

3-2017

Understanding Traffic Characteristics in a Server to Server Data Center Network

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Understanding Traffic Characteristics in a Server to Server Data

Center Network

by

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Computer Engineering

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Dedication

I would like to dedicate this thesis to my parents Mr. Chandrasekaran and Mrs. Gayathri who have supported me from the beginning of my lifetime and my mentor and friends who have supported me throughout my academic endeavors.

Acknowledgements

I take this opportunity to express my profound gratitude and deep regards to my primary advisor Dr. Amlan Ganguly for his exemplary guidance, monitoring and constant encouragement throughout this thesis. Dr. Ganguly dedicated his valuable time to review my work constantly and provide valuable suggestions which helped in overcoming many obstacles and keeping the work on the right track. I would also like to express my deepest gratitude to Dr. Minseok Kwon and Dr. Andres Kwasinski for sharing their thoughts and suggesting valuable ideas which have had significant impact on this thesis. I am grateful for their valuable time and cooperation during the course of this work. I also take this opportunity to thank my research group members for all the constant support and help provided by them.

Abstract

The number of Data Centers and the servers present in them has been on the rise over the last decade with the advent of cloud computing, social networking, Big data analytics etc. This has eventually led to the increase in the power consumption of the Data Center due to the power hungry interconnection fabric which consists of switches and routers. The scalability of the data center has also become a problem due to the interconnect cabling complexity which is also responsible for the increase in the energy used for cooling the data center as these bundles of wires reduce the air flow in the data center. The maintenance costs of the data center is high due to this reason. This brings the challenge of reducing the power consumption as well as improving the scalability of the data center.

There is a lot of cost involved in the establishment of a network in a data center and this network is one of the main source of power consumption. Therefore, there is a need to accurately characterize the data center network before its construction which requires the simulation of the data center models. For the simulation of data center models, we require the traffic which is identical to that of an actual data center so that the results will be similar to a real time data center.

Traditional data center networks have a wired communication fabric, which is not scalable and contributes largely to the power consumption. This has led to the investigation of other methods. There have been transceivers designed that can support the unlicensed 60 GHz spectrum, supporting high bandwidth similar to the wired network present in traditional data centers. These wireless links have spatial reusability and the data centers can make use of this communication medium to meet the high bandwidth demands and also reduce the use of cable thereby bringing down the cost and the power consumption.

This thesis studies the previous traffic models used in the simulation of a data center network. Traffic collected from ten different data centers is then characterized and modelled based on various probability distributions. The implementation of the model tries to generate traffic similar to that of an actual data center. The Data Center Network is then simulated using the traffic generated and the performance of the wired data center is quantified in terms of metrics like throughput, latency and the power consumption of the data center networks.

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Glossary

DCN	Data Center Network
ToR	Top of Rack
LoS	Line of Sight
NS-3	Network Simulator 3

Chapter 1 Introduction

Data Centers have become the backbone of the present digital world as they provide the computing capabilities and the storage required for the billions of devices that are connected to the internet. The raise in the number of data centers and the servers present in them have contributed to the increase in the power consumption of the data centers. A census by the Natural Resources Defense Council (NRDC) claimed that the energy consumed by data centers were 91 billion kWh in 2013 and this is expected to reach 140 billion kWh by 2020 [1]. The increase in the number of servers in the data centers has emphasized the importance of the interconnect architecture in terms of Power consumption, latency and throughput. Traditionally, the data center networks (DCN) have a tree based interconnect topology, utilizing copper and optical cable as the wired links between the three levels of hierarchy namely core, aggregation and access in the tree topology. A major disadvantage of such a topology is that the scalability of such an interconnect topology is difficult and as a result it cannot handle when the Data center network is oversubscribed [2].

This wired interconnect fabric in the data center network, involves power hungry switches/routers and large bundles of the wired cables which obstructs the flow of chilled air which is blown into the data center for cooling. As the data center scales in size, the number of power hungry switches/routers increase and the amount of cabling also increases, causing maintenance challenges and increase in the power consumption of the data center network [3].

The recent advancements in transceivers that utilize the unlicensed 60GHz wireless band have given rise to an idea of a wireless DCN as an alternative to the existing wired DCN

[4]. Recent advancements have shown that transceivers that operate in the 60GHz band, consume low power in the range of mill watt [5][6]. Such Transceivers can communicate over distances of about 10m and can establish multiple channels in the gigabit range for communication [7]. The Spatial reusability of these 60 GHz channels gives room for multiple concurrent links with the same datacenter. The low power consumption of the transceivers combined with the spatial reusability of the 60 GHz channels makes this technology an ideal use in low power wireless DCN.

1.1. Motivation

Data Center Networks have been a heavily researched area both in the industry and the academia due to the increase in the number of data centers and also the over reliance on them for various computational and storage tasks on a daily basis. With the advent of cloud computing, social networking etc. the number of data centers have increased tremendously. The number of power hungry switches have increased causing increase in power consumption. The scalability of data center networks becomes difficult with the ever increasing resources in the Data Center. The ever growing Power consumption along with the scalability issues needs to be addressed as they pose a significant challenge.

Various topologies have been proposed over the years to improve the efficiency of the data center networks in terms of Power consumption, scalability, latency, throughput etc. Since the construction of data center networks incurs significant costs, it is wiser to simulate a data center environment to analyze if the data center network is able to provide the appropriate improvements in the various parameters.

In order to simulate the data center environment data center traffic which is similar to a real world data center is required. Data center traffic information is typically proprietary and difficult to get. Most of the data centers are completely enabled, but if we can accurately model the data center network, this can be avoided and helps in reducing power consumption. These data center network challenges provide the motivation for this work and serve as the reason for characterizing and modelling data center network traffic.

1.2. Thesis Contributions

This work seeks to characterize and model the data center traffic and also implement a data center traffic generation mechanism for various configurations using MATLAB and the mathematically modelled traffic parameters. The scalability of Data Center Networks poses significant challenges as the number of power hungry switches in the interconnect fabric increases, thereby increasing the power consumption. Different topologies have been proposed over the years to address the issue of scalability and reduction in power consumption. However, all topologies cannot be constructed as it involves lot of costs and hence simulation of the data center network to evaluate the parameters is the way. In order to get accurate simulation results, real world data center traffic is required for the simulation. The characterization and mathematical modelling of the various parameters involved in data center traffic are explained in depth in the third chapter.

This proposed work attempts to characterize and model data center traffic based on the traffic available from ten different data centers. The traffic generation is implemented and the characteristics of the generated traffic is then plotted and compared with the characterization done for verification. This traffic that has been generated is used to

simulate the data center environment and the various parameters like energy, latency and throughput are compared. A primary objective of this proposed work is to implement the data center traffic generation for various configurations and utilize the generated traffic to simulate the data center network.

1.3. Thesis Layout

This Chapter on Introduction speaks about the basic problems in a Data Center Network. The increasing power consumption and the non-scalability of the data center networks are the two major problems in the present day scenario. Chapter 2 gives a summary of the background and related work. This section explains the various topologies which were proposed to improve the scalability and decrease the Power consumption in the data center networks. It also explains about the wireless 60GHz channel and its advantages and how it can be used in a data center environment. Chapter 3 explains the characteristics of the data center traffic and how can these be mathematically modelled in accordance with their characteristics. The implementation details along with the generated traffic and their reflection of the characteristics of data center traffic discussed in chapter 3, is shown in Chapter 4 which is the Results and Analysis Section. Chapter 5 will finish with concluding remarks, highlighting the main problems addressed and also include a brief outline of future works.

