CHAPTER 1

THE NETWORK PLANNING PROBLEM

1.1 INTRODUCTION

We are living in the midst of an industrial and social revolution involving the generation, processing, and transmission of information. The topic of this volume is a particular aspect of the technology of information transmission called "network planning."

What is network planning? Information today is transported over a variety of "networks"—collections of communication links and communication nodes. These range from analog and digital wired telephone networks to cellular and personal communication networks to satellite networks to, finally, data networks such as the Internet, ethernets, token rings, ATM local area networks, and metropolitan area networks. A particular organization may run a network comprising several of these technologies.

Any organization possessing and connected to such networks would like to be able to rely on orderly deployment, use, and upgrade of the networking equipment (both hardware and software). This is where the "planning" comes in. The role of network planning (and planners) is to provide an intelligent means for an organization to meet future network needs, using the existing networks as a starting point.

Naturally, as time proceeds, new developments occur. That is why planning is an ongoing process that continually makes use of the latest information to revise plans. This temporal property is a key aspect of the field of network planning—it involves the orderly evolution of networks *over time*.

Network planning is most highly developed in large telecommunication companies, which usually have distinct network planning departments for distinct systems. The large investments involved and today's increasingly competitive environment not only makes efficient planning a necessity; they serve to justify the use of sophisticated planning techniques. More recently, however, organizations with substantial network installations such as private companies, academic institutions, and government agencies, have found some sort of planning function to be necessary.

1.2 AN OPTIMIZATION PROBLEM

The interested reader may recognize what is being described as an optimization problem. Generically, one would like to minimize the cost of outlays for equipment and operations, maximize revenues if one is considering a profit-oriented organization, and do all this *over time* as technology, user requirements, and the economic environment change. Certainly this is a tall order.

In fact, it is impossible to pose the network planning problem, in all its baroque detail, as a single optimization problem for any reasonably sized organization.

Why? There are many reasons. One is the absence of a single optimization criterion. Certainly, cost, reliability, public image, capacity, and potential for growth are all important criteria, but how does one decide to balance them? Another reason is the size of the problem in large organizations, no matter whether it is measured in terms of the number of constraints, the number of people involved, and/or the number of organizational units involved. A third reason is the role of the unexpected: free market competition, new technological developments, and new economic developments.

Therefore what happens in reality is that the overall problem is divided into a (possibly large) number of smaller, more manageable subproblems. The partitioning of the subproblems may not be optimal, and only some of the subproblems may possess optimal solutions. Still, as any good scientist or engineer knows, only by abstracting out the essentials of a situation and posing the problem in a tractable manner can progress be made.

In fact the network planning problem is usually divided temporally as well into short-term, medium-term and long-term plans. These plans, naturally, should be consistent with one another. Moreover they must be periodically updated in what Gupta [Gupt] calls a "continual iterative process."

1.3 PLANNING FACTORS

The context in which a network planner operates is influenced by a number of factors. According to King and Premkumar [King], these include technology factors, business factors, organizational factors, and environmental factors. We discuss each set of factors in turn.

1.3.1 Technology Factors

A key property of technology is the periodic development of new technology that, eventually if not initially, can provide more capacity, increased reliability, and/or reduced cost. The network provider, whether a common carrier or a private organization, must then determine when and how to introduce this technology into an existing network.

Examples of the gradual displacement of older technologies include the use of digital technology in place of analog technology and the use of fiber optic links in place of electrical links. Some new technologies live alongside older technologies, as in the case of transoceanic satellite channels and undersea cables. Finally, when there is no existing infrastructure—as in large parts of today's world—there may be a technological solution such as wireless technology.

There are a plethora of issues that face the network planner as he or she considers a network upgrade. It is obviously necessary to ascertain the point at which the benefits of the upgrade outweigh the costs of deploying new technology. But there are other issues, such as the economic benefits of automation, the amount of importance attached by the network planner to integrating voice, video, and data over a single network, and the perceived desirability of open systems and standards [King].

