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Analysis of Transmission Impairments for ShuffleNet based Electro-Optic Data Center Network

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Abstract:

In this paper we introduce an extemely computation efficient ShuffleNet based electro-optic data center architecture. Data Centre Network (DCN) serves as a backbone infrastructure for large enterprise application and different cloud centric applications. To support high demand of internet service and different web based application the recent DCN architecture contribute high bandwidth, highspeed and required to support thousands or millions of severs. ShuffleNet architecture has an unique advantage of shuffling the lightpath that greatly reduce computational cost with high level of accuracy. The main contribution of this paper is to study and analyse Bit Error Rate (BER) performance for ShuffleNet based electro optic data centre network using intensity modulation scheme. We study BER performance by changing the size of ShuffleNet as well as the hierarchy of the network. Comparative analysis of BER for different Electro optic data centre networks, operating at the central wavelength of 1550 nm are also presented in this paper.

Keyword: Data Center Network, ShuffleNet, Optical Switching, Intensity modulation, BER

I. INTRODUCTION

Currently various information technology related services are built on cloud centric data centers. Data centers form the backbone of an extensive variety of Internet applications like Web hosting, social- networking, e-commerce and various grid or cloud computing related services. To meet this demand the size and complexity of the data centers are increasing in rigorous manner. So it is essential to understand issues, existing and upcoming shortfalls and challenges for designing the data centers.

In general the DCN architectures have been proposed in two broad categories, viz., switch-centric architecture and server-centric architecture. Fat–Tree is a classic switch-centric hierarchical topology using identical commodity switches at all levels (edge, aggregate and core) for full bisection bandwidth, however with huge wiring complexity when scaled up [3]. VL2 is another switch-centric architecture, using commodity switches to form a three-layered tree topology offering a complete bipartite graph between core and aggregate switches [4]. To increase the fault tolerance of DCNs, Aspen Tree has been proposed with hierarchical topology with in-built fault tolerance, however at the cost of scalability of the network [5].

Some of the candidate server-centric DCN architectures include D-Cell, BCube and several others [1]. D-Cell is a server-centric hierarchical topology employing fewer switches along with servers having network interface cards (NICs) as ports, wherein the topology is constructed through a recursive scheme offering excellent scalability [6]. B-Cube is another recursively-constructed topology, which uses a few mini-switches along with the servers having multiple NICs [7].

Due to the unprecedented growth of cloud-centric applications, the next-generation DCNs would require low latency and high capacity (speed) along with a scalable architecture. So far the DCNs have been designed with electrical packet-switching, but the interconnections between the servers, switch and between the switches used optical fiber links. Given the fact that, the DCNs should accommodate huge number of servers, such architectures cannot be recommended as scalable network for future growth, as the network complexity with electrical-switching equipment turns out to be a serious issue due to limited bandwidth in electrical switches, high power consumption and wiring complexity. On the other hand, optical switching technology offers much higher capacity, lower cost and power consumption. However, the optical switches, typically using micro-electro-mechanical switches (MEMS), suffer from high latency (10 ms) at the time of switch reconfiguration and hence cannot handle bursty traffic efficiently.

In the category of electro-optic or hybrid DCNs, C-Through has been a pioneering work on the traditional tree-based topology using optical as well as electrical switching [2]. Helious is another hybrid architecture using two-level multi-rooted tree topology with pod and core switches [8]. Some futuristic topologies have also been examined in the literature, viz., OSA, Mordia, LION etc. [1], all of them employing fully-optical switching architecture promising extremely high speed, while one is not sure at this stage how far these architectures can be scaled in optical domain itself with the evolving DCN demands. In foreseeable future, it is therefore conjectured that, the DCNs need to grow with hybrid architectures to enhance the speed and size, while keeping the power consumption within the affordable limit.

ShuffleNet [9, 10] is a well known multi-hop virtual topology uses Wavelength Division Multiplexing (WDM) [11, 12] with intensity modulation as underlying physical topology. A basic ShuffleNet is designated as (p, k) ShuffleNet consisting of $(k.p^k)$ number of nodes. They are arranged as k number of columns and p^k number of nodes in each column and kth column is wrapped around to the first in a cylindrical way [13]. This architecture can overcome both wavelength-agility and pre-transmission-coordination problems.