Chapter 2 Background and Related Work

There are different approaches that have been proposed to address the data center design issues such as energy consumption, cabling complexity, scalability, and over-subscription. The most common topology used today in datacenter networks is a fat-tree topology. In this topology, servers are connected through a hierarchy of access, aggregate and core layer switches. The core switches also serve as gateways to the external Internet. The data centers utilizing this topology result in a problem of congestion of oversubscription at the upper levels of the hierarchy while the wired links cause maintenance challenges and obstructs the path of chilled air for cooling [2] [9]. Several alternative DCN architectures such as BCube [10], DCell [11], DOS [12], VL2 [13], Helios [14] has been proposed previously. BCube is a recursive topology specially designed for shipping container based modular data centers. DCell is also a recursively defined structure. DOS exploits wavelength routing characteristics of a switching fabric based on an Arrayed Waveguide Grating Router that allows contention resolution in the wavelength domain. VL2 uses Valiant Load Balancing to spread traffic uniformly across network paths. Helios is a hybrid electrical and optical switch architecture that can deliver significant reductions in the number of switching elements. However, these innovations still rely on copper or optical cables and do not eliminate the challenges due to a wired DCN with physical links. Wireless datacenters with mm-wave inter-rack links are envisioned in to alleviate the issues of conventional DCNs with bundles of cables [4] [15] [16] [17]. Most of the recent works on wireless datacenters propose interconnecting entire racks of servers as units with 60GHz wireless links primarily in order to utilize the commodity Ethernet switching between servers inside individual racks [4]. Phased array antennas or directional horn antennas are used to

establish wireless links between Top-of-Racks (ToRs) in the entire datacenter [17] [18]. Line-of-Sight (LoS) communication paths are necessary between the antennas for reliable communication in a wireless datacenter [17]. Paths through metal frames and racks will have increased losses due to obstructions. Hence, reflectors on ceilings and walls in the form of metallic mirrors or signal relays can be mounted to form paths where direct LoS does not exist [19]. In [20] a cylindrical arrangement of servers is proposed to create LoS wireless links between servers. This however, requires non-traditional cylindrical arrangement of servers having implications on cooling, server density and scalability of the DCN which are not well known at this point.

Owing to its capability to deliver very high communication rates, the unlicensed 60GHz wireless band has been the subject of attention for a number of years [21][22][23][24]. These efforts have led to the development and approval of the IEEE 802.11ad wireless local area network (WLAN) standard in December of 2012 [25] [26]. This standard extends the IEEE 802.11 family of WLAN standards to enable networking in the 60GHz unlicensed spectrum band within the V-Band frequencies in the US and achieving data rates of up to almost 7Gbps over distances of up to 10m [27]. A number of works have followed the approval of the standard with the design of the corresponding transceivers [8][28] [29].

This thesis analyses the existing traffic models and does a comprehensive study on these traffic models. A new traffic model is proposed and implemented which is similar to an actual data center. This traffic model is then used to simulate a wireless Top of Rack data center network and its power consumption, latency and throughput are analyzed and a comprehensive comparison with the previous model is done.

Chapter 3 Characteristics, Modelling and Implementation of Data Center Traffic

The number of data centers have been on the raise with the advent of cloud computing, social media and big data analytics. This has created public interest in data center networks as the power consumption and the scalability of the data center networks becomes of paramount importance. There have been many novel technologies proposed for data center networks in order that their operations take place in an effective and efficient manner. It is necessary to verify the characteristics such as power consumption, throughput, latency etc. of the data center, before its actual construction as the construction of such data center network incurs significant costs and it is practically difficult to conduct experiments with so many routes and switches. The way to verify the characteristics and confirm proper operations of the data center is through simulations and it must be ensured that these simulations are very close to the real world data center. One important aspect of such simulations is the traffic that will be used for simulating the data centers. It must be made sure that the traffic used in simulations of the data center networks is close to an actual data center. In many simulations Internet traffic has been used and over the years it has been confirmed that the data center network traffic is not similar to an Internet Traffic. Therefore, there is a need to analyze actual data center traffic and recognize the patterns and try to characterize the various parameters involved in the data center traffic. The next step would be to mathematically model these parameters and then finally implement them in order to have the traffic ready for simulation of the data center.

3.1. Characteristics of Data Center Traffic

The main challenge is characterizing the parameters similar to that of an actual data center traffic. In order to obtain accurate simulation results, the simulation environment must be similar to that of the data center that is going to be built in terms of topology, interconnect architecture, routers and switches etc. Previously, the traffic that was used for the purpose of data center simulation was generated artificially based on mathematical models. These mathematical models were built based on the characterization of Internet Traffic. However, the actual data center characteristics are different from that of Internet Traffic.

There are different kinds of data centers which have different type of traffic. University data center, private enterprise data center like google, Facebook etc. and cloud data centers which are used for cloud computing are the different types of data center. These data centers have been analyzed to see the type of applications in the different data centers, average size of the flows and the time duration of these communications, the amount of inter and intra rack communication etc.

There have been several improved network architectures proposed previously, but most of them were not simulated with traffic similar to that of an actual data center. The characteristics were not measured from any of the real world data center. In this thesis the characterization has been done based on the measurement from ten different data centers. The section below explains the various characteristics of the parameters involved in the generation of the data center traffic.

3.1.1. Overview of Data Centers used for characterization and collection of traffic

The data sets from ten different data centers (3 university, 2 private enterprise and 5 commercial data centers) were collected and analyzed. Table 1 shows the summary of the different data centers from which the traffic was analyzed.

Data Center Role	Data Center Name	Age (Years)	Number of Devices	Number of Servers	Over Subscription
University	EDU1	10	22	500	2:1
University	EDU2	7	36	1093	47:1
University	EDU3	1	1	147	147:1
Private	PRV1	5	96	1088	8:3
Private	PRV2	5	100	2000	48:10
Commercial	CLD1	5	562	10K	20:1
Commercial	CLD2	5	763	15K	20:1
Commercial	CLD3	5	612	12K	20:1
Commercial	CLD4	3	427	10K	20:1
Commercial	CLD5	3	427	10K	20:1

Table 1: Summary of Data Centers Studied

It can be clearly seen that the number of servers in a commercial data center is more than a private data center which in turn is more than a University data center. University and private data centers are hosted nearby, whereas a commercial data center is distributed throughout the world and hence the latency and other performance metrics become an important factor. The traffic patterns were collected on 10 days by polling the switches and nodes in the topology. The volume of traffic was observed in these data centers and the sub-chapter below explains the same.

In this thesis, the traffic from several small size data centers running a typical query-response type of applications like map-reduce and index lookup is used for the analysis and the characterization of the data center traffic. Therefore, the size of the data being

transmitted in a small size data center is typically small compared to the data centers handling video applications.

3.1.1.1. Traffic Volume Characteristics of a Data Center

The data center networks are always enabled for a high workload but they usually work well below their maximum possible workload. The traces collected from the data center shows that the volume of traffic varies daily (checking email), weekly (uploading documents), monthly (pay bills) and yearly (update address and other information). The traffic traces show that the volume of traffic in the data center networks is at its peak during daytime and its least during night.

