Comparative Analysis of Switch Based Data Center Network Architectures

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Abstract: **Data center networks provide cloud-based services and are scaling constantly. Several data center network architectures are proposed to support heterogeneous kind of applications. The architecture majorly influences performance of data center network. In this paper multi-tiered, fat-tree and flattened-butterfly switch-based data center network architectures performance are compared on various variations. The simulation experiment study is performed using OPNET simulator. The simulation results shows that for increasing load fat-tree offers better throughput and better latency on minimal cost.**

Keywords: Data Center, throughput, OPNET, Switch-based network architecture.

I – INTRODUCTION

Data center is a repository of computing and storage resources connected together using communication networks to host Internet-based applications like search engines, video data hosting, social networking, large-scale computing [12]. It is also used to store enormous amount of data. Applications hosted by data center are either data intensive or communication intensive. The thousands of servers may be harnessed to fulfil a simple web search request or database query [6] in different applications set using Internet communication [5] and it is important to understand the performance.

The performance of data centers are mainly measured using three metrics: throughput, latency and reliability. The data centers are designed to achieve high throughput, low latency and better reliability [11] on different load conditions. The oversubscription ratio is also considered as key performance measure of data center networks and 1:1 ratio indicates that communication is at full bandwidth of their network capacity [7].

Data center contains large number of servers to serve various services like scientific computing, financial analysis, data analysis and large-scale computations [7]. Data centers are experiencing tremendous growth in servers. After every two years, number of servers in data centers are getting doubled [6]. Data center demands high aggregate bandwidth requirement to provide required services [7].

Day-by-day loads on data center are increasing and without understanding the complexity, service providers are increasing the network sizes. With the various studies it is understood that increase on size of data center, the complexity is increasing exponentially [2]. Optimizing both performance and cost of data center is one of the major design goals of data center designers [10]. There is big challenge for data center designers to design high performance data center network with minimum infrastructure cost and minimum internetwork complexity [1].

In order to respond quickly to ever changing application demands, dynamic load variance and service requirements, data center networks needs to be agile and reconfigurable. Significant research work is being carried out on designing the data center network topologies for improving the performance of data centers and simultaneously reducing cost [5]. Data center with highest-end switches may still achieve half of the aggregate bandwidth at the edge of the network, with incurring high cost [7]. Non-uniform bandwidth among data center nodes complicates application design and limits overall performance of data center [8].

Different types of application requirements are supported by different data center network architectures. These different data center network architectures can be compared based on throughput, scalability, path diversity, latency and cost metrics [2]. These data center network architectures are classified into three classes as switch-based architecture, server-based architecture and hybrid architecture.

i) *Switch-based architectures: Packet forwarding is implemented using switches. Multi-tiered, fat-tree, flattened butterfly are the examples of switch-based architectures.*

ii) Server-based architectures: Servers are used for packet forwarding. Servers have two responsibilities, first to process applications and second to forward packets. Camcube is Server-based architecture.

iii) *Hybrid architectures: Both switches and Servers are used for packet forwarding. DCell and BCube are examples of hybrid architecture* [4].

Selection of proper network architecture helps designing the data center that become scalable, balance the load, provide high aggregate bandwidth among end-hosts, compatible with existing infrastructure, provides agility and fault tolerance, incurs minimum power consumption and infrastructure costs [6].

Switch-based network architectures are widely used network architectures. They offer high path diversity, high throughput, high scalability and low latency.

In this study attempt is to compare performance of three widely used switch-based network architectures; these are multi-tiered, fat-tree and flattened-butterfly using OPNET simulator. The performance is measured by varying the user load, accessing database service provided by these switch-based data center networks containing fixed number of servers. Section two is the description about multi-tiered, fat-tree and flattened-butterfly network architectures. Section three contains simulation parameters and setup. Comparative result analysis of three switch-based network architectures is given in section four. Last section contains conclusion.

