SATELLITE SYSTEMS FOR PERSONAL APPLICATIONS

CONCEPTS AND TECHNOLOGY

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Preface

People in our modern society are profoundly dependent on technology for their work, well-being and quality of life. In recent years, satellite systems have introduced a universal dimension to this technological landscape – although the individual may not always be aware of the extent of the contribution of satellite systems. Satellite technology is today accessible and affordable by individuals, and this book has been created to lay a strong technical foundation towards understanding the role and functioning of existing and emerging satellite systems for personal (i.e. end-user) applications.

Whereas previous books have addressed satellite technology and the personal role of satellite systems in individual service areas – notably personal satellite communications – this book spans the entire breadth of satellite-enabled end-user applications. The aim has been to present the subject matter in a clear and concise manner with key illustrative examples.

After an introductory chapter, the book presents fundamental concepts applicable generally across all the systems. Subsequent chapters delve into techniques and examples of specific systems and services available directly from personal satellite terminals. Such applications encompass broadcasting, communications (narrowband and wideband, commercial, military and amateur), navigation and satellite-based distress services. The book additionally covers those services that are gradually permeating into the personal domain – in particular, satellite imaging and remote sensing.

Finally, the authors explore the trends and evolution of such satellite systems, taking into consideration the influences, user expectations, technology evolution, regulatory efforts and characteristics of satellite systems.

Readers wishing to glean further useful information about the book, to obtain a list of errata, and/or provide feedback to the authors may wish to visit the website at http://www.SatellitesAndYou.com.

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1

Introduction

1.1 Scope

The past two decades have seen a quiet revolution in satellite-based services. Once the preserve of governments, international bodies, public utilities and large corporations, today the majority of satellite service users are *individuals*, who can now access, *directly*, a wide range of satellite services – typically using personal, mass-market and even handheld devices. These satellite systems now fulfil a variety of personal necessities and aspirations spanning telecommunications, broadcast services, navigation, distress and safety services and (indirectly) remote sensing, in the commercial, military and amateur sectors. It therefore seems an appropriate time for a book that addresses these services from the perspective of their support for, and functionality delivered to, individual users.

This book therefore aims to:

- enhance awareness regarding the expanding role of satellite systems in individuals' daily lives;
- lay a strong technical foundation of the basic principles and functioning of these satellite systems for personal communications, navigation, broadcasting and sensing applications;
- illustrate current practice using selected example systems in each field;
- review current trends in relevant satellite and related technology.

The book aims to address an audience that is inquisitive and keen to understand the role of satellites in our daily lives and the underpinning concepts, and, in contrast to alternative offerings, the focus in this book is on the *individual* and the *end-user application*. It aims to provide all of the relevant concepts, in a clear and concise manner, together with descriptions of key systems as illustrations of their implementation in practice.

Satellite services are formally categorized by the International Telecommunications Union (ITU) according to their broad service types. For example, the Broadcast Satellite Service (BSS) addresses recommendations and specifications related to satellite-enabled broadcasts. This book, instead, attempts to address all the services with respect to a user's application perspective – be it telecommunications, broadcast, navigation, amateur, military or safety-related systems.

Space technology comprises a number of branches – satellite communications, satellite aids to the amateur, space exploration, radio astronomy, remote sensing/earth observation, military reconnaissance/surveillance, deep-space communication, launch technology, interplanetary exploration, radio astronomy, space tourism, etc. This book focuses on those technologies where individuals benefit, in a direct or tangible way, from a satellite system. A user interacts directly with a personal satellite broadband terminal when communicating via satellite or interacts with a direct-to-home television

Satellite Systems for Personal Applications: Concepts and Technology Madhavendra Richharia and Leslie David Westbrook

receiver when viewing a programme directly from a broadcast satellite. Similarly, an individual using satellite navigation interacts directly with a Global Positioning System (GPS) receiver.

In some cases the user may not interact directly but nevertheless benefits from information obtained (only) through the use of a satellite system, with some aspects of user hardware or software typically tailored to exploit that system's capabilities, and such applications are also included in the scope of this book. An application in this category would be viewing images of the Earth's weather system appearing daily on our television and computer screens. Here, the pictures transmitted from the satellite are processed elsewhere for the intended audience. Nevertheless, in such instances the individual is conscious that a satellite system is involved.