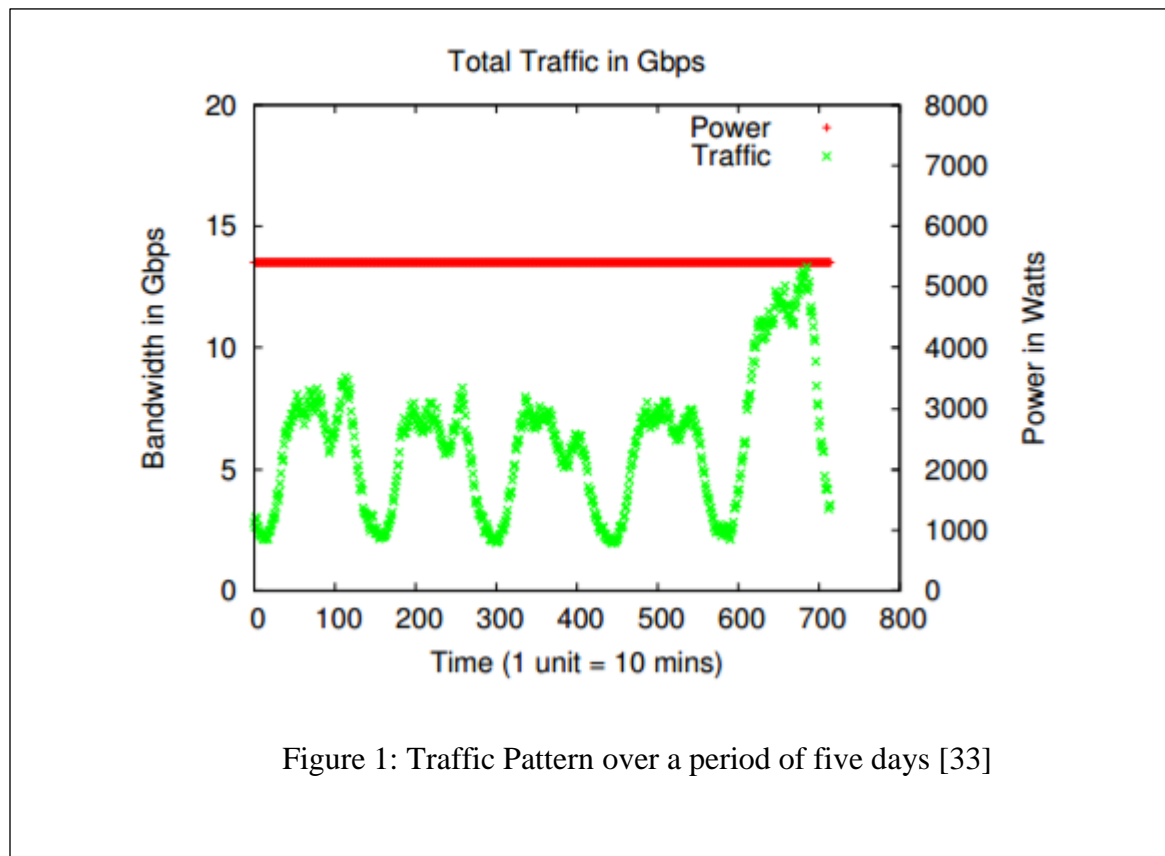


Figure 1: Traffic Pattern over a period of five days [33]

It can be seen from Figure 1 that the peak traffic is during the day and the traffic takes a dip during the night and the levels of traffic is also different on different days. The movement of this traffic in a data center is analyzed and characterized below.

3.1.1.2. Movement Characteristics of Data Center Traffic

Figure 2 shows us the topology of a generic data center. Traditionally, data centers had a 3-tier topology or 3 levels of hierarchy namely Core, Aggregation and Edge. The Edge layer consists of Top-of-Rack switches which connects the cluster of servers to the Data Center Network. The aggregation layer consists of devices which connects the switches in the edge layer together. Finally, the Core Layer connects the entire DCN to the WAN.

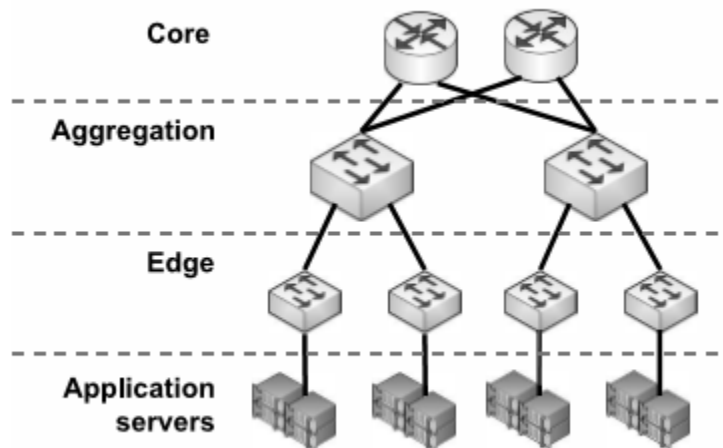


Figure 2: Traditional 3-Tier Data Center [31]

There will be the need for one server to communicate with another in various applications and naturally there will be a source and a destination server for this communication.

Analysis of the traffic from the ten data centers show that 80% of the traffic stays within

the same rack, meaning that only the switches in the edge will be used for this type of communication. This percentage could change depending on the type of data center under consideration but will hold good for most cases. Applications of the same kind are arranged close to each other so that they can communicate with the host easily thereby reducing the cost of communication. This is the reason for the high percentage of intra rack traffic. The remaining 20% of traffic takes place between servers located in different racks. The size and Duration of these intra and inter rack traffic is an important parameter and these are analyzed and characterized in the below section.

3.1.1.3. Size and Duration Characteristic of Data Center Traffic

The terminology “flow” refers to the sequence of data arriving at a particular instance of time, transmitted from a source to a destination, of a certain size at a particular transmission rate. The flow contains the details about the arrival time, source node, destination node, size of that particular communication, transmission rate for that particular communication.

The analysis of the traffic from the ten data centers show that 80% of the traffic are less than 11seconds in duration and less than 10Kb in size. It was seen that only 0.1% of the flows lasted more than 200 seconds. The major volume of traffic is contributed by 10% of the flows.

On plotting graphs for flow duration vs the CDF and flow size vs flow duration it was found that there is no direct relationship between the flow duration and the flow size and hence it is difficult to model them. However, the CDF of flow size over the duration shows that there is a proportional relationship between them.

A correlating factor is required in order to model the relationship between the Flow duration and the flow size. The transmission rate can be considered as the correlating factor in this case.

Now that the parameters have been characterized, it is important to model them mathematically and implement the same for the generation of the data center traffic.

3.2 Modelling and Implementation of Data Center Traffic

It has been well documented that the simulation of the data center network will require traffic which is similar to real world data center. This is a necessity to get accurate results and evaluate the performance of the data center network. In the previous section we have seen how the various parameters have been characterized based on the data available from the ten data centers. It is now important to accurately model these characteristics using various mathematical tools for implementation and get the necessary traffic for simulations. The primary traffic parameter is the arrival rate of the flows/traffic, which is modelled in the below section.

3.2.1. Modelling of the Flow Arrival Rate

The Poisson Shot-Noise Process is used for modelling the data flow arrival in a data center network. The flows are independent from each other [32]. Poisson distribution is an ideal model only if the rate at which the event (flow arrival) occurs is a constant. However, the flow arrival rates change and are different at different points in time. There are more traffic/flows during the day and less during the night. Therefore, we need to model the arrival rate as a non-homogeneous Poisson distribution. The key point here is though the

change in the arrival rate is slow compared to the flow generation interval (usually 1 second). Due to this reason we can model the arrival as a homogenous Poisson distribution with a fixed arrival rate and the Poisson distribution is a good choice to represent the flow arrival rate.

Mathematically, the number of flow arrivals can be represented as (1), where ‘N’ is the total number of flows, T_{start} is the flow start time and T_{end} is the end time of the flow generation and $\lambda(t)$ is the average flow arrival in a given time interval ‘t’.

$$N = \int_{T_{\text{start}}}^{T_{\text{end}}} \lambda(t) dx \quad (1)$$

The value for $\lambda(t)$ for the implementation was 192, meaning an average of 192 flows arrived every second. Depending on the number of flows required and simulation time this number can be changed accordingly. The transmission of these flows from a source to a destination is modelled in the following sections.

3.2.2. Modelling of Topology, Source and Destination Nodes

In a data center servers are piled up in the form of racks and servers handling similar applications are kept in the same rack in order to reduce the communication cost. Hence there are several racks of servers, which are connected to each other through a switch in a traditional 3-tier data center as seen before. In the implementation, the total number of racks has been set to 160 with each rack having 10 servers, thereby having a total of 1600 servers. These parameters can be played around depending on the required configuration for the data center network.