II – SWITCH-BASED NETWORK ACHITECTURES

A) Multi-tiered Network Architecture

Multi-tiered network architecture is traditional data center architecture. A three-tiered architecture contains core switches at the root level, aggregation switches at the middle level, and edge switches at the bottom connected to the servers [6]. Figure-1 shows the sample topology of multi-tiered network architecture.

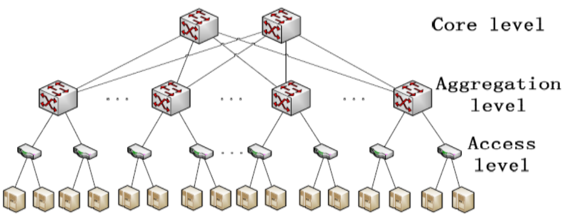

Figure-1: Multi-tiered network architecture

B) Fat-tree Network Architecture

Fat-tree architecture solves the oversubscription, network bottleneck and single node failure problems of traditional network architecture [3]. Fat-tree replaces expensive, more advanced switches and deploys low-cost commodity switches [9]. Therefore cost of fat-tree network is less than traditional network [5].

Fat-tree architecture is composed of N pods, where each pod contains $(N/2)^2$ servers, N/2 access layer switches and N/2 aggregate layer switches in the topology. The core layer contains $(N/2)^2$ core switches where each of the core switches is connected to one aggregate layer switch in each of the pods. The maximum number of servers and switches in fat-tree of N pods is $N^3/4$ and $5N^2/4$ respectively [12]. Figure-2 shows sample topology of Fat-tree network architecture with N=4.

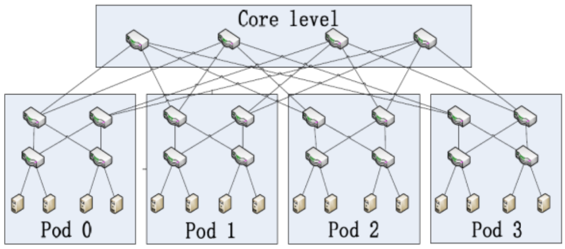

Figure-2: Fat-tree network architecture

C) Flattened-Butterfly Network Architecture

The k-ary n-flat flattened butterfly (FBFLY) is a multi-dimensional topology. In FBFLY k is the number of switches in each dimension and n is the dimension of topology.

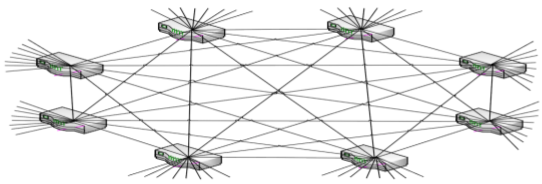

Figure-3: 8-ary 2-flat flattened butterfly network

A k-ary n-flat flattened butterfly is constructed from a k-ary(n-1)-flat flattened butterfly and a k-ary2-flat flattened butterfly [2]. Figure-3 shows the sample topology of 8-ary 2-flat flattened-butterfly network architecture.

III – SIMULATION PARAMETERS AND SETUP

OPNET (modeler 14.5) simulator is used for simulation. The simulation experimental studies are performed on multi-tiered, fat-tree and flattened-butterfly architectures having 16 servers as traffic sources connected with ethernet switches, providing database services on varying number of clients (500,750,1000,1250,and 1500 clients). Duplex ethernet link 10BaseT with 10Mbps transmission rate is used for interconnection and data transfer. Data center and client subnets are connected to Internet through PPP_DS1 link of 1.544 Mbps bandwidth. All routers, firewalls and internet support OSPF routing protocol. The database application traffic has been considered as services at servers. Table-1 shows details of simulation parameters and table-2 shows the database application traffic generation details.

