Omega 63 (2016) 23–40

Contents lists available at ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Fiber optical network design problems: A case for Turkey ☆

Başak Yazar, Okan Arslan, Oya Ekin Karaşan *, Bahar Y. Kara

Bilkent University, Department of Industrial Engineering, Bilkent, 06800 Ankara, Turkey

ARTICLE INFO

Article history:
Received 12 December 2014
Accepted 2 October 2015
Available online 8 October 2015

Keywords:
Location
Allocation
Telecommunications
Application

ABSTRACT

In this paper, we consider problems originating from one of the largest Internet service providers operating in Turkey. The company mainly faces two different design problems: the green field design (area with no Internet access) and the copper field re-design (area with limited access over copper networks). In the green field design problem, the aim is to design a least cost fiber optical network that will provide high bandwidth Internet access from a given central station to a set of aggregated demand nodes. Such an access can be provided either directly by installing fibers or indirectly by utilizing passive splitters. Insertion loss, bandwidth level and distance limitations should simultaneously be considered in order to provide a least cost design to enable the required service level. In the re-design of the copper field application, the aim is to improve the current service level by augmenting the network with fiber optical wires, specifically by adding cabinets to copper rings in the existing infrastructure and by constructing direct fiber links from cabinets to distant demand nodes. Mathematical models are constructed for both problem specifications. Extensive computational results based on realistic data from Kartal (45 nodes) and Bakırköy (74 nodes) districts in Istanbul show that the proposed models are viable exact solution methodologies for moderate dimensions.

1. Introduction

In telecommunications networks, design problems involve either constructing the network from scratch or improving the existing network in terms of capacity or speed. Our problem is motivated from a real-world application of Turkey's largest service provider. In Turkey, due to the competitive environment in the telecommunications market and privatization of big companies, a highly qualified, efficient and cost effective service in data communication is crucial. The practice of the market leader is critical for today's market share and will determine the market positioning in the near future. Following the needs of our service provider, we introduce two different problem definitions to the literature, namely, the green field network design problem and the copper field re-design problem.

In the green field, the fiber optical network is to be designed from scratch. Every customer point will be reachable from a central station. This central station is assumed to have a direct link to upper level networks and reach world-wide Internet. In reaching the customers, different numbers and types of passive splitters, which are special telecommunication equipments that split the incoming fiber optical wire into several different wires carrying the same data signal, are utilized. Due to the application dynamics of the problem, the service quality is measured in terms of bandwidth and insertion loss.

In the copper field, the design problem seeks to provide improvement in an area that the company has already been serving via copper cables. The existing copper infrastructure will be augmented with fiber optical wires in order to improve the speed of the Internet at the desired points.

1.1. Green field network design problem

The Information and Communication Technologies Authority in Turkey regulates that any new customer should be served with a fiber Internet access so as to ensure either directly or through capacity expansion, the future demand. To this end, the green field design problem is solved in areas where the service provider currently has no infrastructure at all. Aggregated demand locations are to receive high-speed Internet access as defined by the service provider. In the particular setting under consideration, there is a central station at a fixed location. Each customer needs to be connected to this central station via a path of fiber links to be installed. Passive splitters will aid in carrying data in bulk up to

☆This manuscript was processed by Associate Editor Lodi.

* Corresponding author. Tel.: +90 312 290 1409; fax: +90 312 266 4054.
E-mail addresses: basakyazar@gmail.com (B. Yazar), okan.arslan@bilkent.edu.tr (O. Arslan), karasan@bilkent.edu.tr (O.E. Karaşan), bkara@bilkent.edu.tr (B.Y. Kara).

