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An access network design problem with end-to-end QoS constraints

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ABSTRACT

In this paper, we present an access network design problem with end-to-end quality of service (QoS) requirement. The problem can be conceptualized as a two-level hierarchical location-allocation problem on the tree topology with nonlinear side constraints. The objective function of the nonlinear mixed integer programming model minimizes the total cost of switch and fiber cable, while satisfying demand within the prescribed level of QoS. By exploiting the inherent structure of the nonlinear QoS constraints, we develop linearization techniques for finding an optimal solution. Also, we devise an effective exact optimal algorithm within the context of disjunctive constraint generation. We present promising computational results that demonstrate the effectiveness of the proposed solution procedure.

1. Introduction

In this paper, we deal with a local access network design problem arising from the deployment of Ethernet-based access networks (EBAN). The Ethernet-based architecture has been developed to fulfill network requirements such as scalability, flexibility, security, high availability, manageability, and quality of service. As shown in Fig. 1, which depicts the EBAN architecture, Layer 2 switches provide connectivity between customer locations and a central office, support multiple classes of multi-media services, and give security to the network, while guaranteeing the end-to-end quality of service (QoS) [5]. In particular, the end-to-end QoS is critical for offering triple-play service (TPS) and transparent LAN service (TLS) to residential and corporate customers. Recently, Korea Telecom provides the QoS guaranteed 100Mbps multi-media service, which is the first commercial service in the world.

In Fig. 1, a residential gateway is a device that connects the access network to customer equipment such as IPTV and Wi-Fi hubs [9]. The traffic of the residential gateway is routed to the core edge switch of Layer 3 through two-level Layer 2 switches such as an access switch and an aggregation switch. The access switch enables the residential gateway to access the core network. And the aggregation switch grooms traffic from access switches and provides value-added services such as load balancing, fire walling, and secure sockets layer off-loading to the server across the Layer 2 switches. At the central office, the core edge switch of Layer 3 interchanges the traffic between access networks.

In this paper, we focus on the design of Layer 2 networks in the metropolitan area. Due to the high density of office buildings and high-rise apartment complexes in the Seoul metro area, a tree topology of the existing infrastructure (physical network) has been deployed for 20 years. A tree topology consists of leaf nodes and intermediate nodes (including the root node) as shown in Fig. 2(a). We assume that a leaf node, which denotes a demand node, has several residential gateways that represent physical network equipment such as IPTV set-top boxes. Since the underlying topology is tree, each demand node has a unique traffic path to the root node. And there exist intermediate nodes (except for the leaf node) at which access and aggregation switches can be installed, while deploying access switches and aggregation switches at the same node is allowed. And, we assume that there exists a core edge switch of transport networks at the root node. Note that we allow the allocation of demand nodes to the switches on a path to the root node to be non-split, which is a modeling requirement for the operation and administration management of access networks. On the unique path to the root node, non-split allocation means that a demand node is assigned only to a single node of access switch and the total traffic of the demand node must be processed at that access switch. Also, the number of access switch ports limits the number of links from residential gateways of the demand node assigned to the access switch.

A key design issue of EBAN is the location-allocation optimization of the trade-off between switch and cable cost on tree topology while satisfying the QoS requirement. Fig. 2(b) depicts an example of switch location with QoS requirements. If we install switches closer to the root node, we can reduce the switch cost

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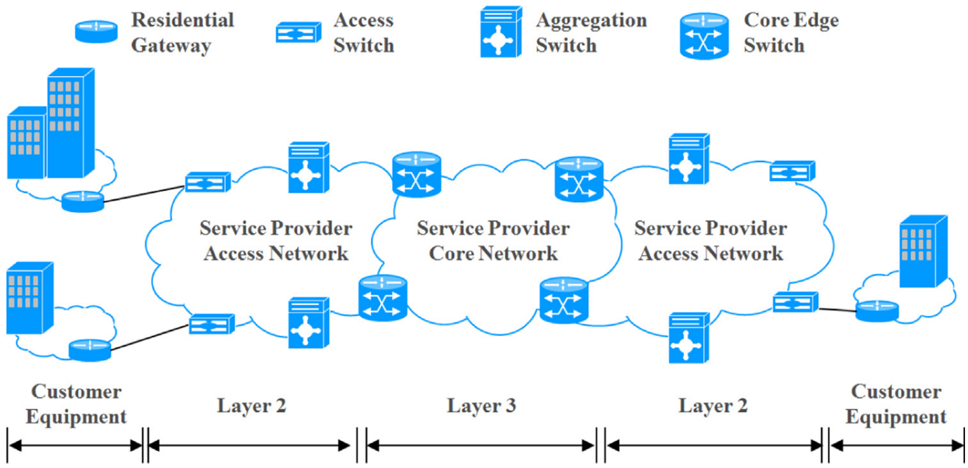

Fig. 1. EBAN architecture.