It is known from the previous analysis of the traffic data that 80% of the traffic stays within the rack and only 20% is rack to rack communication. Therefore, selection of the source and the destination nodes must be in such a way that 80% of the times, the source and destination nodes are from the rack and 20% of the times they are from different racks. This can be modeled as a Bernoulli distribution with the probability of source and destination being picked within the same rack is 0.8 and servers being picked from different racks is 0.2.

$$\mathbb{P}([S_n = k]) = \binom{n}{k} p^k (1 - p)^{n-k} \quad (2)$$

The Bernoulli distribution is given by (2), where ‘p’ represents the probability of servers being picked are from the same rack and ‘q’ represents the probability of servers being picked are from different racks. ‘p’ is equal to 0.8 as that is the probability of success that servers being picked are from the same rack and ‘q’ is equal to 0.2 as that is the probability of success that servers being picked are from different racks. The modelling of the protocol for the different flows is followed up in the next section.

3.3.3. Modelling of the Protocol for Communication

There are two major protocols used in data center networks for communication between servers namely TCP and UDP. It has been seen from the studies of the data center traffic that 85% of the communications happens through the ‘TCP’ and 15% of the communications take place through the ‘UDP’ [32]. Therefore, this can be modelled as a Bernoulli distribution with parameter ‘p’ as the probability of ‘TCP’ protocol being used

(with a value equal to 0.85) and ‘q=1-p’ is the probability of ‘UDP’ protocol. The duration for which each of these flows exists is modelled in the below mentioned section.

3.3.4. Modelling of the Flow Duration

From the analysis of the traffic data from the ten different data centers, it was seen that 80% of the flows last less than 11 seconds. On the other hand 0.1% of the flows last longer than 200 seconds. This type of characteristic is similar to a Pareto distribution which was originally used to describe of wealth among individuals. Larger portion of the wealth is owned by a smaller percentage of people and vice versa. Therefore, the flow duration can be modelled using a Pareto Distribution by adjusting the shape parameter a_p and the scale parameter M_p in the Pareto Distribution. When the values for a_p and M_p were 1.504 and 1.0001, it represented the duration obtained from the traffic obtained from the ten data centers, the best. The duration can be represented by the Pareto Distribution as shown in (3).

$$Pr(X > x) = \begin{cases} (\frac{x}{M_p})^{a_p} & \text{for } x \geq M_p \\ 1 & \text{for } x \leq M_p \end{cases} \quad (3)$$

The inter arrival time, which the time difference between two consecutive flow arrivals can be represented by an exponential distribution. The modelling of the transmission rate and the size of the flows is discussed in the below mentioned section.

3.3.5. Modelling of the Flow Transmission Rate and Size

It has been seen from the characteristics of the size and duration of the traffic that they are not independent of each other and also that they are not in a linear relationship. However,

from the characteristics discussed in previous chapter it can be concluded that they are in a proportional relationship. Accurately modelling a Joint distribution for the size and the duration is very difficult. To simplify the modelling, two distributions for the size and the duration is used. The transmission rate is used to correlate the relationship between the size and the duration. If, S_n is the size of the n^{th} flow and D_n is the duration of the n^{th} flow then the mean transmission rate Y_n correlates the size and the duration as in (4).

$$S_n = Y_n \cdot D_n \quad (4)$$

In order to find S_n , we will need to find the distribution of Y_n , for which we need to analyze the transmission rate pattern from the traffic obtained from the ten different data centers. Since the transmission rates are studied from the several traffic flows from the ten different data centers, from the empirical observation, it can be concluded that the transmission rate follows a Gaussian distribution. In general, any data that is studied over long periods of time follows a Gaussian distribution. Y_n , is modelled as a Gaussian distribution as shown in (7) and Y_n and D_n are independent random variables. In order to mathematically model and implement the transmission rate we will need to find the mean and the variance of the transmission rate as shown in (5) and (6).

$$\mathbb{E}[Y_n] = \frac{\mathbb{E}[S_n]}{\mathbb{E}[D_n]} \quad (5)$$

$$Var[Y_n] = \frac{\mathbb{E}[\frac{S_n^2}{D_n}]}{\mathbb{E}[D_n]} \quad (6)$$

$$Y_n \sim f_g(x, \mathbb{E}[Y_n], \sqrt{Var[Y_n]}) = \frac{1}{\sqrt{2\pi \cdot Var[Y_n]}} e^{-\frac{(x - \mathbb{E}[Y_n])^2}{2Var[Y_n]}} \quad (7)$$

From the above mentioned calculations, it was found that the mean of the transmission rate of the traffic obtained from the ten data centers was 4.303 KBps and the standard deviation was 264.45 Bps. Similarly, the mean of the size of the flows were found to be 8517.91 Bytes.

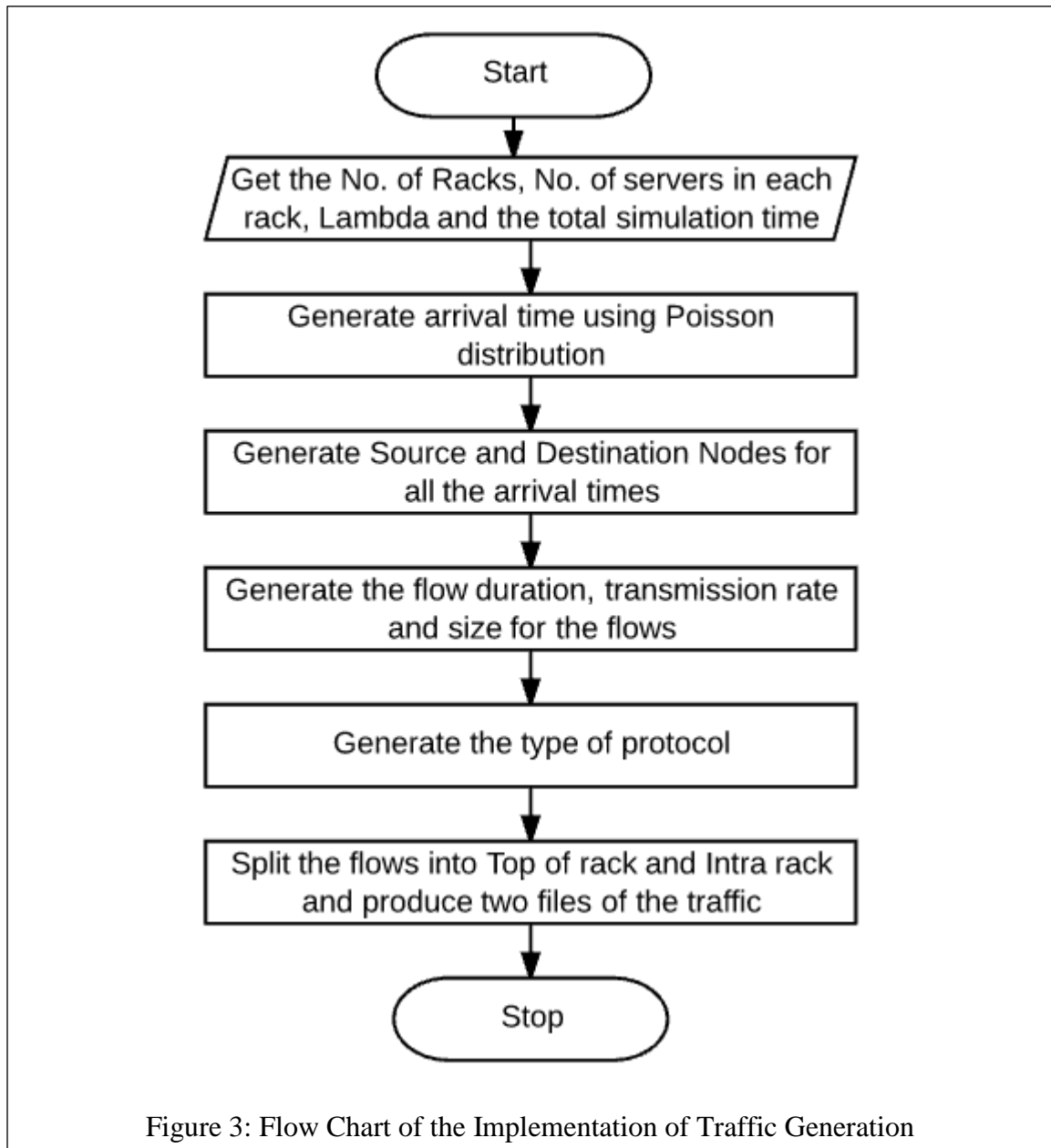
Name	Model	Parameters
Flow Arrival Rate	Poisson	$\lambda(t) = 192$; Can be varied according to reqd. configuration
Intra Rack Flow Ratio	Bernoulli	$p =$ probability of internal rack flow= 0.8
TCP Flow Ratio	Bernoulli	$p =$ probability of TCP flow= 0.85
Flow Duration, Dn	Pareto	$\alpha_p = 1.504$; $M_p = 1.0001$
Flow Transmission Rate, Yn	Gaussian	Mean= 4.303 KBps, S.D= 264.45 Bps
Flow Size, Sn	Yn . Dn	Mean= 8517.97 Bytes

