Investing in the Development of a Space-Based Information Network Infrastructure

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Abstract

This paper addresses the issue of direct government investment in the basic research and development of a future space-based information network infrastructure for the United States (U.S.). An envisioned space network infrastructure is being designed for military applications. The classic public goods rationale is used to justify public investment in space telecommunications for government missions (e.g., national security purposes) because the net benefits to society of space systems may be greater than the benefits that private individuals or firms can offer. To date, the private market has failed to capture the value of space communications and deliver enough valuable applications and services to sustain its business. Examples of private market failures in global satellite communications are given. The potential of greater public benefit from the military space network infrastructure can be obtained from an open access policy for the private sector. The government-funded Global Positioning System (GPS) is analyzed as a possible technology and policy model to follow for the development of a space-based information network infrastructure. Issues of technology transfer, dual-benefit technology design and an open access policy that impact both public and private research and development (R&D) investments, technology diffusion and technology standards are discussed. Conclusions and recommendations for further work are presented.

1 Introduction

Advances in the computer industry and in telecommunications applications are driving innovations in space communications and networks. The convergence of computer technology and space technology creates the potential for new capabilities (e.g., observation, navigation, communications, surveillance and reconnaissance) in orbit, although there are still many engineering and business barriers to the development and deployment of space systems. Space systems are characterized as being slow to design and build, very expensive and difficult to upgrade on orbit. The only effective way to upgrade them is to implement software updates, though the new functions are fundamentally limited by the capability of the initial hardware that is deployed. This state of being slow and expensive has placed many space systems in one corner of the cost/risk space (i.e., high risk and high costs). Developing space systems is an expensive investment, as the costs can be overwhelming, with estimates ranging from $4 billion to more than $12 billion for global communications space systems [4]. The desire for designing a robust space system (e.g., high reliability through radiation hardness and redundancy) with a long lifetime will further increases the cost.

Satellites today are used for navigation, communications, environmental monitoring, and weather forecasting. Broadcast satellite to the home using digital video broadcast technology is the most visible satellite service to date. The capability of broadcasting will continue to be attractive for video, audio, and data delivery purposes because the downlink signal is available everywhere within the footprint of a satellite. For the military, a space network infrastructure has the potential to provide continuous and seamless connectivity for deployed forces anywhere in the world, and access to surveillance and remote sensing applications. Requirements for proposed satellite applications and services (e.g., surveillance missions, climate and weather sensing, database accesses and Internet multimedia) have grown tremendously and greatly challenge the capabilities of existing space systems. Progress in hardware and software technologies continue to provide new choices for greater performance of space modules in a spacecraft. The architect not only has to base his or her decisions on the choices available today, but also has to keep in mind the expected changes in technology during the life of the system. Technology S-curves must be examined and understood before system integration. Future space systems will have to be economically designed and configured. Design choices impact the ability of a system to grow, in terms of usability, flexibility and scalability.

The envisioned space-based information network infrastructure will be a highly connected global and heterogeneous network, integrating fiber, wireless and space communications. Although the future space-based information network infrastructure is currently being tailored for carrying out American military missions, it has the potential of providing numerous global mobile voice and data services for the private sector. Global mobile satellite voice and data services are ideal for industrial applications such as heavy construction, defense/military, emergency services, maritime, mining, forestry, oil and gas, and aviation. Studies of the satellite multimedia business in the United States (U.S.) have predicted a convergence of broadcasting, entertainment, Internet and telecommunications services. Worldwide current events (e.g., terrorists attacks and power grid outages) have bolstered the interest in having satellites serve as a back-up communications system for cities during times of crisis (e.g., natural and unnatural disasters such as blackouts, earthquakes, and war). Satellite communication networks offer advantages over terrestrial and cellular networks as they have high availability and are difficult direct targets for man-made weapons. Satellite communications can thus arise to be a significant alternative or complementary communications technology to terrestrial and cellular communications technology worldwide.