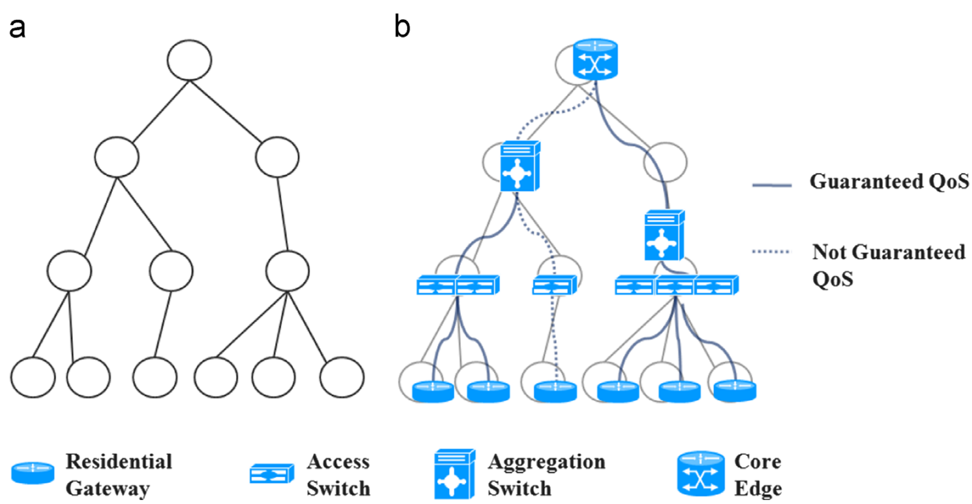

Fig. 2. Topology of Layer 2 of the Ethernet-based access network.

because a switch covers a large geographical area. However, the fiber cable cost is increased because the distance between the demand node and the switch is increased. On the other hand, by locating a switch close to demand nodes, we can reduce the cable cost between the demand node and the switch. Note that a demand node should be connected to the root node both by an access switch and by an aggregation switch without violating the predetermined level of QoS and traffic of demand node can be routed all the way to the root node without blocking [18]. The end-to-end QoS requirement is defined as a nonlinear function of the blocking probability of access and aggregation switches. The blocking probability of access and aggregation switch can be defined as a nonlinear function of the amount of traffic and the capacity of switches. In particular, an access switch can be shared by several demand nodes as long as the sum of demands of the assigned demand nodes is within the switch capacity. Note that the number of switch ports limits the total number of demands (residential gateways) assigned to the switch, while the capacity of a switch restricts the total amount of processed demands within the prescribed level of QoS. In Fig. 3, nodes 1 and 2 satisfy the predetermined level of QoS while node 3 fails to satisfy the QoS. Note that we need to place sufficient switches for the demands allocated to switches for guaranteeing the end-to-end QoS either at node 5 or at node 6. Also, although the traffic of the access switch at node 4 is more than that of the access switch at node 5, the blocking probability of node 4 is smaller than that of node 5 because two access switches at node 4 are available while one access switch is available at node 5. And, although the total demand of access switch at nodes 4 and 5 is 46 and 24, respectively, the traffic from access switch at nodes 4 and 5 to aggregation switch at node 6 is reduced because some traffic is blocked at nodes 4 and 5 due to the QoS restriction. Finally, the end-to-end QoS probability of access switch at node 4 and aggregation switch at node 6 is 0.972 within a predetermined level of QoS, while the probability of access switch at node 5 and aggregation switch at node 6 is 0.941 that fails to satisfy the predetermined level of QoS.

The problem in this paper can be conceptualized as a two-level location-allocation problem with nonlinear QoS constraints. Several studies have been conducted for two-level (or two-echelon) facility location problems. Aardal et al. [1,2] deal with the two-level capacitated and uncapacitated facility location problems, and find facet defining constraints for the problem with a separation problem for identifying the violated facet. Landete and Marin [11] consider a two-stage uncapacitated facility location problem and devise new facet defining inequalities to enhance the formulation. Tragantalerngsak et al. [19] deal with a two-echelon facility location problem, where a customer is served both by an uncapacitated facility in the first echelon and by a capacitated facility in the second echelon. They develop a branch and bound algorithm based on Lagrangian relaxation. Gabor et al. [14] consider a new integer programming formulation for the multi-level facility location