26 NETWORK RELIABILITY OPTIMIZATION

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Abstract: This chapter presents design of reliable networks. The exact calculation of any general network reliability measure is NP-hard. Therefore, network designers have been reluctant to use reliability as a design criterion. However, reliability is becoming an important concern to provide continuous service quality to network customers. The chapter discusses various network reliability measures and efficient techniques to evaluate them. Two genetic algorithms are presented to demonstrate how these techniques to estimate and compute network reliability can be incorporated within an optimization algorithm. Computational experiments show that the proposed approaches significantly reduce computational effort without compromising design quality.
Keywords: Network reliability, network resilience, network design, network survivability.

26.1 INTRODUCTION

While planning a telecommunication network, several competing interests such as cost, throughput, performance, connectivity requirements, and reliability must be considered. Among them, reliability has become an important concern in recent decades. Many new telecommunication technologies such as fiber-optic cables and high capacity switches have provided economical benefits by means of capacity concentration (Ball et al., 1995). As a result, telecommunication networks tend to be sparser com-

pared to networks based on traditional copper cables (Balakrishnan et al., 1998). A high capacity sparse network, however, is vulnerable to component (links and nodes) failures. Even a single component failure can significantly disturb the service quality of a network or leave many customers disconnected. Therefore, as the dependence on telecommunication networks increases and network topologies become sparser, network reliability becomes an important concern while designing new networks.

In the most general form, network reliability describes the ability of a network to continue network services in the case of component failures. This chapter focuses on designing reliable networks. The most challenging aspect of this problem is computing a reliability measure of a network. The exact calculation of most reliability measures is NP-hard (Ball, 1980). Therefore, an overwhelming body of research on network reliability has focused on developing efficient techniques to evaluate network reliability, including exact methods, theoretical bounds, and simulation. However, work on optimal reliable network design did not fully exploit or implement these efficient techniques in an optimization framework.

The chapter is organized as follows: Section 26.2 presents network reliability modeling and major reliability measures. Efficient evaluation of network reliability is very important for optimal network design. Therefore, the methods to evaluate network reliability measures are given in Section 26.3. Existing work on network reliability optimization is summarized in Section 26.4. Sections 26.5 presents a genetic algorithm (GA) to design reliable networks with an emphasis on demonstrating use of efficient reliability evaluation in a search algorithm. Section 26.6 presents a bi-objective GA to design resilient networks.

26.2 NETWORK RELIABILITY MODELING

Telecommunication networks consist of imperfect components. Both the links and the nodes of a network are subject to failure. Failure mechanisms of network components, especially those of links, have not been well defined in the literature (Ball et al., 1995). Nonetheless, failure rates can be derived from historical data. A telecommunication network with unreliable components is usually modeled as an undirected probabilistic network $G = (E, V)$ with node set V and arc set E such that each arc can be in either of two states: operative or failed, with associated probabilities p_{ij} and $1 - p_{ij}$, respectively. In this model, nodes represent telecommunication devices such as routers, switching stations, and computers, and arcs represent links connecting these devices. Although p_{ij} can be interpreted differently, it is usually defined as the probability that arc (i, j) is in the operative state at a random point in time. The common assumptions of this model are:

- Arc failures are independent;
- Nodes are perfectly reliable;
- No repair is allowed.

Hence, the probability of observing a particular state of the network is as follows:

$$Pr\{\mathbf{X}\} = \prod_{(i,j)\in E} [1 - p_{ij} + x_{(i,j)}(2p_{ij} - 1)] \qquad (26.1)$$