BCube Connected Crossbar and GBC3 Network Architecture: an Overview

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Abstract— **Traditional tree network topologies with their technological infrastructure do not allow to grow, expand, and scale because they cannot offer sufficient bandwidth and constant latency performance due to the thousands of servers connected to the network. This incident is a challenging issue related to being able to provide better service to its customers. The trend of the data center network structure is towards managing large volumes of data and anticipating growth (scalability). Then, the network of the data center appeared, which had a greater impact on society, economy, and life. In this way, the network continues to evolve, and a new network model emerges at the historical moment. The information that exists regarding the data center network is important to consider for future projects in this area. That is why the article addresses data center network structures related to BCube Connected Crossbar (BCCC) and GBC3, since both provide good operation and performance by making use of low-cost products available in the networking industry such as switches and servers. This issue is very important for researchers because it allows them to study server-centric data network topologies.**

I. Introduction

The emergence of new technological advances has allowed massive are data centers to emerge, which made up of thousands of servers whose main function is to provide an online service, through large companies such as Google [1], Amazon [2], and Microsoft [3], since the operational flexibility (resilience) provided by the network structure is essential for solving faults in very particular aspects of the network related to link failures, low bandwidth, information forwarding, server crash, so on, and this causes the entire network to hang, being able to restore the topology of the network, once it goes down and stops working, implies that the services provided are paralyzed [22] [23]. The various investigations that they propose on the network architectures of the data center networkraise various characteristics related to the topologies of networks centered on switches and servers, respectively. In [4],[8] it is mentioned that switch-centric network topologies perform tasks related to packet routing and packet forwarding, while server-centric network structures send and receive packets between a source and destination nodes located in the network architecture. Correspondingly, switch-centric networks represent in Fat-Tree [9]-[11], Jellyfish [12], and F10 [13]. In turn, server-centric networks carry out activities related to the forwarding of data through servers that act not only as end nodes but can also be used as an information repeater between one node and another node. This issue can be represented in DCell [14], BCube [15], FiConn [16], and BCN [17] networks. In the same direction, server-centric networks allow infrastructure at the network hardware level. It allows the activities carried out to be transferred to servers with greater computational power. Similarly, to the extent that the server is connected to a central node and is equipped with the best network infrastructure, it will be able to manage the various processes in a better way, optimizing the performance of the network structure.

In this same direction, the authors in [15] outline that the BCube network structures allow better operation and performance of the network since they allow the optimization of information forwarding and their links between nodes are robust. Simultaneously, BCube has a limitation, which is its ability to expand, as if an expandable BCube network, incurring excessive use of hardware and human effort; because network structures, being recursive and scalable, are constantly changing and their respective servers must have network ports available for possible interconnection through their network cards NICs. BCube network structures limit their use to the number of applications they can manage each time, so the servers may have an operational and functional overload, so the network structure may not work properly. Another issue raised by BCube is the cost of the hardware level, which is why more network hierarchies are needed because it is a network architecture in which each connected server requires the availability of NIC ports. However, most servers with a basic configuration provide only two [18] NICs.

In this article, BCube Connected Crossbars (BCCC), consists of basic two-port servers and switches to provide a cost-effective network for the data center, on a large scale. Another of the properties of BCCC networks is that they can be expanded more quickly, as the changes in the network structure are minimal. In the BCube Connected Crossbar network structures, the increase in links between nodes is linear, which means that the latency level is low with respect to the FiConn and BCN network structures, respectively. Under these circumstances, bidirectional paths of the same length exist in the BCube Connected Crossbar network structures. Through these paths, the BCCC network can provide sufficient bandwidth for the network and maintain the best level of flexibility.

