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Elastic Multi-Controller based BCube Connected Crossbars (BCCC) for Higher Energy Efficiency

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Abstract

It is a challenging task to propose an efficient cost-effective network topology to provide consistent performance for large networks consists of more number of Servers and Nodes. From the literature survey, this Research Work noted a few popular Server-Centric Network Topologies such as BCube, Bidimensional Compound Network (BCN) and FiConn were proposed. However, it was noticed that these topologies are not expandable and demand high cost during expansion. This is the major issue and concern to expand or upgrade the Data Centre. With the massive growth in the modern Data Centres, the energy consumed by the network constitutes a significant amount of total power cost in the data centre. One of the straightforward and efficient ways for varying the size of DCN in accordance with traffic demands is by turning OFF the idle network devices to reduce the energy consumption. The Software Defined Networking (SDN) is the current promising solution for controlling the resources of DCN. But, the SDN has not been leveraged completely to enable the power saving in large-scale DCN. To address the above mentioned issues, it is highly needed and important to propose an efficient model that needed to improve the power efficiency for Data Centre Network (DCN). This research work proposed a Hybrid Model called Elastic Multi-Controller (E^3MC) based BCube Connected Crossbars (BCCC) Model to achieve high energy efficiency. The proposed E^3MC based BCCC Model was implemented simulated and studied thoroughly. From the simulation results, it was noticed that the proposed model achieves high performance as compared with the existing BCCC in terms of Energy Efficiency, Path length, Server Resource Utilization, Throughput, Link Failure Rate and Server Failure Rate.

Keywords : BCube Connected Crossbars (BCCC), Data Centre Network (DCN), Energy Efficiency, elastic Multi-Controller (E3MC), Software Defined Networking (SDN).

INTRODUCTION

Large online service providers such as Google, Amazon and Microsoft have built thousands of Servers in the huge Data Centres. The Data Centre Network (DCN)[1,2,4] can be classified as Switch-Centric Networks and Server-Centric Networks. In a Switch-Centric Network [1,2,5,6], the switches are accountable for routing and addressing and the servers are used only to send and receive packets. In a Server-Centric Network [1,2,3], the servers are responsible for the Routing. The Server acts as end hosts and relay nodes. The main advantage of this network is low hardware cost. The most complex task can be shifted to the servers, by using inexpensive commodity switches. The Server-Centric Network can accelerate the network innovation, as the servers are programmable than the switches.

BCube [1,8] is a popular Server-Centric Network with benefits such as Low Network Diameter and High Routing Efficiency. But it is limited to poor expandability[10,11,12], as it incurs tremendous human effort and hardware replacement. It is impossible to manipulate the existing network structure.

A server-centric network topology called as BCube Connected Crossbars (BCCC) [1,7,8,9] was proposed which constructed using dual-port commodity servers and commodity switches. This makes it a cost-effective network solution for large-scale data centres. This is easily expandable, without requiring any change to the existing network infrastructure or the number of server ports. However, it is revealed that the BCCC fails to focuses Energy Efficiency.

To address the identified issue, this paper proposed an Energy Efficiency - Elastic Multi-Controller (E3MC) based BCube Connected Crossbars (BCCC) to improve Energy Efficiency of the large Data Centers. In E3MC based BCCC, there is a dual consideration of power optimization for forwarding plane and control plane. In the forwarding plane, the multi-path routing with traffic/flow split is used to improve power efficiency. Also, the power saving of multiple controllers is studied in control plane. In this work, the energy consumption model is used to choose the key devices and other idle devices/ports could be shut down to optimize the energy efficiency in DCNs.

The remaining sections are organized as follows: Section II describes the BCCC network structure and the structure properties of BCCC. In section III, the proposed E3MC-BCCC is discussed. Section IV presents the performance analysis of the proposed E3MC-BCCC and findings are concluded in Section V.

BCUBE CONNECTED CROSSBARS (BCCC)

The BCCC Network Structure and Structure Properties were described in this section.