In this paper, our objective is to analyze the BER on a candidate route during transfer of data in the ShuffleNet based electro optic data centre network. The allowable receiver BER is always lower than that of a specified threshold (e.g. 10^{-12}) [14]. In the present work the BER of a candidate light path is analyzed by varying the size of the ShuffleNet and for different layer of ShuffleNet. A comparative analysis is also presented to show the BER performance of different electro optic DCNs.

The rest of the paper is organized as follows: section II is the description of the framework. Section III gives the mathematical modelling to analyze BER for ShuffleNet based electro-optic DCN. Section IV presents the comparative analysis of BER for different electro-optic DCNs using MATLAB. Finally section V is the conclusion of the paper.

II. DESCRIPTION OF THE FRAMEWORK

Fig. 1 shows the proposed architecture of hybrid electro optic data center network architecture. The architecture consists of three discrete portions: 1st portion consists of several number of Top of Rack (TOR) switches. Each TOR switch handles several numbers of users. All users are connected to the TOR through optical links. The 2nd portion is the fat tree based electrical switching enabled sub network. Each TOR is connected to this sub network to support packet switching. The final or the 3rd portion is the hierarchical ShuffleNet based optical network. TOR switches are connected to the hierarchical ShuffleNet based optical network in parallel with fat tree based electrical switching enabled sub network. The integration of these two architectures is used to handle two different types of traffic present in the network. The traffics are classified into two types: small size bursty traffic commonly called mouse traffic and large volume of traffic called elephant traffic. All bursty traffic follow packet switch enabled fat tree based electric switch domain. And all large volume of traffic follow the ShuffleNet based optical network. This type of traffic segregation and transmission significantly enhance the switching speed and reduce power consumption of the network.

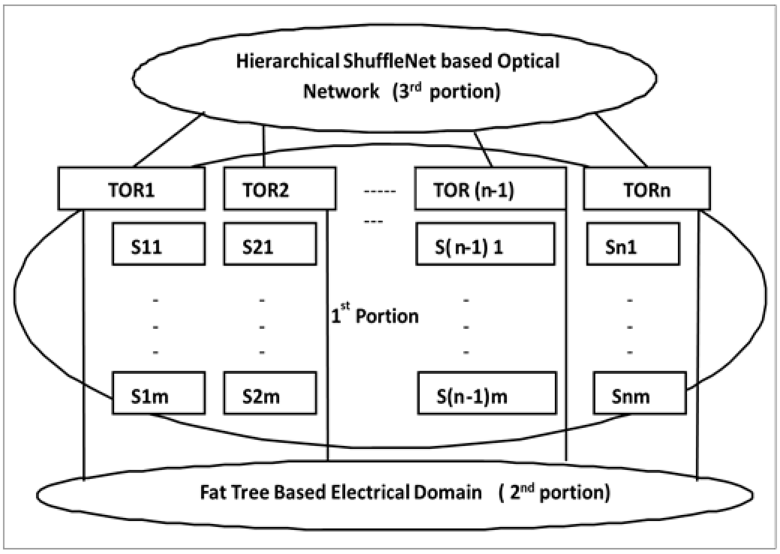

Fig. 1 Proposed hybrid electro optic data center network

In Fig. 1 “n” number of TOR switches are used and marked as TOR1 to TORn. Each TOR switch can support “m” number of Server marked as S11 to Snm. Each TOR support equal number of users. Each TORs are connected in parallel with both electric fat tree enabled domain and ShuffleNet based optical domain.

In this architecture we restricted our study in the ShuffleNet based optical domain.

To develop hierarchical ShuffleNet structure the total number of TORs is divided into some number of groups. This grouping is done to reduce the structure of the ShuffleNet.

Fig.2 shows the hierarchical ShuffleNet structure for the proposed model. Here there are “a” number of ShuffleNet are used to support “n” number of TORs. They are designated as ShuffleNet 1, ShuffleNet 2 to ShuffleNet a. All these ShuffleNets are controlled by a master ShuffleNet designated as ShuffleNet M. When the data is transferred from one TOR to another between two different ShuffleNet, packets are transferred through ShuffleNet M. An optical switch is also connected in parallel with the master ShuffleNet to reduce the load in master ShuffleNet. If the packet size is too large then it follows the optical switch.