The article is organized as follows. In the first part, I. Introduction, the network centered on switches and servers is present, and the latter must update the existing traditional network architecture by adapting to the data center network. The second part presents related work. In the third section, the data center network structures and some of the most relevant events of this type of network structure are outlined. In the fourth section, the Bcube Connected Crossbar and GBC3 network structure are outlined, considering the growth capabilities of the network and the number of links between nodes. The fifth part present the BCCC and GBC3 network topologies comparison. The sixth part of the document presents the conclusionsof the work and emphasizes that the BCCC and the GBC3 network structures, allow them to be considered as reference network structures for the construction of a data center network.

II. RELATED WORK

In data center networks, the available network topology must be capable of being scalable and resilient, whereas the latter term should allow the network to replicate data and continue to operate without having to stop if a fault occurs. In this way, the entire operational part that develops at the level ofa data center network will not block, to the extent that the request for services from customers increases [13]. At the research level, a lot of work done on data center network topology and other typical architectures is proposed.

In the literature [18], almost optimal connectivity and networks based on the diameter between nodes, since at the level of distribution and location of the network topology, it is necessary to set up new structured cabling to the extent that thelinks between the nodes grow, although it is not applicable in data center networks.

Therefore, the network structure of a data center is made up of nodes, switches, servers, and links. Thus, in [37] the authors propose α-type links that allow linking two types of nodes. There is another type of link, β, that links the physical structure of a switch to a node and a third type of link, γ, that links two switches. Similarly, the β link, the connection it establishes is one of the most efficient since it provides multiple paths, which allows multiple servers to be connected to different ports with NIC cards on the switches.

The performance of a data center network topology is a crucial and critical aspect for the performance of a network topology. The growth of the data center network structure plays an important role in computer networks. In [38] the authors propose a data center network structure based on BCCC, with very good performance in terms of growth and robustness.

In [39] they expose an affective addressing scheme and routing algorithms for a BCCC network topology that allows to improve the bandwidth and the level of latency in the network.

In [19], the BCCC network topology was proposed, which is a server-centric data center network topology, and its topology is based on BCube. So, add in [20] the GBC3 networktopology proposing, which is an improvement of the BCCC architecture at the level of the number of switches in use and the links at the level of switches and servers in the host. Thus,[21] shows the diagnostic results of the measurement (n, k) graphs in star-shaped network topologies, according to the PCM model.

III. DATA CENTER NETWORKS

The network architectures that make up the traditional tree-shaped network structures do not support the number of network users where there are server farms connected to each other and to the rest of the world. This problem causes the network performance to be affected by the bottlenecks forming [25], making the network quality of the services offered are insufficient since it does not allow growth in the network and satisfactory management of the volume of data.

Hence, data centers are critical infrastructures that support on-demand access to network architectures at scale. Thus, the demands of computing services demand the proliferation of thenumber of data center implementations on a global scale [27]. From a practical point of view, the network structure of the data center network takes a tree form made up of switches that allow interconnection between servers. However, this tree adaptation, reflected in the network topology of the data center network at lower levels, allows the racks to be located with their respective servers in a total of 20 to 80 servers, which are interconnected to a switch. on rack [13]. This allows having different higher levels where each server is configured througha central switch. In this same direction, a two-layer tree network structure can support thousands of servers. We can see this type of network structure in the BCCC and GBC3 network topologies proposed in section IV of this article.

It is important to note that any data center network topologymust have a growth plan which must be taken into consideration when designing and building a data center network. Thus, the different levels of scalability of the data center network will allow an exponential increase in the use ofservers, as well as the incorporation of higher levels of necessary links when installing the switches. Depending on the type of services to be installed and contracted by the users, these will be the costs incurred.

In this same direction, the data structures of data center networks use high-end interconnected servers designed to produce better performance and yield concerning the investment price [26].

In turn, a series of problems arise related to the operation ofthe nodes in the network structure that will paralyze the operational flexibility of the network, which translates into highcosts when the services are restored [22], [23]. Under these circumstances, it is recommended to install a central node in the data center network as seen in Fig. 1.

