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Designing data center network by analytic hierarchy process [☆]

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ABSTRACT

The demand for delivery services for large-sized content such as video has increased dramatically, and the use of cloud computing services in which users can use IT services via networks has also increased. To provide these services with high quality and high reliability, ISPs need to carefully design network topology and the positions of data centers. However, network topology and data center location strongly affect various evaluation criteria, such as cost, path length, and reliability; therefore, these criteria with different respective units need to be considered simultaneously when designing a data center network. The analytic hierarchy process (AHP) is a way to make a rational decision considering multiple criteria. This paper proposes to design data center networks by evaluating both network topology and data center locations simultaneously using AHP and also shows the numerical results of applying the proposed design method to the three areas of Japan, USA, and Europe. We investigate the properties of desirable data center networks in these three areas, and compare the results with those obtained by the enumeration method.

1. Introduction

User demand for viewing video over networks is strong, so the number of people using user generated content (UGC) delivery services, e.g., YouTube, has increased dramatically. As the transmission capacity of access links grows, delivery services for rich content of high quality and huge size, e.g., movies and TV dramas, have been widely provided by many ISPs. Moreover, cloud computing services, in which ISPs instead of users own and manage computer hardware, software, and data and provide computing services to users with usage-based charging, have been widely used.

The infrastructure providing these distribution services for rich content and cloud computing services consists of data centers with storages and processors of large capacities and networks connecting multiple data centers at geographically distant locations and users. In this paper, we call the infrastructure consisting of data centers and networks a *data center network*. It is important for ISPs to adequately design data center networks to provide content delivery and cloud computing services of high quality and high reliability at low cost. However, optimally designing data center networks is difficult because the network topology and data center locations of data center networks strongly affect many evaluation criteria such as service quality, reliability, and cost. To increase redundancy to improve reliability, creating more routes between user nodes and data centers by providing more intermediate nodes, links, and data centers is desirable. However, the increase in links or data centers will also increase equipment and operating costs. For users, avoiding congestion at intermediate nodes and having a shorter path length to reduce packet network delay is desirable. If we decrease the number of links or data centers to reduce network cost, the flexibility of path design is degraded so suppressing path length becomes difficult. Therefore, when designing a network topology, we need to consider multiple incompatible criteria with different respective units.

The analytic hierarchy process (AHP) is a way to make a rational decision considering multiple criteria [4,12]. Using

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AHP, we can reflect the relative importance of each criterion in the evaluation result. AHP treats all the related factors as a hierarchical structure and quantifies qualitative factors, such as the importance of each criterion, using paired comparison. Therefore, we have applied AHP to network topology design to consider multiple criteria simultaneously [7]. However, in [7], we evaluated only the network topologies without considering the locations of data centers. The locations of data centers as well as the network topology strongly affect service quality, reliability, and cost, so we need to evaluate both the data center locations and network topology when designing data center networks.

Therefore, in this paper, we propose to design data center networks by using AHP to consider all the possible combinations of data center locations and network topologies as a candidate set of data center networks.[1] We also investigate the results of applying the proposed design method to three areas: Japan, USA, and Europe, and we compare them with those obtained by the enumeration method, i.e., a straightforward approach to strictly obtain the ideal candidate with considering just a single criterion as the optimization target.

We describe the related works in Section 2. Section 3 summarizes AHP, and we present the design method of data center networks using AHP in Section 4. We describe the numerical results in Section 5 and conclude the paper in Section 6.

2. Related works

There are many works designing network topologies. Chattopadhyay et al. [1] and Gersht et al. [3] presented heuristic approaches using a branch-and-bound method or a greedy method to solve the cost minimization problem with a constraint on the delay between nodes. Steiglitz et al. [14] presented a heuristic method using a local search that solves the cost minimization problem with the constraint that all node pairs have more than a specified number of disjoint routes. Wille et al. [16] depicted heuristic approaches using a tabu search and genetic algorithm for solving the same problem with the constraint that the connectivity between any pair of nodes is maintained for any single-node failure. However, all these works consider only a single criterion, i.e., cost, as the optimization target. Moreover, they design only the network topology without designing the data center location.