TABLE-1: SIMULATION PARAMETERS

Parameter	***Value***
Number of Servers	16
Number of Clients	500, 750, 1000,1250 and 1500
Ethernet Link	10BaseT
Serial Link	PPP_DS1
Routing Protocol	OSPF
Application	Database
Simulation Time	30 Minutes

TABLE-2:DATABASE APPLICATION TRAFFIC GENERATION PARAMETERS

Attribute	***Value***
Database Transaction Interarrival Time	5 (seconds)
Database Transaction Size	50.000 (Kbytes)

Figure-4 is the network consisting of data center and number of client subnets. Figure-5 to figure-7 are the internal structures of multi-tiered, fat-tree and flattened-butterfly data center networks respectively, each containing 16 database servers. Figure-8 is the internal structure of one of the client subnet containing 50 ethernet workstations, a router, switch and firewall.

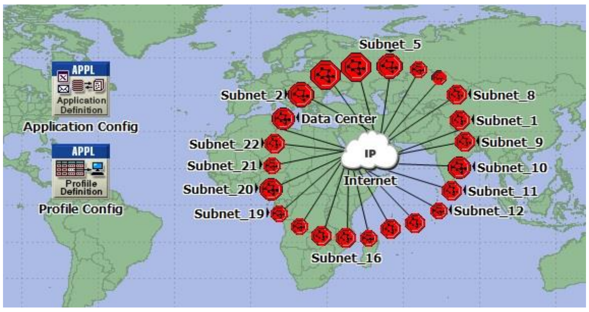

Figure-4: Network topology containing data center network and 22 client subnets

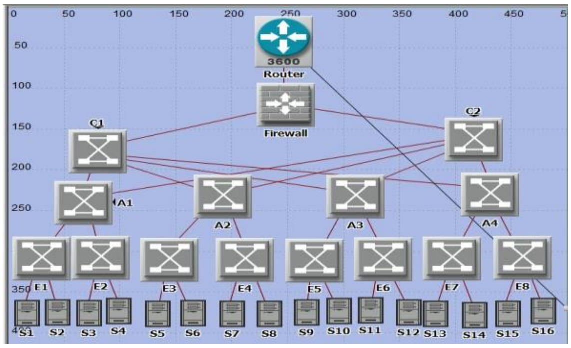

Figure-5: Multi-tiered data center network with 16 servers

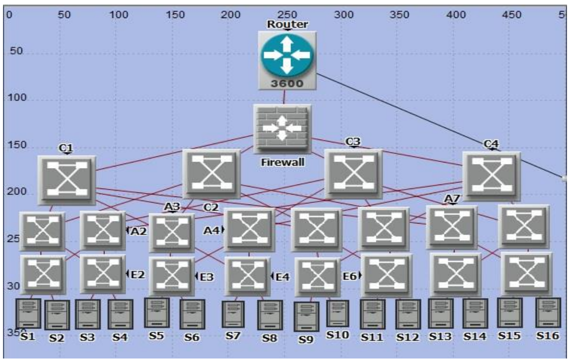

Figure-6: Fat-tree data center network with 16 servers

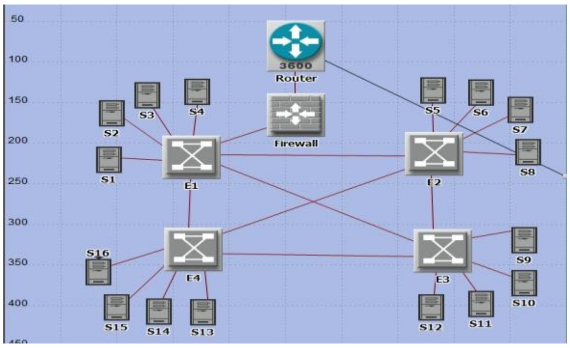

Figure-7: Flattened-butterfly data center network with 16 servers

