社団法人　電子情報通信学会
THE INSTITUTE OF ELECTRONICS,
INFORMATION AND COMMUNICATION ENGINEERS

信学技報
TECHNICAL REPORT OF IEICE.

サービスネットワーク連携のための高信頼化ネットワーク基盤構築手法

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あらまし　情報通信技術が社会に深く浸透し、あらゆる機器や人が情報ネットワークを構成する時代が到来しつつある。特に近年は、ネットワーク仮想化技術の進展を背景に、いくつかの（マイクロ）サービスネットワークを連携させ、新たなサービスを創発するネットワークシステムが注目されている。本稿では、複数のサービスネットワークがネットワークを介して相互に接続される “Network of Networks” に着目し、トポロジー構造およびトラヒックフローの振る舞いの観点から相互に接続されたネットワークの性質を明らかにする。固有ベクトル中心性にもとづいてノードを Central ノードと Periphery ノードに分類し、これらのノードの接続組み合わせによる４つの相互接続ネットワークを生成し、ノード故障発生時のスループット性能の変化を調べた。その結果、ネットワークのコアとなるノード近隣の固有値ベクトル中心性が低い Periphery ノード同士を接続することで、高い信頼性と効率性が得られることが明らかとなった。

On the Strategy of Making Reliable Inter-Connected Network for Cooperative Service Networks

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Abstract　In recent years, developing a new service by collaborating two or more (micro-)services has attracted much attention. Such the trends of service development lead to increase the importance on understanding inter-networking of service systems. In this paper, we investigate characteristics of inter-connected networks from both topological and traffic-flow perspectives. Based on the eigenvalue centrality and location of nodes, four strategies for connecting two networks are developed and examined for constructing inter-connected networks. The results showed that high reliability and efficiency are achieved by connecting periphery nodes, which have low eigenvalue centrality, around core nodes.

Key words　Inter-connected networks, Network of networks, Resilience, Network design, Eigenvector centrality

1. Introduction

Many people enjoy Internet services such as SNS or cloud services and expect new Internet services to further improve our Internet life. In recent years, developing a new service by collaborating two or more (micro-)services has attracted much attention. One of examples is a concept of API economy where Internet services connect and collaborate each other through web APIs. Such the trends of service development lead to increase the importance on understanding inter-networking of services, a. k. a, network of networks.

Several studies investigate topological characteristics of inter-connected networks. Refs. [1, 2] evaluate the reliability of inter-connected networks by changing structure for connecting two networks. They introduce two metrics, inter degree-degree coefficient (IDDC) and inter-clustering coefficient (ICC), to characterize the structure for connecting two networks. IDDC represents the similarity of degree of two nodes that form an inter-connected link, while ICC represents the clustering coefficient among nodes that form inter-connected links. Using the random network and scale-free network, they show that the reliability of inter-connected network improves with high values of IDDC and ICC. Brummit et al. [3] showed that too many inter-connected links increase the risk of large-scale failures because inter-connected links help to propagate impact of failures from one network to another network.

In the case of interconnections between communication networks, these evaluations are not sufficient because they do not consider about traffic flow. Their evaluations are only based on topological metrics. However, in communication networks, traffic flow is important because the quality of communication is dependent on not only connectivity but also on the traffic concentration of some nodes. The difference of connecting structure between networks is dependent on which nodes are connected. Therefore, it needs to consider about the amount of traffic flow on links and which nodes are connected for making an inter-connected network.

In this paper, we investigate the characteristics of inter-connected networks from both topological and traffic perspectives. Although the actual application of a network of networks should suppose multiple networks, we investigate the simplest scenario where two networks are connected via inter-connected links (Figure 1). Moreover, we assume that there is a cooperative relationship between two network operators, and thus some information such as topological information to decide the inter-connected nodes is available. Then, we will provide an approach to generate an inter-connected network and evaluate the reliability of generated inter-connected networks before and after failures. For generating the inter-connected networks, nodes are first classified into Central nodes and Peripheral nodes based on their roles of nodes in the network. Next, we prepare some connection strategies to construct inter-connected networks with different inter-connected structure such as CC (Central node connects to Central node) or CP (Central node connects to Peripheral node). With the inter-connected networks with different connection strategies, we evaluate the reliability from the viewpoint of not only topological metrics but also traffic-flow metrics.

