

Increase the Latency: Emulation Approaches for Real Network Conditions

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Abstract—The increasing complexity of network setups in Information Technology fields and companies directly increases the need for constant testing and validation of the network. It is often important for the main network, or the production network, to be running constantly without interruptions, and to be running at full capacity without the additional overhead of testing software. Therefore, many companies resort to using a testbed, a network built to closely resemble the production network. Because a testbed is usually hosted in a singular location and is not set up exactly like the production network, additional factors must be introduced for accurate testing. The main method of achieving a setup, that closely resembles the complexity of the production network, is network emulation. Another way of approaching this problem is network simulation, but the findings in this paper suggest that by using a emulation network setup, including actual traffic as opposed to simulated traffic, the production network can be emulated more accurately. This paper focuses on latency, as a specific emulation factor. In order for a testbed to accurately emulate the real latency behavior of network flow through a real Wide Area Network (WAN), multiple technological approaches are analyzed, such as the use of free software emulators like NetEm, NistNet, and Dummynet, or all-in-one hardware emulators, such as the Netropy 100G, and the Attero 100G. Alternatively in fiber networks, Fiber Optic Delay Lines such as the Fiberplus D8 can be used for emulation. This paper compares each of the different approaches and evaluates them based on emulation ability, costs and configuration efforts.

Index Terms—network emulation, software link emulators, hardware wan emulators, fiber optic delay lines

1. Introduction

Testing, validating, and implementing new technologies in a computer network is a core aspect of achieving a solid network infrastructure. The optimal way of doing so is to carry out the testing in the actual production environment, since this is the actual network setup through which all of the live traffic flows, and thus is already setup in the optimal way. But since testing in the production environment can also result in major downsides, such as unwanted crashes and down-times of nodes in the network, this does not present the ideal way of testing or expanding a network [1].

The solution to this problem is to set up a testbed, which is an environment that mirrors or imitates the production network, so that new technologies, expansions

in soft- and hardware and general testing of the network devices can be tested. Since a testbed network setup is usually hosted in a single location, this provides the setup with overly ideal conditions. The cable lengths are short, usually staying below 100 m, and there are no additional network nodes, which would be introduced if the network was geographically separated and had to utilize WAN connections. Connections over a WAN can impose delays, latency and other types of interferences simply due to additional network nodes in the network, or propagation delay induced by longer cable routes.

This poses the question of how a testbed can reproduce the characteristics of a live environment, especially over longer distances, in order to make the testing even more accurate. A common answer to this question is network simulation. Network devices are modeled in a virtual environment, which allows for simulation based testing [2]. This is a valid first step in order to test the functionalities and study the behaviors of the network. However, network simulation quickly reaches its limits, since it fails to reproduce the real conditions imposed on the production network.

We propose to use network emulation, which introduces additional factors in terms of actual network devices, while still keeping the valuable aspects of a simulation environment [2]. In order to test the hardware and software, and various types of behaviors within the network over a longer distance, and additional number of devices in the network while still remaining in the local testbed, emulation methods have to be introduced. Traffic over a WAN, for example, introduces latency, packet loss, delays etc. This can be achieved by a variety of methods and techniques, for example a simple Linux device running NetEm, an extension of the already available network manipulation functions of Linux, which can be used to add fixed amounts of delays with additional random latency variation to outgoing packets [3].

This paper focuses on emulation techniques in order to accurately simulate a production environment and analyzes their benefits and limitations in terms of introducing actual network behaviors such as the latency introduced by the cable lengths in WANs. The structure of the paper is as follows: Section 2 lists and compares free software link emulators. Section 3 lists and compares all-in-one hardware WAN emulators. In the following Section 4 a comparison of the functionalities of free software emulators and hardware emulators is made. Section 5 discusses the use of fiber optic delay lines in fiber networks. Finally, Section 6 summarizes and contrasts all of the previously mentioned approaches.