1.3.2 Business Factors

Let's consider a common carrier service provider first. A key business factor is access to capital for building network infrastructure. A good example of this is the necessity to secure financing by LEO (low earth orbit) satellite providers such as Motorola's Iridium system. While such LEO systems have a certain technological glamour attached to them, the need to pay for infrastructure development applies equally to more mundane telecommunication systems.

There are a number of issues faced by a network planner at a common carrier. In many cases the cost of networks must be traded against their reliability. For instance, the widespread introduction of fiber optics has meant that a network may be able to function with fewer transcontinental links, thus saving on construction costs. However, the failure of one of the small number of remaining links can be catastrophic.

The introduction of new technology, once financed, can lower costs and increase reliability. However retiring old equipment may present a loss if an extended time in service had been contemplated.

Free market competition presents a wild card that can upset the best laid plans. The uncertainty in user demand for new services and the cost of deploying new services can present a situation that is akin to asking what came first—the chicken or the egg? This last problem gives weight to the argument for integrated network technologies such as ATM. A truly integrated network could support new services without the expense of dedicated specialized networks.

A common carrier network planner also faces issues of access to markets, spectrum allocation for wireless services, market penetration, and revenue maximization.

A user organization faces many of the same issues as a common carrier in terms of trading cost against reliability and the introduction of new technology. A user organization in today's business environment may have many common carriers and vendors to choose from for services and equipment. Determining the "best" offering can be a significant task in itself.

Finally, for user organizations that are profit driven, King and Premkumar [King] have stated that various strategies for gaining competitive advantage can be used in conjunction with properly planned telecommunications. These strategies include product differentiation, internal cost reduction, improved accessibility to markets, spawning new businesses, and changing competitive scope.

1.3.3 Organizational Factors

A great deal has been written over the years on the best ways in which organizations should operate. This literature is not recapped here. However we make a few specific points for common carrier service providers.

Perhaps not in the short term, but in the long term, organizations must exploit new technologies to survive and prosper. Thus it is important to guard against the development of a "not invented here" culture in a common carrier organization. The skepticism with which satellite communication and packet switching were greeted with by some in the telecommunications industry is an example of this.

More recently, with the increased competition in the telecommunications industry, one may wonder whether telecommunications is driven by technology or cost. A technology-driven organization can be expected to allocate substantial resources for research and developments efforts. A cost-driven organization may view telecommunications as a commodity that must be brought to the public, organizationally, at the lowest possible cost. Naturally the telecommunications world is more complex than this. Successful research and development can reduce costs and, in the drive to reduce costs, it is sometimes necessary to use new technologies. Still, an organization's mind-set can influence the decisions that are made.

For a user organization [King], there are often noted similarities between information (computer) processing and telecommunications activities. This similarity has led to efforts at integration—both technologically and organizationally. In any case, the network planner at a user organization must be knowledgeable about a broad mix of technologies. Resources (i.e., the amount of money available for network operations and upgrades) form a key constraint in the duties of such a planner. Two important concerns of network planners in user organizations are the visibility of networking in the organization and the involvement of top managers in key decision making.

1.3.4 Environmental Factors

In this context, environmental factors are taken to be regulatory, economic and health questions. The environment a network planner at a common carrier service provider operates in is quite complex. The regulatory environment varies from country to country. The spectrum for wireless services in particular is heavily regulated. Attempts to "deregulate" telecommunications in recent years have led to a regulatory environment that is simpler, but more competitive. In the United States it is expected that telephone and cable companies will be competing for what was traditionally viewed as each other's core business.

The economic environment adds another layer of complexity to the network planner's role. The economic environment affects the resources available for network operation and expansion, the cost of money, and the money available for customers to spend on telecommunications. The economic environment varies from country to country, and its future evolution is hard to predict. Naturally the economic environment is linked to the competitive environment.

Finally, there can be public health concerns such as those recently raised concerning wireless technology and high frequency electromagnetic fields.

Many of these same issues affect—either directly or indirectly—user organizations, where the economic environment appears in the form of budgetary concerns. Transborder information flow regulations cause concern in multinational organizations. Standards are important for user organizations desiring multiple vendor sources for critical equipment.