Network Structure

The BCube Connected Crossbars BCCC [1,8] is a recursively defined structure that is built with the switches and dual-port servers. Within an element, each server is connected to the switch using its first port, and the second port is left for expansion purpose. The BCCC is denoted with order 'k' as BCCC (n, k), where 'n' is the number of servers connected to each switch in each element. A BCCC (n,0) is simply constructed by one element and 'n' switches, in which each server in the element is connected to one of then switches using its second port. A BCCC(n, k) is constructed by 'n' BCCC(n, k−1)s connected with nk elements.

To build BCCC (n,k), there is a need for indexing n BCCC(n,k-1)s from 0 to n-1. In each, the servers are denoted as $a_{k+1}a_k a_{k-1} \ldots a_0$, where $a_0 \in [0, k-1], a_i \in [0, n-1], 1 \le i \le k+1$. Here a_{k+1} is the most significant digit of the server with the address $a_k a_{k-1} \ldots a_0$ in a BCCC(n,k-1). To build BCCC (n,k), there is a need for $(k+1)n^{k+1}$ dual port servers, $(k+1)n^k$ n-port switches and n^{k+1} $(k+1)$ port switches. Two types of switches called as type A and type switch are required. A type 'A' switch has 'n' ports used to form an element. Type 'B' switch has (k+1) ports used for connecting different elements. Hence, the intra-element communication between the servers within an element is conducted through the first port of each server. The inter-element communication between the servers in different elements is conducted through the second port of the server.

A server is connected to a (k +1) port switch through its second port, when it satisfies the condition that server $a_{k+1}a_k a_{k-1} \ldots a_0$ is connected to switch $s_k s_{k-1} \ldots s_0$ with $s_i = a_{i+1}, \forall i, 0 \le i \le k$. Thus the addressing scheme is given to build BCCC(n,k), each server in those elements denoted as $a_{k+1}a_k a_{k-1} \ldots a_0$, where $a_0 = k$ is connected only to a switch in one of the n BCCC(n,k-1)'s denoted as $s_k s_{k-1} \ldots s_0$ through the second port under the rule that $s_i = a_i + 1$, where $0 \le i \le k$. Based on the above construction, a pair of servers acts as neighbors, such that they are connected to the same switch, only if $\exists i, i = a_0 + 1$ or $i = 0$, such that $a_i \ne a_i'$, and $\forall j, 0 \le j \le k+1, i \ne j$, such that $a_j = a_j'$.

If the server $A = a_{k+1}a_k a_{k-1} \ldots a_0$ and its neighbor $A' = a_{k+1}' a_k' a_{k-1}' \ldots a_0'$, $\exists i \in [0, k+1]$ such that $a_i \ne a_i'$ and $a_j \ne a_j'$, where $\forall j, 0 \le j \le k+1$ and $j \ne i$ are connected by a switch $s_k s_{k-1} \ldots s_0$ equal to.

$$\begin{cases} a_{k+1}a_k a_{k-1} \ldots a_{i+1}a_{i-1} \ldots a_1\{i-1+n\} & i = a_0 + 1 \\ a_{k+1}a_k a_{k-1} \ldots a_1 & i = 0 \end{cases} \quad (1)$$

Where $\{i-1+n\}$ is the least significant digit in the address of the switch. Fig.1 shows the example of BCCC(4,1). BCCC(4,1) has four BCCC(4,0)s and four elements. Servers 000, 010, 020 and 030 belong to the first BCCC(4,0) and they are connected to switch 04 through their first ports. Servers 001, 101, 201 and 301 belong to the same element, and they are connected to switch 05 through their first ports.