This paper is organized as follows. Section 3 shows our strategies for making inter-connected networks. In Section 4, we evaluate performance of inter-connected networks and its reliability against node failures. Finally, Section 5 concludes this paper.

2. Construction of Inter-connected Networks

It is important to consider the connecting structure among net-

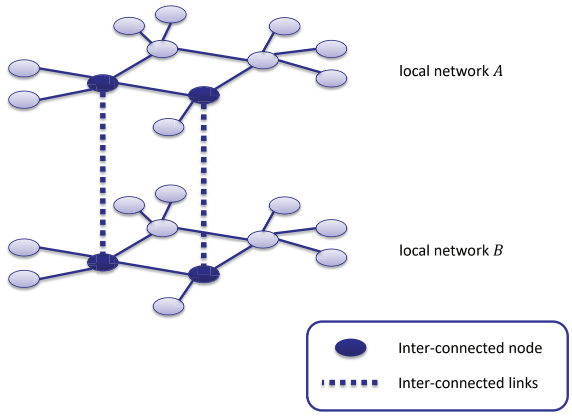

Figure 1: Illustration of an inter-connected network

works for designing reliable and efficient networks. In this section, we discuss what properties of nodes are suitable for deciding inter-connecting nodes when two networks cooperatively connects each other for the common goal of constructing a reliable and efficient inter-connected network. Here, reliable represents that a network can keep the connectivity among nodes as much as possible even when failures occur, and efficient represents that a network can communicate with high throughput. We first explain a basic strategy and some premise on making an inter-connected network. Then, we define the properties of nodes to use and explain connecting strategies to construct inter-connected networks.

2.1 Basic Strategy for Communication Networks

When constructing an inter-connected network by connecting communication networks under the number of inter-connecting links is not limited, resilience of the inter-connected network between networks is the highest when all nodes have inter-connecting links. That is, it is more difficult to separate an inter-connected network into two networks when failures occur. However, it is not realistic because of a lot of operational cost. Owing to this, under the number of inter-connecting links is limited, we construct an inter-connected network to enhance the reliability.

A problem is what properties of nodes to make inter-connecting links. The properties represent the role or importance of nodes. One of approaches is to attach inter-connecting links to nodes in the core part of networks as we can easily imagine. Nodes in the core part of networks are the placed at the center of networks and play an important role in networks. Another approach may use nodes around periphery nodes. In this paper, we investigate which is better whether core or periphery nodes for inter-connected nodes.

To classify nodes into core and periphery, what criteria should be used? In our study, we use eigenvector centrality as criteria. Eigenvector Centrality indicates the importance of a node's neighbors, and can be high because a node has either numerous or important neighbors. In the communication networks, eigenvector centrality can be regarded as the amount of traffic through nodes. Intuitively, it is natural that the amount of traffic traversing a node increases when its neighbors also process so much traffic. Hence, using eigenvector centrality of nodes, we can suppose how much traffic is processed on each node, i.e. the importance of each node in networks. Thereby, nodes with high eigenvector centrality can be regarded as core nodes and nodes with low eigenvector centrality can be regarded as periphery nodes, such as placed on the edge of networks. Although the study focusing on an inter-connected network of Web pages [4] also use eigenvector centrality as criteria to classify nodes, their goal of the inter-connection is to enhance eigenvector centrality of networks (the sum of eigenvector centrality of each node in network). Because in communication networks regarding eigenvector centrality as traffic, enhancing eigenvector centrality of only a part of nodes means enhancing loads of them, as for our study, we construct an inter-connected network to enhance reliability and efficiency, not to enhance eigenvector centrality.

In our current approach, the topological information of two networks is required to calculate eigenvector centrlaity. However, in an actual scenario, the topological information may not be disclosed as Internet's ASes are. It may be hard to know the information to calculate eigenvector centrality of another network. However, under cooperative relationship, the essential information required for inter-connection can be shared. In this paper, we assume that the information to calculate eigenvector centrality is available and use topological information in the evaluation.