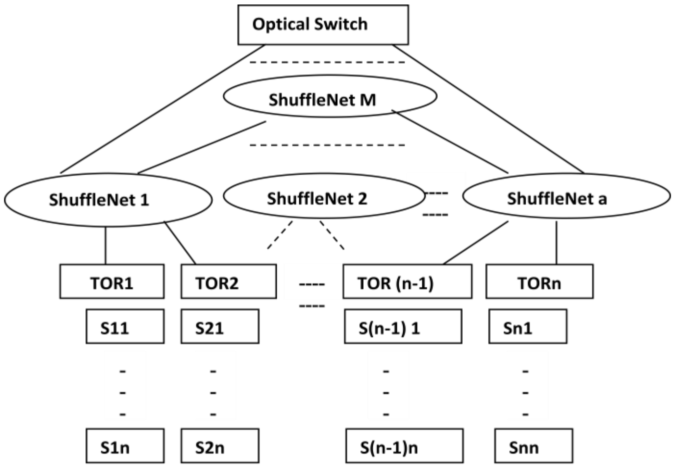

Fig.2 Hierarchical ShuffleNet structure for the proposed model

There are three paths on which a packet can travel in optical domain. Firstly, the packet is transferred from one TOR to another under same ShuffleNet, secondly from one TOR to another under different ShuffleNet, the packet is transfer through master ShuffleNet.

II. OPERATION OF THE FRAMEWORK

In this section the operation of the framework is described in detailed. For end-to-end delivery of the packet the following steps are followed:

- Traffic monitoring and managing
- Traffic demultiplexing

- Path selection
- Packet transfer

A. Traffic monitoring and managing

The network estimates the end user traffic demands in an application-transparent manner by increasing the per connection socket buffer limit and per connection socket occupancy time. Per flow basis queuing has an advantage that it can avoid blocking between concurrent flows. Therefore, low bandwidth latency sensitive data is not at all experience any extra delay due to high bandwidth data flow.

The buffers are connected to the servers (end host) not to the TOR switch as the DRAM used by the end host is more available than that of the TOR switches. Each server calculates the total byte waiting in the queue and reports the respective TOR switch.

B. Traffic Demultiplexing

Depending upon the request and type of traffic from the servers each TOR assigns the path for the traffic. If the traffic is brusty in nature and latency sensitive, TOR assigns the electric ports for the traffic similarly for high bandwidth large volume of traffic TOR assign the optical port for the traffic transfer.

C. Path Selection

Fig.3 shows the ShuffleNet architecture for the proposed model.

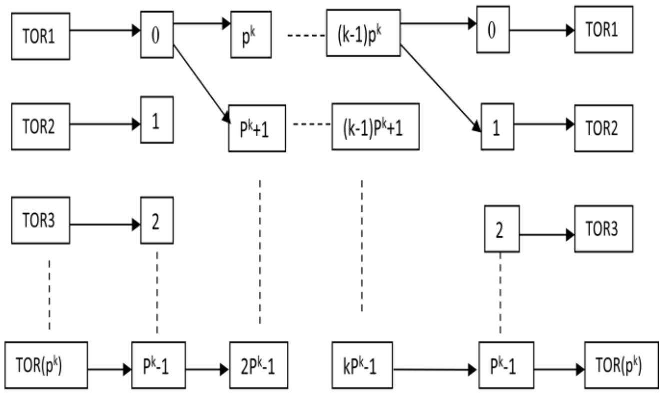

Fig. 3 (p,k) ShuffleNet configuration for proposed model

As per the configuration of (p,k) ShuffleNet, the total number of nodes it can support is ‘kp^k’.

When a request is come from any server to the respective TOR first it will check the destination address of the server. If the address of the destination server belongs to same ShuffleNet, it will forward the traffic to the ShuffleNet node and the packet is reached to its destination through ShuffleNet routing algorithm.

If TOR founds that the destination address is not belong to same ShuffleNet it will forward the traffic to the master ShuffleNet.