This paper explores the issue of government investment in a U.S. space informtion network in terms of the classic public goods argument for government support of infrastructures. In Section 2, the justification for public investment in space telecommunications is broken down into four arguments: (1) serving government missions, (2) balancing private underinvestment in research and development (R&D), (3) addressing private market failures, and (4) ensuring access and fair prices. Government investment in R&D creates value for the application of space technologies. While the current architecture for the space information network is being designed for military applications, technology transfer and diffusion into the private sector will allow firms to capture the value of space technologies by offering a broad base of satellite services to consumers. However, due to recent private market failures in the satellite communications industry (e.g., Iridium and Globalstar), it may be necessary for the proposed military space-based information network to be dual-use and dual-benefit. In Section 3, the dual-benefit technology and open access policy of the Global Positioning System (GPS) is examined to serve as a model for the space-based information network infrastructure. The implications on public and private R&D investments, technology diffusion and technology standards due to technology transfer, dual-use and dual-benefit technology design, and an open access policy are discussed in Section 4. Conclusions and further work in developing a policy for government-funded high-risk technology projects is presented in Section 5.

2 Public Investment in Space Telecommunications

Infrastructures, such as highways, water and sewer systems and airports, require direct federal government funding because the net benefits to society from infrastructure investment may be larger than the benefits that private individuals or firms can offer. This section examines the classic public goods argument for direct government investment in infrastructures, in the context of space systems, especially satellite communications. The main points of the classic public goods argument, as seen in [3], can be separated into the following: (1) serving government missions, (2) addressing private market failures, (3) balancing private underinvestment in R&D and (4) ensuring access and fair prices.

2.1 Serving Government Missions

Serving government missions is the case used to defend federal investment in R&D and advanced communications systems for defense, intelligence and space and operations. Traditionally, national security agencies and the U.S. Department of Defense (DoD) build and operate their own telecommunication networks. While many systems have remained separate for defense missions, there are networks that have evolved to become part of the current U.S. telecommunications infrastructure. Examples of systems that have originated in the military and have evolved include the secure military communications links to the ARPANET (precursor of the Internet) and the Global Positioning System (GPS).

2.1.1 ARPANET

ARPANET began as a low-cost computer-to-computer network, developed by the Defense Department's Advanced Research Projects Administration and funded by the U.S. Air Force in the early 1960s. Built for military use and to test packet switching technology, ARPANET was a fully government-funded network connecting the DoD and its contractors. The success of ARPANET led to proposals to develop similar networks for non-defense uses. In the early 1980s, the National Science Foundation (NSF) funded NSFNET to link supercomputer sites and networks around the world, thereby expanding the backbones of the Internet. Today, the Internet connects millions of computer users and has become an example of a successful public private network. The Internet has grown beyond its initial role for universities and the research community, becoming less of a private network and more of a publicly-accessible network of networks [11].

2.1.2 GPS

GPS, originally known as NAVSTAR (Navigation System with Timing and Ranging), was developed by the DoD and deployed by 1993 to provide military ground, sea and air forces with all-weather round-the-clock navigation ability. Today, GPS has become an important asset in many civilian applications and industries around the world (e.g., corporate vehicle fleet tracking, surveying, boating, aircraft, travel directions). GPS was made available to the commercial sector only after being pressured by the companies that built the equipment who saw the enormous potential market for it. Thus, GPS satellites broadcast two signals, one for civilian use and one that only the military can decode. In 1996, the White House reaffirmed peaceful scientific, civil and commercial use of GPS services globally and at no cost. Summaries of the two GPS signals are given in Table 1. The DoD intentionally degrades the Standard Positing Service (SPS) accuracy. Precision Positioning Service (PPS) signals are only available upon DoD authorization. Issues involving the dual-benefit technology of GPS and the open access policy are discussed in Section 3.