2.2 Criteria of Central and Peripheral Nodes

In this section, we explain criteria of Central and Peripheral nodes. For reference [4], the nodes are classified into Central nodes and Peripheral nodes based on eigenvector centrality of nodes. Eigenvector centrality is calculated as the first eigenvector $\vec{x}$ of the adjacency matrix M. Centrality of node i is the ith factor of $\vec{x} = \{v_1, v_2, ..., v_N\}^T$ (N is the number of nodes). Eigenvector Centrality indicates the importance of a node's neighbors, and can be high because a node has either numerous or important neighbors. In the communication networks, eigenvector centrality can be regarded as the amount of traffic through nodes. Intuitively, it is natural that the amount of traffic traversing a node increases when its neighbors also process so much traffic. Hence, we can regard nodes with higher eigenvector centrality as more important nodes. Based on the eigenvector centrality, we classify nodes into Central and Peripheral. The definition is explained in Section 2.3.

2.3 Making Reliable and Efficient Inter-connected Networks

For construcging an inter-connected network from network A and B, we consider four connecting strategies based on the role of inter-connecting nodes as follows.

- CC: Central node in network A connects to Central node in network B
- CP: Central node in network A connects to Peripheral node in network B
- PC: Peripheral node in network A connects to Central node in network B
- PP: Peripheral node in network A connects to Peripheral node in network B

When choosing inter-connecting nodes, we consider following two intentions. One is that each node in network A and B with closer distance are connected. This is because it is known that the costs of constructing links are dependent on their length [5]. For example, in CC, a Central node in the east (in the case of U.S.A) of network A connects a Central node in the east of network B. As a result, we can get inter-connected networks with different connecting structure between networks. The other intention is that inter-connecting nodes should be selected so as not to concentrate on one place. When inter-connecting nodes are concentrate on one place or city/state, all inter-connecting nodes might be failed simultaneously when large-scale disasters occur. For example, considering the topography in the United States, it is better to pick nodes from New York, Chicago and San Francisco than to pick nodes from only New York. Therefore, we use the information of the module structure of network in order to distinguish the location of nodes. Based on the information of module structure and eigenvector centrality of nodes, Central and Peripheral nodes are defined as follows.

- Central

We pick nodes with links between modules as the candidate of Central. We calculate eigenvector centrality for adjacency matrix of a local network. In each module, a node with the highest eigenvector centrality is defined as Central node.

- Peripheral

We calculate eigenvector centrality with adjacency matrix of each module, which means the regarding each module as network. In each module, a node with the highest eigenvector centrality is defined as Peripheral node. Peripheral nodes can be chosen as the same nodes as Central but we allow that.

Assuming that the number of inter-connecting links equals to the number of modules at first of evaluation. It is the situation that the place of inter-connecting nodes is well distributed. However, it is better that the number of inter-connecting links is few as much as possible. Therefore, we regard the number of inter-connecting links as a parameter, and consider decreasing the number in evaluation.

3. Evaluation

3.1 Local Networks

We consider an inter-connected network by connecting network A and B. As for network A and B, we use an ISP topology, which has 523 nodes and 1304 links, as shown in Figure 2.

Since all nodes have the properties of states based on its location information, we regard one state as one module. However, there are some exceptions because of the size of states. In the ISP topology, 82 nodes belong to California while only one node belongs to Kentucky. Since small-scale states (with a few nodes) are a part of large-scale states (with many nodes) generally, it is not suitable for

