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Emulation of Satellite Links using 'NIST Net' Emulator – 'A Real Test-Bed'

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Abstract: The performance measurement of various wireless links is done using a simulator, emulator, or in real-time focusing on a variety of major performance parameters of the wireless links. Satellite links are one of the most widely used communication mediums for long-distance communication whose performance affects the overall performance of the heterogeneous networks. The simulation is the first step in performance evaluation which gives a synthetic environment with most of the things programmed and controlled which generally is unlike the real-time scenario. On the contrary, real-time testing has a constraint of availability, as well as, it is very difficult to arrange and control parameters in real-time. Whereas, the emulation provides a more realistic environment compared to the simulator by involving realistic hardware and links as well as allows the incorporation of performance parameters and network dynamics to see its real-time effects on packets being transferred. The research article focuses on emulating LEO, MEO, and GEO satellite links to study the effect of the performance parameters in run-time during actual communication. An in-depth analysis of the results and plots is carried out to understand the quality measures of satellite communication. The work concludes that the emulation results have higher similarity to real-time testing compared to simulation environment. Also, delay latency, file size and other link constraints affects the performance and hence they play an important role in deciding overall performance of data transfer.

Keywords: *GEO, Heterogeneous Networks, LEO, MEO, NIST Net, RTT, Satellite Link*

1. Introduction

The Internet has grown at a tremendous rate with a variety of wired and wireless links and networks. The field of high-speed communication has several distinct challenges to overcome to satisfy the requirements of data transfer at a higher rate. This in turn demands the best resources and methodologies to evaluate the performance of links in the presence of various link and network parameters affecting the actual performance in real-time as well as to come out with useful solutions from the performance evaluation study. Researchers use simulation, emulation, and finally, a real-time testing facility to evaluate the performance and the effect of various constraints that affect the overall performance of the communication. In heterogeneous networks, satellite networks play a vital role in establishing long-distance high-speed links for data transfer [1]. The satellite links have completely different constraints compared to short-distance wireless links. Performance evaluation of Satellite links requires a completely different approach which is considered to be the most important part of this research article. To set up a more realistic environment unlike the simulation in a programmed and controlled environment called software, is more challenging and the emulation technique is considered here for obtaining actual results [2]. One of the most famous network emulation tools 'NIST Net' is used to create a real test-bed for testing. The satellite links under test consider the Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geostationary Earth Orbit (GEO) satellite links [3], [4].

Section II explains the use of the NIST Net as a WAN Emulator. Section III describes the real test-bed setup and testing procedure. Section IV organizes the emulation results in tabular format. Section V focuses on comparing emulation results in the form of plots and analyzing the effects of network and link constraints on overall performance whereas Section VI concludes the research work.

2. NIST Net as a WAN Emulator

NIST Net is a network emulation tool that sits on an intermediate Linux server acting as a router to emulate a variety of network conditions, such as congestion loss, packet reordering, or asymmetric bandwidth conditions. Simply, the NIST Net can be seen as a "Network in a Box", as shown in Figure 1.

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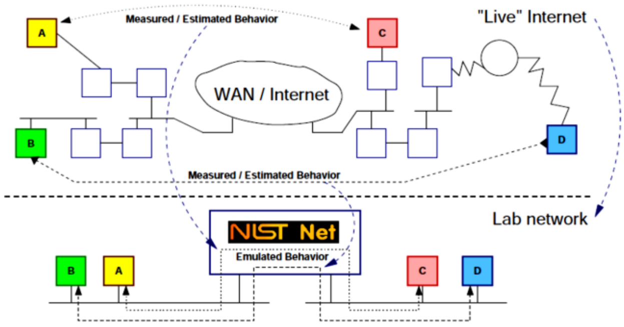

Fig. 1. NIST Net - A "Network in a Box"

As shown in Figure 2, NIST Net works through a GUI having emulator entries in the form of rows and columns. Each entry consists of three parts: A set of specifications of which packets are matched by this entry, A set of effects to be applied to matching packets, and A set of statistics of which packets have been matched by this entry [6], [7].