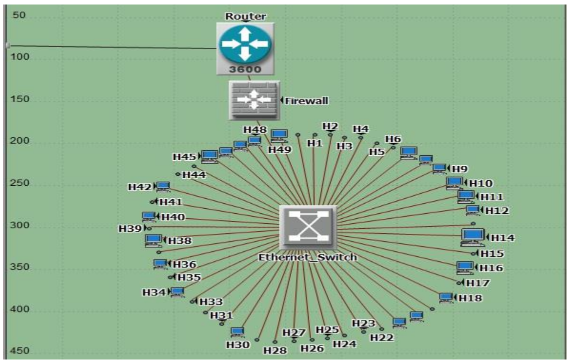

Figure-8: Client subnet

IV – RESULTS ANALYSIS AND DISCUSSION

i) Throughput analysis

The throughput in multi-tiered, fat-tree and flattened-butterfly data center network architecture are measured by varying number of clients (500,750,100,1250 and 1500) while accessing database services and results are captured in figure-9 to figure-13.

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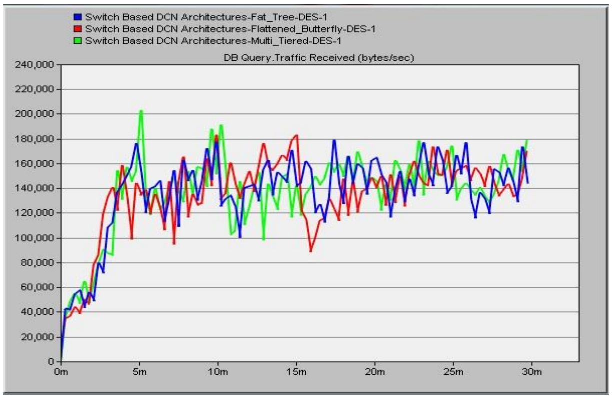

Figure-9: Throughput in multi-tiered, fat-tree and flattened-butterfly network architecture having 16 servers with the load of 500 clients

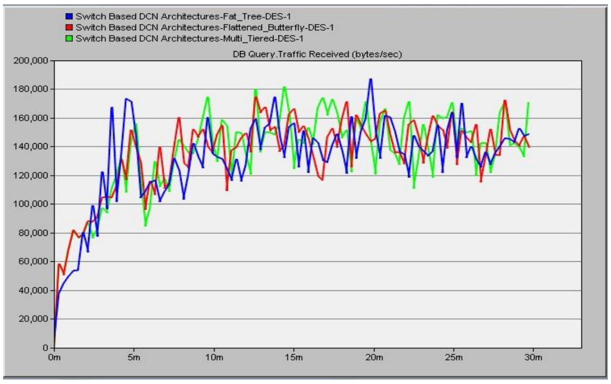

Figure-10: Throughput in multi-tiered, fat-tree and flattened-butterfly network architecture having 16 servers with the load of 750 clients.

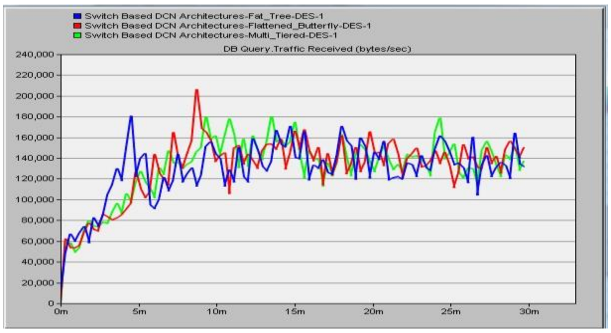

Figure-11: Throughput in multi-tiered, fat-tree and flattened-butterfly network architecture having 16 servers with the load of 1000 clients

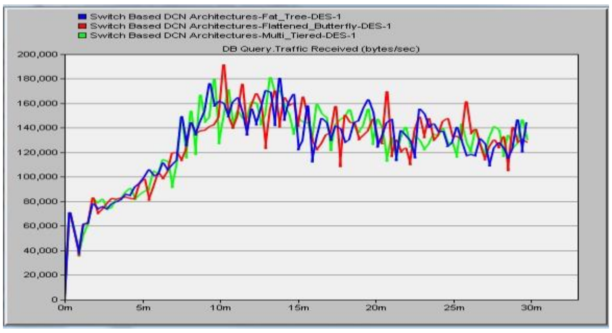

Figure-12: Throughput in multi-tiered, fat-tree and flattened-butterfly network architecture having 16 servers with the load of 1250 clients