2. Free Software Link Emulators

2.1. NetEm

NetEm is a free extension to the already existing Linux Traffic Control package. It is used for its emulation functionalities for simulating the characteristics of a WAN, making it an important tool for testing. Command line parameters allow introducing latency to outgoing packets, packet loss, corruption, re-ordering and control bandwidth through rate control. This paper investigates the latency functions of Net Em. Installation is kept simple, when using a Linux kernel 2.6 or higher, it is already enabled. In older kernel versions the implementation is also simple and can be enabled in the Networking Options [3].

Listing 1: NetEm Delay with non purely random variation

```
# tc qdisc change dev eth0 root NetEm
delay 100ms 10ms 25%
```

The command line snippet Listing 1 is taken out of the official NetEm for Linux documentation [3]. The 100 ms parameter adds a fixed delay of 100 ms. The 10 ms adds or subtracts additional 10 ms in a purely random fashion, meaning the outcome of the delay value is 90 ms or 110 ms. Because WAN connections do not usually behave in a purely random fashion, the 25 % percent parameter is necessary to approximate real variation, meaning that the next random element of the delay is dependent on the previous outcome by 25 % [3].

2.2. Nist Net

Nist Net is a free Linux-based package used for network emulation. Much like its descendant NetEm, which was mentioned previously, it runs as an extension of the Linux kernel. It can be used to test and simulate a wide array of WAN properties, such as packet loss, bandwidth limitations, latency, and network congestions. The word "emulation" is defined by the two creators Mark Carson and Darrin Santay as the testing of a network in a simulated environment in addition to a real hardware network setup [4]. The real component in this sense is the actual machine running Nist Net, and the simulated component being the simulation factors such as introducing delays or bandwidth limitations in a logical sense inside of the Nist Net package. Therefore, Nist Net, much like NetEm, benefits from the simulation environment, which is easily changed and reproducible, but also benefits from the factors of a real network device setup [4].

The implementation of Nist Net is simple, as it is implemented and configured through a Linux operating system command line, and, for example, only requires a simple PC-router setup in order to use its emulation functionalities. By changing parameters in the Nist Net configuration, the user can define the desired network manipulation rules in a table of emulator entries, in which the user must also specify for which packets the rules apply, and which emulation factors should be applied [4]. The delay parameter sets the delay of incoming packets in milliseconds and has multiple parameters which can be applied to the delay behavior. For example the added delay can be static, following a random distribution, or

by default follow a right tailed delay distribution which closely resembles the actual distribution of ping delays, tested in a three hour connection of machines in a Network, as observed by the authors of Nist Net [4].

Listing 2: Configuration of Delay in Nist Net

```
cnistnet -a 0.0.0.0 0.0.0.0 --delay 60
```

The delay parameter in Listing 2 adds 60 ms of simple delay to all traffic passing through a network node running Nist Net [5].

2.3. Dummynet

Dummynet is a network emulation tool developed in the late 1990s [2]. It was originally designed for running configurable experiments in network setups and has been developed for FreeBSD, a Unix-like operating system, for which it later became a default package. Across the years the support for other operating systems was expanded, now supporting Linux, MacOS, and Windows [6]. Dummynet works as a network emulator by utilizing pipes, which are used as a communication link with configurable bandwidth and other factors, such as delay [6]. These pipes are combined with different queuing methods which simulate those used by actual network devices, with FIFO queues being the default setting of Dummynet [6] [2]. The user can choose which traffic gets routed through which pipe, or alternatively, set up a pipe, which accepts any traffic. By defining the parameters of a pipe, for example the delay parameter, any traffic set to pass through the pipe has these parameters applied. The following command snippet shows how to define a simple delay of 60 ms and route all traffic through a pipe, the emulated link [6].

Listing 3: Adding simple delay and configuring traffic to a pipe in Dummynet

```
ipfw pipe 1 config bw 2Mbit/s delay 60ms
ipfw add pipe 1 ip from any to any
```

The parameter "bw 2 Mbit/s" in Listing 3 defines the bandwidth and the following "delay 60 ms" sets a delay of 60 ms to pipe 1. The second line routes all the traffic through pipe 1 [6].