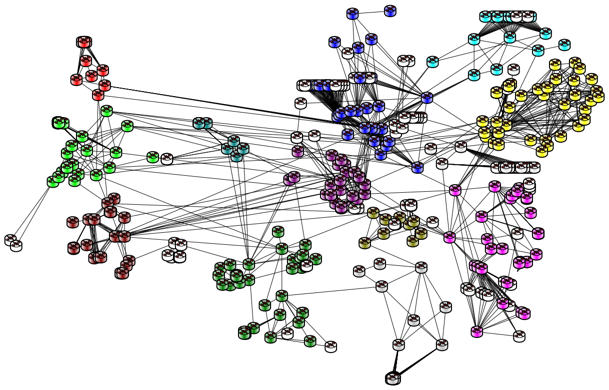

Figure 2: ISP topology

using such nodes as inter-connecting nodes, under the purpose of obtaining distributed inter-connecting nodes. Thereby, small-scale states are not regarded as modules. 12 states remain after excluding small-scale states, where the number of nodes in states is less than 11. To the contrary, there is a so large-scale state. The number of nodes in California is about 1.5 times larger than that of in New York, which is the second largest state. In addition, the area of California is large and its domain expands from north to south widely. To select inter-connecting nodes adequately, we divide California into two states heuristically. Consequently, we can obtain 13 states. In this figure, nodes are colored by module structure. The same colored nodes are in the same module and non-colored nodes are in small-scale modules. We choose inter-connectingnodes from each state.

3.2 Link Capacity

An inter-connected network has two classes of links: internal links and inter-connected links. The link capacity of internal links within network A is set based on the amount of traffic through its link when all node pairs in network A communicate. The link capacity of inter-connecting link i is based on the amount of traffic S_i through its link when all node pairs in inter-connected network communicate. Then, the capacity of inter-connecting link i is defined as

$$c_i = \frac{S_i}{N_A * N_B} * C_{total}, \quad (1)$$

where C_{total} is the total capacity of inter-connecting links and N_A (and N_B) is the number of nodes in network A (and B).

3.3 Characteristics of Inter-connected Networks

In this section, we evaluate the characteristics of inter-connected networks. Based on the strategies CC, PP, CP and PP, we generated four inter-connected networks. We set the number of inter-connecting links to 13, which equals to the number of modules, and the sum of link capacity of inter-connecting links C_{total} to the number of node pairs whose minimum hop path passes through the inter-connected links. Thus, C_{total} is set to $N_A \times N_B$. Hereafter, we call inter-communication as the communication between node pairs across the inter-connected links and intra-communication as the communication between node pairs that do not use the inter-connected links.

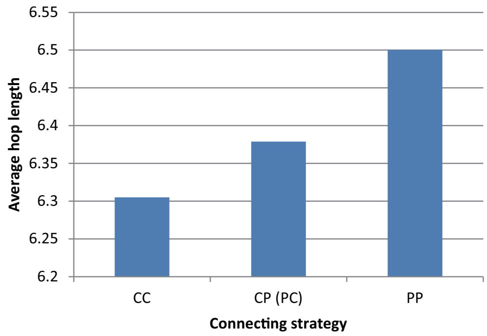

Figure 3: Average hop length

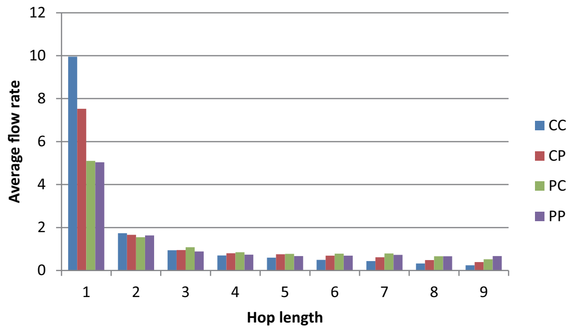

Figure 4: Average flow rate of intra-communication before failures

Figure 3 shows average hop length $\overline{d}$ of inter-communication. In the figure, X-axis shows each connecting strategy and Y-axis shows average hop length $\overline{d}$. We can see that $\overline{d}$ is the shortest in CC network and is the longest in PP network. Figure 4 shows the average flow rate of intra-communication. The flow rate of each node pair is calculated such that the link capacity is fully utilized. Here, we focus on node pairs in network A as intra-communication. In these figures, X-axis shows the hop length of node pairs and Y-axis shows the average flow rate per hop length of node pairs. We can see that, in CC and CP network which use Central nodes in network A as inter-connecting nodes, the average flow rate of long-range communication becomes low. However, in PC and PP network where Peripheral nodes in network A are used as inter-connecting nodes, the average flow rate is still large even in long-range communication.