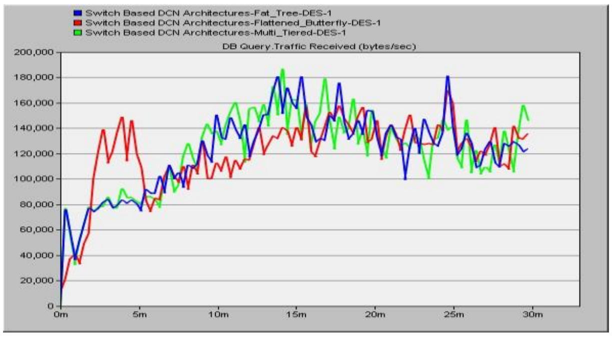

Figure-13: Throughput in multi-tiered, fat-tree and flattened-butterfly network architecture having 16 servers with the load of 1500 clients

The behaviour of throughput on varying load are measured and tabulated in table-3 for multi-tiered, fat-tree and flattened-butterfly network.

TABLE-3: COMPARATIVE ANALYSIS OF THROUGHPUT FOR MULTI-TIERED, FAT-TREE AND FLATTENED-BUTTERFLY NETWORK IN VARYING LOAD SCENARIO

Number of Clients	***Throughput (Kbyte/Sec)***		
	Fat-Tree	***Multi-Tiered***	***Flattened-Butterfly***
500	135.646	132.512	136.712
750	132.061	133.833	132.880
1000	129.521	128.268	129.790
1250	125.302	124.228	124.243
1500	120.614	117.962	120.458

The average database traffic received (bytes/sec) by multi-tiered, fat-tree and flattened-butterfly network for varying number of clients is given in figure-14 and figure-15.

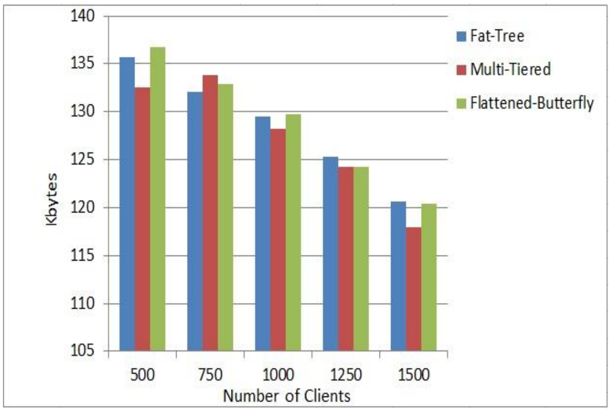

Figure-14: Throughput (Kbytes/sec) comparison for multi-tiered, fat-tree and flattened-butterfly network architecture in varying load scenario

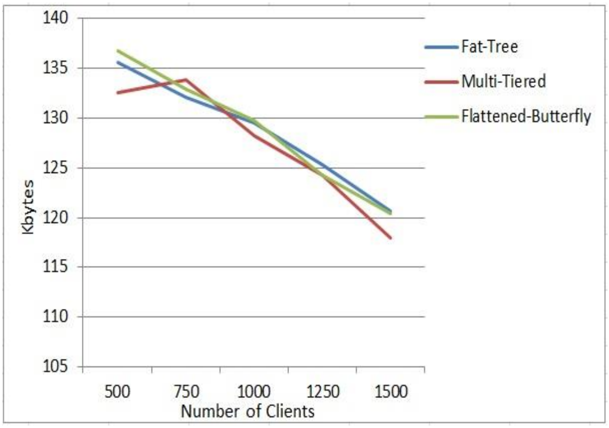

Figure-15: With varying load, throughput behaviour of multi-tiered, fat-tree and flattened-butterfly network.