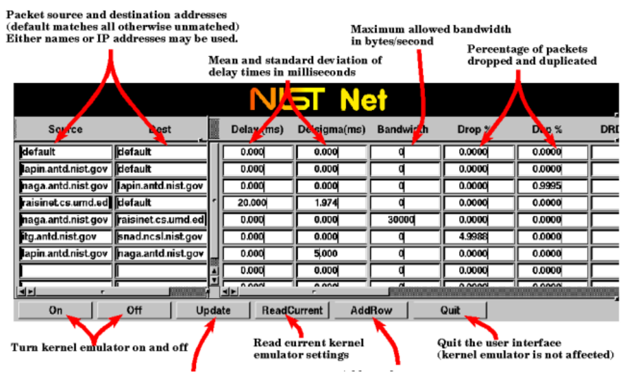

Fig. 2. NIST Net GUI

The set of network effects NIST Net can impose includes packet duplication, packet loss, packet delay, packet reordering, both fixed and variable (jitter), both random and congestion-dependent, and bandwidth limitations [8].

3. Test-Bed Setup and Testing

The setup consists of three desktop computers; two on either side of an intermediate desktop to create two different networks with the centre computer acting as a router, as shown in Figure 3. The NIC cards are configured in such a way that either NIC of the intermediate desktop creates a unique network with either side of the computers that emulates the source and destination are part of different networks. The NIST Net emulator software is installed on the intermediate node, i.e. router and default gateways are set in such a way that all source to destination and vice-versa communication passes compulsorily through the router. The satellite link parameters are set in NIST Net and file transfer is performed to generate traffic. The network dump is captured to note down required observations and to plot the communication response of the links under test [6], [7].

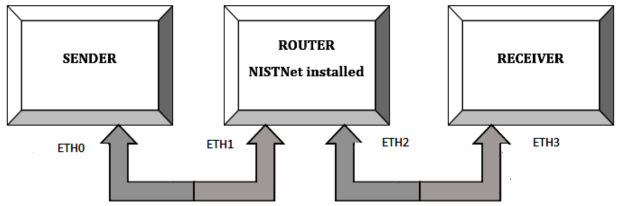

Fig. 3. Test-Bed Setup

4. Emulation Result Analysis and Discussion

Standard satellite links such as LEO, MEO, and GEO are considered for testing and the standard Round Trip Time (RTT) of these links i.e. 300ms, 400ms, and 500ms are taken as a delay reference respectively [11]. Percentage Bit Error Rates (BERs) of satellite links 0.1, 0.01, 0.001, and 0.0001 are inserted to introduce standard errors the packets suffer during the data transfer, and a case of no error 0.0 is taken as a reference to have an ideal response of the protocol under ideal test conditions. File sizes of 1 MB, 2 MB, and 5 MB are transferred to emulate and observe the effect of a small file size, a moderate file size, and a large file size transfer. Average throughput is considered as a data rate of the communication and the time taken to transfer file is the performance measuring and comparison parameters [5].

File Transfer Protocol (FTP) is used to generate traffic by transferring the variable file sizes via FTP sessions. To reduce the effects of network dynamics and other parameters like the speed of the computer, internal processes, and hardware configuration, all the observations are taken three times and averaged out. The observations are tabulated through the Tables 1 to 5.

An in-depth analysis of emulation outcomes and plots reveals the following facts about the quality of data transfer: Table 1 shows the observations for the emulation performed on the test-bed for 0% (No Error) rate which is considered as a reference for comparison of performance parameters in case of various error rates. In case of no error, LEO link outperforms by an average of 38% better than MEO link and an average of 61% better than GEO link whereas MEO link performs an average of 14.33% better than GEO link. For the LEO link, file transfer session of 5MB performs 42.5% better than 2MB and 2MB performs 56.58% better than 1MB. In MEO link, FTP session of 5MB performs 40.84% better than 2MB and 2MB performs 45.02% better than 1MB. In case of GEO link, data transfer of 5MB performs 42.15% better than 2MB and 2MB performs 41.44% better than 1MB.