D. *Packet Transfer*

For simplicity consider an example that Server A wants to send some data to Server B through Optical Domain. ServerA is connected to TOR1 and ServerB is connected to TOR 3. Both TORs are under same ShuffleNet. The structure of the ShuffleNet is (2,2). The connection of ShuffleNet and TORs for (2,2) ShuffleNet is shown in Fig.4.

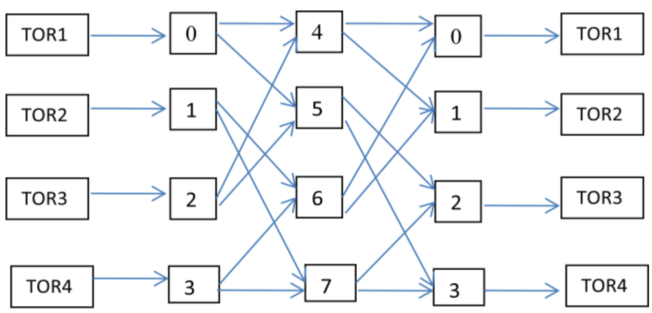

Fig.4 (2,2) ShuffleNet structure

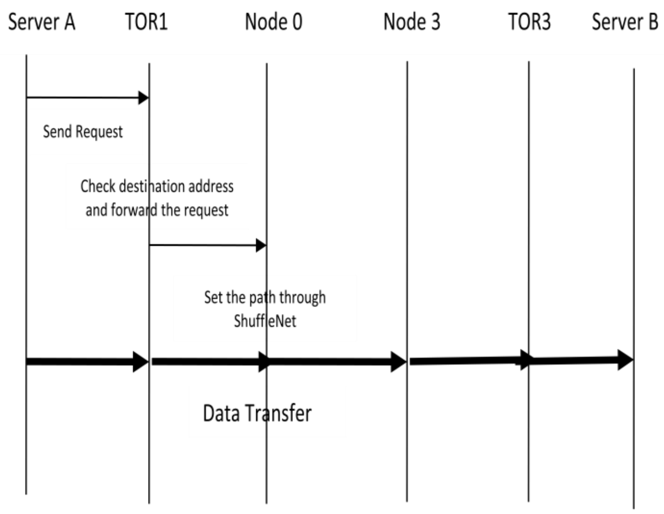

Fig.5 Signal flow diagram for path set up and data transfer

For sending packet, Server A sends a request to TOR1. TOR1 checks the destination address, if TOR1 finds that the destination TOR is under same ShuffleNet, it forward the packet to the corresponding ShuffleNet node. The signal flow graph for this particular case of packet transfer is described in Fig.5. First, Server A sends a request to TOR1 as it wants to send a packet to Server B which belongs to TOR3. TOR1 checks the destination address and forward the request to the corresponding ShuffleNet node. After proper path selection the data reached the destination Server B through TOR3.

Packet Transfer between different ShuffleNet

In this case, some ports of the ShuffleNet nodes are connected to the higher hierarchical ShuffleNet. So when a communication required from one ShuffleNet to another the packet is forwarded through higher level ShuffleNet. As for example, consider Server A which is connected to TOR12 in ShuffleNet1 wants to communicate with Server B which is connected to TOR24 in ShuffleNet2. Fig. 6 shows the path of packet transfer from TOR12 to TOR24 through higher level ShuffleNet.

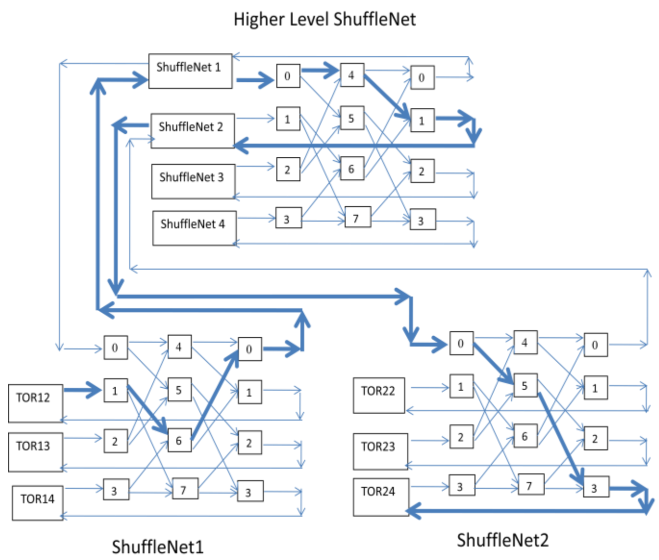

Fig.6 Packet transfer between two different ShuffleNet

III. MATHEMATICAL MODELING

This section provides the detail calculation to find the power requirement to fulfill the desired Bit Error Rate (BER) of the framework.