Table 2: Summary of the Names, their models and their parameters

Table (2) summarizes how the various parts of the flows are mathematically modelled along with their respective parameters.

Figure 3 is the flowchart of the implementation of the Traffic Generation. The configuration of the Data center network is obtained as the first step. This includes information such as the number of racks of servers present in the data center, the number of servers present in each rack of the data center, the total simulation time of the data center

and the value of arrival, in case it needs to be manually changed. The default value for lambda is 192. The total simulation time and the value of lambda is passed as arguments to the function implementing the arrivals rates based on a Poisson distribution, and also returns the total number of flow arrivals for the entire simulation duration. The total number of flows along with the number of racks and the number of servers is then passed on to the function implementing the start and end node generation, which then produces pairs of source and destination nodes, in the same rack based on Bernoulli distribution with a probability of success of 0.8 and in different racks with a probability of 0.2. The number of flows is then passed to the function which generates the rate, duration and the size for the flows based on the distributions and parameters mentioned in Table 2. The protocol for all the flows is then generated based on a Bernoulli distribution with ‘TCP’ having a success rate of 0.85 and ‘UDP’ having a success rate of 0.15. The traffic is then split into two files based on source and destination nodes being intra rack and inter rack.



Chapter 4 Results and Analysis

The characteristics and the modelling of the data center traffic was done in the previous chapter. The characteristics that have been mathematically modelled was then implemented using MATLAB and its inbuilt functions. Individual functions were written to generate the flow arrival rate (based on Poisson distribution), Start and End node generation (80% Intra Rack and 20% Inter rack), Flow Duration, Transmission Rate and Flow Size (Pareto, Gaussian and Product of the two distributions). A main script was written which takes the Number of racks of servers present in the data center, the number of servers present in each rack, the total time duration of the simulation and the value of lambda as the inputs and will pass on these parameters to the various functions to generate the required data center traffic. The evaluation of the implementation of the traffic generation was done by plotting the graphs for the various traffic characteristics described in the previous section and comparing them with the graphs of the distribution of those probability distributions as well as comparing the graphs plotted in the previous papers for the various traffic characteristics and comparing those with the same graphs produced by the generated traffic. In the implementation, the Number of racks of servers present in the data center was 160, the number of servers present in each rack was 10, the total time duration of the simulation was 100 seconds and the value of lambda was 50.

4.1. Flow Arrival Rate

From the characteristics it was mathematically modelled that the flow arrival rate follows a homogenous Poisson process from the start time to the end time. For this implementation

the value of lambda was fixed to 50 to limit the total number of flows for the total simulation time.

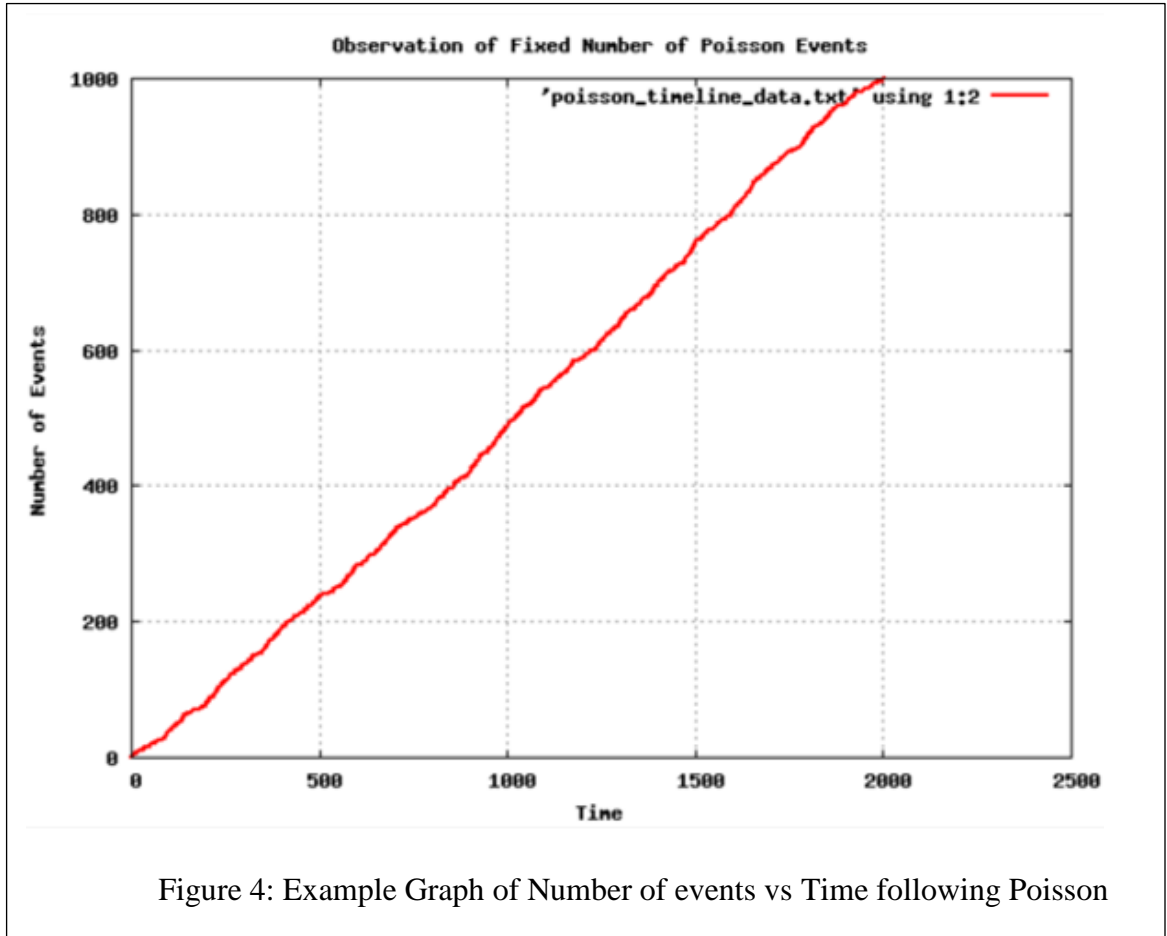


Figure 4: Example Graph of Number of events vs Time following Poisson

It can be seen from figure 4 how the number of events over time keeps increasing gradually for a homogenous Poisson process. Similarly from the implementation of the arrival rate for the traffic generation figure 5 was plotted for the number of events vs the entire simulation period of 100s and the above graph was obtained.