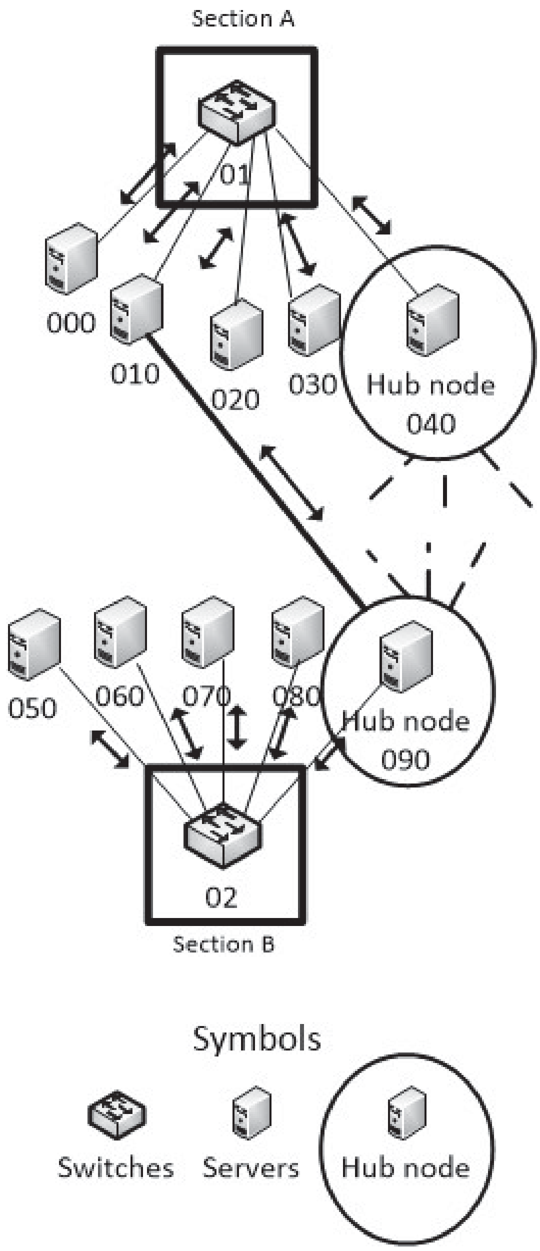

Fig.1. Location of a hub node

The switches, as shown in Figure 1., located in sections A and B, respectively, are assigned a cluster of servers linked to each other and other components in the network structure, and one is identified as the central host. This central node has the task of maintaining the flow of information in a constant and interrupted manner, thus maintaining the growth of the links between hosts, at the level of the network structure and its connection with other artifacts of the same network. This situation of resilience that the network architecture presents allows that, if a network node is disconnected due to a malfunction, the rest of the network structure can continue to function without interruption, thus offering various services to its customers. The dashed lines indicate that the central node ismade up of other ports with their respective NICs, which allows linking with other devices in the network topology.

Some issues that arise in data center networks are detailed below.

A. Problems present in DCN

The development of data center infrastructure, server clusters that support the development of cloud computing, and the use of establishing virtualization processes in a data center network mean that the network structure adapts its traditional layers in network structures that house greater processing capacity at the level of the various network components. This problem allows all network devices to connect to the central network device, which means that data information is forwarded by the central device. However, the complexity of the DCN architectures brings a series of problems [28], [29],[30].

Some of the problems in DCNs are:

- It is essential that the services provided in a data center network structure allow for improved performance at the level of data addressing in the MAC. Dataforwarding between nodes on the network is carried out at the MAC address level, so multiple data centers are required to implement layer 2 forwarding [25]. In turn, this problem increases the requirements for the MAC capacity of the devices connected to the network.
- The network structure of the data center, by allowing various technological network components to be accommodated and to grow numerically, presents drawbacks when establishing the respective domains for the transmission of data in the network. In this way, every device connected to the network sends broadcast packets, resulting in greater bandwidth consumption. In turn, the data transmission considering as multicast only towards the node requesting the message or to set up the broadcast suppression for the broadcast message [25], that is, the node's broadcast traffic reaches a threshold, while the message broadcast will be discarding [25].
- The use of virtualizable components is often used periodically in the data center network. For example, a DCN is made up of a network device that is virtualized to be able to connect to other virtual devices of the users [25]. However, this measure saves network resources and costs, but in turn, brings many problems [25]. The ideal is to be able to attend to the node that loses the link, without having to affect the rest of the network's operation. Even more than that, there is a network security issue that virtualizes the devices [25]. However, the devices located in the cloud, despite being physically connected at the virtual level, are connected by logical addresses [25] [34],[35]. If any of these artifacts suffers some type of malfunction, their performance at the level of the applications they managemay be affected[25],[31], [32], [33].

