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A Study on Data Center Network Architecture for NPPs

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1. Introduction

The Advanced Power Reactor 1400 MWe (APR1400) has developed in 2002 [14] and latest Nuclear Power Plants (NPPs)' networks have been designed with approved IEEE 603-1991 and applied IEEE 603-1998. They requires only three words; redundancy, reliability and independence.

The APR1400 Instrumentation and Control (I&C) system is designed with the network-based distributed control architecture. Further, it uses the conventional Tree-based network architecture. It connected with switches and cables having 100Mbps bandwidth in part.

The NPP's Data communication systems in I&C consist of the following three kinds of data communication networks or links with different protocols; Safety system data network (SDN) for safety systems, Serial data link (SDL) for safety systems and Data communication network and also information (DCN-I) network for non-safety systems [11].

Though I&C system and networks are very important feature in NPPs, I&C system in NPP were designed to satisfy just its requirements; reliability, independence and redundancy [12], [13]. Of course, these words are not enough to explain the different networks' optimized use. Recently, the new systems, including its equipment and instruments, have been added on NPPs.

Thus, we verified the present state in NPP's networks and considered its weakness. Then we found more reliably redundant network architecture and optimized network algorithm for the NPPs.

In this paper, we review some network architecture, having stronger redundancy than conventional NPP network architecture. It is concerned with application of Data Center Networks (DCN) architectures for the NPPs.

2. Comparison of Network Architecture in NPPs

Over the past 10 years, various DCN architectures have been proposed and used in Data Centers; e.g., Redundant Tree-based network, Fat-Tree [7] and VL2 [8] of switch-centric network architectures from Clos Networks [4], DCell and BCube of server-centric network architectures.

Generally, it is required that the round trip latencies in DCN should be extremely small and DCTCP [5] is able to get to full link utilization using just 17% buffers [6] compared with TCP Reno [2], [3]. In this respect, application of DCN architecture in NPP would reduce the time delay to actuate or stop the system components and this improvement will prevent abnormal operation.

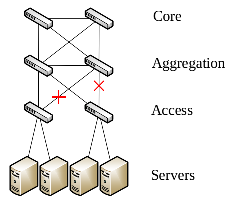

Fig. 1. Simple Data Center Topology.

Besides, common DCN topology provides redundancy for all single failures and some double failures shown as in Fig. 1. Naturally, DCN has the reliability from redundancy.

In this paper, we review the characteristics of DCN architectures. Then we suggest its application in NPPs.

2.1. Data Center Network Architectures

Charles Clos designed a network topology that provides a high level of bandwidth to many end devices [4]. It is one of the most important topologies for DCN. Also, VL2 and Fat-Tree consists of a network built from Clos topology which is switch-centric network architecture.

There are other architectures DCell and BCube, which have server-centric hierarchical topology through a recursive construction. In addition, there are some hybrid architectures which consist of Elec-trical/Optical Element Based Topologies and Electrical/Wireless Element Based Topologies.

But we mainly review two switch-centric network architectures, VL2 and Fat-tree.

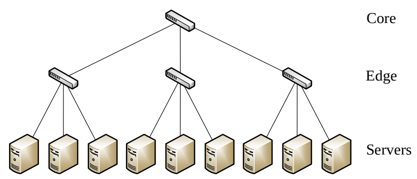

Fig. 2. Two-tier Tree-based network architecture.

Fig. 2 shows weaknesses of a simple Tree-based architecture. If Core Switch (CS) is fail, all of Edge switches (ESs) are not able to connect each other. If one of the core switch links fails, 3 servers fail. Also, increasing the number of servers, this hierarchical architecture causes lack of bisection bandwidth.

Most of the DCN architectures have multiple CSs for redundancy. In addition, each of DCNs has specific architecture and technologies such as MapReduce, to solve the oversubscription problem.

2.1.1. VL2 Architecture

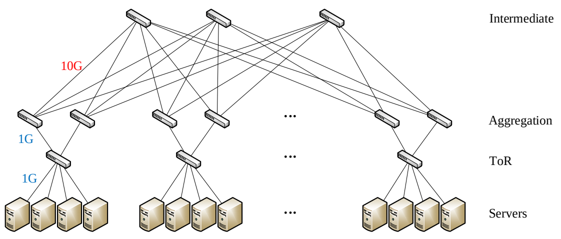

Fig. 3. Simple VL2 topology.

Microsoft Research's A. Greenberg et al., proposed using a Clos network for DCN; VL2. As shown in Fig. 3.

Each of Top of Rack (ToR) switch is connected to two Aggregation switches (ASs) with 1Gbps link. ASs are connected to Intermediate switches(ISs) with 10Gbps link. D_A-ports Aggregation, D_I-ports ISs, and connect these switches such that the capacity between each layer is $D_I D_A/2$ times the link capacity (10Gbps). ToR switches are given by $D_I D_A/4$. If there are M servers attached with a 1Gbps link and the links between IS and AS are at 10Gbps, we obtain M by the equation with total bandwidth from the AS to the ToR switches and from IS to AS.

$$\mathrm{M} \times \frac{D_I D_A}{4} = 10 \times \frac{D_I D_A}{2}, \qquad \text{that is } \mathrm{M} = 20$$

It means 20 servers per ToR, the network can support a total of $5D_I D_A$ servers, with a full bisection bandwidth of 1Gbps between any two servers. Also, the VL2 architecture uses Valiant Load Balancing (VLB) to spread the traffic through multi-paths.