A server A=a_(k+1) a_k a_(k-1) ⋯ a_0 is in the ith dimension, if a_0=i-1, where 1⩽i⩽k+1. By this token, the dimension of servers within the same element is same and dimension of servers connected by type B switch is different. The size of a BCCC(n,k), S_BCCC (n,k) is the number of servers within a BCCC(n,k) network. Then

$$\begin{cases} S_{BCCC}(n,0) = S_{element}(n) = n \\ S_{BCCC}(n,k) = n \cdot S_{BCCC}(n,k-1) + n^k \cdot S_{element}(n) \end{cases} \quad (2)$$

Thus, the size of BCCC(n,k) is $(k+1)n^{k+1}$. Let $L_{BCCC}(n,k)$ denotes the number of linking wires required to build BCCC(n,k) and 'd' is the degree of each server. Each server is connected to switches through two wires. There is no wire between any pair of servers.

$$L_{BCCC}(n,k) = d \cdot S_{BCCC}(n,k) = 2(k+1)n^{k+1}$$

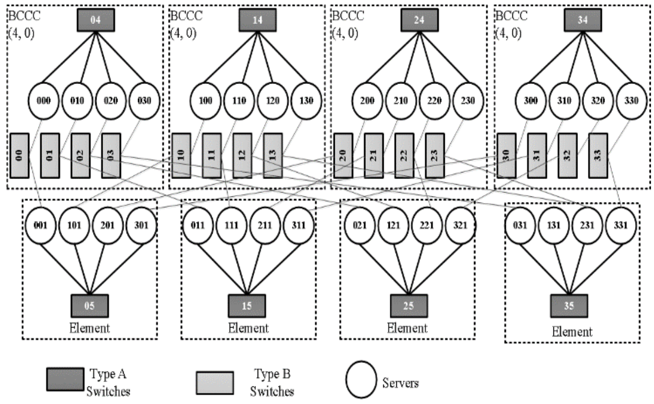

Figure 1. Topology of BCCC(4,1) comprising 4 BCCC(4,0)s along with 4 elements

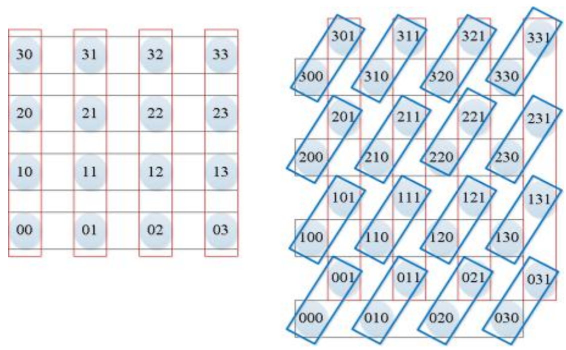

Figure 2. Geometrical view of BCube(4,1) and BCCC(4,1).

Structure properties of BCCC

Some important properties of BCCC that are critical to the routing performance are analyzed with the following Theorem.

Theorem: The diameter of a BCCC(n, k) is 2(k+1). Consider the BCCC (4,1) as an example. Its diameter is 4. If a packet is to be sent from server 001 to server 221, one possible path is 001, 000, 020, 021 and finally to 221. The number of hops through this path is 4. Another candidate path is from 001, to 201, 200, 220, and finally to 221. The number of hops for this path is also 4.

Algorithm 1:

BCCC routing algorithm

Input: source A and destination A' where

A is $a_{k+1}a_k a_{k-1} \ldots a_0$ and $A[i] = a_i$; $A'$is $a'_{k+1}a'_k a'_{k-1} \ldots a'_0$ and $A'[i] = a'_i, i \in [0, k+1]$ and

$\prod$ is the permutation of $[k+1, k, k-1, \ldots, 1]$

Output: A list of intermediate servers of path from A to A', path (A, A')

BCCC Routing $(A, A', \prod)$ Path (A, A') = {A}; B=A;

for $(i = k+1; i > 0; i--)$//k+1 iterations;

if $A[\pi_i] \neq A'[\pi_i]$ { $B[0] = \pi_i - 1$;}

if $A \neq B$ { append B to path (A, A'); $B' = B$; $B'[\pi_i] = A'[\pi_i]$; $B' = B$;append B' to path (A, A'); }

if $A' = B'$ { append A' to path (A, A');} return path;

Algorithm 2:

Building Multipath between pair of source and destination

Input: source A and destination A' where

A is $a_{k+1}a_k a_{k-1} \ldots a_0$ and $A[i] = a_i$

$A'$is $a'_{k+1}a'_k a'_{k-1} \ldots a'_0$ and

$A'[i] = a'_i, i \in [0, k+1]$

Output: A set of all parallel paths, PathSet

BuildingMultiPaths(A, A')

