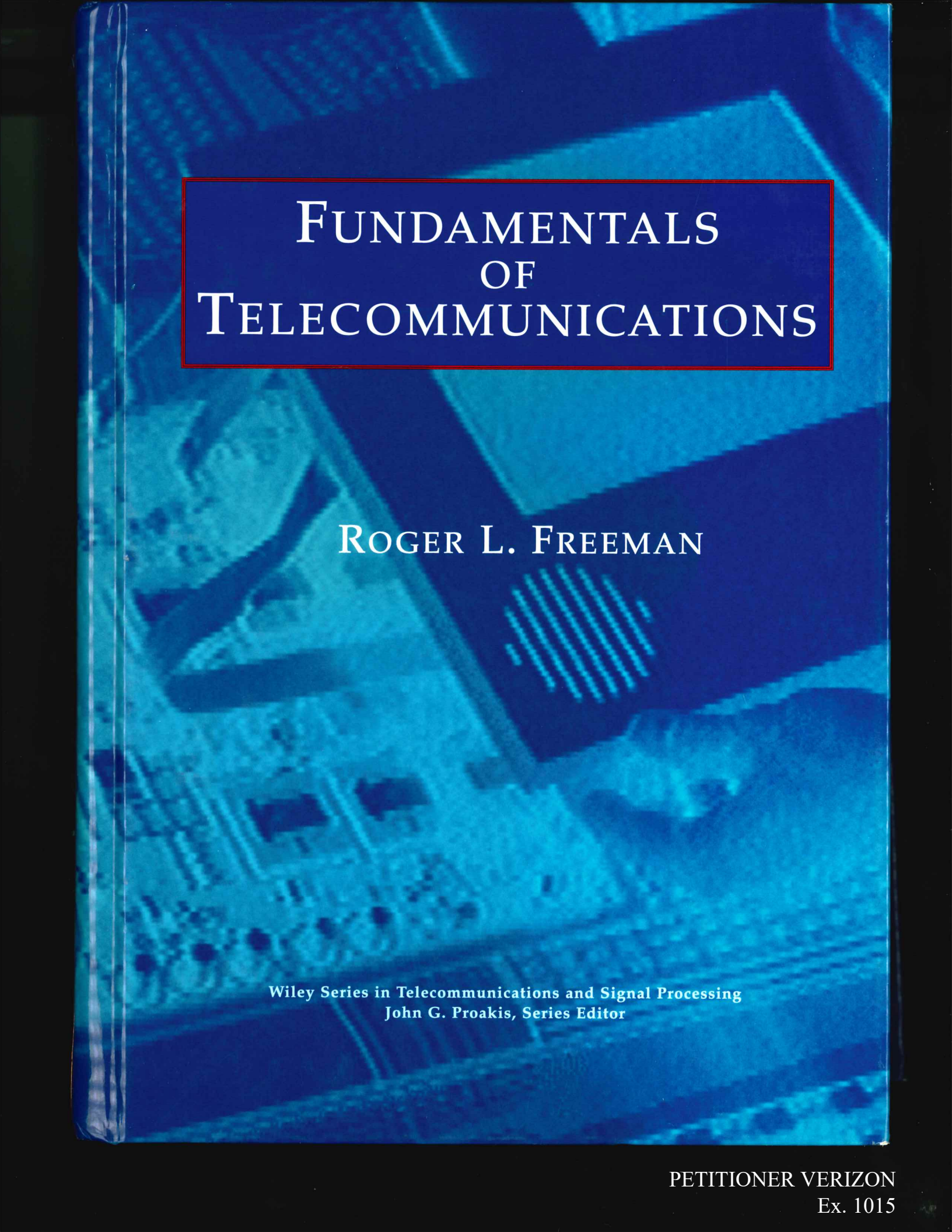


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FUNDAMENTALS OF TELECOMMUNICATIONS

ROGER L. FREEMAN

Wiley Series in Telecommunications and Signal Processing
John G. Proakis, Series Editor

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Roger L. Freeman



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CELLULAR AND PCS RADIO SYSTEMS

16.1 INTRODUCTION

The cellular radio business has expanded explosively since 1980 and continues to expand rapidly. There are several explanations for this popularity. It adds a new dimension to wired PSTN services. In our small spheres of everyday living, we are never away from the telephone, no matter where we are. Outside of industrialized nations, there are long waiting lists for conventional (wired) telephone installations. Go down to the local cellular radio store, and you will have telephone service within the hour. We have found that cellular service augments local telephone service availability. When our local service failed for several days, our cellular telephone worked just fine, although air time was expensive.