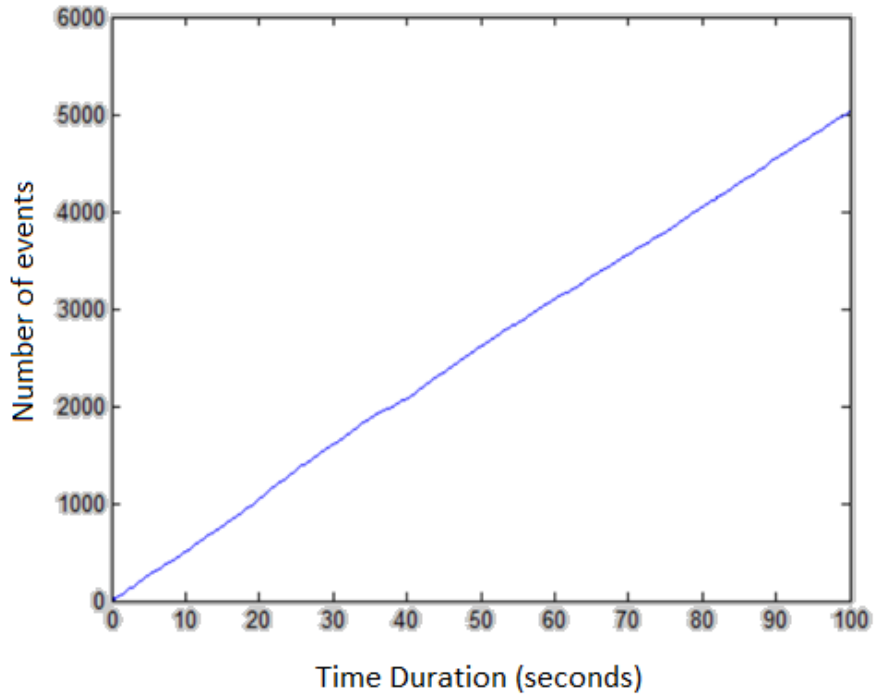


Figure 5: Graph of Homogenous Poisson Process for Arrival rate

4.2. Source and Destination Node generation

It was seen from the characteristics of the data center traffic that 80% of the traffic stayed within the rack (intra rack) and only 20% of the traffic left the rack (inter rack). This was modelled as a Bernoulli distribution with the probability of the source and destination nodes from the same rack being 0.8 and the probability of the source and destination being from different racks being 0.2.

In the implementation, from a total 4926 flows that were generated 3957 flows were intra rack contributing to 80.33% of the total number of flows and 969 flows were inter rack contributing to 19.67% of the total number of flows. Figure 6 shows a pictorial representation of the percentage of the inter rack flows versus the intra rack flows. In the

Pie Chart as shown below, 80.33% (marked in red) of the flows are intra rack flows, meaning the communication stays within the rack and only 19.67% (marked in blue) of the flows move from one rack to another. This is in conformance to the characteristics observed in the Data Center traffic and helps in evaluating the generated traffic.



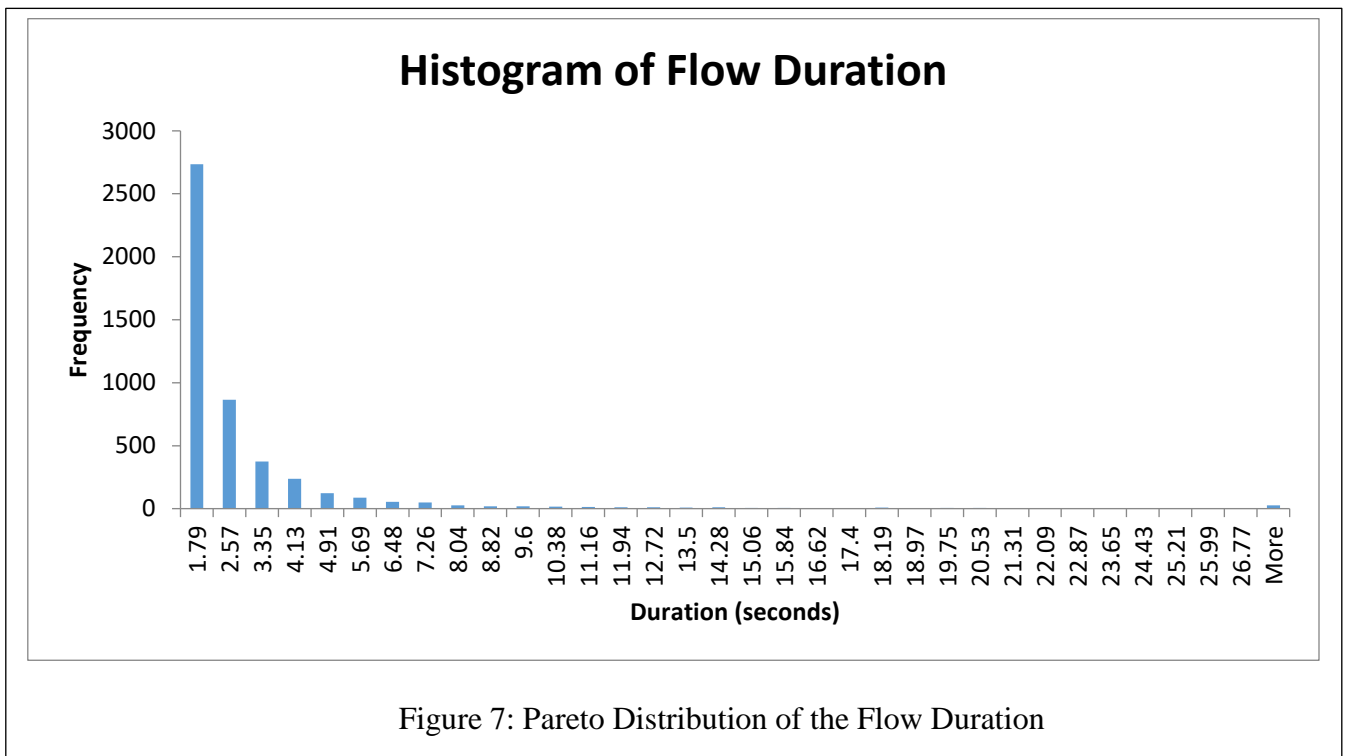
Figure 6: Split of the Intra rack and Inter rack flows

4.3. Flow Duration, Transmission Rate and Flow Size

As documented in the previous chapter the relationship between the Flow duration and the Flow size is not linear but a proportional relationship. Instead of having a joint distribution of the flow duration and the size, we have two distributions for the duration and size and correlate them using the transmission rate. The duration was modeled as a Pareto distribution and the Transmission rate was modelled as Gaussian distribution. The Flow size was modeled as a product of the transmission rate and the flow duration.

4.3.1. Flow Duration

According to the characteristics mentioned, 80% of the flows last less than 11 seconds and only 0.1% of the flows last longer than 200 seconds. This was modeled as a Pareto Distribution, which was used to describe the wealth owned by people. In a Harvard Business Review which classified the wealth among people of America, it used a Pareto Distribution.



The Pareto distribution was used as a part of the Harvard Business Review on wealth distribution in the United States of America was used to show that the larger portion of the wealth was owned by a smaller population and the smaller portion of the wealth was owned by a larger population. This is similar to the traits of the Flow duration. Large number of flows have a small duration and a small number of flows have a large duration. The value of the shape parameter was taken as 1.504 and that of the scale parameter was taken as

1.0001 for the implementation of the duration as a Pareto distribution. Upon implementation of the flow duration as a part of the traffic flow generation the histogram of flow duration was plotted. Figure 7 represents the histogram of the flow duration which is similar to a Pareto distribution. It was also verified that 80% of the flows lasted less than 11 seconds.

4.3.2. Transmission Rate

The transmission rate which is used to correlate the Flow duration and the Flow size is modelled as a Gaussian distribution. The mean for the Gaussian distribution was 4.303 KBps and its standard deviation was 264.45 Bps. The same was implemented in MATLAB and the transmission rates for the flows were obtained as a part of the traffic generation. Upon implementation of the traffic generation, the Probability Distribution Function of the transmission rate was plotted and Figure 8 was obtained as its result. It can be seen that the mean is the point in x-axis for which the graph has the maximum value of y and this case the mean between 4000 and 4500, approximately close to 4300 which is the requirement for the transmission rate in the traffic generation.