Those applications and systems where satellites remain in the background are not addressed here, although the same technical concepts apply in the majority of the cases. Examples of this category are interconnection between telecommunication traffic nodes or terrestrial base stations, remote sensing for government (e.g. monitoring vegetation), military surveillance and communications dealing with weapons delivery, television programme distribution between broadcasters, etc. Space tourism (personal spaceflight) is not included in this edition of the book.

1.2 Perspective

Modern society leans heavily on technology for its personal needs – be it entertainment, communications, travel, safety services or domestic appliances. This book deals with the role of satellites in the consumer (or individual) technology paradigm. Consequently, generic user terminal technologies such as terrestrial mobile systems, personal digital assistants, personal computers, etc., are discussed where relevant to personal satellite systems use.

The dependency on satellites in the developed world is quite remarkable. Furthermore, it continues to increase in both the developing and the underdeveloped world owing to falling technology costs together with a growing awareness of the accruing benefits. It must be remarked here, though, that there is a significant difference in priorities in each sector. In an affluent modern society, a majority of people expect a ubiquitous voice service with broadband Internet access, whether they are at home, away or travelling. Many individuals also now aspire to owning a converged handset encompassing some or all of the complementary features such as computing and database functionalities, a hi-fi digital music player, a camera, including video, a radio receiver and mobile television.

In the less developed world, individual requirements and aspirations are curtailed by lower affordability, infrastructure limitations and social conditions. It has been observed that the Gross Domestic Product (GDP) of an economy increases in direct proportion to the improvements to the communications infrastructure. Therefore, there is a great interest in the developing world for deploying wired and wireless technologies such as mobile telephony, the wireless local area network (WLAN) and satellite communications. In the developing world, there is typically minimal fixed infrastructure, with the result that satellites offer an attractive means to build up services, before it becomes economic to introduce fixed assets. One also expects some modifications to mainstream technologies for them to be cost effective and relevant in this environment. The notion that a personal handset is unaffordable, or that the average daily use of such terminals is miniscule, is offset by the fact that such resources are often shared by groups or communities. An example of technical adaptation in a developing region is the extended WLAN trials reported by Raman and Chebrolu (2007) where WLAN coverage was extended to a much wider area than in developed countries, to support scattered rural communities.

Computation, television, broadcast and navigation solutions continue to converge rapidly, enabled by digitization, the vast strides in large-scale integration and mass production techniques resulting in attractively priced converged handsets and accompanying infrastructure enhancements, as the operators reposition themselves in this new paradigm. A number of enabling technologies are instrumental in shaping such converged solutions.

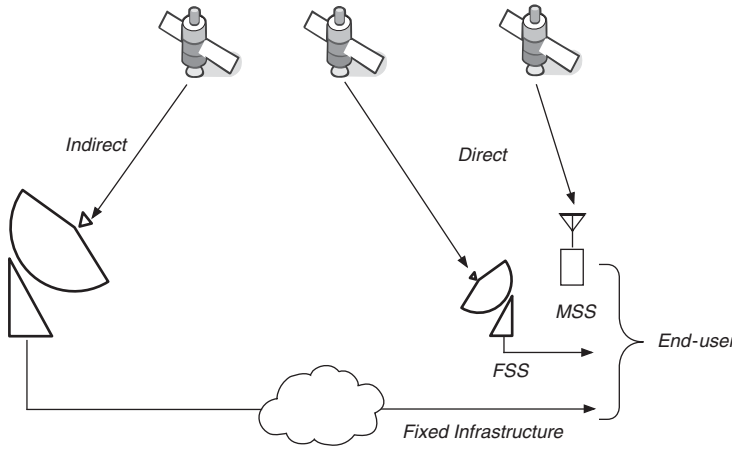

Figure 1.1 The personal (end-user) satellite applications domain.

The unifying force of the Internet offers unprecedented connectivity and tailored solutions such as Internet Protocol (IP) telephony, e-mail, e-learning instruments and audio/video streaming. The evolution in processing capability of personal computers continues unabated. Furthermore, cellular radio technology, based on the concept of radio spectrum multiplication through spatial reuse, now provides instant connectivity across continents. Within a span of just two decades, three generations of cellular systems have been fielded, and research for the introduction of the fourth and even the fifth generation is well under way. The unprecedented success of personal mobile systems has laid the foundations for the commercial viability of WLAN, which enriches the lives of millions through wireless accessibility to the Internet – not only at home and in the office but also in public areas such as cafes and airports.

