Various infrastructure networks in modern society form the basis of many social and economic activities and are continually increasing in complexity and importance. Network science plays an important role in simplifying them as networks consisting of nodes and links and in analyzing information, resources, or their flow within networks. In fact, network science has revealed that real networks commonly have a scale-free (SF) structure. The most important feature of SF networks is that their degree distribution follow a power-law. This indicates that a few nodes (called hubs) have a lots of links, and most nodes have relatively few links. Since almost all nodes are connected to hubs, the network has a high efficiency in disseminating information because the hub can shorten the paths between nodes in the network. Although SF networks are robust against random failures, they are extremely vulnerable to malicious attacks targeting hubs. Therefore, hubs are advantageous for information dissemination, but they are also structural weakness. Moreover, many real networks are frequently threatened by natural and man-made disasters. Since infrastructure networks support our society, it is necessary to overcome their inherent weaknesses and construct robust structures.

Conventional studies for network robustness have mainly focused on degree correlations. For example, it is shown that onion-like structures with positive degree correlation have optimal robustness to malicious attacks. However, with too high degree correlation, networks have low robustness. Therefore, it is necessary to find new principles to construct a robust structure. Recently, it is shown that loop structures are more important than degree correlations to construct robust networks. The reason is that a network without loops become a weak tree structure. Thus, in order to construct robust structure, it is important to enhance loops so that prevent the network from becoming a tree structure. Several rewiring methods based on enhancing loops have been proposed. These methods construct more robust networks than the method increasing the degree correlation. Furthermore, it is commonly confirmed that the networks rewired by such methods have small width of degree distributions. Having small width of degree distributions corresponds to decreasing the gap between the maximum and the minimum degrees. Thus, as an extreme example, a random regular graph with the zero gap has optimal robustness. Such optimal robustness of a regular graph is verified by perturbation analysis.

Based on the above backgrounds, this paper has the following three objectives. First, we propose a self-healing method based on enhancing loops and reducing the width of degree distribution. Then, we clarify the effect of community structure on network robustness. Finally, we propose a method to make configurations of data-centers that has robust and even load distribution.

keywords: Robustness of connectivity, Enhancing loops, The minimum gap of degree distribution,

Distributed self-healing, Community structure, Data-center configuration.