Enter PCS (personal communications services). Does it supplement/complement cellular radio or is it a competitor? It is an extension of cellular, certainly in concept. It uses much lower power and has a considerably reduced range. Rappaport (Ref. 1) points out that cellular is hierarchical in nature when connecting to the PSTN; PCS is not. It is hierarchical in that an MTSO (mobile telephone switching office) controls and interfaces up to hundreds of base stations, which connect to mobile users. According to the reference, PCS base stations connect directly to the PSTN. However, a number of PCS strategies have a hierarchy similar to cellular where an MSC (mobile switching center) provides the connectivity to the PSTN. Cellular radio systems operate in the 800-MHz and 900-MHz band; in the United States narrowband PCS operates in the 900-MHz band, and wideband PCS operates in the band 1850-MHz to 1975-MHz. Other PCS operations are specialized, such as the wireless PABX, wireless LAN (WLAN), and wireless local loop (WLL). By WLL we mean a transmission method that will operate in lieu of, supplement, or complement the telephone subscriber loop based on a wire pair.

16.1.1 Background

The earliest radio techniques served a mobile community, namely, ocean vessels. This was followed by vehicular mobile radio including aircraft. Prior to World War II there were police- and ambulance-dispatching systems, followed by growth in the airline industry. However, not until Bell Telephone Laboratories published the famous issue of the *Bell System Technical Journal* devoted entirely to a new system called AMPS (advanced mobile phone system), did the cellular idea take hold. It remains the under-

lying cellular system for the United States and in some Latin-American countries. It uses FM radio, allocating 30 kHz per voice channel.

AMPS set the scene for explosive cellular radio growth and usage. What set AMPS apart from previous mobile radio systems is that it was designed to interface with the PSTN. It was based on an organized scheme of adjoining cells and had a unique capability of handoff when a vehicle moves through one cell to another, or when another cell receives a higher signal level from the vehicle, it will then take over the call. Vehicles can *roam* from one service area to another with appropriate handoffs.

In the late 1980s there was pressure to convert cellular radio from the bandwidth-wasteful AMPS to some sort of digital regime. As the reader reviews this chapter, it will be seen that digital is also bandwidth-wasteful, even more so than analog FM. Various ways are described on how to remedy the situation: first by reducing the bandwidth of a digital voice channel, and second by the access/modulation scheme proposed. Of this latter proposal, two schemes are on the table in North America: a TDMA scheme and a CDMA scheme. They are radically different and competing.

Meanwhile, the Europeans critiqued our approaches and came up with a better mousetrap. It is called Ground System Mobile (GSM) (from the French), and there is some pressure that it be adopted in the United States. GSM is a TDMA scheme, fairly different from the U.S. TIA standard (IS-54C).

As mentioned earlier, PCS is an outgrowth of cellular radio; it uses a cellular concept. The cells, however, are much smaller, under 1-km diameter. RF power is much lower. As with cellular radio, TDMA and CDMA are vying for the national access/modulation method. Unlike the North American popular press, which discriminates between PCS and cellular radio, ITU-R takes a more mature and reasonable view of the affair by placing the two in the same arena. Earlier, CCIR/ITU-R called their conceptual PCS *future public land mobile telecommunication system* (FPLMTS). The name has now changed to UMTS (*universal mobile telecommunication system*). The FPLMTS/UMTS concept breaks down into three terrestrial operational areas: (1) indoor environments (range to 100 m), (2) outdoor environments (100 m to 35 km) for more rural settings, and (3) an intermediate region called outdoor-to-indoor environments, where building penetration is a major theme. They also describe satellite environments.

16.1.2 Scope and Objective

This chapter presents an overview of mobile and personal communications. Much of the discussion deals with cellular radio and extends this thinking inside buildings. The coverage most necessarily includes propagation for the several environments, propagation impairments, methods to mitigate those impairments, access techniques, bandwidth limitations, and ways around this problem. It will cover several mobile radio standards and compare a number of existing and planned systems. The chapter objective is to provide an appreciation of mobile/personal communications. Space limitations force us to confine the discussion to what might loosely be called "land mobile systems."