The extent and speed of introduction of satellite-enabled solutions into the personal domain has surpassed expectations. In broad terms, such applications fall in the areas of personal communications, navigation, broadcast, distress–safety, Earth observation and amateur radio.

Figure 1.1 illustrates conceptually the use of satellite systems for personal applications, indicating the wide scope covered by this book.

1.3 Background and Applications

1.3.1 Background

The space era began with the launch of Sputnik and Explorer by the former Soviet Union and the United States in 1957 and 1958 respectively. Following a series of innovative technical developments, the era of geostationary satellite communications dawned with the launch of Early Bird in 1965. Until the mid-1970s, these communication satellites were mainly used to interconnect large telephone exchanges on national or, more usually, international trunk routes – an application quite remote from individuals. For the individual, the only manifestation of the satellite routing was the propagation (and echo) delay. In parallel, satellite applications extended to numerous other disciplines, namely Earth observation, navigation and radio amateur communications, etc. Monitoring of the Doppler frequency shift of radio signals from the first Sputnik satellite led to the concept of using satellites for navigation, and the first TRANSIT navigation satellite was subsequently launched in 1959 by the US Navy.

Space-enabled technology was furthered by space agencies, manufacturers and operators, leading to a wide range of applications. Direct broadcasts and mobile communications were demonstrated in the 1970s. The well-known Navigation System for Timing and Ranging (NAVSTAR), commonly known as the Global Positioning System (GPS), was launched in 1978 by the US Department of Defense (DoD). A competing system known as the Global Navigation System (GLONASS) was launched by the former Soviet Union in 1986. Yet another system known as the Galileo Positioning System, or simply Galileo, initiated by the European Union and the European Space Agency, is due for launch in early 2014.

Earth observation is a generic term used for a variety of satellite monitoring or, more precisely, remote sensing functions related to environment, meteorology, map-making, forestry, agriculture, etc. Vanguard-2 (launched 1959) was the first earth observation satellite, although TIROS-1 (Television and Infrared Observation Satellites – launched 1960) is widely regarded as the first successful Earth observation (weather) satellite, owing to a malfunction on Vanguard-2. Today, several countries and international bodies own and operate Earth observation satellites. This book encompasses applications such as weather monitoring and map-making where they are directly perceived by individuals. Some existing Earth observation satellites are:

- GMS (Geosynchronous Meteorological Satellite) – these satellites are placed in a geostationary orbit for meteorological sensing;
- Landsat – These satellites are placed in 700 km polar orbit for monitoring mainly land areas;
- NOAA (National Oceanic and Atmospheric Administration) – these satellites are placed in 850 km in polar orbit for meteorological observation and vegetation monitoring.

Amateur radio operators (affectionately known as 'hams') share an interest in construction and communication through non-commercial amateur radio satellites. Ham satellites are known generically as Orbiting Satellite Carrying Amateur Radio (OSCAR), the first of which, OSCAR 1, was launched into a low Earth orbit in 1961. There were almost 20 of these satellites operational in 2006 with plans of numerous additional launches. The Radio Amateur Satellite Corporation (AMSAT) was formed in 1969 as a non-profit educational organization, chartered in the United States to foster amateur radio's participation in space research and communication. Similar groups were formed throughout the world with affiliation to each other. These individuals have pioneered several breakthroughs and continue to do so.

As an aside, we present a few interesting observations that reveal some of the less obvious strengths of satellite systems and position them favourably in a modern context (Robson, 2006/2007).

- A typical Ariane 5 satellite launch emits about half the carbon dioxide emission of a transatlantic jumbo flight.
- Satellites are solar powered and hence environmentally friendly.
- By eliminating or reducing the need for terrestrial infrastructure where possible, it is feasible to reduce environmental load and costs (e.g. through lower use of electricity).
- Satellites are the most cost-effective delivery method for television broadcasts over a wide area.
- Terrestrial TV is heavily dependent on satellites for programme distribution.
- Personal broadband service in remote areas is more cost-effective via satellite than terrestrial techniques.
- Satellites can sometimes offer higher maximum speeds for broadband Internet access for individuals than terrestrial wireless mobile systems (albeit at a higher cost).
- Free satellite broadcast channels are available to users, much as their terrestrial counterpart; hence, the notion that satellite broadcasts are unaffordable to the less well off is debatable.
- The space economy is growing at a rapid rate, proportionately benefiting companies and individuals associated with the industry.