	Precision Positioning Service (PPS)	Standard Positioning Service (SPS)
Users	U.S. and Allied military, U.S. government agencies, Selected civil users	Civil users worldwide
Access	US Government approval; Requires cryptographic equipment and keys and specially equipped receivers	Free of charge, No restrictions
Horizontal Accuracy	22 meters	100 meters
Vertical Accuracy	27.7 meters	156 meters
Time Accuracy	200 nanoseconds	340 nanoseconds

Table 1: Global Positioning System signals.

2.2 Balancing Private Underinvestment in R&D

As seen in the field of information economics, new knowledge is costly to produce but generally inexpensive to reproduce or duplicate. As a true public good, the social returns of new knowledge exceed private returns. The necessity for government investment to balance private underinvestment in R&D is the claim used to support federal funding of basic research and support of technological advances and prototypes that are not in the marketplace, e.g., laser satellite communications, because private individuals and firms tend to invest less in R&D than is socially optimal. Nonappropriability may also cause private sector underinvestment in basic R&D. The infeasibility of private firms or individuals to gain all the benefits derived directly from their production and/or consumption of certain goods is referred to as nonappropriability. Support of R&D of fundamental technologies will thus help to advance telecommunications state of the art. Private investments in applied research of the proven technologies can then lead to commercialization and the development of a mass market.

2.3 Addressing Private Market Failures

Satellite networking is an emerging market with enormous opportunities to provide many telecommunications services. However, global mobile voice and data services have not been able to compete in price with comparable services provided by terrestrial technologies (e.g., fiber optical links and cellular technologies). The problem has not been that the satellite technology did not work. Rather, the difficulty has been the ability to build a commercially viable global satellite communications system, i.e., gaining market acceptance. Satellite technology will probably not be able to replace the terrestrial access mechanisms, but their unique features are a necessary complement.

2.3.1 Iridium

Iridium, began in 1989, is a satellite network system consisting of 66 low-earth orbiting (LEO) satellites providing wireless telecommunications service anywhere on the globe. Satellites communicated with each other via inter-satellite links. The FCC (Federal Communications Commission) application was filed in 1990 and clusters of satellites began to be launched in 1997. The venture cost $5 billion to construct and maintain and required 800,000 users within five years to be viable. The targeted market segment is business customers in remote areas where service would be valuable because wireline connections were limited. Customers had to be willing to invest thousands of dollars in the telephone handset in addition to paying for access at a rate beyond that of international calling rates (e.g., $3-$8 a minute). In terms of technology diffusion,

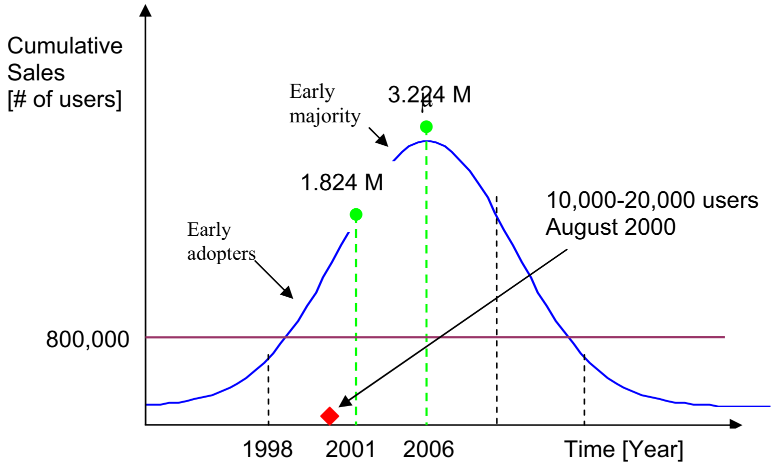

Figure 1: Iridium's projected technology diffusion curve. (Not drawn to scale.)