IV. Network topologies based on data centers

This section introduces two server-centric data center network topologies, considering mapping rules, inter-node representation, and network performance. Therefore, a brief analysis is made between the BCCC and GBC3 network architectures. As for the BCCC network structure, it makes use of two ports for server connection, considering the development of multi-port technology for servers. In which there are changes in the number of ports for the server and the rules in the mapping of the nodes in the network infrastructure when considering the best technology that best adapts to the needs, requires new requirements for the new services offered by the data center network structure.

A. BCCC network architecture (BCube connected crossbars)

The network structures of the data center, specifically at the server level, have their confirmation based on the BCube network structure. The BCCC structure allows for a huge advantage in scalability. This scalability principle allows more servers and switches to be incorporated into the data center based on the existence of a BCCC-type network architecture, which has undergone slight changes. In the BCube Connected Crossbar network structure, being made up of bidirectional links of equal length between its various servers, this allows for the gradual growth of the network, allowing the BCCC topology not only to deliver a sufficient bandwidth and latency capacity towards the end nodes but also to allow switching and reset any component in case it fails [19]. However, the BCCC network topology allows many servers to be adjusted according to the needs of the existing network infrastructure and to maintain the network diameter.

The BCube Connected Crossbar network structure, being a recursive network structure, allows multiple servers to connect through the network ports to the switches. In a telecommunication room, each component consists of n servers, which are connected to a switch with n ports. Then, each server is connected to the first port activated by the switch, and the remaining ports are used for subsequent connections.

In a BCube Connected Crossbar network structure, there are n numbers of links connected to switches. Each link port in the switch is identified with the parameter k (indicates the order of each port in the switch), therefore, the BCCC (n,0) network structure is made up of n switches that allow interconnecting a variety of servers. Then a BCCC(n,1) network topology is composed of five BCCC(n,0) elements, and the switch B in each BCCC(n,0) allows to connect the respective servers. Similarly, a BCCC(n,k) is composed of several BCCC(n,k-1) and n components.

To design a BCCC (n, k) with n elements and several BCCC (n, k-1) it is necessary to identify that are the numbers from 0 to n-1 respectively, since each server representing as a tuple of $a_{k+1}a_ka_{k-1}\ldots a_1a_0$, where:

- $a_0 \in [0, k + 1]$,
- $a_i \in [0, n - 1]$,
- $1 \le i \le k + 1$.

So, a_{k+1} refers to the highest verification bit on the server, so the server can locate $a_ka_{k-1}\ldots a_0$ through a_{k+1} in several (a_{k+1}+1) and BCCC (n,k-1). In turn, the BCube Connected Crossbar network structure is broken down into two zones: section A and section B, respectively. The switch in section A located in the BCCC network topology and made up of links and order of the ports (n,k), has n ports in use as an element, while section B has k+1 ports identified in two links from different components.

In turn, in the network topology, BCCC (n, k) consists of the following parts:

- $(k + 1)\, n^{k+1}$, which refers to multiple ports on the server.
- $(k + 1)\, n^k\, n$, this is the switch ports,
- $n^{k+1}\,(k + 1)$, which refers to the links of a switch.

Correspondingly, the tuple made up of $s_ks_{k-1}\ldots S_1S_0$ is used to represent the switches, where:

- If $S_i \in [0, n\text{-}1]$, the number of links to the switch.
- $1 \le i \le k + 1$, a sequence that must have the order of thislink.
- $S_0 \in [0, n + k]$, the number of links plus the order of theselinks to the switch.