16.2 BASIC CONCEPTS OF CELLULAR RADIO

Cellular radio systems connect a mobile terminal to another user, usually through the PSTN. The "other user" most commonly is a telephone subscriber of the PSTN. However, the other user may be another mobile terminal. Most of the connectivity is extending "plain old telephone service" (POTS) to mobile users. Data and facsimile services

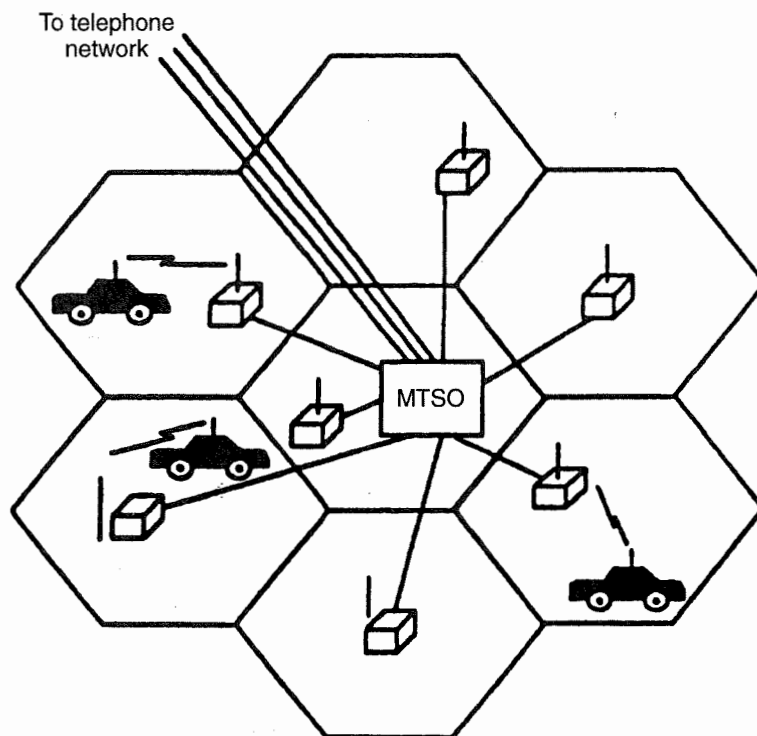


Figure 16.1 Conceptual layout of a cellular radio system.

are in various stages of implementation. Some of the terms used in this section have a strictly North American flavor.

Figure 16.1 illustrates a conceptual layout of a cellular radio system. The heart of the system for a specific serving area is the MTSO. The MTSO is connected by a trunk group to a nearby telephone exchange providing an interface to and connectivity with the PSTN.

The area to be served by a *cellular geographic serving area* (CGSA) is divided into small geographic cells, which ideally are hexagonal.¹ Cells are initially laid out with centers spaced about 4–8 m (6.4–12.8 km) apart. The basic system components are the cell sites, the MTSO, and mobile units. These mobile units may be hand-held or vehicle-mounted terminals.

Each cell has a radio facility housed in a building or shelter. The facility's radio equipment can connect and control any mobile unit within the cell's responsible geographic area. Radio transmitters located at the cell site have a maximum effective radiated power (ERP) of 100 W.² Combiners are used to connect multiple transmitters to a common antenna on a radio tower, usually between 50-ft and 300-ft (15-m and 92-m) high. Companion receivers use a separate antenna system mounted on the same tower. The receive antennas are often arranged in a space diversity configuration.

The MTSO provides switching and control functions for a group of cell sites. A method of connectivity is required between the MTSO and the cell site facilities. The

¹CGSA is a term coined by the U.S. FCC. We do not believe it is used in other countries.

²Care must be taken with terminology. In this instance ERP and EIRP are *not* the same. The reference antenna in this case is the dipole, which has a 2.15-dBi gain.

support location registration, updating, and paging, and enable Telepoint subscribers to receive calls. The CT2+ band is 944–948 MHz.

DECT takes on more of the cellular flavor than CT2. It uses a picocell concept and TDMA with handover, location registration, and paging. It can be used for Telepoint, radio local loop (RLL), and cordless PABX besides conventional cordless telephony. Its speech coding is similar to CT2, namely, ADPCM. For its initial implementation, 10 carriers have been assigned in the band 1880–1900 MHz.

There are many areas where DECT will suffer interference in the assigned band, particularly from “foreign” mobiles. To help alleviate this problem, DECT uses two strategies: *interference avoidance* and *interference confinement*. The avoidance technique avoids time/frequency slots with a significant level of interference by handover to another slot at the same or another base station. This is very attractive for the uncoordinated operation of base stations because in many interference situations there is no other way around a situation but to change in both the time and frequency domains. The “confinement” concept involves the concentration of interference to a small time–frequency element even at the expense of some system robustness.

Base stations must be synchronized in the DECT system. A control channel carries information about access rights, base station capabilities, and paging messages. The DECT transmission rate is 1152 kbps. As a result of this and a relatively wide bandwidth, either equalization or antenna diversity is typically needed for using DECT in the more dispersive microcells.