Dummynet can be set up as a network router, which accepts the incoming traffic, applies the emulation factors and then forwards it to the network. It can also be established in a distributed fashion, where every device in the network must have Dummynet enabled [2].

2.4. Comparison of NetEm, Nist Net and Dummynet

In some network setups it might be sufficient to test the network behavior under the effects of simple constant latency, but this is sometimes not enough for more complex network setups and testing them under real network conditions. With Dummynet it is only possible to add a constant amount of delay to a given pipe. It does not offer more complex distributions for the latency that are possible in Nist Net and NetEm. When performing simple experiments in a emulated network, Dummynet is definitely sufficient for adding constant latency, but it

cannot accurately simulate the latency behaviors of a real network setup with WAN characteristics like it is possible in Nist Net and NetEm [7].

In NetEm and Nist Net, the user can define the delay distribution to be constant, or alternatively specify a more complex distribution so that the latency follows a real latency behavior more accurately. In this regard, Nist Net and NetEm are similar, allowing for the latency to follow all kinds of distributions with optional correlation [2].

Emulation accuracy is also an important factor to consider, especially for emulating latency behaviors in a network setup. The more accuracy the emulation is able to achieve, the better one can test and approximate the network setup towards the real environment. In the context of the previously mentioned free network emulation tools NetEm, Nist Net and DummyNet, this accuracy is achieved by the used time resolution of the kernel clock [7]. DummyNet is able to utilize the system clock at the maximum of 10 kHz, whereas Nist Net and NetEm under Linux are only able to achieve up to 1 kHz [2]. In more recent Linux kernel versions, NetEm can utilize High Resolution Timers, providing even more accurate emulation effects [7].

The point of emulation plays a role in deciding for the optimal setup of a emulation network. DummyNet is able to emulate inbound and outbound traffic, and, therefore can be set up as a network router with emulation functionality, or in a distributed way, in which every device in the network will run a copy of DummyNet [2]. NistNet on the other hand is only able to emulate inbound traffic, while NetEm can only emulate outbound traffic [7]. Therefore NetEm is effectively setup in a distributed fashion, in which every device has to run NetEm for the emulation network to function properly, whereas Nist Net must be setup as a router between network nodes [2].

3. All-in-one Hardware WAN Emulators

Hardware Emulators typically do not differ drastically to the free software emulators in respect to their functionality and emulation capabilities, since a dedicated computer running a software network emulator could technically also be specified as a Hardware Emulator.

The Hardware Emulators discussed in this paper, however, will be those typically used in a network setup in a corporate environment, which has additional functionalities compared to the available free software emulators. These Hardware Emulators are costly, and, therefore, only a few of them will be used in such environments, in most companies only one of them will be used in order to emulate the whole network [2]. The installation effort of commercial all-in-one hardware emulators compared to the software emulators is much simpler, they need to be physically installed in the testbed setup and can be configured through user friendly GUIs. Additionally, the companies offering these all-in-one solutions often include additional services in case of faulty equipment, or troubles while installing the devices. The software emulators are targeted towards the "do it yourself" networking specialists, and require a certain skill set in networking, such as the Linux traffic control package, and routing the network flow. Additional configuration also needs to be expected when a software emulator is to be used.

Where the previously discussed free software emulators and hardware emulators drastically differ, are the speeds at which they support emulation. The software emulators support the speeds of its underlying computers, which will usually remain under 1 Gbit/s, while the Hardware Emulators such as the Netropy 10G or Netropy 100G are built for speeds of up to 10 Gbit/s and 100 Gbit/s respectively, which makes them very suitable for a real network emulation setup [2].