In the case of S_0 and A, we have:

- $n \le S_0 \le n + k$

In zone B, for S0, the switches are:

- $n \le S_0 \le n - 1$

In Fig. 2., you can see the network architecture and the links in BCCC.

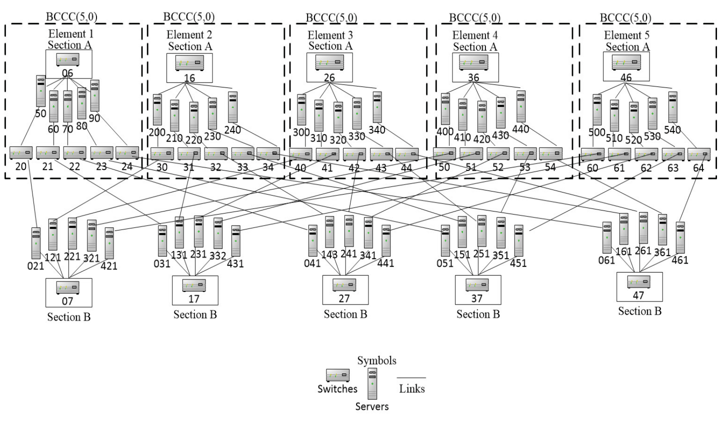

Fig. 2. BCCC network topology with n = 5 and k = 1

The structure of the BCCC network, as we can see in Fig. 2., consists of a series of elements that go from 1 to 5. Therefore, the switches are in zone A and B, respectively, and are responsible for establishing the links, respectively, to the servers. In turn, each of these servers is linked to another switch, which allows links to be established through several servers connected to the corresponding switch located in part B.

B. GBC3 network architecture

In this way, the BCube Connected Crossbar network structure allows short links to be established in the network structure, allowing the network to grow dynamically and comprehensively at a low cost. Thus, the number of ports of a server is two in the BCCC network structure, which is applicable in today's network technologies [16]. The GBC3 network architecture making up of multiple ports at the server and switch level, so that its network structure presents good scalability, and the growth job can be completed by adding components without changing the initial structure, while GBC3 presents also good performance in network diameter, capital investment, fault tolerance, resilience, etc.

In turn, the GBC3 network topology is a recursive network structure, constructed by servers and switches with multiple ports, considering the basic aspects of the BCube and BCCC network topology.

Thus, the dimensions of a GBC3 network structure, k-order, are GBC3 (n, m, k), where n is the number of servers connected to a single switch, m is a positive whole number not less than 2, and k can be expressed as a dimension of GBC3. In this same direction, GBC3 (n, m, 0) is a basic unit composed of one element in the form of n^{m-1} (k + 1) - switch ports [24].

BCube (n, m-2) refers to a component in the GBC3 network topology. In one element, a cluster of servers with m port numbers n^{m-1} and switches with n port numbers (m-1) n^{m-2} coexist. Hence, each server has a disabled NIC port that is later actuated by the link to connect to other network infrastructures.

Therefore, if we have (k≥1) and GBC3(n,m,k), the composition would be (n^{m-1})(GBC3 (n, m, k-1)) and $n^{k\ (m-1)}$ element links. Similarly, in the GBC3 (n, m, k) network topology, the total of servers is identified with the parameter S (n, m, k) is calculated from the following formula:

$$S\ (n,\ m,\ 0) = S_{element} = S_{BCube}{}^{(n,\ m-2)} = n^{\ m-1}$$

$$S\ (n,\ m,\ k) = n^{m-1}.S\ (n,\ m,\ k-1) + n^{\ k(m-1)}.S_{element} \quad (1)\ [20]$$