Iridium had trouble crossing the chasm of early adopters to early majority, as shown in Figure 1. The depicted segmentations in the technology diffusion curve, from left to right, represent innovation, early adopters, early majority, late majority and laggards. Iridium had projected 1.824 million users by 2001 and 3.224 million users after 10 years, in the year 2006. By August 2000, Iridium had only delivered service to 10,000-20,000 users and was forced to file for bankruptcy protection.

2.3.2 Globalstar

Globalstar filed an FCC application in June 1991 for a $2 billion mobile communications system that consists of 48 LEO satellites cooperating with existing public mobile networks, public switch telephone networks (PSTNs), government networks and private networks. The system aims to provide low-cost, high-quality telephony and other digital telecommunications services such as data transmission, paging and facsimile. Unlike Iridium, Globalstar did not employ any intersatellite links in its communications network. Users would make or receive calls using hand-held or vehicle-mounted terminals, similar to cellular phones of the late 1980s, that are able to switch from conventional cellular telephony to satellite telephony as required. A subscriber's phone goes through one of 48 LEO satellites down through a gateway connected to a PSTN and on to the party called. If the call is destined for another portable Globalstar phone, the call will continue to second gateway, up to a satellite and back down to the receiver. Globalstar's design architecture led the company to face many challenges and issues in obtaining license agreements for the location of international gateways. Following in the footsteps of Iridium, Globalstar announced bankruptcy in 2001. The company had trouble convincing customers of the advantages of satellite service. While useful for the military, maritime and oil rig workers and outdoor adventurers, satellite phone service has not been accepted by the mainstream population.

2.3.3 Failures in Capturing and Delivering Value

The examples of Iridium and Globalstar have shown that private markets, thus far, have not been able to gain a widely acceptable satellite telecommunications services consumer base for global mobile satellite voice and data services. The problem is not the technology, but market acceptance (e.g., technology diffusion).

Obstacles to market acceptance include clunky handsets (in the face of ever smaller cellular phones), limitations of satellite phones to work indoors (lack of line of sight to orbiting satellites) and the expensive price of a call (usually several dollars a minute). In summary, the following factors are known to be general reasons for private market failure:

- *Network externalities:* Unlike other infrastructures, this problem is specific to telecommunications because the value of the network increases as more users connect to it. The first subscribers to a network are usually those who highly value communications within their small community. Users with less to gain will postpone connecting to the network until prices drop. The concept of network externality arises as the network expands. The existing subscribers' average value of membership increases as more users join the network and connectivity spreads.
  - *Time to market is crucial in the presence of competing technologies.* Market forecasts for the growth of satellite communications did not adequately take into account the competition and rapid growth of terrestrial cellular service.
  - *Competitive advantages in niche markets are not exploited.* An independent global wireless network is an excellent tool for the military in areas of conflict, journalists, aid workers and refugees in remote areas. Other commercial niche markets include travel cruise ships. Providing to these vertical markets in the beginning might have increased the number of subscribers and revenues.
- *Lack of information to the public:* Users have to be informed about available telecommunications services. For example, Globalstar had found that its cellular network partners were not promoting the Globalstar satellite phone service due to the fear that satellite phones would cannibalize the terrestrial mobile service sales.
- *High transaction costs to the users:* This occurs due to lack of information and lack of a large user population.
  - *Price is too prohibitive to develop an adequately large market.* For example, the cost of an Iridium telephone handset was initially $3,000 and later reduced to $1,500. Potential customers are usually put off by large unit prices and often do not invest in new technology and unknown applications.

2.4 Ensuring Access and Fair Prices

The argument for ensuring access and fair prices revolves around the debate about the gap between the "information rich" and "information poor." The information rich have good access to information, through means such as the Internet, newspapers, radio, television and books. The information poor do not have such access and are vulnerable to all kinds of pressure because they cannot plan their lives and react to changes in situations around them on the basis of what they know and what they can find out. To lessen the widening gap, the government should ensure that all its citizens have fair access to and use of essential infrastructure. The vehicle to this goal is through the regulatory process. For example, in the Communications Act of 1934, the FCC set basic rules for common carrier, broadcast and cable services. Prices for service can be regulated by state and local government agencies which often provide lower rates to certain groups of subscribers through cross-subsidies from other subscribers. Direct government investment can also achieve "universal access." For example, REA-subsidized loans were provided for rural telecommunications systems. The Rural Electrification Act (REA) in the U.S. sought to equip and improve electric and telephone service in rural areas.