1.3.2 Applications

A wide range of personal applications has been enabled through the collective effort, encouragement and financial support of the satellite industry and various governments, complemented by the assistance of the regulatory authorities and an innovative research community. The recent trend in liberalization and privatization has introduced considerable motivation for an enhanced commercialization of the satellite industry. A notable feature of the changed environment is that industry's attention is likely to be favourable towards personal applications that promise a mass market. This trend is likely to result in a wider portfolio of personal satellite services and solutions in conjunction with cost benefits due to economies of scale.

When dealing with progress in technology, it is convenient to group applications by their service class owing to their inherent commonality. Typical applications of personal satellite systems categorized by their services are listed in Table 1.1, and an evolution timeline is summarized in Table 1.2. Appendix A lists a more comprehensive set of personal satellite applications.

Table 1.1 Personal applications by service category

Service category	Applications
Telecommunications: (fixed and mobile)	*Social*: Mobile communications from remote locations (e.g. a remote holiday destination) or while travelling (e.g. on a ship, in a car, or an aircraft)
	Business: Broadband communications from small offices or remote larger offices
	Emergency: Communications from an individual in distress (e.g. during a mountaineering expedition or a maritime rally)
	Entertainment: Interactive Internet gaming, live television and radio during flight
	Military: Command and control; Situation awareness; Welfare communication
Broadcast	*Television*: Direct-to-home broadcasts
	Radio: Direct broadcasts for long-distance car travel, expatriate listening, live broadcast to aircrafts, etc.
	Multicast: Broadcast to a group/region (e.g. weather forecast, sports results)
	Unicast: Broadcast to individuals – financial/stock exchange update
Navigation	*Location dependent:* (e.g. road traffic conditions)
	Route guidance: (e.g. SATNAV)
	Distress
	Trekking
	Agriculture: (e.g. crop spraying)
	Military
Earth observation	*Weather*: Daily TV broadcasts
	Photographs/maps: Education, city maps
Distress and safety	*Internationally approved system*: GMDSS
	Local or regional service
	Ad hoc arrangements
Amateur	*Amateur communication*
	School projects
	Distress and safety
	Innovation

Table 1.2 Evolution timeline of personal satellite applications

Personal system	Approximate year of entry
Amateur radio	1961
Low-speed data land /maritime	Late 1980
Maritime phone	Early 1980
Direct-to-home broadcasts	1989 (Europe)
Fixed broadband	Early 1990
Personal navigation aid	Early 1990
Aeronautical phone	Early 1990
Maritime medium-speed data	Early 1990
Remote pay booth	Mid-1990
Desktop portable phones	1997
Handheld phone	1999
Affordable satellite imagery	Late 1990
Satellite radio	2001
Digital video broadcasting – satellite handheld	2004
Portable multimedia	2005
Satellite digital multimedia broadcast	2005
Mobile multimedia (ships, aircraft, land vehicles)	2007–2008

1.3.2.1 Telecommunications

Personal satellite telecommunication applications are most effective in remote regions without adequate terrestrial infrastructure, as well as in a mobile environment. The low penetration of satellite communication systems in areas lying within a terrestrial coverage is attributed to the relatively high end-user costs of satellite systems. However, satellite-enabled solutions are becoming increasingly synergistic and cost effective.

1.3.2.2 Fixed Satellite Service

In the Fixed Satellite Service (FSS) arena, steady inroads into the fixed personal broadband have continued, beginning in the early 1990s. The uptake of personal satellite broadband service has increased steadily, particularly in rural and remote areas of developed countries, because of an increasing reliance on Internet-delivered services and applications. There were around 2 million Very-Small-Aperture Terminals (VSATs) dispersed around the world in 2010 (Source: David Hartshorn, Global VSAT forum, 2009). VSAT networks are suited for content distribution, interactive services or services for interconnected mesh networks. In addition to well-entrenched applications, Internet-enabled applications such as TV over IP protocol (IPTV) and Voice over IP (VoIP) are increasing in popularity. Many enterprises have widely dispersed offices that are often inaccessible using only terrestrial networks. Such enterprises typically exploit Virtual Private Networks (VPNs) over satellite because these ensure the desired connectivity tagged with security at an attractive cost. Other applications where fixed satellite solutions are proving beneficial include both one-way and two-way interactive distance learning and telemedicine.