A. *BER Evaluation Module*

To transmit and receive packet through TOR, each TOR have minimum one number of Trans-Receive Port. This port consists of one transmitter and one receiver operating on same wavelength. Fig. 7 shows how trans-receive ports are connected to a N, N ShuffleNet.

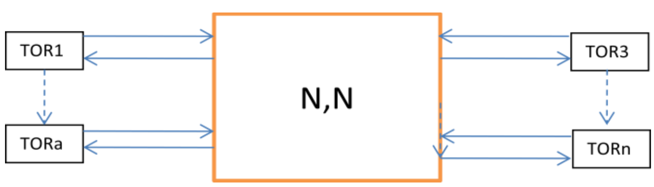

Fig. 7 Trans-receive ports are connected to N, N ShuffleNet

When the optical signal falls on the receiver module two types of noises are associated with the signal. They are Thermal noise and Gaussian Noise.

Let,

Transmitted optical power = P_T

Received optical power = $P_R = P_T/N$

Variance of thermal noise = $\sigma_T^2 = \dfrac{4KTB}{R_L}$

Short Noise Power Variance = $\sigma_s^2 = 2qR_\lambda P_R B$

Total Noise variance $\sigma^2 = \sigma_T^2 + \sigma_s^2 = \dfrac{4KTB}{R_L} + 2qR_\lambda P_R B$

Here, K = Boltzman Constant

T = Temperature in degree Kelvin

B = Bandwidth

R_L = Load resistance

q = Charge of an electron

R_λ = Responsivity of photo detector

The receiver BER is calculated by proper choice of threshold current I_{TH}

The optimum value of $I_{TH} = \dfrac{\sigma_0 I_{S0} + \sigma_1 I_{S1}}{\sigma_0 + \sigma_1}$

Here, $\sigma_0 =$ Short noise variance for ‘0’ bit transmission

$\sigma_1 =$ Short noise variance for ‘1’ bit transmission

I_{S0} =Signal current for ‘0’ bit transmission

I_{S1} =Signal current for ‘1’ bit transmission

$\sigma_0 = \sqrt{((2 * q * R_\lambda * B * P_{R0}) + (\sigma_T^2))}$

$\sigma_1 = \sqrt{((2 * q * R_\lambda * B * P_{R1}) + (\sigma_T^2))}$

P_{R1} = the received power for 1 bit transmission

P_{R0} = the received power for 0 bit transmission

Consider $P_{R0} = 0.1P_{R1}$

Therefore, $Q = R_\lambda * (P_{R1} - 0.1 * P_{R1}) / (\sigma_0 + \sigma_1)$

$$= R_{\lambda} * 0.9 P_{R1} / (\sigma_0 + \sigma_1)$$

And $$BER = 0.5 * erfc\left(Q / \sqrt{2} \right)$$

Therefore the final expression of Q for N,N ShufflenNet

$$Q = R_{\lambda} * (0.9 P_T / N) / (\sigma_0 + \sigma_1)$$

IV. COMPARATIVE ANALYSIS OF BER

Table 1. Shows the mathematical modeling of BER for different electro-optic DCN under study.

Table 1. BER value for different protocol

Name of electro-optic DCN architecture	Expression of received power to calculate Q for BER (in dbm)
N,N ShuffleNet	$P_R = P_T$ -10*log(N)
OSA	$P_R = P_T$ - 45

The P_R is calculated for OSA model as per the reference [15].

Here, we use MTLAB to analyze the comparative performance analysis of BER for ShuffleNet based DCN and OSA. Fig. 8 shows the BER performance of 4,6 ShuffleNet and OSA model respectively with respect to transmitted power in dbm.