Table 1. Drop rate 0% (No Error)

File Size \ Delay		LEO (300 ms)	MEO (400 ms)	GEO (500 ms)
1 MB	Avg. T'put (KBps)	725.80	542.40	473.32
	Avg. Time (Seconds)	1.59	2.42	2.46
2 MB	Avg. T'put (KBps)	1105.50	786.80	669.20
	Avg. Time (Seconds)	2.28	3.20	3.46
5 MB	Avg. T'put (KBps)	1575.42	1107.47	951.90
	Avg. Time (Seconds)	3.32	4.47	5.50

The graphical representation as shown in Figure 4 supports the analysis of the observations. A 3-D plot is chosen to represent the effects of various error rates and delay on data rates in terms of average throughput. The standard satellite links LEO, MEO and GEO links are marked on the X-axis, the average throughput is on the Y-axis, and on the Z-axis various file sizes are marked.

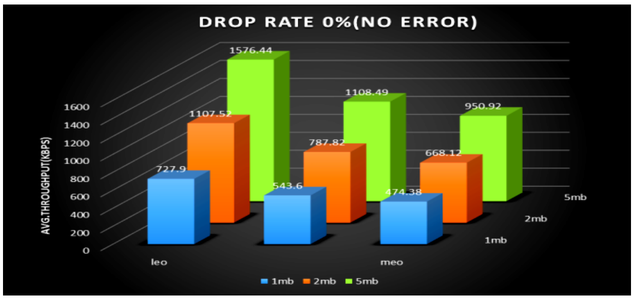

Fig. 4. Drop Rate 0% (No Error)

Table 2 shows the observations for the emulation performed on the test-bed for 0.1% error rate which is to be compared with a reference for comparison of performance parameters in case of various error rates. In the case of a 0.1% error rate, LEO link performs at an average of 27.66% better than MEO link and an average of 60.33% better than GEO link. The LEO link, file transfer session of 5MB performs 27.82% better than 2MB and 2MB performs 56.58% better than 1MB. The MEO link, FTP session of 5MB performs 39.91% better than 2MB and 2MB performs 25.04% better than 1MB. In the case of GEO link, data transfer of 5MB performs 25.45% better than 2MB and 2MB performs 66.17% better than 1MB.

Table 2. Drop rate 0.1% (BER - 10-3)

File Size \ Delay		LEO (300 ms)	MEO (400 ms)	GEO (500 ms)
1 MB	Avg. T'put (KBps)	668.79	591.45	402.45
	Avg. Time (Seconds)	1.49	2.21	3.20
2 MB	Avg. T'put (KBps)	1046.20	739.40	668.25
	Avg. Time (Seconds)	2.41	3.40	3.55
5 MB	Avg. T'put (KBps)	1335.22	1034.26	838.24
	Avg. Time (Seconds)	3.58	4.56	6.20

The graphical representation as shown in Figure 5 supports the analysis of the observations. As shown in the plot, LEO link performs consistently better than MEO and GEO links, whereas, MEO link consistently performs better than GEO links due to the delay variation factor. It is also confirmed that the throughput increases with the increase in file size for all respective observations in all types of links.

