**2.D.2.** A Network Performance-Aware Routing for PRAGMA Cloud

As noted above, there is a great deal of emphasis in PRAGMA on virtualizing computing, and in particular building virtual computing clusters. To build a virtual computing cluster from aggregated computing resources requires network virtualization technologies that provide a virtual private network for each user. We have therefore focused on the recently emerged concept of Software Defined Networks (SDN) and the open standard, OpenFlow technology as a possible solution that allows us to control network resources in a dynamic manner with software-based technologies.

Virtual network technologies are helpful in establishing network connectivity among computing resources by hiding the topologies and policies of the physical networks. however, hiding topologies and policies often causes performance problems in the virtual network. Since mapping between the actual network topologies and the virtual topologies is hidden, it becomes difficult to optimize network routing to increase network performance. This poses a significant problem, especially when a virtual network is established over widely distributed computing environments like the PRAGMA Cloud.

We have therefore introduced an OpenFlow-based, network performance-aware routing method, which controls network routing automatically by taking into consideration the observed inter-domain network throughput and latency, i.e., how fast or slow messages pass between networks, a key measurement for any real or software defined network. The premise behind this method is to allow us to keep track of dynamic network topologies, network throughput and latency, and then allocate appropriate network resources based on the demand of user applications for virtual computing environments.

As a prototype, we have developed an OpenFlow controller that controls the network routing based on the observed network throughput and latency (see Figure 1). We have expanded the OpenFlow network environment deployed at PRAGMA 22 and constructed an experiment environment consisting of five organizations in PRAGMA Cloud as illustrated in Figure 2. Network throughput and latency observed by Netperf (software that provides network performance between sites) and ping (a tool to determine if a specific address is reachable) at a certain point in time are indicated in Figure 2. As shown, the performance of each link differs. At PRAGMA 24, we successfully demonstrated the network performance-aware routing controller taking optimal paths for virtual networks in this experiment environment.

Following PRAGMA 24, we have improved the implementation of this OpenFlow controller. For the network performance-aware routing, the measurement method of network performance is an important key factor. However, the prototype implementation of the network measurement at the time of PRAGMA 24 was not sophisticated enough. We therefore have decided to include a distributed network monitoring system, “OverLoad,” developed by the Kasetsart University team, into our OpenFlow controller. For this development, we have formed an international development team.

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