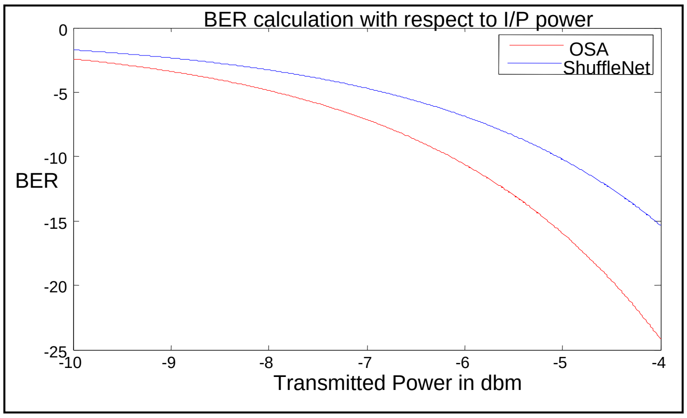

Fig. 8 BER performance for ShuffleNet and OSA

From the graph it is seen that the specified BER (10^{-12}) is achieved for OSA model is -6 dbm transmitted power and -4.5 dbm transmitted power for ShuffleNet based architecture. Fig. 9 and Fig. 10 shows the BER performance for 4,6 and 4,7 ShuffleNet respectively. In both the cases the transmitted power required to get specified BER is less than 1dbm.

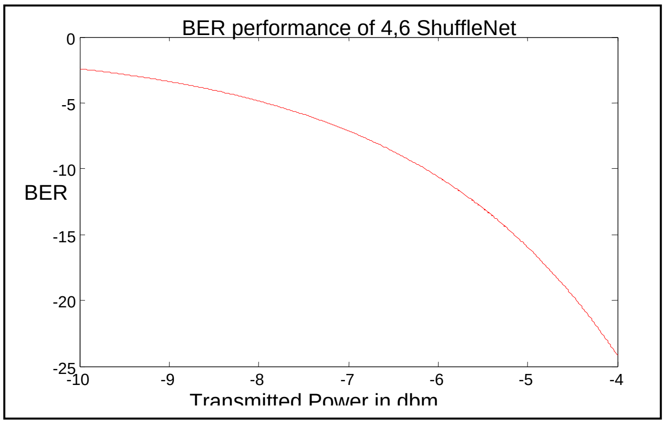

Fig. 9 BER performance of 4,6 ShuffleNet

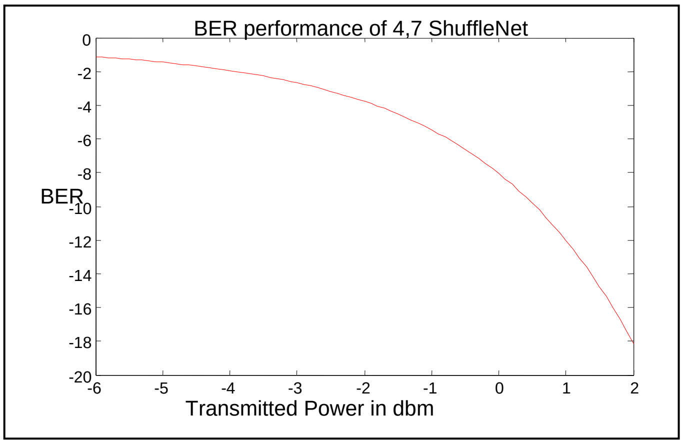

Fig. 10 BER performance of 4,7 ShuffleNet

Table 2 shows the number of TORs possible to connect in the particular size of the ShuffleNet.

Table 2. Possible number of server can be connected

Size of the ShuffleNet	No. of nodes
4,5	5120
4,6	*24576*
4,7	*114688*
OSA	*Use 320 port MEMS to support 2560 servers (OSA)[15]*

From Table: 2 it is clear that ShuffleNet based optical DCN architecture can support more number of nodes rather than OSA model.

V. CONCLUSION

In this paper, we present the BER performance of ShuffleNet based hybrid electro optic DCN architecture and made a comparative analysis with OSA model. From the BER performance it is clear that both the protocols works parallel but from the scalability point of view ShuffleNet based architecture can support more number of nodes than that of OSA model. So it can be say that the ShuffleNet based architecture can be a feasible solution for the next generation DCN architecture.

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