Observations: From figure-14 and figure-15 it is observed that, flattened-butterfly architecture has better throughput than multi-tiered and fat-tree data center architectures while supporting medium number of clients (500 and 1000). With increasing number of clients (1250 and 1500), data center network with fat-tree architecture offers better throughput than multi-tiered and flattened-butterfly architectures.

ii) Delay analysis

Figure-16 to figure-20 are the results of delay in multi-tiered, fat-tree and flattened-butterfly data center network architectures by varying number of clients (500,750,100,1250 and 1500) accessing database services.

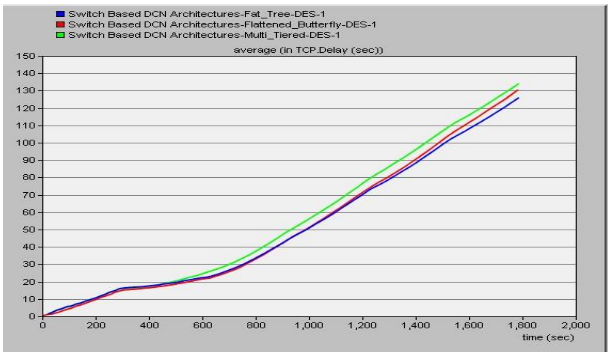

Figure-16: Delay of fat-tree, flattened-butterfly and multi-tiered network architectures having 16 servers with the load of 500 clients

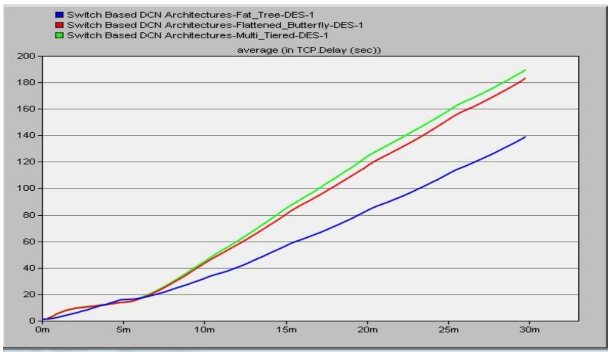

Figure-17: Delay of fat-tree, flattened-butterfly and multi-tiered network architectures having 16 servers with the load of 750 clients

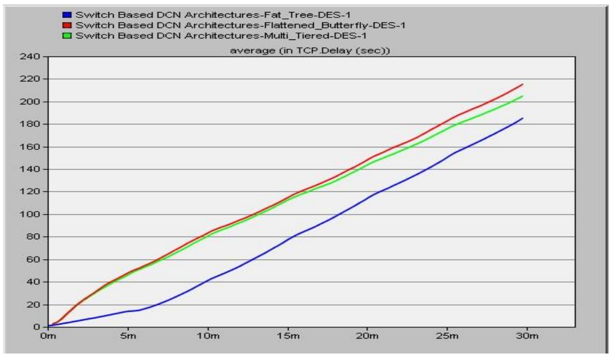

Figure-18: Delay of fat-tree, flattened-butterfly and multi-tiered network architectures having 16 servers with the load of 1000 clients

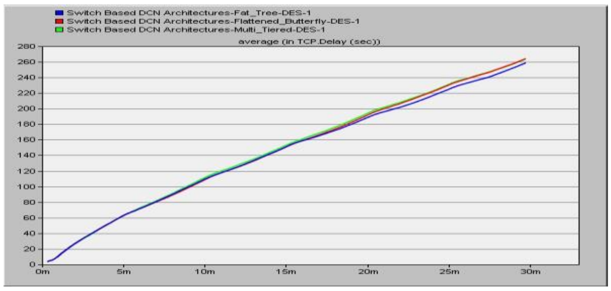
Figure-19: Delay of fat-tree, flattened-butterfly and multi-tiered network architectures having 16 servers with the load of 1250 clients