PathSet = {};

for $i = 1; i \leq k; i++$

if$A[i] \neq A'[i]$ { $P_i = \text{DirectRouting}(A, A', i)$; }else { $P_i = \text{IndirRouting}(A, A', i)$; }add P_i to PathSet;

return PathSet

DirectRouting(A, A',i)

d=1;

for $j = 1; j \geq i - j; j--$

{ $\pi_d = j \bmod (k+1) + 1$;

$// \prod = \pi_{k+1}\pi_k \ldots \pi_0$} d++;

return BCCCRouting$(A, A', \prod)$;

IndirRouting(A, A',i)

path ={A}; B = A;

if $A[0] + 1 \neq I$ { $B[0] = i - 1$;

path += B; set B[i] to a value different to A[i]; path += B; d = 1;

for $j = i - 1; j \geq i - 1 - k$; j—

{ $\pi_d = j \bmod (k+1) + 1$; } d++;

path += BCCCRouting $(B, A', \prod)$;

return path;

Identified Problem

The energy saving of control plane is not considered in BCCC which designed for large-scale data centres. Though there have been some resource-efficient studies on distributed control plane, the profile of power consumption and energy efficiency for the controller are not combined in BCCC model. Hence, we needed an efficient model to address the above identified issue. This Research Work focuses on to reduce energy consumption significantly and thus it proposed an Elastic Multi-Controller (E3MC) based BCube Connected Crossbars (BCCC) which dynamically combining the workloads onto a small set of devices and shut the redundant devices, which discussed in Section III.

ELASTIC MULTI-CONTROLLER BASED BCUBE CONNECTED CROSSBARS (BCCC)

This Research Work studied BCube Connected Crossbars (BCCC) thoroughly and noted that it was highly structured topology model which couldn't achieve power consumption for the large Data Centre Networks (DCNs). To address this identified issue, an Elastic Multi-Controller (E3MC) based BCube Connected Crossbars (BCCC) Model was proposed, discussed and Studied thoroughly in this Section.

Multi-Controller Structure for Large Data Centers

The Multi-Controller designed through Software Defined Network that improves the scalability of the Data Centre. As to achieve power consumption, the Energy Efficiency via Elastic Multi-Controller (E3MC) Structure was integrated with BCCC. There is a separate and dedicated network used for SDN south-bound interface channels.

In the multi-controller SDN, each controller maintains a portion view of the forwarding network and each switch has only one master controller. As the mapping between the switches and controllers is dynamic, when a master controller is down, the switches under its control can be migrated to another one. When there is a decrease in the aggregated load, the controller pool can shrink to save energy.

E3MC Architecture

The E3MC was developed to manage and enhance the energy efficiency of multi-controller DCN. Multi-controller DCN is the modular architecture. The clusters of controllers and OpenFlow switches dynamically grow or shrink according to the traffic conditions and the switches and controllers can map dynamically. It comprises the following four logical modules and the responsibilities of these modules are also discussed below.

- Information Database (IDB) : It collects the traffic demands, maintains the topological resource state and sends them to Energy Optimizer EO. The EO first executes the power model for forwarding plane and calculates the flow paths to obtain the minimum subset of ports and switches. Based on the calculation result, the EO runs the power saving model for control plane and calculates minimum subset of controllers
- Energy Optimizer (EO) : This is the Kernel of the System, running the energy models on E3MC server, to achieve energy-efficient mechanism
- State Converter for Switches (SCS) and State Converter for Controllers (SCC) : With the output of EO, the SCS and SCC change the power states of ports, switches and controllers and it is supporting to improve system scalability

Various rules for switching/routing could be deployed to process the incoming flow. If a controller is to be Turn OFF or Turn ON, the action will be executed when all switches under its control have been assigned to a new master controller. Since the duration of switch migration takes a few tens of milliseconds, the model will support QoS.