3.1. Apposite Technology Netropy 100G

Netropy 100G made by Apposite Technology is a special example of a Hardware WAN Emulator, since it allows speeds of up to 100 Gbit/s, a remarkable feature and one of the first to offer such high speeds in an all in one Emulator [8]. The Installation of the Emulator is straight forward. It is installed directly into the testbed, similarly to the installation of a switch or server. Its 100 Gbit/s emulation engine supports 15 concurrently running WAN connections, allowing for complex network setups and concurrent testing [8]. It offers network degradation features similar to the previously discussed free software link emulators, including a variety of bandwidth, latency, latency variation, and packet loss functionalities [8]. The device is able to impose anywhere from 0 to 10 000 ms of delay to each of its simulated WAN links, with the user being able to impose additional distributions similar to NetEm and NistNet, including normal, constant, uniform and many other distributions [8]. The Netropy device lineup also comes with an easy to use user interface, offering live traffic monitor, recording of loss and delay behaviors and most importantly configure the paths and emulation characteristics of the device [8].

3.2. Spirent Attero-100G

The Attero-100G is manufactured by the company Spirent and provides line delay of up to 256 ms for speeds of up to 100 Gbit/s. A delay rate of 256 ms on 100 Gbit/s emulation speeds, translate roughly to 50 000 km of a typical WAN, making it useful for emulating real WAN conditions [9]. The Attero 100G is a versatile all-in-one solution, since it can be used for testing many network types, such as VoIP, Telecommunication Applications, Cloud Computing and many more. Additionally, it can also be used as a tool for WAN emulation and acceleration [9]. It offers similar traffic impairment functions to the Netropy 100G, such as packet corruption, duplication, reordering, bandwidth manipulation, latency and jitter, and does so with a timing accuracy of 5 ns, providing a very swift emulation onto the packets [9]. Through the restful API, the user can reach the web based GUI, and manipulate impairment functions by configuring profiles [9]. The product comes with two profiles as a standard, providing emulation to one incoming and one outgoing stream, but this can be extended to 16 profiles with 8 incoming and 8 outgoing emulated packet flows concurrently [9]. The Attero-100G emulator offers a range of delay functions such as gaussian-, uniform- and not limited to gamma distributions, which can be explained as continuous probability distributions of the latency. The independent traffic flows allow for a different delay set up

for each profile, allowing for a complex testing network setup [9].

4. Comparison of Hardware WAN Emulators and Free Software Link Emulators

Having either an all-in-one Hardware WAN emulator or a computer, set up with one of the previously mentioned free software emulators, up and running, the results of latency emulation does not differ significantly between the two. In terms of the ability to emulate a real WAN environment latency behavior, both solutions are able to attain similar results. Taking NetEm and the Netropy 100G for example, the functionalities are very similar. The delay can be imposed in a simple fashion, but also in a more complex variation distribution. The speeds at which both, the hardware emulators, and software emulators are able to emulate depend on the hardware model, and the software emulators depend on the underlying computer, which it runs on. This certainly also has to be noted, since for high emulation speeds of up to 100 Gbits, the computer must be equipped with the necessary hardware, which, if not already available, becomes costly. The Netropy 100G and the Attero-100G are specific models that have ports, which support up to 100 Gbits right from the manufacturer.

Performance can differ greatly between a software and all-in-one hardware emulator, depending on the hardware used for software emulation. A PC running a software emulator shares its CPU resources with all of the operating system related processes in addition to the emulation software. The CPU resources needed by other processes can vary greatly and in return lead to a lower performance of the software emulator in terms of emulation speeds. This becomes even more apparent when more connections and impairment functions are handled by the software, increasing the CPU load by significant amounts [2]. The hardware emulators on the other hand are specifically built and optimized for handling multiple connections with multiple impairment profiles at the exact speeds which are specified by the different models available.