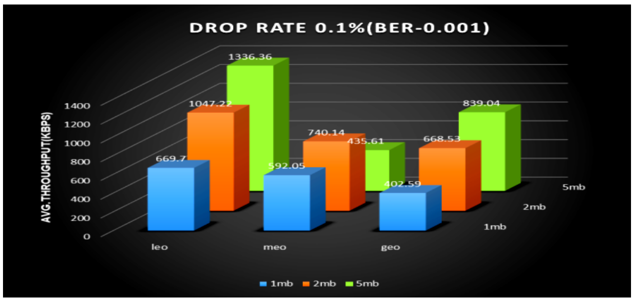

Fig. 5. Drop Rate 0.1%

Table 3 shows the observations for the emulation performed on the test-bed for 0.01% error rate which is to be compared with a reference for comparison of performance parameters in case of various error rates. In the case of a 0.01% error rate LEO link performs at an average of 27.33% better than MEO link and an average of 63% better than GEO link. The LEO link, file transfer session of 5MB performs 45.10% better than 2MB and 2MB performs 44.32% better than 1MB. In the case of a 0.01% error rate in the MEO link, FTP session of 5MB performs 50.51% better than 2MB and 2MB performs 34.59% better than 1MB. In the case of a 0.01% error rate in the GEO link, data transfer of 5MB performs 50.48%

better than 2MB and 2MB performs 44.16% better than 1MB.

Table 3. Drop rate 0.01% (BER - 10-4)

Delay / File Size		LEO (300 ms)	MEO (400 ms)	GEO (500 ms)
1 MB	Avg. T'put (KBps)	722.32	584.33	437.10
	Avg. Time (Seconds)	1.58	2.22	2.59
2 MB	Avg. T'put (KBps)	1042.22	786.60	630.21
	Avg. Time (Seconds)	2.40	3.20	4.20
5 MB	Avg. T'put (KBps)	1512.24	1183.34	948.25
	Avg. Time (Seconds)	3.43	4.40	5.53

The graphical representation as shown in Figure 6 supports the analysis of the observations. The increment in file size gives chance to enter in steady state response of the protocol to achieve higher throughput compared to smaller file sizes, which faces only initial response of the protocol.

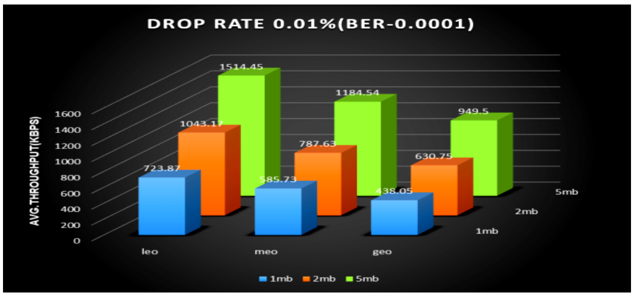

Fig. 6. Drop Rate 0.01%

Table 4 shows the observations for the emulation performed on the test-bed for 0.001% error rate which is to be compared with a reference for comparison of performance parameters in case of various error rates. In the case of a 0.001% error rate, LEO link performs at an average of 27.67% better than MEO link and an average of 24.67% better than GEO link. The LEO link, file transfer session of 5MB performs 46.28% better than 2MB and 2MB performs 48% better than 1MB. The MEO link, FTP session of 5MB performs 50.96% better than 2MB and 2MB performs 43.77% better than 1MB. The GEO link, data transfer of 5MB performs 50.48% better than 2MB and 2MB performs 44.83% better than 1MB.

Table 4. Drop rate 0.001% (BER - 10-5)

Delay / File Size		LEO (300 ms)	MEO (400 ms)	GEO (500 ms)
1 MB	Avg. T'put (KBps)	727.26	546.22	435.25
	Avg. Time (Seconds)	1.58	2.40	3.01
2 MB	Avg. T'put (KBps)	1076.30	785.24	630.10
	Avg. Time (Seconds)	2.34	3.21	4.01
5 MB	Avg. T'put (KBps)	1574.22	1185.12	948.21
	Avg. Time (Seconds)	3.32	4.41	5.51

The graphical representation as shown in Figure 7 supports the analysis of the observations. The effect of delay is reflected in proportion in case of small file size transfer but it is affecting lesser in case of large file size transfer which in turn achieves the higher overall throughput.