Japan has developed the personal handyphone system (PHS). Its frequency allocation is 77 channels, 300 kHz in width, in the band 1895–1918.1 MHz. The upper-half of the band, 1906.1–1918.1 MHz (40 frequencies), is used for public systems. The lower-half of the band, 1895–1906.1 MHz, is reserved for home/office operations. An operational channel is autonomously selected by measuring the field strength and selecting a channel on which it meets certain level requirements. In other words, fully dynamic channel assignment is used. The modulation is $\pi/4$ DQPSK; average transmit power at the handset is 10 mW (80-mW peak power) and no greater than 500 mW (4-W peak power) for the cell site. The PHS frame duration is 5 ms. Its voice coding technique is 32-kbps ADPCM (Ref. 9).

In the United States, digital PCS was based on the wireless access communication system (WACS), which has been modified to an industry standard called PACS (personal access communications services). It is intended for the licensed portion of the new 2-GHz spectrum. Its modulation is $\pi/4$ QPSK with coherent detection. Base stations are envisioned as shoebox-size enclosures mounted on telephone poles, separated by some 600 m. WACS/PACS has an air interface similar to other digital cordless interfaces, except it uses frequency division duplex (FDD) rather than time division duplex (TDD) and more effort has gone into optimizing frequency reuse and the link budget. It has two-branch polarization diversity at both the handset and base station with feedback. This gives it an advantage approaching four-branch receiver diversity. The PACS version has eight time slots and a corresponding reduction in channel bit rate and a slight increase in frame duration over its predecessor, WACS.

Table 16.2 summarizes the characteristics of these several types of digital cordless telephones.

16.10 WIRELESS LANs

Wireless LANs (WLANs), much as their wired counterparts, operate in excess of 1 Mbps. Signal coverage runs from 50 ft to less than 1000 ft. The transmission medium

Table 16.2 Digital Cordless Telephone Interface Summary

	CT2	CT2 +	DECT	PHS	PACS
Region	Europe	Canada	Europe	Japan	United States
Duplexing	TDD		TDD	TDD	FDD
Frequency band (MHz)	864–868	944–948	1800–1900	1895–1918	1850–1910/1930–1990 ^a
Carrier spacing (kHz)	100		1728	300	300/300
Number of carriers	40		10	77	16 pairs/10 MHz
Bearer channels/carrier	1		12	4	8/pair
Channel bit rate (kbps)	72		1152	384	384
Modulation	GFSK		GFSK	$\pi/4$ DQPSK	$\pi/4$ QPSK
Speech coding	32 kbps		32 kbps	32 kbps	32 kbps
Average handset transmit power (mW)	5		10	10	25
Peak handset transmit power (mW)	10		250	80	200
Frame duration (ms)	2		10	5	2.5

^aGeneral allocation to PCS; licensees may use PACS.

Source: Ref. 19, Table 2.

can be radiated light (around 800 nm to 900 nm) or radio frequency, unlicensed. Several of these latter systems use spread spectrum with transmitter outputs of 1 W or less.

WLANs using radiated light do not require FCC licensing, a distinct advantage. They are immune to RF interference but are limited in range by office open spaces because their light signals cannot penetrate walls. Shadowing can also be a problem.

One type of radiated light WLAN uses a directed light beam. These are best suited for fixed terminal installations because the transmitter beams and receivers must be carefully aligned. The advantages for directed beam systems is improved S/N and fewer problems with multipath. One such system is fully compliant with IEEE 802.5 token ring operation offering 4- and 16-Mbps transmission rates.

Spread spectrum WLANs use the 900-MHz, 2-GHz, and 5-GHz industrial, scientific, and medical (ISM) bands. Both direct sequence and frequency hop operation can be used. Directional antennas at the higher frequencies provide considerably longer range than radiated light systems, up to several miles or more. No FCC license is required. A principal user of these higher-frequency bands is microwave ovens with their interference potential. CSMA and CSMA/CD (IEEE 802.3) protocols are often employed.

There is also a standard microwave WLAN (nonspread spectrum) that operates in the band 18–19 GHz. FCC licensing is required.

Building wall penetration loss is high. The basic application is for office open spaces.

16.11 MOBILE SATELLITE COMMUNICATIONS

16.11.1 Background and Scope

This section contains a brief review of satellite PCS/cellular services. It is hard to discern whether these services are PCS or cellular. Most of the active and proposed low earth orbit (LEO) satellite systems discussed here utilize frequency reuse and are based on a cellular concept. By the year 2000 or just after we expect at least two “broadband” satellite systems designed to deliver such services as Internet and various other forms of “high-speed” data. By broadband, we mean bandwidths well in excess of those bands available between 1.5 GHz and 2.6 GHz. Among this group are Teledesic and Celestri.