The Commercial all-in-one Hardware WAN Emulators are definitely more suitable for more complex network structures, since the setup, physical installation and configuration is straight forward. The software emulators are more complex to install, since they must be configured manually and the traffic flow through a PC running a software link emulator must be specified as well. The Attero-100G and Netropy 100G offer remotely accessible GUIs with ways to configure network degradation functions and real time performance statistics. This makes the commercial emulators useful for immediately evaluating the network behavior after imposing new delays, packet behaviors, etc. While these factors in terms of user friendliness and network evaluation are a clear improvement to the free software emulators, the high price of the commercial emulators weighs in on a decision between the two.

5. Fiber Optic Delay Lines

Fiber Optic Delay Lines can be considered as another type of Network Emulation Hardware with regard to

adding latency. They are another way of introducing fixed delay for network traffic, specifically in an optical network setup using glass fiber cables. A Fiber Optic Delay Line functions by receiving input traffic through a fiber cable connection, then routing the traffic through the length of the spooled fiber cable inside of the Fiber Optic Delay Line, and routing it back to an output channel [10]. The inherent characteristic of a fiber cable in being relatively resistant to interference factors, and having a low amount of propagation loss, makes this option suitable for adding a low amount of delay in an optical network [10]. Since the amount of delay added is proportionate to the length of the cable inside of the Fiber Optic Delay Line device, the introduced insertion loss will increase, meaning that the strength of light in the input is slowly lost through the length of the cables, but in most cases of hardware available, it is a negligible amount [11] [10]. A downside of using a Fiber Optic Delay Line is the increasing size and scale of the device, since the more delay is required, the more wound up fiber cable needs to be present inside of the device [11]. Another downside of this type of hardware are the amount of devices and ports needed to emulate a more complex network, since each Fiber Optic Delay Line needs its own switch port [11].

5.1. Fiberplus D8 Series

The Fiberplus D8 is a Fiber Optic Delay Line, which is installed in a server rack. The device can hold up to 45 km of fiber, or additionally 90 km of fiber cable spooled up inside of the device [12]. It offers network degradation emulation factors, such as loss, time delay and fiber emulation such as reflectance [12]. The amount of delay added is only available as a constant value, since the delay is not added artificially, but realistically, since the amount of cable that the traffic passes through is actually present. Since the propagation delay of fiber is about the vacuum speed of light [10], the total amount of delay added within the device will be in the example of the Fiberplus D8 in total up to 440 μ s with a minimum of 12 μ s [12].

5.2. Discussion of Fiber Optic Delay Lines

Since Fiber Optic Delay Lines are engineered towards optical networks, it is not directly comparable to conventional WAN emulators, the added delay can only be constant, since the delay is not simulated, but rather achieved by actual cable traffic within the device. But the fact that the network traffic which is to be emulated, actually travels over a fixed amount of cable, makes it useful for testing and emulating an actual geographically long distance optical network.

6. Conclusion

In conclusion, network emulation is a valuable tool for accurately approximating a test network environment in terms of real network behavior. Accurately simulating the latency behavior of a real network setup composed of multiple network nodes, including WAN structures, is an important step to achieve these real conditions. Multiple

approaches were listed and analyzed in this paper. This includes free software link emulators, such as NetEm, Nist Net, and Dummynet, which need an underlying computer to run its emulation software on, but also hardware emulators, such as the all-in-one devices Netropy 100G and the Attero-100G. The difference in the ability to emulate real latency to a specified network flow once either a software or hardware solution is set up is not great, therefore any of the listed approaches can be used to acquire a similar result. The configuration efforts and acquisition costs vastly differ between the software and hardware approaches. On one hand the software emulators discussed in this paper are free to use, they impose a more significant configuration effort and require a certain knowledge of its underlying operating system. On the other hand, the hardware emulators offer an all-in-one package, keeping the installation and configuration simple, and offering user friendly GUIs, with a drawback of high acquisition costs. For a large company, a all-in-one hardware package might be preferable, as one device can be sufficient to emulate a large scale network, while the software solutions offer a more budget friendly approach. For fiber optic networks, Fiber Optic Delay Lines can provide realistic network emulation, as these devices house the actual length of cable inside, therefore routing the traffic through the actual cable length and not just emulating it within software.

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