2.1.2. Fat-Tree Architecture

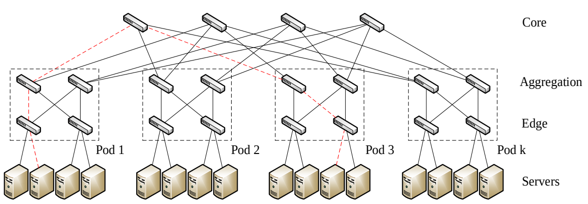

Fig. 4. Simple Fat-Tree topology.

M. Al-Fares et al. [7], proposed another Clos-based DCN architecture called Fat-tree that provides a sufficient bandwidth between all server pairs. The Fat-Tree was a tree with multiple root nodes. Each node in this topology uses half of its ports to connect to the nodes of the upper layer, and the other half of its ports to connect to the nodes of the lower layer.

As shown in Fig. 4, if there is a network that is connected with k-ports 1Gbps switches and k pods, each containing two layers of $\mathrm{k}/2$ switches. Each k-port switch in the lower layer is directly connected to $\mathrm{k}/2$ hosts. Each of the remaining $\mathrm{k}/2$ ports is connected to k/2 of the k ports in the aggregation layer of the hierarchy. There are $(\mathrm{k}/2)^2$ k-port CSs. Also, there are $(\mathrm{k}/2)^2$ hosts in each pod and the number of pods is k.

Thus, Fat-tree built with k-port switches supports $k^3/4$ hosts. And the total bandwidth between the CS and AS layer is $k^3/4$.

So if there are 4-ports 1Gbps switches, it is possible to connect 16 hosts 16Gbps total bandwidth network using 8 ASs and 8 ESs.

It means Fat-tree topology can reduce the cost for building a network by using former low bandwidth switches with few ports; instead of using expensive high bandwidth switches with many ports.

Really, Fat-tree is one of the most popular network architectures for DCN.

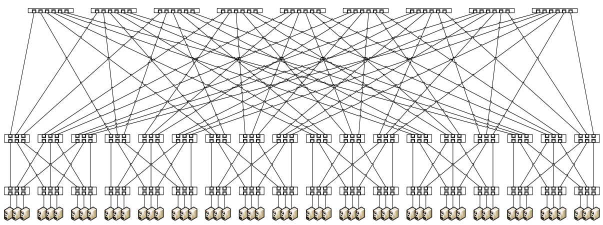

Fig. 5. Fat-Tree topology using 6-port Switches.

Also, Fat-tree and the other DCN architectures which have a full bisection bandwidth have a weakness. It is wiring overhead as in Fig. 5. However, this is a weakness that cannot be avoided because it uses cables.

2.2. Network Architecture in NPPs

The main features of the I&C system are the use of distributed control system (DCS) and Programmable Logic Controllers (PLCs) for the control systems and protection systems. The workstations and PCs (personal computers) uses for data processing systems. To protect against Common Cause Failures (CCF) in software due to the use of software-based I&C systems, DCS and PLCs will be required in the redundant systems for diversity. For data communication, a high-speed fiber optic network based on standard protocols is used. The remote signal multiplexer is also utilized for the safety and non-safety systems field signal transmission [14].

Definitely, safety system data network and non-safety network is physically, electrically separated network.

M.G. Min et al. [10], shows the part of NPP network connections as in Fig. 6. It looks like redundant Tree topology. Certainly, their paper just presents a test of failover verification.

But if two of root switches are fail, all of their system would be failed. This is not only the problem of safety-related system but also the problem of NPP operation.

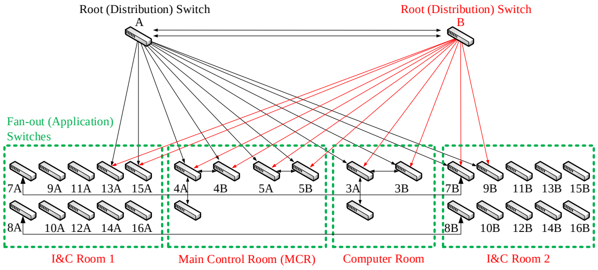

Fig. 6. A simplified part of NPP network architecture.

2.3. Applicability of DCN Architecture in NPPs

The APR1400 has developed in 2002 [14] and latest NPP's networks have been designed with IEEE 603-1991 and IEEE 603-1998.

In fact, the codes are too old to follow up the new technologies. Maintaining availability of the networks is one of the most important performances in NPP that use the network-based distributed control architecture.

We expect more powerful redundancy, by applying the DCN architecture Fat-tree in NPPs. The Fat-tree architecture guarantees hierarchical redundancy in each of layers with redundant ASs and ESs.

Also, Fat-tree topology can build the architecture, using the former switches without changing the link bandwidth. Further, it provides sufficient bandwidth with multipath.

Finally, application of DCN in NPP will improve the network performance of NPP I&C system with lower delay and hierarchically multiple redundancies.

3. Conclusions

Originally, DCN architectures and algorithms are designed for huge number of hosts over thousands. And some of them, e.g., VL2, need high bandwidth switches for upper hierarchy. Also, DCN architecture uses many switches more than Tree-based topology. It may affect the complexity in Computer Room and I&C Equipment Room. Maybe the application of DCN architecture in NPP is not the best way now.

But we have to do our best to reduce the time delay in NPP networks. Replacing the conventional Tree-based network with the Fat-tree architecture will secure the sufficient bandwidth and reduce the network delay. Also, it will increase the redundancy of networks in each layers.

Meanwhile, a lot of additional systems and components have attached on NPPs. It has increased the usage of network bandwidth.

Furthermore, we need to secure the redundant bandwidth and links for implementation of Nuclear-IT convergence technologies and another next generation technologies.

We suggest the application of the most popular DCN architecture in NPP for the more reliably redundant safety operation.

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