3 The GPS Model

As mentioned previously, GPS originated as a military system designed to support strategic and tactical missions. It is a technology that has advanced an extremely wide range of applications. This section briefly explains the system architecture and discusses the issues that arose from the dual-benefit nature of the technology and the open access policy. The issues and decisions of GPS policy can serve as a model to the difficult policy questions regarding the development of a space network infrastructure and its commercial potential.

3.1 System Architecture

GPS is made up of three segments: (1) the Space Segment - satellites, (2) the Control Segment - management of satellite operations, and (3) the User Segment. The Space Segment and the Control Segment fall under the responsibility of the DoD. The User Segment consists of military and civil GPS user equipment (i.e., receivers) development and related activities. Market forces fundamentally drive the development of receivers and services in the civil sector. However, it is clear that the civil sector has benefited greatly from the DoD investments in the development of military receivers in the 1970s and 1980s. developments in the 1990s in civil receiver design and manufacturing.

3.2 Open Access Policy

In 1996, a policy change in open access by the U.S. government granted free use of GPS to the world. The U.S. policy on GPS is based on balancing the basic requirement of retaining the military advantage of the technology with considerations of commercial and international policy. The U.S. government is committed to provide a stipulated level of service from GPS free of charge, shown in Table 1. This guarantee has allowed considerable investment to be made by industry in the development of hardware, software, and systems that, to be viable, depend upon the long-term availability of GPS signals. The private sector has successfully recognized and captured the value of GPS and delivered valuable products and services worldwide (e.g., civil aviation, travel directions, corporate vehicle fleet tracking, and land surveying).

3.3 Dual-benefit Technology

Applying the term ”dual-use technology” to GPS is a misnomer. Not only are other groups seeking the technology of satellite radionavigation, but access to the system. In this sense, GPS is similar to the Dwight D. Eisenhower System of Interstate and Defense Highways. The major commercial and private benefits of the interstate highways is derived from the direct use of the system rather than derived from new road-building technology that could be sold or exported. Both systems are shared by the military due to their commercial and private utility. The addition of commercial and private usage supports justification that the DoD might need to sustain funding for the GPS system.

3.4 Public Good

Referring to GPS as a "public good" implies that it should continue to be made available by government. Generally, a public good is nonrivalrous and non-excludable in use. Nonrivalrous means that one person's benefit does not diminish another's opportunity to benefit from it as well. A non-excludable good means that, once it exists it, is difficult or impossible to selectively deny the benefit to particular persons. For example, a user of GPS cannot deny another user from receiver GPS signals. The classical example of a public good is national defense.

4 Issues with a Space Network Infrastructure

The issues involved with the construction of a global satellite information network are numerous and very complex. The economics of space and the pace of technological change provides a rationale for funding space R&D programs. Mobile satellite communications have not proven to be a viable market. GPS, on the other hand, has been a commercial success, and serves as a model of publicly supported basic research. However, there are aspects to the GPS system which are not comparable to the space network infrastructure. Open access to the space network infrastructure may be too risky due to capacity constraints and security concerns. Therefore, the strategy of technology transfer and commercial development of a similar or duplicate infrastructure must be considered.

4.1 System Architecture

Unlike GPS, but similar to the highway system, sharing of the space network infrastructure may reduce military utility of the system by reducing its availability. In the case of GPS, it is a passive or nonrivalrous system, where one user does not prevent anyone else. Because GPS is a one-way broadcast, users need only receivers to pick up the signals. The reception of GPS signals is not affected by the number of users. In the case of the highway system, this reduction in military utility has not proven to be a problem because the military need for the interstate system has been relatively small to its total capacity. Network capacity, however, is a precious resource and is not yet infinitely abundant in space. Demands for high-speed connectivity and high data throughput on the terrestrial data networks have grown tremendously over the last decades and show no signs of letting up.