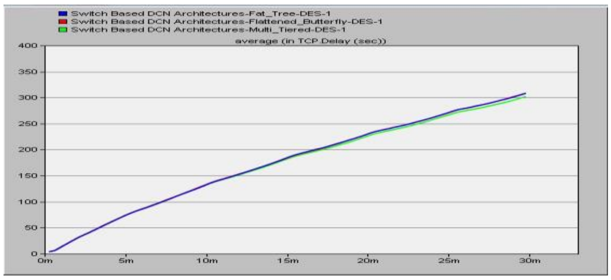
Figure-20: Delay of fat-tree, flattened-butterfly and multi-tiered network architectures having 16 servers with the load of 1500 clients

The statistical data of average delay (seconds) of multi-tiered, fat-tree and flattened-butterfly network for varying number of clients is tabulated in table-4.

TABLE-4: AVERAGE TCP DELAY (SECONDS) OF MULTI-TIERED, FAT-TREE AND FLATTENEDBUTTERFLY NETWORK FOR VARYING USER LOAD

Number of Clients	***Delay (Seconds)***		
	Fat-Tree	***Multi-Tiered***	***Flattened-Butterfly***
500	126.6	130.65	126.38
750	134.01	178.76	167.51
1000	174.71	215.68	217.2
1250	261.18	263.58	262.83
1500	305.09	303.49	308.24

The average TCP delay (sec) of multi-tiered, fat-tree and flattened-butterfly network for varying number of clients is shown in figure-21, figure-22.

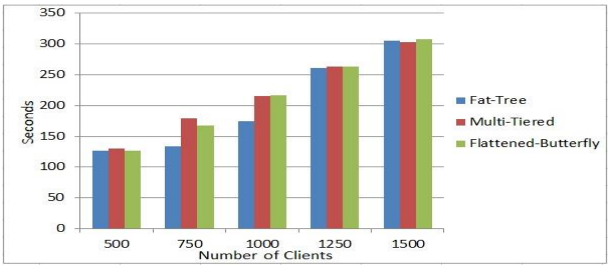

Figure-21: Average TCP delay (seconds) of multi-tiered, fat-tree and flattened-butterfly network for varying user load

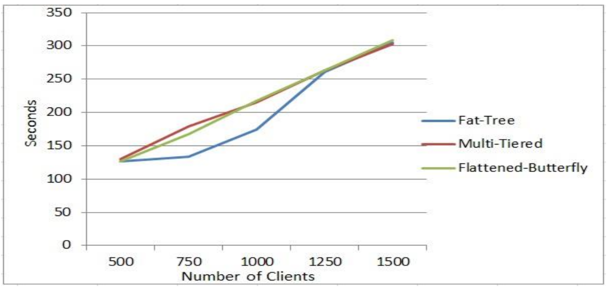

Figure-22: With varying load, delay behavior of multi-tiered, fat-tree and flattened-butterfly network.

Observations: From figure-21 and figure-22 it can be observed that, fat-tree data center network architecture offers minimum delay compared to multi-tiered and flattened-butterfly data center network architectures while supporting 500, 750, 1000 and 1250 clients. Fat-tree has slight more delay than multi-tiered architecture for 1500 clients.

V- CONCLUSION

The performance of three switch-based data center network architectures (i.e. multi-tiered, fat-tree and flattened-butterfly) each having 16 database servers with varying user load has been analysed using OPNET modeler. The simulation result shows that for increasing number of client's fat-tree offers better throughput than multi-tiered and flattened-butterfly. Fat-tree network architecture has minimum delay than multi-tiered and flattened-butterfly network architectures. Fat-tree architecture is economically feasible network architecture, widely used for designing large scale and high performance computing data center networks. Fat-tree offers high path diversity and low latency.

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