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Study on the virtualization of network segregation in the APR1400 MMIS Digital Twin

Soonae Lee*, Jung-Woon Lee
Onetec System Co., Deajeon Office, 361-17, Gapcheon-ro, Yuseong-gu, Daejeon, South Korea
Corresponding author: soonaelee@onetec.co.kr

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1. Introduction

A digital twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity [1].

Digital twins and digital twin-enabling technologies are expected to be incorporated into future nuclear reactor designs, while potentially improving the operation of existing nuclear plants [2]. Digital twins in nuclear power plants have potential benefits that include increased operational efficiencies, enhanced safety and reliability, improved security engineering, reduced errors, faster information sharing, and better predictions [3]. Some of the potential application areas of digital twins in the nuclear industry are design, licensing, plant construction, training simulators, predictive operation and maintenance, autonomous operation and control, failure and degradation prediction, physical protection modelling and simulation, and safety and reliability analysis [3].

For Korea's nuclear power plants, the Central Research Institute of Korea Hydro & Nuclear Power is leading the development of the APR1400 MMIS virtual simulator. This is aimed at supporting the design & construction phase and the operation & maintenance phase of APR1400 [4].

There are several challenges in implementing nuclear I&C systems; 1) Synchronization and Architecture: One of the critical challenges is ensuring synchronization between the digital and physical twins. The architecture of digital twins needs to be carefully constructed to enable the synchronization and determine which signals from the physical domain should be sent to the digital twin [5], 2) lack of standardization of data and models: Technical challenges include the lack of standardization of data and models, which can hinder the implementation of digital twins in industrial settings [6], 3) Expertise and Specialists: Non-technical challenges, such as a lack of expertise and specialists, are also significant impediments to the successful implementation of digital twins in industry [6].

In the case of operating nuclear power plants, it is difficult to collect and analyze network packets due to safety and operational issues. To capture the network packets for analysis and research, the MMIS digital twin needs to implement the physical structure of the Korean MMIS in a virtual environment and build the network in the same way as in the field.

However, due to the limitations of the platform, it does not support hierarchical topology [7]. In this paper, we present the considerations for building a virtualized network in the MMIS digital twin, how to segregate the network, and how to utilize the virtualized network.

2. Method and Results

2.1 MMIS Digital Twin Virtualization Network Considerations

One of the many important considerations when selecting a platform to build an MMIS Digital Twin is the ability to build a virtualized network. To build a virtualized system, you need a hypervisor. A hypervisor is a logical platform for running multiple operating systems simultaneously on a host computer. These hypervisors are generally divided into two types [8]. Figure 1 shows a diagrammatic representation of these two types.

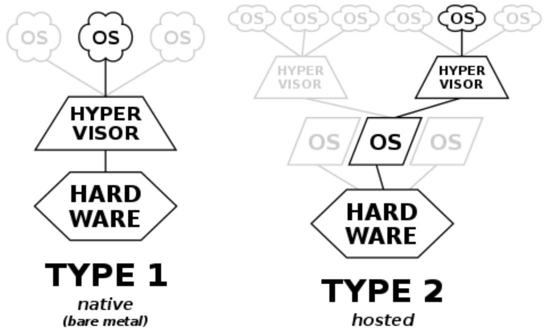

Fig. 1. Hypervisor Type[8]

TYPE 1 is where the hypervisor runs directly on its hardware and the guest operating system runs as a second level on top of the hardware. TYPE 2 runs on the host operating system like a normal program, and the guest operating system running inside the virtual machine(VM) runs as a third level on the hardware.

There are hardware limitations to creating a VM on top of a hypervisor to install and operate a guest operating system. In the case of TYPE 2, you can create multiple networks in a single VM, but you will need as many physical network cards to connect to the VM on physically separated PCs as you want to separate the networks. This is not ideal for designs where you want to configure your entire MMIS as a Digital Twin.

Based on these and other important considerations, the MMIS digital twin was built using VMware's vSphere, known as a TYPE 1 hypervisor, and vCenter (a platform for the integrated management of several vSphere).

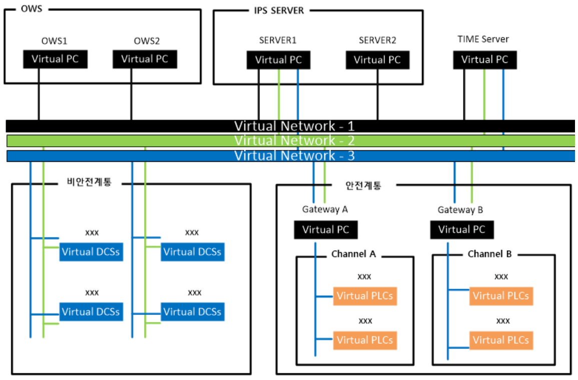

Fig. 2. Virtualization network segmentation diagram

As shown in Figure 2, the network is designed to allow data communication by separating the network. However, it is not possible to create a physical topology such as a switch configuration. It is to construct a logical network topology [7].

By separating the data sent and received through the simulator and virtual controller, which generate the same I/O signals as the field, to use only the network for the purpose, each network can be configured to acquire and analyze data similar to the field.