Next, we show the average flow rate of inter-communication. Figure 5 shows the average flow rate of node pairs in the same module and Figure 6 shows the average flow rate of node pairs whose nodes belongs to the different module. In these figures, X-axis shows individual connecting structure. We can see that it achieves higher flow rate of node pairs in the same module by using Peripheral nodes regardless of network A or B.

Hereafter, we show the characteristics of inter-connected networks after a node failure. Note that, because we use the same topology for network A and B, we assume that the node in network B in the same place of failed node in network A is also failed

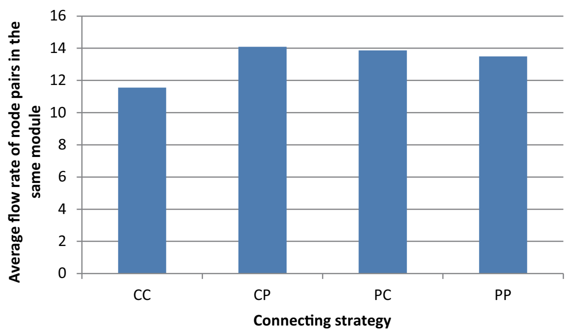

Figure 5: Average flow rate of node pairs in the same module

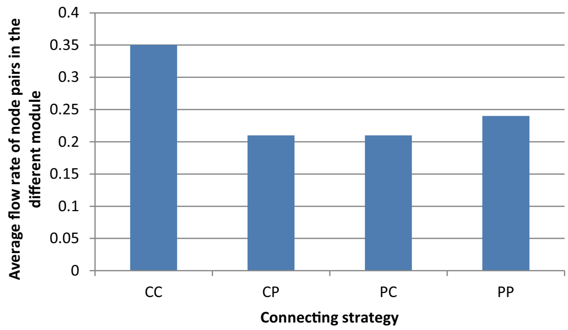

Figure 6: Average flow rate of node pairs in the different module

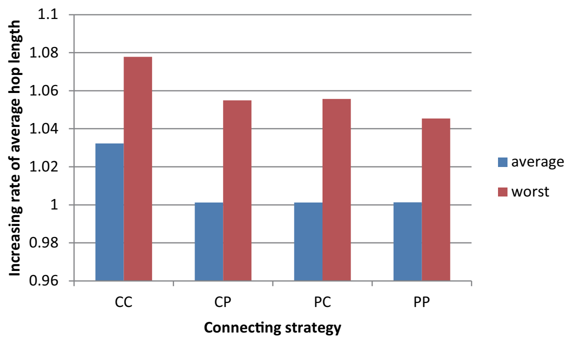

Figure 7: Increasing rate of hop length after a single failure in average and worst case

at the same time. Figure 7 shows the changes of average hop length of inter-communication after a single node failure. Here, the average hop length is calculated as an average of average hop length of all patterns of a single node failure. In the figure, the average hop length is normalized by an average hop length before the failure occurs. Blue bar represents the average of average hop length of all pattern of a single node failure. Red bar represents the worst case scenario, i.e., the average hop length is maximally increase. We can see that CC network receive the worst influence from failures compared to other connecting strategy. In addition, PP network can keep the increasing rate low even in the worst case. Thus, it is revealed that PP network is not affected largely by failures.

Finally, we show the changes of flow rate after a node failure. For all pattern of a single failure, we focus on fluctuation of flow