Elastic Multi-Controller (E3MC) based BCube Connected Crossbars (BCCC) Model

As shown in the Fig. 3, the efficient and effective Reconfiguration Routing is achieved by integrating BCCC and E3MC. i.e, As BCCC doesn't have a procedure to identify traffic demands and the topological resource state status, this Research Work utilized the features of E3MC to understand the traffic demands and resources state statuses. The hybrid model achieves energy efficiency and stability of a Large Network as well.

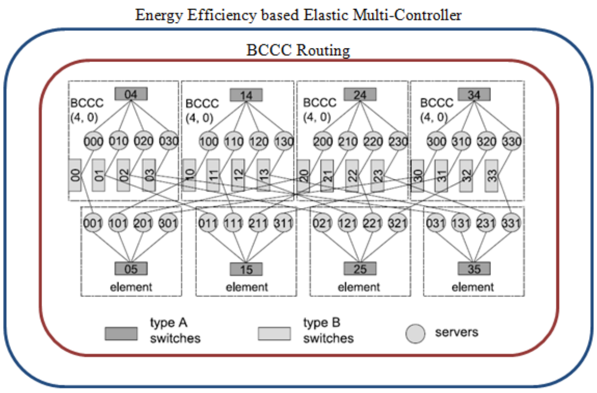

Figure 3. Proposed E^3MC based BCCC Model

The Model was implemented and studied thoroughly. The performances of the proposed model were discussed in the following section.

PERFORMANCE ANALYSIS

This Research Work conducts Simulations to evaluate and study the proposed model and the simulation conducts as shown in the Fig. 4. The model was constructed with 33 nodes in the network and nodes '6', '20' and '12' are defined as the properties of the multi-controller SDN.