2.2 Hypervisor-based virtualization network segregation methods

We were able to create a virtual network adapter on the VM through the hypervisor and set it to the corresponding port group so that only data with the same VLAN ID can be sent and received. We will describe the technical method for network segregation in this way.

We used vSphere to create a VM and Virtual Network Interface Card(NIC). The guest operating system recognizes this as a physical network card and can assign it an IP address.

For data between multiple virtual machines to communicate on the same network, it is possible to specify a port group and assign a VLAN ID to it so that NICs with the same ID can communicate.

This is the same concept as VLANs, which are commonly used in switches. One can connect all the PCs to a physical switch, and inside the switch, then logically divide each port into groups for communication so that only the same group can communicate with each other.

Internal communication between VMs within the same vSphere is possible without physical adapters unless a physical adapter is attached to the virtual switch to provide an uplink.

However, creating and communicating with many virtual machines requires hardware, even if it is virtualized. It would be also necessary to consider communicating with VMs that are installed on different hardware.

To communicate with VMs in the hypervisor installed on each hardware, we need as many physical NICs as we need, which can be separated into switches.

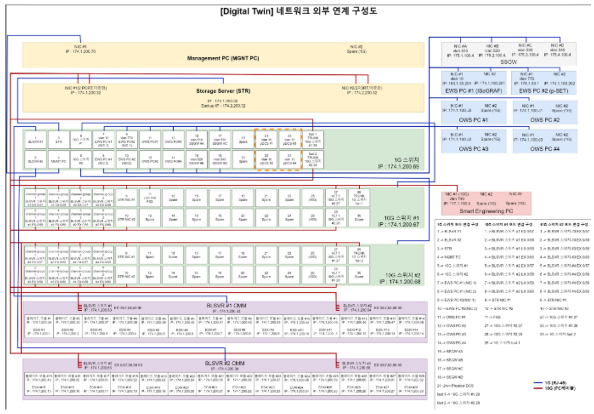

Fig. 3. Configuring external network connectivity

As mentioned earlier, switches become necessary to build large systems where multiple pieces of physical hardware exist and connect them. As shown in Figure 3, by applying the same VLAN concept to physical switches, we were able to design the link between the virtualized system and external systems.

3. Results

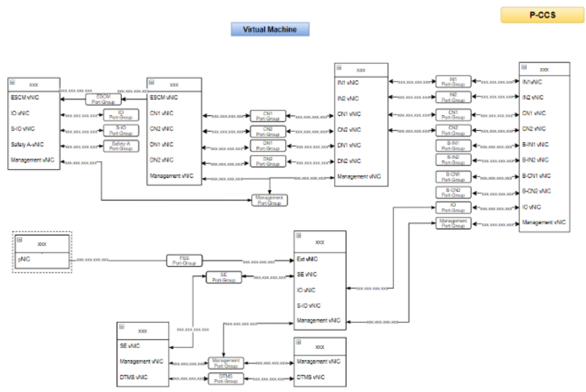

Fig. 4. Virtualization network topology (example)

Each system in the P-CCS system is arranged as a virtual machine, and the virtual NIC assignment and connection (port group) information for each virtual machine is shown in Figure 4 above. In this way, the virtualization network is separated and designed to communicate data according to the characteristics of each network just like in the field.

As shown in Figure 5, the network status of each VM can be viewed through the platform's GUI to analyze network information that is difficult to identify.

In addition, we wanted to improve the usability by providing the ability to acquire packets for a certain period using the PCAP driver so that they can be analyzed in Wireshark through the virtual NIC selected by the user based on each VM.

We can research and develop surveillance, response, and prevention technologies by taking cyber-attacks from a security perspective in this virtualized network environment, and research on the latest security threats. It will also contribute to the acquisition, analysis, and utilization of data for education and the integration of various technologies.

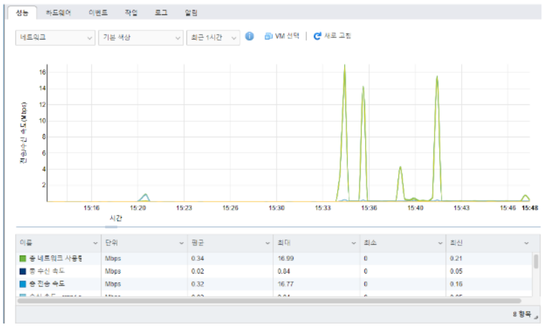

Fig. 5. Network Status Monitoring of Virtual Machine

4. Conclusions

The R&D project "Development of digital twin of Korea digital MIS to enhance power plant life cycle engineering " being conducted by Korea Hydro & Nuclear Power Central Research Institute (KHNP-CRI) is not only at the forefront of this trend but will also make a significant contribution to the field of nuclear power generation.

As one of the important technologies, the design and construction of virtualized networks holds a lot of promise in terms of technology application and utilization. Currently, we have designed a virtualized network separation based on the features provided by the platform, but we expect that further research will enable us to improve the technology, such as simulation of network switches and diagnosis of virtualized network performance.

We believe that this will eliminate difficulties in data acquisition and analysis due to safety and operational issues in the field and provide an environment for the development of instrumentation and control and cybersecurity technologies.

5. Acknowledgements

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