Decisions must be made as to whether or not to allow open access to the space network backbone for non-military users. The following questions affecting the system architecture arises from an open access policy:

- How will network access be prioritized?
- How will network capacity be allocated?
- How will military standards for security and robustness be affected?
- How must the architecture change to accommodate non-military users?
- Will services be provided free of charge?

The most important long-term policy decision affecting system architecture is the government's commitment to stable funding and management for dual-use and dual-benefit space systems to serve both national security and economic interests.

4.2 Public-Private Relationship

U.S. defense projects can affect the survivability of the space industry. For example, U.S. defense contractors (e.g., Lockheed Martin Corp., Boeing Co., and Northrop Grumman Corp.) experience private effects depending on their participation. Faced with ever-increasing costliness of defense equipment, the limited defense budget and the importance of industrial competitiveness in a global economy, the government turns to the process of competitive bidding in awarding contracts. For the government, competitive bidding is an approach in procurement to reduce costs and improve efficiency and transparency. Firms that receive contracts may acquire technological advantages over competitors without contracts. To avoid conflict, the government must decide whether to spread contracts among many competitors or to centralize the project in a government lab or an industry joint venture. While efficiency considerations may make centralization more attractive, fragmentation is more likely to be attractive in concentrated industries such as aerospace.

In general, public investment in high-risk technologies can enable private sector organizations later to take advantage of the commercial possibilities of the proven technologies.The government attempts to identify new technologies and/or applications that may be at least 10 - 20 years ahead of the curve. Technology transfer of the know-how can occur so that the commercial sector can use proven technologies to build similar systems and develop applications. Figure 2 illustrates the public-private relationship on the S-curve of emerging technologies. In the ferment stage, the government invests in research activities to explore, develop and demonstrate new technologies (e.g., space laser communications on SILEX). The private sector can then take over during the take-off stage to invest in applied research to create new products and services and bring them to maturity.

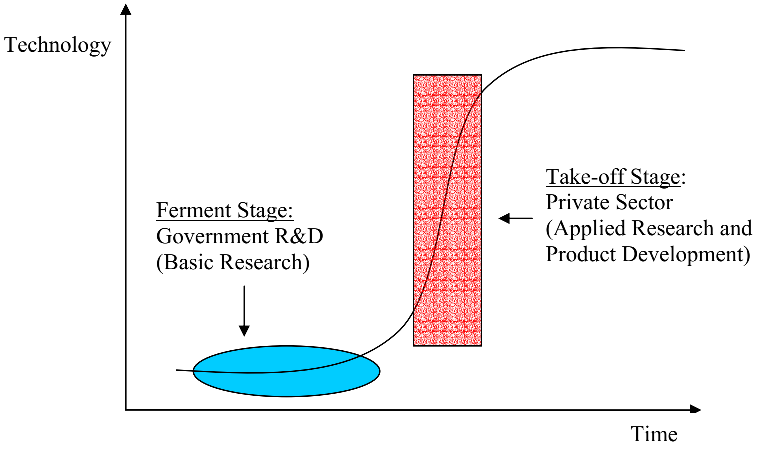

Figure 2: Public-private relationship on emerging technology S-curve.