In turn, a GBC3 (n, m, k) network topology is composed upof n^{m-1} GBC3 (n, m, k-1) and $n^{k\ (m-1)}$ elements, so GBC3 (n, m, k-1) is marked from 0 to n^{m-1}-1. The GBC3 network topology, shown in Figure 3, the addressing of the servers are identified by the following tuple (u_k+1u_k…u_0), and the following statement (v_k+1v_k…v_0) represents the identities called switches.An addressing tuple (u_k+1$u_k u_{k-1}$…$u_1 u_0$) is used to represent theserver on GBC3(n, m, k-1), where:

- $u_i \in (0,1,\ \ldots,\ n^{m-1}\ \text{-}1)$,
- $i \in (1,2,\ \ldots,\ k+1)$,
- $u_0 \in (0,1,\ \ldots,\ k\text{-}1)$.

In this same direction, the servers located in each of the $S_{elements}$ representing by an addressing tuple $u_{k+1} u_k u_{k-1} \ldots\ u_1 u_0$, where:

- $u_i \in (0,1,\ \ldots,\ n^{m-1})$,
- $i \in (1,2,\ \ldots,\ k+1)$,
- $u_0 = k$.

In the BCCC network architecture, as in the GBC3 network structure, the switches are in section A, where the links between the elements and other external devices are established. On the other hand, section B is used to identify which elements are to be linked.

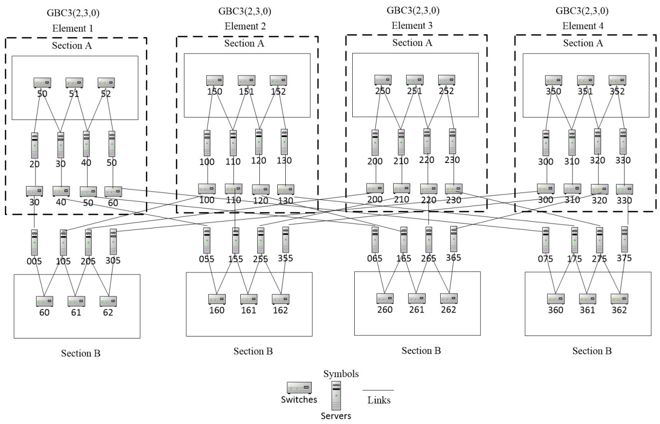

Fig. 3. GBC3 network topology with n = 4 and k = 1

Similarly, the numbers of links are (m-1) (k + 1) $n^{(k+1)(m-1)-1}$ and $n^{(k+1)(m-1)}$, proportionally, and the following statement (v_k+1$v_k v_{k-1}$…$v_1 v_0$) represents the identities called switches. The tuple can be expressed as an exchange part B when $0 \le v_1 \le n^{m-1}$ - 1, and the switch can be expressed as $n^{m-1} \le v_1 \le n^{m-1} + k$ [36].

In turn, as shown in Fig. 3., there are four elements identified as GBC3(2,3,0), located by zone A and B, respectively, and each of these elements consists of six switches (n=3), to which connections are established from two servers (m=2) for each of the switches located in zones A and B, respectively, and the connections of the switches located in area B are parameterized by bidirectional connections. The server 055 and 155 with different u_2 bits belongs to the same element and the link of the B segment switch with the same u_3 u_2 bits.

V. BCCC AND GBC3 NETWORK TOPOLOGIES COMPARISON

Some of the following metrics [40] are summarized in Table I below.