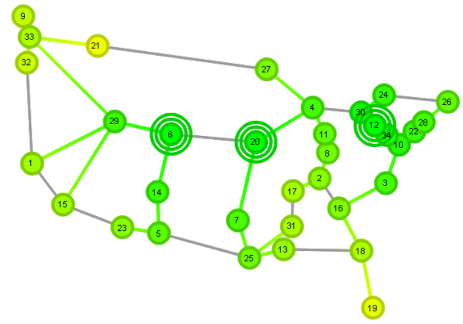

Figure 4. Simulation view of E-DCN

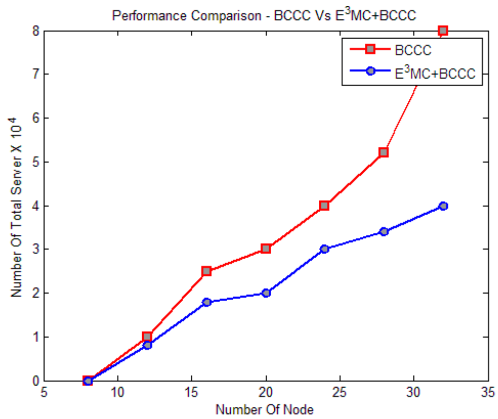

Figure 5. Number of total Servers versus number of Nodes

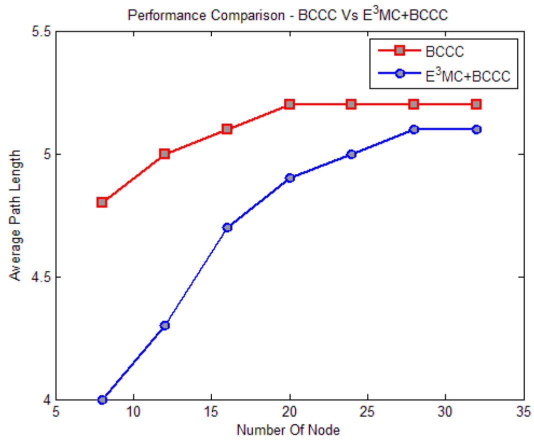

Figure 6. Average path length analysis

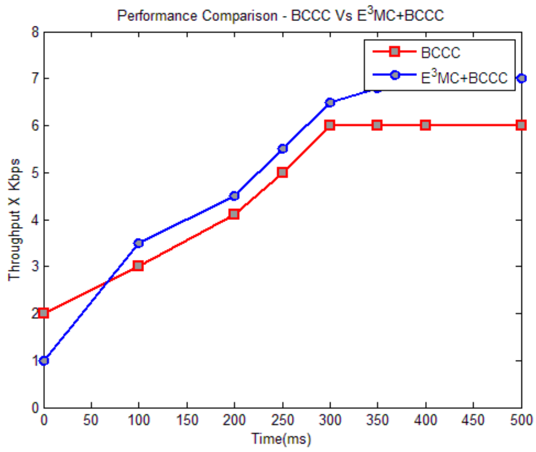

Figure 7. Throughput analysis of BCCC and E^{3}MC+BCCC

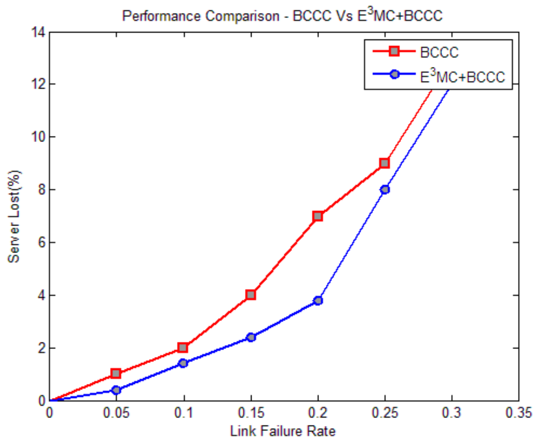

Figure 8. Evaluation result of connectivity of each structure under Link Failure Rate

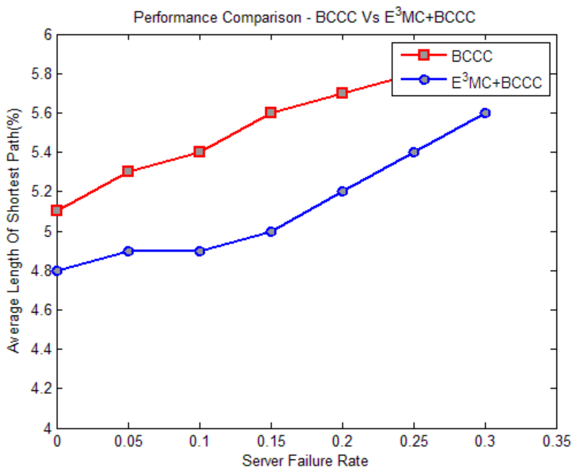

Figure 9. Average Length of Shortest Path vs Server Failure Rate

As shown in the Fig.5, the proposed Model E3MC based BCCC needs relatively less number of Servers needed to accommodate and configure more number of Nodes as compared with BCCC. This helps to reduce Server maintenance cost and power consumption as well. ie it understood that the proposed model is relatively more practical than that of BCCC. From the Fig.6, it reveals that the proposed

Model E3MC based BCCC needs less path length as compared with BCCC to configure Switches and Servers through ports. And also noted that the proposed model is supporting well for small as we as large networks. The proposed model achieves better throughput which shown in the Fig.7. A server is lost if it cannot be reached from the source server. The simulation on the percentage of lost servers in the total number of servers in a network is conducted and depicted in Fig.8. The proposed model has better connectivity than that the BCCC. The Server Failure Rate of the proposed Model is less as compared with that of the existing BCCC Model which is shown in the Fig. 9.

CONCLUSION

This paper proposed an efficient and effective Hybrid Model called Elastic Multi-Controller (E3MC) based BCube Connected Crossbars (BCCC) Model to achieve high energy efficiency. This model was implemented, simulated and studied thoroughly. From the simulation results, it was noticed that the proposed model achieves high performance as compared with the existing BCCC in terms of Energy Efficiency, Path length, Server Resource Utilization, Throughput, Link Failure Rate and Server Failure Rate. It is also noticed that the proposed model saves energy up to 40-50% than that of BCCC.

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