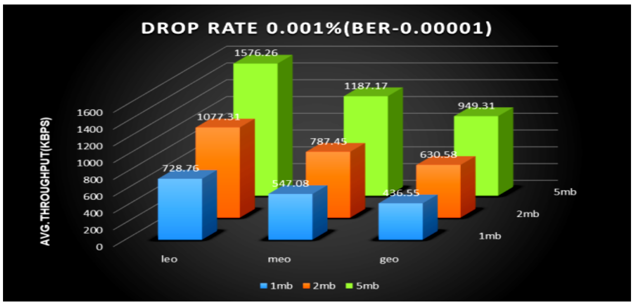

Fig. 7. Drop Rate 0.001%

Table 5 shows the observations for the emulation performed on the test-bed for 0.0001% error rate which is to be compared with a reference for comparison of performance parameters in case of various error rates. In the case of a 0.0001% error rate, LEO link performs at an average of 31.67% better than MEO link and an average of 66% better than GEO link. The LEO link, file transfer session of 5MB performs 50.09% better than 2MB and 2MB performs 36.64% better than 1MB. The MEO link, FTP session of 5MB performs 50.76% better than 2MB and 2MB performs 33.22% better than 1MB. The GEO link, data transfer of 5MB performs 42.71% better than 2MB and 2MB performs 52.87% better than 1MB.

Table 5. Drop rate 0.0001% (BER – 10-6)

Delay / File Size	LEO (300 ms)	MEO (400 ms)	GEO (500 ms)

1 MB	**Avg. T'put (KBps)**	767.21	590.17	435.23
	Avg. Time (Seconds)	1.55	2.21	3.01
2 MB	**Avg. T'put (KBps)**	1048.26	786.27	665.21
	Avg. Time (Seconds)	2.40	3.21	3.28
5 MB	**Avg. T'put (KBps)**	1573.27	1185.23	949.42
	Avg. Time (Seconds)	3.34	4.44	5.54

The graphical representation as shown in Figure 8 supports the analysis of the observations. A thorough comparative analysis of tabulated and plotted results reveals several facts about how the communications were handled by the protocol stack in the absence and presence of various network performance parameters. It is clearly seen that the delay and file size plays an important role in overall performance.

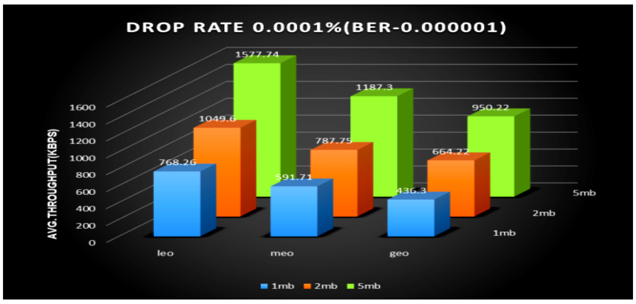

Fig. 8. Drop Rate 0.0001%

5. Conclusion

After a thorough analysis of the observations obtained, the following findings are concluded. The comparative analysis of observations and plots shows that the throughput decreases with the increase of delay latency. Also, with the increase in drop rates, performance goes down due to more number of retransmissions.

In addition to the above findings, it is also observed that the large-size file achieves higher throughput compared to the other two smaller file sizes. The reason is the small file size gets time to face only an initial response whereas the large file size gets additional time to face an initial as well as sustained response of the protocol. Hence, each takes different times for data transfer. Also, in case of higher file size, the throughput is higher and the effects of delay and especially loss become less prominent.

Further, Emulations and an in-depth analysis can be carried out to see the performance of various protocols working at different layer in case of variety of satellite links and dynamically varying parameters. A real-time testing can also be done on real satellite links to study and compare the performance of the parameters emulated as well as to check the effectiveness of the emulator and test-bed used for emulation.

5.1. Acknowledgment

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Conflicts of interest

The authors declare no conflicts of interest.