There are also some works designing data center locations for a given network topology. Li et al. [9] presented an optimum design algorithm based on a dynamic programming approach minimizing the total delivery cost for a tree-type network topology. Cronin et al. [2] and Qiu et al. [11] proposed approximation algorithms to optimally place mirror servers among candidate positions on networks with arbitrary topology, and they showed that greedy-based algorithms achieved the best results. However, all these works also consider only a single criterion, i.e., cost, as the optimization target. Moreover, they design only the data center location without designing the network topology.

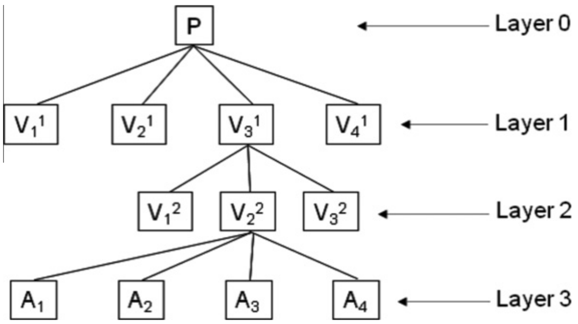

Fig. 1. Layered structure in AHP.

As an approach that considers multiple criteria, the concept of the Pareto frontier is well known [15], and one study applied this concept to logical topology design [5]. Assume that there are M criteria, $V_1, \ldots, V_M$, and let $V_{m,x}$ denote the mth criterion of candidate x. Candidate x is better than candidate y in the Pareto sense only if $V_{m,x} \leqslant V_{m,y}$ for any m and if criterion m satisfies $V_{m,x} < V_{m,y}$. (Assume that smaller values are desirable for all the criteria.) All candidates that are surpassed by no other candidates are the optimum solution set, i.e., the Pareto frontier. However, a large number of candidates are regarded as the Pareto frontier, so it is difficult to effectively limit the optimum candidates and select one candidate to use.

3. Overview of AHP

In a decision-making problem, there are normally three kinds of elements, i.e., *problem P*, *evaluation criteria V*, and *alternative plan A*. As shown in Fig. 1, AHP treats the relationship among these elements as a hierarchical structure. AHP links related elements,[2] and evaluation criteria V can take multiple layers, V^1, V^2, ... By calculating the relative strength (weight) for each pair of related elements, AHP derives the score S_i of each alternative plan A_i.

We need to quantify the relative importance of each criterion V against the problem P. AHP achieves this by comparing the elements on each level in pairs. For two elements X_i and X_j in layer c, the values shown in Table 1 are set to a_{ij}, the relative importance of X_i against X_j. Defining w_i as the true weight of X_i, we ideally have $a_{ij} = w_i/w_j$. Let $\boldsymbol{A}$ and $\boldsymbol{w}$ denote a matrix of pairwise comparisons a_{ij} and a vector of w_i, respectively. By multiplying $\boldsymbol{A}$ by $\boldsymbol{w}$, we obtain $\boldsymbol{Aw} = n\boldsymbol{w}$, where n is the number of elements in the layer. Therefore, $\boldsymbol{w}$ is the principal eigenvector and n is the maximum eigenvalue.

In practice, it is difficult to consistently set a_{ij} for all pairs of elements, so we need to judge the degree of inconsistency. If we let $\lambda_{\max}$ denote the maximum eigenvalue of $\boldsymbol{A}$, we obtain $\lambda_{\max} \geqslant n$ [4,12]. Consequently, we can judge the degree of inconsistency using the *consistency index* C.I. defined by

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[1] A shorter version of this manuscript was presented in [8].

[2] In the figure, only some of the links are shown for simplicity.