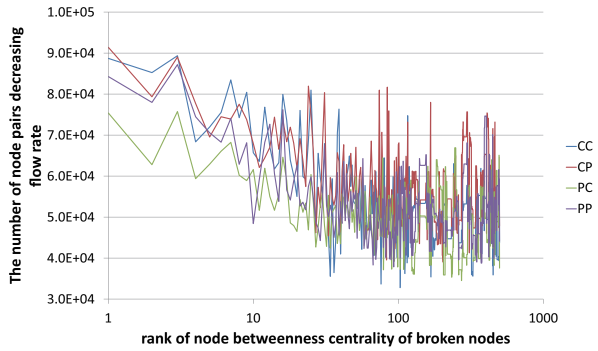

Figure 8: The number of node pairs of intra-communication decreasing flow rate when nodes other than inter-connecting nodes fail

rate between before and after failures. As for intra-communication, we show the results when nodes other than inter-connecting nodes break in Figure 8. In this figure, X-axis shows the rank of node betweenness centrality of failed nodes and Y-axis shows the number of node pairs decreasing flow rate by failures. This represents that the smaller values are better. We can see that the values can be kept low for PC network, so it is revealed that PC network is the most reliable. However, it is too simple to use PC strategy for constructing inter-connected networks. This is because, this results represent flow rate of node pairs in only network A. From a viewpoint of network B, PC strategy equals to CP strategy. We can see that the values are larger in CP network. When network A wants to use PC strategy, does network B agree with such unfair connection? The answer is No. Therefore, we pick up the results of CC and PP network and show them in Figure 9. We can see that the values in CC network are mostly larger than the values in PP network. The discussion about CP and PC strategy is also applied to intra-communication. Therefore, in the following evaluation, we show the result in CC and PP network. As for inter-communication, we show the results when nodes other than inter-connecting nodes break in Figure 10. The definition of X-axis and Y-axis are the same as Figure 9. We can see that the values in CC network are larger than the values in PP network. In other words, CC network is affected by failures more than PP network. For these results, when we compare CC and PP network, PP network is more reliable than CC network.

4. Conclusion

In this paper, we investigated characteristics of inter-connected networks from both topological and traffic-flow perspectives. We first discussed that eigenvalue centrality and location of nodes are important for making inter-connected networks more reliable and efficient. Folllowing the discussion, nodes in the network were classified into Central nodes and Peripheral nodes based on their eigenvector centrality of nodes. Then, we examined four connecting strategies CC, CP, PC, and PP to construct inter-connected networks with different inter-connected structure. We evaluated the reliability and efficiency from the viewpoint of not only topolog-

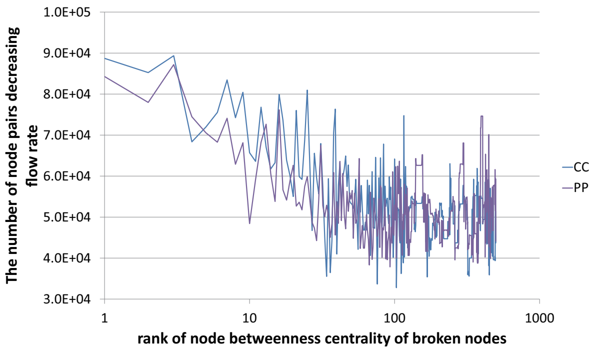

Figure 9: The number of node pairs of intra-communication decreasing flow rate when nodes other than inter-connecting nodes fail (CC, PP)

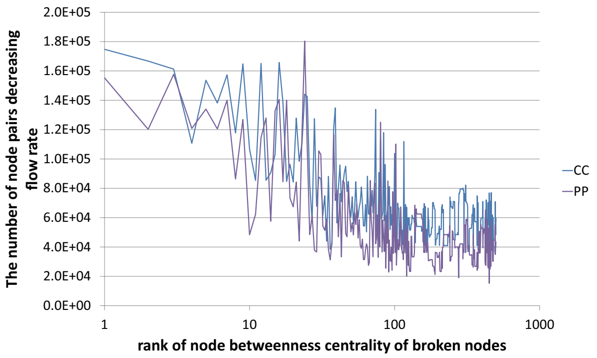

Figure 10: The number of node pairs of inter-communication decreasing flow rate when nodes other than inter-connecting nodes fail

ical metrics but also traffic flow when failures occur. The results showed that high reliability and efficiency are achieved by using periphery nodes around core nodes as inter-connecting nodes. Our future work is to consider the interdependency between two service networks and investigate good connecting strategies for the interdependent networks.

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