Today's typical high-end VSAT system includes a user terminal capable of supporting multiple telephone channels and Personal Computer (PC) networks, connected to a host network capable of delivering toll-quality voice and IP transmission. These solutions particularly appeal to small office/home office (SOHO) users, Internet cafe owners, etc.

VSAT networks are based on both proprietary technology and open standards. The latter allow economies of scale owing to competition. A case in point is the widely used Digital Video

Figure 1.2 A broadband personal terminal. Reproduced by permission of © Pearson Education. All rights reserved.

Broadcast–Return Channel by Satellite (DVB-RCS) standard developed in Europe with international participation. By providing an asymmetric data rate return channel from the users, it offers interactivity useful in applications such as interactive TV, the Internet and distance education.

Various refinements are under way to enhance the viability of the personal VSAT service. Migration to Ka band (30 GHz uplink/20 GHz downlink) is predicted to lower the user terminal cost and service charge through smaller-diameter antennas and higher space segment capacity (resulting from increased power and frequency reuse through smaller coverage patterns). IP acceleration and network optimization solutions improve the throughput, thereby enhancing quality of service and reducing service cost.

Figure 1.2 shows a typical VSAT terminal for providing broadband Internet at home.

1.3.2.3 Mobile Satellite Service

The Mobile Satellite Service (MSS) era dawned in the late 1970s with the launch of the Marisat satellite by COMSAT in the United States and the successful demonstration of MSS technology. Subsequent formation of the International Maritime Satellite Organization (Inmarsat) at the initiation of the International Mobile Organization (IMO) began the era of a public mobile satellite service. Beginning with large portable maritime user sets weighing hundreds of kilograms and capable of supporting only a single telephone channel, technology has evolved to a point where the smallest modern MSS terminals with an identical capability resemble a cellular phone. The data throughput has increased from a few kilobits per second to half megabit per second (Mb/s), and the services extend to the aeronautical and land sectors.

Figure 1.3 (left) illustrates a dual-mode satellite phone capable of operating either via terrestrial or via a low-Earth-orbit satellite infrastructure, as desired. Figure 1.3 (right) shows a phone with a similar capability but operating via a geostationary satellite system.

An interesting development in this sector is the migration of VSAT (broadband) and direct television broadcast services, traditionally associated with fixed services, to the mobile domain, transcending the service distinction formalized by the ITU.

In-flight real-time audio/video and the Internet MSS facilities are now available via L or Ku band systems. Ku-band systems (14/12 GHz) have an edge in throughput owing to increased spectrum allocation, whereas the L-band systems ($\sim$1.6/1.5 GHz) lead in terms of wider and more robust coverage and lower terminal and service migration costs. Trials have also shown the viability of

Figure 1.3 Handheld dual-mode satellite phones (Not to scale) used in: (a) a low-Earth-orbit satellite system. Courtesy © Globalstar; (b) a geostationary satellite system. Courtesy © Thuraya.

using cellular phones during a flight, where the aircraft acts as a mobile picocell connected to the terrestrial systems via a satellite terminal – leading to the introduction of commercial systems.

There are ambitious service and business plans to exploit for communication a technique known as Ancillary Terrestrial Component (ATC), where the satellite signals are retransmitted terrestrially in areas of poor satellite coverage to enhance coverage reliability. Other emerging mobile technologies are mobile TV and multimedia services.

Figure 1.4 illustrates a broadband personal portable device capable of supporting a data rate up to 0.5 Mb/s.

1.3.2.4 Direct Broadcast Service

The earliest interest in direct satellite television broadcast reception is attributable to enthusiasts who intercepted TV programme distribution transmissions (via satellite) for personal viewing.

Figure 1.4 A broadband mobile user terminal for packet or circuit-mode operation. Courtesy © Nera Satcom.

An industry grew around this mode of (unauthorized) viewing by the mid-1970s to the extent that programme distributors began encrypting transmissions. The Satellite Instructional Television Experiment (SITE), conducted by the Indian Space Research Organization (ISRO) in India in collaboration with NASA via Application Test Satellite-6, demonstrated the powerful potential and viability of direct broadcasts. Direct-to-home broadcasts were first introduced in Europe in the late 1980s. Currently, dozens of DBS systems and tens of millions of users are receiving the service throughout the world. The majority of these transmissions are subscription television, but large numbers of free broadcasts are also available. Considerable regulatory participation and decisions are necessary in bringing direct broadcast to the public domain, and the timing and the complexity of such decisions vary by country and region. To this day, the direct broadcast service is not permitted in some countries.