1.4 TYPES OF PLANNING

There are a variety of classification approaches for different types of network planning. We partially follow the authors already cited [Gupt] [King] in listing a number of possibilities for common carrier service providers and user organizations.

1.4.1 By Level of Detail

- **Administrative planning** Goals, long-range plans, financial policy, regulatory efforts, forecasting, technology trends, strategies for competitive advantage
- **Fundamental technical planning** Plans for network, management, switching and routing, addressing, signaling, operations, provisioning, and maintenance
- **Engineering** Detailed and immediate plans

1.4.2 By Network Components (Telephone Nets)

- Local exchanges
- Toll exchanges
- Interexchange transmission
- Loop plant
- Signaling network
- Customer premises equipment

1.4.3 By Network Components (Computer Nets)

- Local area networks
- Packet networks
- PCs, workstations, minis, mainframes
- Routers, bridges, gateways
- Links (cables and wires, fiber optics, radio)

1.4.4 By Network Services (Telephone Nets)

- Plain old telephone service (POTS)
- Narrowband ISDN service
- Broadband ISDN service
- SMDS and/or frame relay service
- Packet service
- Video service
- Cellular telephone service

1.4.5 By Network Services (Computer Nets)

- E-mail
- Remote login
- File transfer
- Image transfer
- Voice connection(s)
- World Wide Web

1.4.6 By Time

- Long term (5–20 years)
- Medium term (2–5 years)
- Short term (1–2 years)

A temporal breakdown of ways to classify plans for a user organization appears in [King] [Clel].

1.5 NETWORK FEATURES

Typical communication networks have a number of characteristics that are independent of the actual implementation. These include [Gupta] the following.

1.5.1 Statistical Loads

Demand for telecommunication services is the result of the decisions of perhaps millions of individual users as to the time at which a service will be engaged, the type of service, and its duration. The time scales of these activities varies widely [Gupt], from milliseconds for e-mail to minutes for a voice call to weeks for a leased line. There are daily variations, weekly variations, and annual variations in traffic. Certain unpredictable events such as earthquakes or storms can also stimulate significant demand.

There is a large body of literature available on the characterization and prediction of this demand using statistical techniques. Among the most relevant techniques are stochastic processes and queueing theory [Gros] [Klei 75] [Robe 94]. Stochastic processes usually deal with the evaluation of series of events over time. Queueing theory, named for the British word for a waiting line, is the study of things waiting in a line. These things could be packets in a switch or calls in an exchange. Queuing theory is widely used to predict the performance of electronic systems.

1.5.2 Large Number of Subnetworks and Services

Most large "networks" are composed of a variety of subnetworks. This is particularly true of the Internet, which is an amalgamation of hundreds of smaller networks. But it is also true of large telephone networks. Here one has local networks, regional networks, long-distance transcontinental networks, and international networks. Some portions of these networks are segmented off into private corporate and government networks [Gupt].

Most existing large networks also offer a wide variety of services, some of which were outlined in Section 1.4. The large variety in subnetworks and services requires dedicated and specialized planning.

1.5.3 Growth

While POTS (plain old telephone service) is a relatively mature technology with low growth rates in developed countries, there is the potential for rapid growth in underdeveloped countries. Moreover, while a market may be static in overall growth, individual service providers and geographic areas may experience large growth rates in the process of attracting new customers and residents, respectively.

Certain parts of the telecommunications market have experienced rapid growth in recent years. This is particularly true of wireless technology such as cellular telephones. Wireless technology has experienced rapid growth in developed countries because of its convenience and in underdeveloped countries because of the need for minimal infrastructure. During the 1980s the number of local area networks deployed grew rapidly. It remains to be seen whether ATM technology will follow this pattern. Internet traffic has experienced phenomenal growth over the past decade with no end in sight.

Rapid growth in networks makes it necessary to install higher capacity systems and is an important motivation for proper network planning.

1.5.4 Hardware and Software Variety and Advance

A large network has a large variety of installed hardware and software with differing dates of manufacture. This is because of technological change (which makes new equipment cost effective) and the large investments involved (which lead to the use of equipment for extended periods of time). Naturally, this diversity of hardware and software, while economical, complicates network management and planning.