http://dx.doi.org/10.1016/j.omega.2015.10.001
0305-0483/

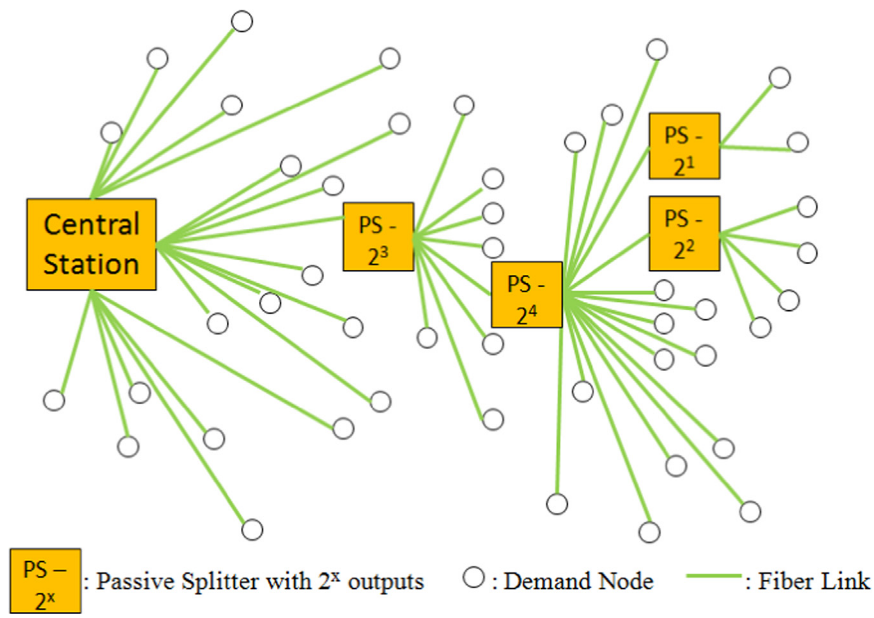

Fig. 1. Green field network design problem illustration.

certain locations to avoid costly direct connections from the central station. Thus, the locations and the splitting capacities of the passive splitters are very crucial in a cost-effective design. Furthermore, such decisions are crucial in the resulting quality of service. Fig. 1 illustrates a sample green field design.

One aspect of the quality of service is measured in terms of decibels (dB). The dB level of data experiences insertion loss and decays with the distance travelled and with the increasing number of ports encountered at the splitters. The requirement is to have all demand points within a dB radius from the central station. Another service quality criterion is the speed of the Internet access. Originating from the central station, the bandwidth power splits into the number of ports it encounters at a passive splitter. The service provider would like to serve all its customers with a minimum threshold level of bandwidth.

Decisions entailing to the location and the type of passive splitters involve a trade-off between the cost of fiber cables, the insertion loss and the bandwidth division. In this respect, the locations of the splitters, their capacities, and their allocations should be made considering competing objectives.

In summary, the green field design problem includes the selection of passive splitter locations, their splitting numbers and fiber links between demand nodes and passive splitters including the central station. While minimizing the total costs, the insertion loss requirements and bandwidth target values should be respected.

1.2. Copper field re-design problem description

The second problem seeks to improve the existing telecommunications service in a region named as the “copper field”. The copper field is composed of some copper or related wires that are used for normal speed data transmission. In order to improve the Internet access bandwidth, fiber wires could be used completely from the central station to the end-user or to a certain point closer to the end-user. Hence, data transmission can be performed with both fiber and copper wires and this hybrid usage of fiber and copper will lead to a quicker, safer and a better performing Internet access. Fiber cables starting from the central station are to be wired up to some point in the network and the remaining transmission is to be done via existing copper cables. Since data travels a shorter distance on the copper wires, the transmission speeds up.

There is a central station which is already in use for Internet access via copper wires. The existing network consists of rings (loops) of copper cables around the central station. There might be one or more copper cable rings around a central station depending on the geographical span of the region. Fiber wiring should start from the central station and touch the copper ring(s) at some point(s) to improve the bandwidth. Such a point of touch needs a special equipment called “cabinet”. The cabinet acts as the central station of its ring and it is assumed that a cabinet provides the same quality of service as a central station does. Each cabinet is required to be connected to the central station via two arc disjoint paths to ensure a reliable connection to the backbone network. This property comes out as a ring structure between cabinets including the central station as depicted in Fig. 2. In this manner, the central station can also be considered as a cabinet.

If any demand node is in close proximity (say at most γ meters) to a cabinet over the copper wiring, the particular demand node is accepted as receiving fiber access. Hence, demand nodes in γ neighborhood over the copper ring to a cabinet can be covered and served by this cabinet. If a node is located further than this proximity from a cabinet, it is not considered as served by the cabinet, in which case a direct fiber cable from the cabinet to this node is required. Note that, for a node, being geographically close to a cabinet node does not qualify it to be in the γ neighborhood of the cabinet. The node and the cabinet also need to be in the same copper ring as well.

In the network design problem over an existing copper network, some customers may require to use fully fiber wire. Such customers are referred to as premise customers by our company. Thus, they require a sole fiber path from the central station up to their building. In addition, premise nodes also require having a direct connection to at least one other premise node. Fig. 2 illustrates such premise customers and their linkage demands.

In the copper field network re-design problem, there is also a distance restriction for the fiber access measured from the central station up to the end-user. This distance is a threshold for wiring the fiber cable.

Our aim is to serve all nodes with fiber connectivity by installing a minimum cost fiber network over the existing one.