

HTTP/1.1, by default, does support persistent connection and is therefore the version that is referenced in this methodology. Proxy based DUT/SUTs may monitor the TCP connection and after a timeout, close the connection if no activity is detected. The duration of this timeout is not defined in the HTTP/1.1 specification and will vary between DUT/SUTs. If the DUT/SUT closes inactive connections, the aging timer on the DUT SHOULD be configured for a duration that exceeds the test time.

While this document cannot foresee future changes to HTTP and it impact on the methodologies defined herein, such changes should be accommodated for so that newer versions of HTTP may be used in benchmarking firewall performance.

APPENDIX B: Connection Establishment Time Measurements

Some connection oriented protocols, such as TCP, involve an odd number of messages when establishing a connection. In the case of proxy based DUT/SUTs, the DUT/SUT will terminate the connection, setting up a separate connection to the server. Since, in such cases, the tester does not own both sides of the connection, measurements will be made two different ways. While the following describes the measurements with reference to TCP, the methodology may be used with other connection oriented protocols which involve an odd number of messages.

When testing non-proxy based DUT/SUTs , the establishment time shall be directly measured and is considered to be from the time the first bit of the first SYN packet is transmitted by the client to the time the last bit of the final ACK in the three-way handshake is received by the target server.

If the DUT/SUT is proxy based, the connection establishment time is considered to be from the time the first bit of the first SYN packet is transmitted by the client to the time the client transmits the first bit of the first acknowledged TCP datagram(t4-t0 in the

following timeline).

t0: Client sends a SYN.
t1: Proxy sends a SYN/ACK.
t2: Client sends the final ACK.
t3: Proxy establishes separate connection with server.
t4: Client sends TCP datagram to server.
*t5: Proxy sends ACK of the datagram to client.

* While t5 is not considered part of the TCP connection establishment, acknowledgement of t4 must be received for the connection to be considered successful.

APPENDIX C: Connection Tear Time Measurements

While TCP connections are full duplex, tearing down of such connections are performed in a simplex fashion -- that is, FIN segments are sent by each host/device terminating each side of the TCP connection.

When making connection tear down times measurements, such measurements will be made from the perspective of the client and will be performed in the same manner, independent of whether or not the DUT/SUT is proxy-based. The connection tear down will be considered the interval between the transmission of the first bit of the first TCP FIN packet transmitted by the tester requesting a connection tear down to receipt of the last bit of the corresponding ACK packet on the same tester interface.

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