Figure 9 shows the histogram of the transmission rate plotted from the transmission rates that were generated as a part of the traffic generation.

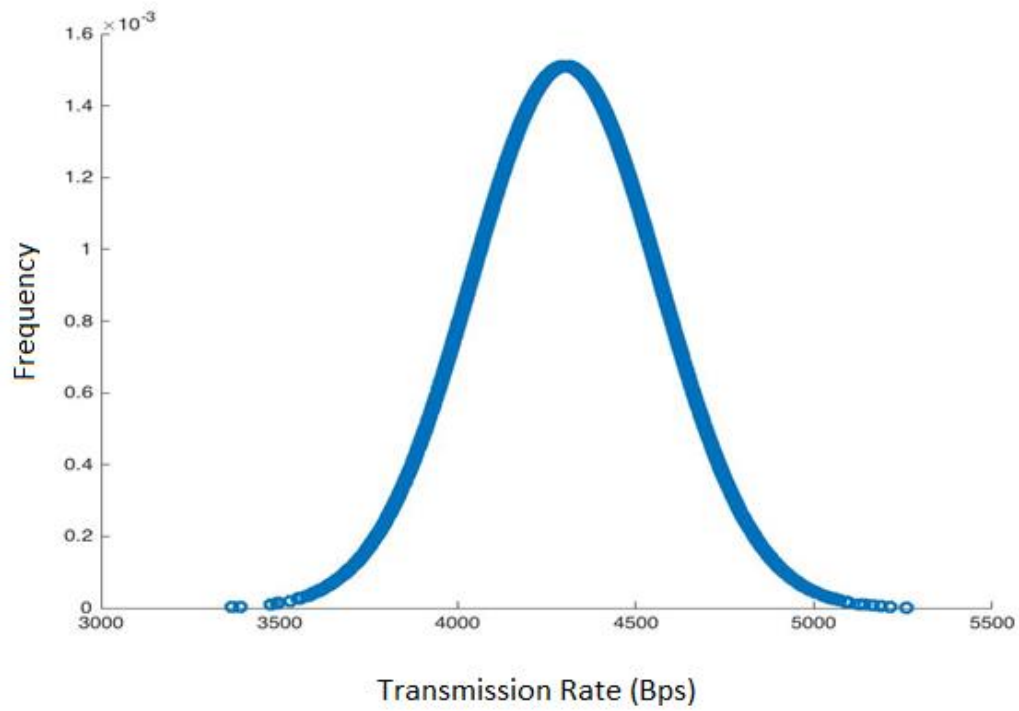


Figure 8: PDF of the Generated Transmission Rate

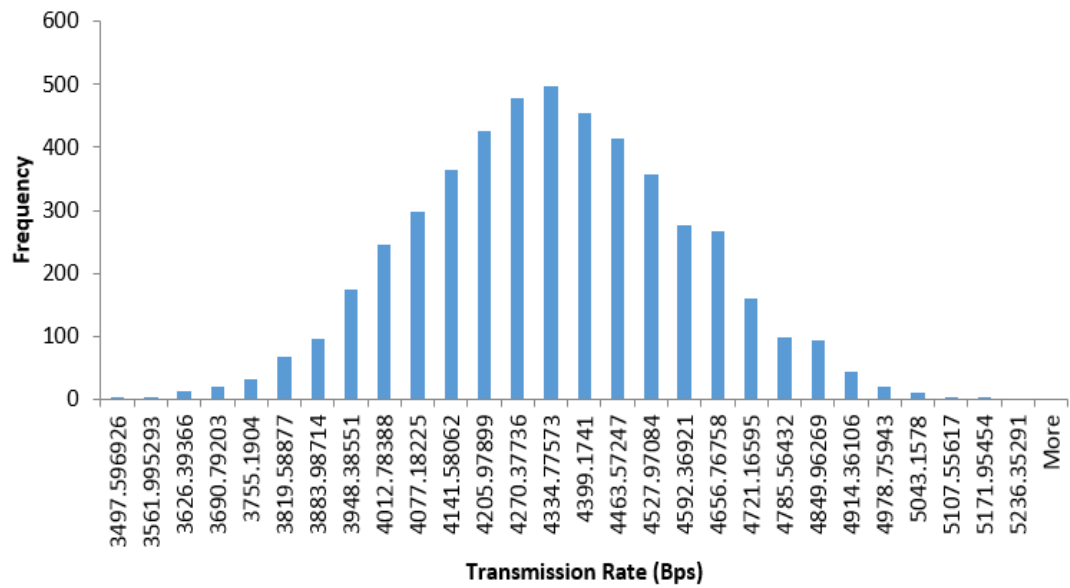


Figure 9: Histogram of Transmission Rate

4.3.3. Flow Size

The flow duration and the flow size are not in a linear but a proportional relationship. Instead of having a joint distribution of the flow duration and the size, we have two distributions for the duration and size and correlate them using the transmission rate. The flow size is given as the product between the Duration and the Transmission rate which correlates them. Once the Flow Duration and Transmission rates have been individually modelled and generated, they are multiplied in order to get the Flow size. Since the Duration and the Transmission are not a joint distribution, the distribution of the size cannot be accurately modelled as a distribution. Hence, once the Flow size is generated, the various plots are generated and these are compared with similar plots generated by the original data center traffic to verify its correctness. Some of the plots that are generated upon implementation of the traffic generation are the Flow Duration vs CDF, the Log (Flow Size) vs CDF, the size vs the duration. These plots are then compared with the similar plots generated from the original data center traffic. Figure 10 depicts the plot of Flow Duration vs CDF for the generated traffic, which is how the graph is expected to be from the characteristics of the data center traffic. Figure 11 depicts the plot of Log (Flow Size) vs CDF for the Generated Traffic, which is how the graph is expected to be from the characteristics of the data center traffic. . Figure 12 shows the plot of the cumulative distribution of the flow size over flow duration and it can be clearly seen that their relationship is not linear but a proportional relationship.