TABLE I. METRICS FOR COMPARING TOPOLOGY

Metrics	*Description*
Scalability	It is the capacity that the network structure must adapt to new technological changes and incorporate them into the network architecture.
Modularity	It is the number of networks that can be incorporated from the respective nodes and the number of subnets that can be generated from these nodes, too.
Energy consumption	They are the Kwh (Kilowatts/hour) consumed by the equipment or elements that constitute the data center network.
Hardware Redundancy	It is the resilience capacity of each of the elements that make up the data center network when it comes to solving specific problems.
Number of elements	These elements are identified by the number of switches, servers and any other device that can be incorporated into the network structure.
Number of network interfaces by server	It refers to the network ports that can communicate with the switch.
Number of hops on multiple paths	It drives latency.
Bandwidth	It is the speed with which the data is sent in bidirectional mode between the various nodes that make up the network architecture.
Oversubscription	Balance of cost and bandwidth from server to server located in the rack.
Load balancing (Throughput)	It is the way how the network manages the amount of data on the network at a given time.
Cabling Complexity	It depends on how quickly the existing structured cabling is installed and reused in the network topology.
Cost	It will depend on the costs that are incurred during the construction of the new network topology as well as its maintenance.

In the case of the BCCC and GBC3 network topologies, we select the following metrics, as can be seen in Table II.

TABLE II. METRICS FOR COMPARING TOPOLOGY BCCC AND GBC3

Metrics	*BCCC*	*GBC3*
Scalability	Good	Good
Bandwidth	Sufficient	Sufficient
Network diameter	Allows maintenance	Good performance
Network structure	Recursive	Recursive
Resilience	Good performance	Good performance
Cost	Low	Good performance
Fault Torelance	Good performance	Good performance
Grow	Dynamically	- Adding components without changing the inicial structure
Take basic aspect of:	- BCube	- BCube - BCCC
Latency Capacity	Sufficient	Sufficient
Type links	Bidirectional	Bidirectional
Length of the links	Equal length (short links)	Equal length (short links)
Number of ports per server	Multiple ports	Two ports

As we can see in Table I, which are the comparative metrics proposed by some authors and the comparative metrics in Table II., for the BCCC and GBC3 network topologies, which we propose allow us to face the current needs required by the networks of data center. The needs that arise from the data centers in relation to the quality of services, bandwidth, latency, network diameter, so on, make these dynamic network structures in constant growth and innovation. The use of data centers with public data with 73% and growth with respect to private data with 27% [41], is clear evidence of the current market trend.

If we take the parameters of the network topology GBC3 (n,m,k), where:

n= Identifies the port number on the switch.

m= identifies the speed of scaling.

k= identifies layer number.

Let be the parameter k, which we are going to evaluate by considering that n=6 and m=10, as we can see in Table III.

TABLE III. TOTAL OF SERVER AND SWITCHES WITH n=6 AND m=10

Parameter k	*Total of Server*	*Total of Switches*
2	1600	665
3	25,400	12,835
4	3,796.000	240,290
5	5,695.400	4,315.960
6	11,770.400	8,872.210

As we can see in Table III., as the parameter k increases, the total of servers and switches increases gradually and quickly. This means more switches will be needed to connect more servers. When the parameter k increases from 3 to 5, the average ratio between switches and servers is around 1.35 to 0.8, which implies the acquisition of infrastructure at a low cost to be able to be implemented according to the new needs that arise.

Let be the parameter n, which we will evaluate considering that m=6 and k=3, as we can see in Table IV.

TABLE IV. TOTAL OF SERVER AND SWITCHES WITH m=6 AND k=3

Parameter n	*Total of Server*	*Total of Switches*
4	100	75
12	200	100
36	300	125
108	400	150
324	500	175

As we can see in Table IV., to the extent that the parameter n increases, the same happens with the total of servers and switches. As the n parameter only identifies the switch port number and not the total number of servers, the number of switches to use increases exponentially. Therefore, the ratio between the total of servers and switches when the parameter n ranges from 4 to 36, is from 1.5 to 0.6, respectively.

Let be the parameter m, which we will evaluate considering that n=3 and k=3, as we can see in Table V.

TABLE V. TOTAL OF SERVER AND SWITCHES WITH n=3 AND k=3

Parameter m	*Total of Server*	*Total of Switches*
8	100	75
9	150	110
10	202	150
11	254	190
12	306	230

As we can observe in Table V., the increase in servers or switches from parameter m will depend on the number of ports attached to the switch (n) and (k+1) which would be the number of links.