4.3 Standards

Because an infrastructure includes multiple networks with different functions, capabilities, patterns of ownership and use, an important role of government is assuring interconnection and interoperability so that society can gain the maximum value from both public- and private-sector investments in telecommunications infrastructure. For maximum interconnection and interoperability, open standards should be used. However, because many parts of the space-based information infrastructure have not reached the status associated with mature product markets, one can make a case for government regulation of standards. Government intervention is justified when minimal standardization is lacking and technical chaos is commonplace. In general, standardization allows designers to foresee interconnection requirements and improve system parts. Standards allow consumers to make investments in assets (e.g., satellite phone handsets or terminals) and be assured that the assets' value will not depreciate due to loss of connectivity. Yet, this coordination comes at a price because standards restrict the options that users and vendors have. Both system users and vendors become locked-in to a set of technical products that they may change only at a high cost (e.g., switching costs). Lock-in is particularly costly when technical possibilities change quickly.

5 Conclusions

This paper has identified the need for government investment in a space-based information network infrastructure. Space systems are generally characterized as being slow to design and build, very expensive (e.g., large non-recurring costs), difficult to upgrade on-orbit and very risky for business ventures. The government must invest substantially in order to create the infrastructure needed to exploit space. In the context of space telecommunications where market mechanisms have failed, the three important rationales for government investment are: (1) redressing underinvestment in research and development, (2) achieving critical mass in new technologies, and (3) achieving equity in access. Because research and development (R&D) in space systems is a creative and high-risk process, government funding of basic R&D allows for the creation of the know-how and the know-why of new technologies, materials and applications that eventually translate into commercial development. Products and services having economic value greater than their cost of production and level of risk involved need to be realized as they are drivers for commercialization. Even without direct investment, the government can have a much greater impact through policies, standards, and regulations. Government investment should support the creation of interoperability standards. These mechanisms that the government can implement will foster sustaining an innovative, competitive telecommunications infrastructure provided by private-sector firms. Because there are still numerous open questions in technical design and system management and policy, further work is necessary to understand the complex role and effect that the government has in its investment strategy and policy in the development of a space-based information network infrastructure for both military and commercial users.

References

[1] *Highway History.* U.S. Department of Transportation Federal Highway Administration. http://www.fhwa.dot.gov/infrastructure/history.htm.

[2] GPS and Galileo: Navigating the future. *The Economist*, 367(8330):66, June 28th - July 4th 2003.

[3] Walter S. Baer. Government investment in telecommunications infrastructure. In National Research Council, editor, *The Changing Nature of Telecommunications/Information Infrastructure*, pages 179–194. National Academy of Sciences, Washington, DC, 1995.

[4] David Baker, editor. *Jane's Space Directory.* Jane's Information Group Limited, Surrey, UK, seventeenth edition, 2001.

[5] Barry M. Leiner, Vinton G. Cerf, David D. Clark, Robert E. Kahn, Leonard Kleinrock, Daniel C. Lynch, Jon Postel, Larry G. Robrts, and Stephen Wolff. *A Brief History of the Internet.* http://www.isoc.org/internet/history/brief.shtml.

[6] Pratap Misra and Per Enge. *Global Positioning System: Signals, Measurements, and Performance.* Gana-Jamuna Press, Lincoln, Massachusetts, 2001.

[7] Scott Pace, Gerald Frost, Irving Lachow, David Frelinger, Donna Fossum, Donald K. Wassem, and Monica Pinto. *The Global Positioning System: Assessing National Policies.* RAND, Santa Monica, California, 1995.

[8] F. Shahrokhi and K. E. Harwell. Space benefits: Roles of developing countries. *Acta Astronautica*, 19(9):737 – 742, September 1989.

[9] Barbara A. Stone. Economic benefits of commercial space activities. *Acta Astronautica*, 19(9):743 – 747, September 1989.

[10] Karen G. Strouse. *Strategies for Success in the New Telecommunications Marketplace.* Artech House, Inc., Norwood, Massachusetts, 2001.

[11] Paul Teske. When the public goes private. In Eli Noam and Aine Níshúilleabháin, editors, *Private Networks Public Objectives*, pages 83–92. Elsevier Science B.V., Amsterdam, The Netherlands, 1996.

[12] Jeffery J. Wheatley. *World Telecommunications Economics.* The Institution of Electrical Engineers, London, UK, 1999.