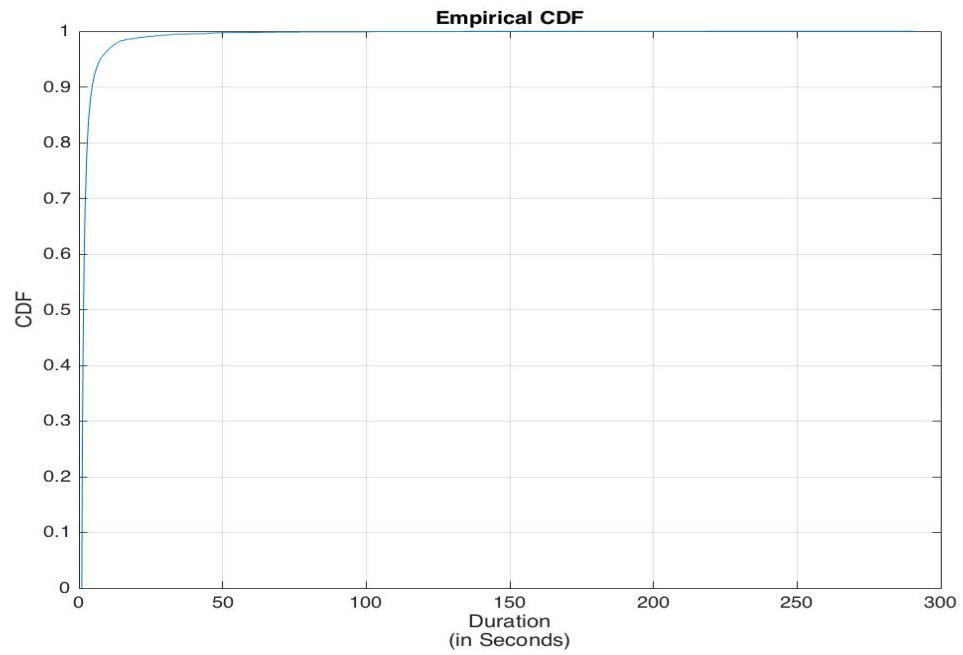


Figure 10: The plot of Flow Duration vs CDF for Generated Traffic

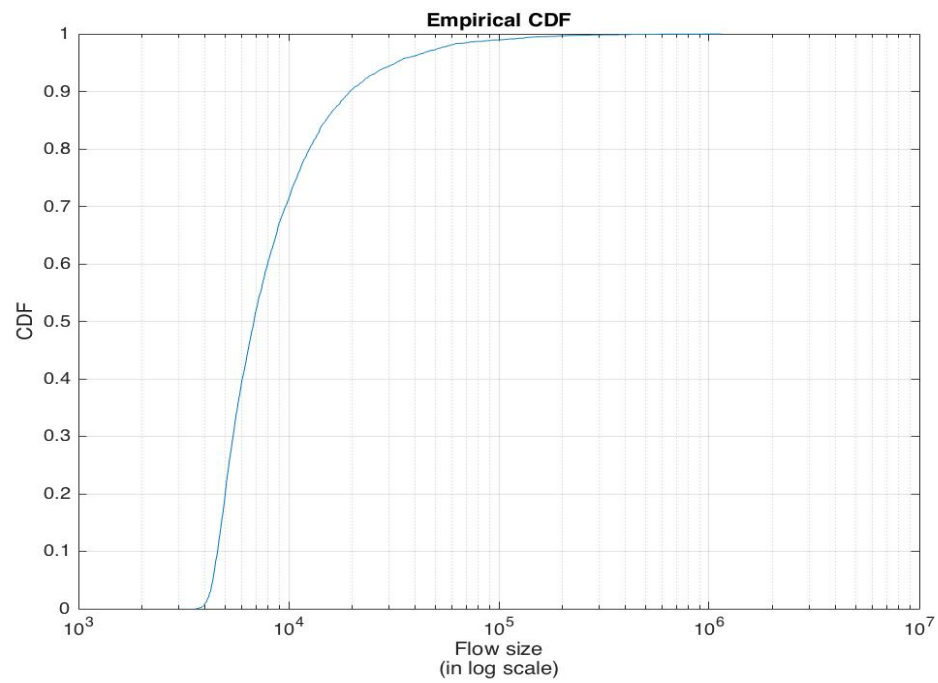


Figure 11: The plot of Log (Flow Size) vs CDF for Generated Traffic

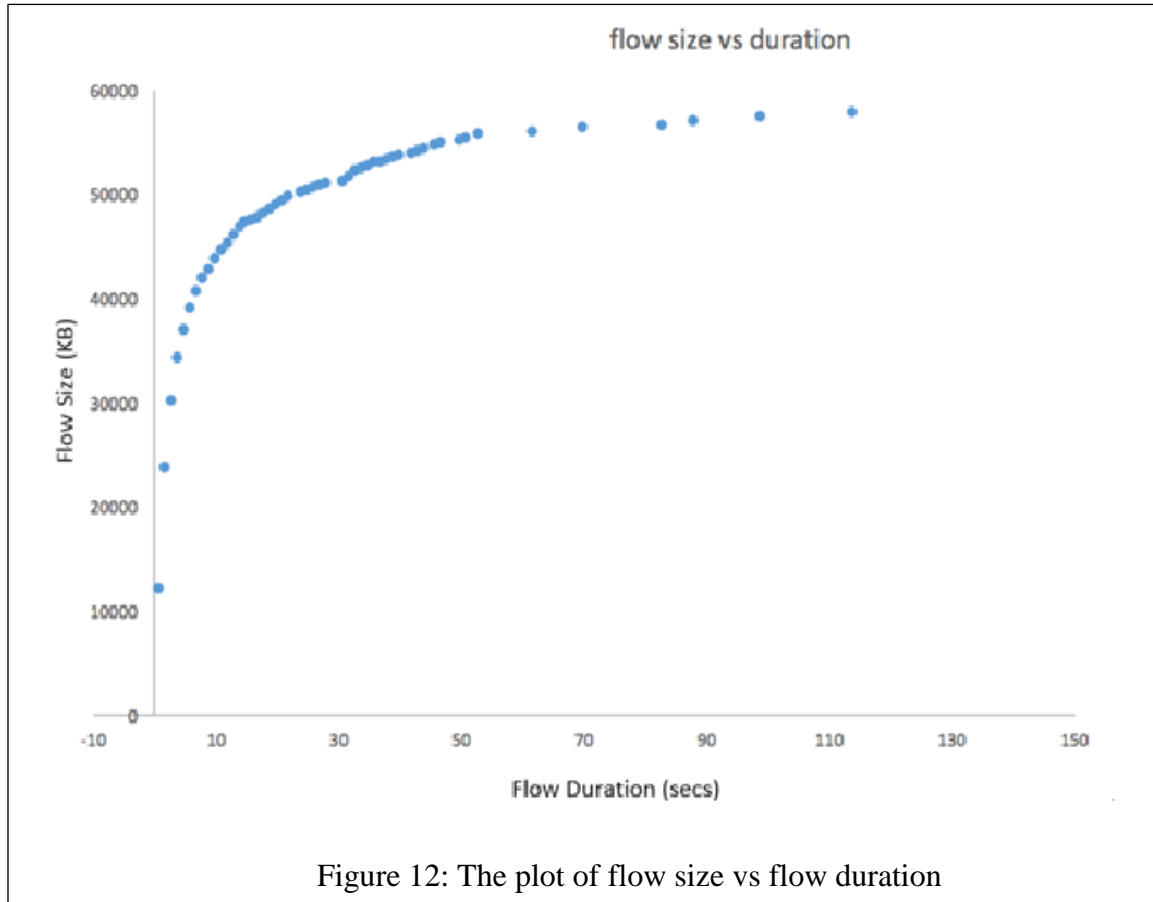


Figure 12: The plot of flow size vs flow duration

The graph above reiterates the fact that there is no accurate mathematical model to represent the relationship between the flow size and the flow duration. From the above graph it can be seen that the flow size and the duration are in a proportional relationship, but not in a linear relationship. The flow size keeps increasing initially, after which it seems to become a constant. Additionally, as the flow duration increases the transmission rate decreases.

Chapter 5 Conclusions

5.1. Concluding Remarks

In this work data center Traffic was characterized, modelled and implemented and the plots of the implemented Traffic was compared with the way it was modelled for verification. The Arrival rate was modelled as a Homogenous Poisson Distribution with a Lambda value of 50, simulation time as 100 seconds, the number of racks of servers in data center as 160 and the number of servers in each rack as 10. The Source and destination node was modelled as a Bernoulli distribution with 80% of data staying within the rack and 20% moving from one rack to another. The Flow Duration was modelled as a Poisson distribution with appropriate shape and scale parameters. The Transmission rate was modelled as a Gaussian distribution with appropriate mean and variance. The flow size was computed as a product of the transmission rate and duration.

The Traffic was generated for the simulation of the data center network. The plots of the various parameters of the traffic was generated for verification. The configuration of the data center network can be changed and different traffic can be generated as per our requirement.

5.2. Future Work

This work provides an in depth analysis of the data center traffic. The characterization, modelling of the traffic was explained and the same was implemented and verified at the flow level. The method generates data center network traffic at the flow level. However, generating the traffic at the network packet level would be a future work. In this work the

arrival rate, ratio of traffic in same rack, flow duration and size and the transmission rates are appropriately characterized. One of the main future tasks would be to develop the traffic at the network packet level. The characteristics of the packets in the data center network needs to be studied in depth. These characteristics need to be mathematically modelled using appropriate distributions followed by the implementation of the Data Center Traffic at the Packet level.

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