In Fig.4, we can observe the assessment of the number of servers and nodes in the BCCC and GBC3 data center network topologies, respectively.

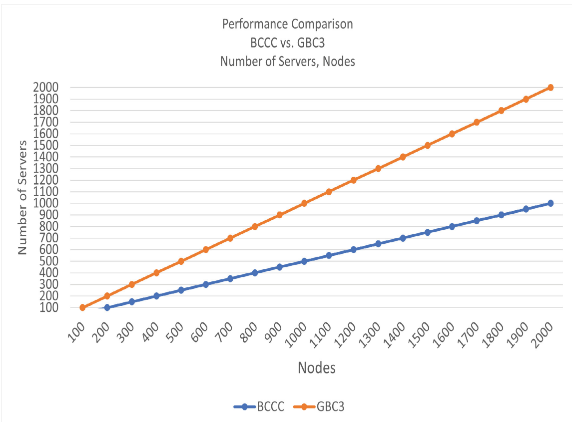

Fig. 4 Assessment of number of servers vs. nodes

The performance of the GBC3 network topology is higher by 1000 servers in relation to the BCCC network topology, which means that in the GBC3 network topology, there is a greater number of network ports linking through its various servers.

In Fig. 5, the relation between Time (ms) and Throughput (Kbps) is shown in the BCCC and GBC3 network topologies, respectively.

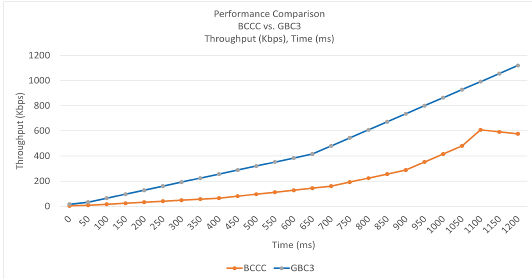

Fig. 5 Assessment of Time (ms) vs. Throughput

In the case of the data center network topology, GBC3 presents a better performance with respect to its counterpart BCCC. The network topology, BCCC, suffers a drop of 600 Kbps, with a time of 1100 ms, which means network congestion or, on the other hand, a failure in any of the links between the nodes that make up the network structure. However, the network topology, GBC3, reaches its maximum level of network data flow at 1200 Kbps with 1120 ms.

In Fig. 6, we can observe the loss of packets in the servers with respect to the average failure in the links, where the BCCC network topology presents a 68% loss of packets in the server with respect to 35% of GBC3 network topology.

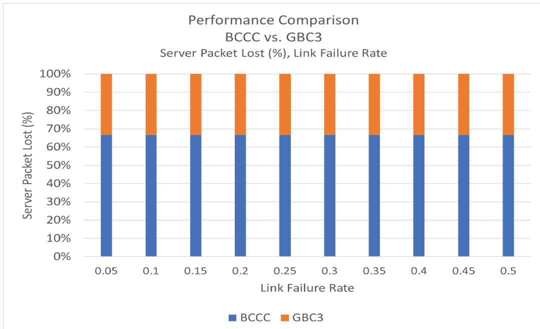

Fig. 6 Assessment of Server Packet Lost (%) and Link Failure Rate

VI. CONCLUSIONS

This article presents an introduction to the BCCC and GBC3 network topologies, respectively, in which the mapping rules and network performance considering. However, modern network structures imply at the DCN level, locating network infrastructure, for example, switches and servers, for greater data transmission close to end-users and clients. Thus, the data traffic generated by machines considering, which includes machine-to-machine communications, in our case communication between switchesand servers, and the increase in the connection and installation of devices at the infrastructure level. Therefore, server-centric topologies and traditional tree topologies, and switch-centric topologies enable a reliable and cost-effective network scalability process. In turn, service providers need to improve network functionality to support faster and greater data processing for technologies related to telemedicine, large-scale smart cities, virtual reality, as this enables better leveraging of computing from edge or gateways to edge resources. It is important to note that research related to data center network topologies with server-centric network topologies provides significant learning for future network development.

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