1.5.5 Technological Change

New technologies are being deployed into networks at an increasing rate. The coexistence of competing technologies is a reason for caution on the part of the network planner. On the up side, new technologies can promise reduced operating costs, enhanced capabilities, and increased reliability. However, it may not make sense to invest in a new technology unless one is sure that it has staying power in terms of market share, can be supplied by multiple vendors, and really does offer some or all of the advantages cited above.

1.5.6 Investing in the Future

Ideally telecommunications network infrastructure should last 8 to 20 years before requiring replacement. Thus the choice of hardware and software requires careful consideration on the part of the network planner.

1.5.7 Standards

In the network planning process the role of standards is important. Open standards allow a variety of vendors to bring compatible hardware and software to market at low prices. However, the timing of standards is important. Standardization at too early a point may suffer from incomplete research and development experience. Standardization at too late a point may be irrelevant if large number of users are locked into proprietary products and standards. A successful standard gives assurance to the network planner that hardware and software will be readily available on a long-term basis.

1.5.8 Economies of Scale

The phenomenon of economies of scale is responsible for the tendency of larger systems to be more cost effective than smaller systems. That is, while a larger system will cost more than a smaller system in total investment, the rate of increase actually decreases as systems become larger. Thus, on a per-user or per-circuit or per-packet basis, the larger system is actually cheaper.

Naturally, this doesn't imply that organizationally, larger is necessarily better. But in terms of specific telecommunications systems, such as transmission facilities or switches, savings due to economies of scale can be quite real.

1.5.9 Finite Resources

The resources available to a network planner for network modernization are usually limited and in fact can be significantly less than ideal. This serves to encourage a conservative approach to network planning. Awareness that resources are finite also provides a powerful incentive to try to install the right amount and type of equipment at the right time and place. Finally, the presence of such limitations necessitates the involvement of upper management in the planning process.

1.6 THE REST OF THIS BOOK

This book gives a tutorial look at the fundamentals of the theory of network planning. Chapter 2 discusses the use of mathematical programming for planning. Mathematical programming is widely used in large telecommunications companies to reduce costs. Chapter 3 examines a variety of other algorithms for network planning. Reliability theory is discussed in Chapter 4. This theory is used in a variety of applications including network planning. While general text-length treatments are available, key concepts are discussed in Chapter 4. Chapter 5 introduces key software technologies as well as a number of new optimization methodologies useful for network planning. Finally, Chapter 6 covers data analysis techniques that are network planning related.

1.7 PROBLEMS

1 What is network planning?

2 Why is network planning called a "continual iterative process"?

3 Why can network planning be viewed as an optimization problem?

4 Why is it impossible to pose the network planning problem for any reasonably sized organization as a single optimization problem?

5 Why is the network planning problem divided into smaller subproblems?

6 What criteria must an organization balance through network planning?

7 Give some examples of technologies that have displaced older technologies.

8 What are some of the issues that face a network planner who is considering a network upgrade?

9 Why is new technology periodically developed?

10 What are some of the business factors faced by a planner at a common carrier? At a user organization?

11 How does the uncertainty in demand for new user services affect network planning?

12 What are some strategies for gaining competitive advantage for organizations that are profit driven?

13 Why must organizations exploit new technologies to survive and prosper?

14 What is the difference between a telecommunications organization that is cost driven and one that is technology driven?

15 What are some important concerns of network planners in user organizations?

16 Describe the operating environment of a network planner in a common carrier. A user organization.

17 Differentiate types of planning by level of detail.

18 How are types of planning for network services and for network components related?

19 Why are network loads considered statistically? What are some of the relevant techniques used?

20 Why does a large network have a multiplicity of subnetworks and services?

21 Can there be organizational growth in a static market?

22 Why is there usually a large variety in the base of installed hardware and software?

23 How does technological change relate to network planning?

24 How long should telecommunications infrastructure be expected to last before it must be replaced?

25 What are some of the trade-offs between introducing technical standards too early and too late?

26 What is the concept of economies of scale?

27 What are some of the effects of the limitations on resources available to a network planner for network modernization?