Satellite broadcast systems are both complementary as well as competitive to their terrestrial counterparts; however, in remote regions, direct broadcast systems are the only viable solution. With the recent introduction of satellite-delivered high-definition television (HDTV), it would appear that the era of home cinema has truly arrived. Figure 1.5 depicts a personal satellite 'dish' (antenna) that folds into a suitcase ready for easy transportation – perhaps to a remote holiday destination. Direct broadcast services to ships and aircrafts are available commercially, enriching the quality of life of thousands of crew and passengers alike.

Satellite Digital Multimedia Broadcasting

Satellite Digital Multimedia Broadcasting (S-DMB) refers to a recent standard for the transmission of multimedia television, radio and data to mobile devices. It has a hybrid satellite–terrestrial architecture where terrestrial repeaters retransmit the signal in areas of poor satellite coverage. The service was trialed in several countries, including China for a possible service roll-out to cater for the 2008 Olympics. A commercial service in Korea already provides television, radio and data, as well as a short message service, to mobile receivers integrated with various types of personal device such as laptop computers and cell phones.

Figure 1.5 Left: A portable dish with a low-noise front end to receive Sky broadcasts in Europe; the dish folds into a briefcase. Right: A satellite receiver. Reproduced from © Maplin Electronics Ltd.

Digital Video Broadcasting

Digital Video Broadcasting DVB is a suite of international video broadcasting standards that caters for numerous transmission media while ensuring equipment compatibility. The widespread adoption of these standards has enabled the cost of broadcast equipment and receivers to be lowered dramatically through economies of scale.

The DVB-S (DVB-Satellite) standard for satellite television was introduced in 1995. The multimedia transport scheme is based on the Motion Picture Expert Group (MPEG)-2 standard. It is a commonly used format for broadcast feed and services such as Sky TV (Europe) and Dish Network (United States).

DVB-S2 (DVB-S, second generation), ratified in 2005, replaces the DVB-S standard. This standard deploys a more advanced transmission technique than DVB-S, allowing change and adaptation of code rate in real time (in response to changing propagation conditions), and provides a throughput gain of about 30% over DVB-S, together with more flexible data encapsulation (with backwards compatibility). Its main current application is the distribution of high-definition television (HDTV). It is suitable for television broadcasts and interactive services with access to the Internet. The return message sent by a user can be channelled through a telephone, an optical fibre or a satellite medium. The DVB-S2 standard also permits professional applications such as content distribution and Internet trunking.

Digital Video Broadcast to Satellite Handheld (DVB-SH), proposed by Alcatel, is yet another potential satellite handheld solution comprising a hybrid satellite–terrestrial architecture at S-band (2–3 GHz) similar to that of S-DMB but using a more powerful geostationary satellite. Alcatel proposed to introduce a DVB-SH service in Europe in 2009. The DVB technical module, called Satellite Services to Portable Devices (SSP), has started to develop a standard for satellite handheld along these lines.

1.3.2.5 Satellite Radio

Commercially introduced around 2001, satellite radio – by which high-fidelity, specialist radio channels are wide-area broadcast directly to users – is growing rapidly in terms of subscriber base. This service holds a niche in the developed world, targeting individuals or businesses such as hotels wanting specialist audio channels – uninterrupted music, sport or news – on fixed sets, long-distance car travellers desiring uninterrupted high-quality broadcasts throughout a journey, people/businesses wanting regular weather forecasts, commercial airliners desiring live music or news, expatriates aspiring for a rebroadcast of their home channel, etc. In developing regions, direct transmissions are the only source of a wide listening choice. A variety of English and regional language news, entertainment, sports and popular music channels are available in far-flung regions of over a 130 countries around the world. Figure 1.6 shows a typical satellite radio used in the Asian and European regions.

1.3.2.6 Navigation

There are two global navigation satellite systems currently available to the general public, GPS and GLONASS, although use of the GPS system is more prevalent (GLONASS having fallen into disrepair). Numerous personalized location services are available around these systems. Many personal devices – such as cellular phones – can now integrate GPS functionality, allowing integrated location-based applications. Navigation aids for car owners, trekkers, mountaineers and other adventure activities are in regular use. In addition, there are other existing and planned regional systems, as discussed in Chapter 14.

Owing to their proven merits and truly global coverage, satellite navigation systems are useful even in areas where terrestrial communication systems dominate, although satellite navigation