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.

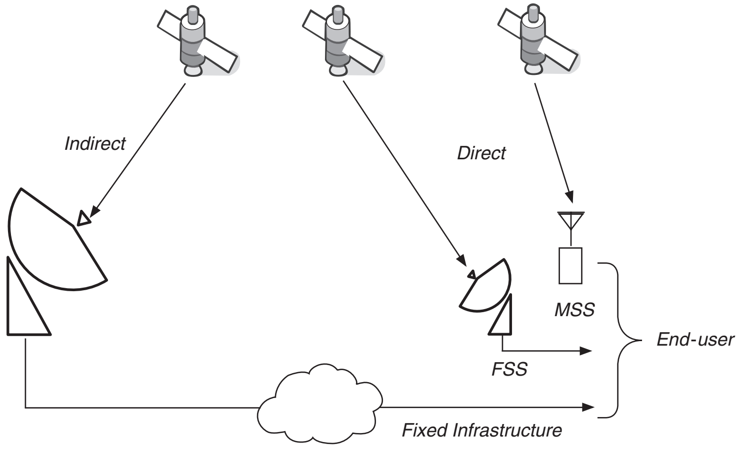

Figure 1.1 The personal (end-user) satellite applications domain.

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

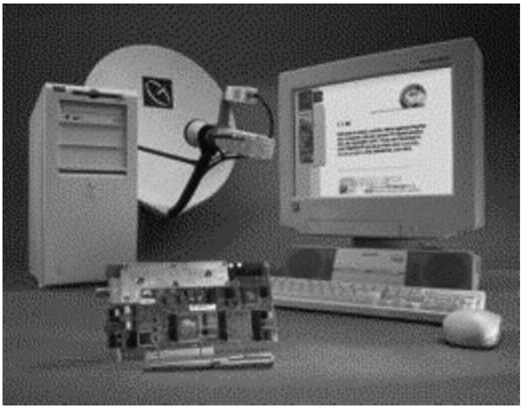

Figure 1.2 A broadband personal terminal. Reproduced by permission of © Pearson Education.

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 (~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

Figure 1.6 A home satellite radio set. Reproduced from © Worldspace.

systems are unreliable indoors because of the low penetration and non-line-of-sight path of navigation signals within buildings or heavily shadowed locations. Figure 1.7 illustrates a navigation receiver integrated with a mobile phone and a Personal Digital Assistant (PDA), illustrating the trend in converged handheld solutions.

1.3.2.7 Distress and Safety

Satellites are a powerful means of supporting distress and safety services because of their ubiquitous and unbiased coverage. In a satellite-enabled distress and safety system, a navigation receiver determines the position of the affected party while a transmitter delivers the distress message, along with the position fix, to a rescue and coordination centre. Alternatively, the fixed component of the satellite distress system itself determines the transmitter location. Hence, satellite distress

Figure 1.7 A navigation receiver integrated with a mobile phone and a PDA. Reproduced from © Mio Technology.

and safety systems are vital for the international maritime and aeronautical transport industries, as well as for facilitating the management of distress situations in remote locations. There are at least two safety and distress application categories:

- delivery of distress messages;
- communication support from a disaster zone.

The former application is formalized internationally for maritime applications through the Safety of Life at Sea (SOLAS) treaty. For inland events, local authorities generally offer the requisite service. The latter application is improvised; here, individuals and/or aid agencies utilize an ad hoc satellite infrastructure until the terrestrial infrastructure is set up, which may take from days to months or even years in extreme cases such as the aftermath of a war. A common practice to establish the desired connectivity is to establish a mobile satellite solution initially, followed by deployment of a fixed satellite system. The MSS requires little set-up time because the terminals are ready to use and free from regulatory formalities, however, the service provides a limited bandwidth. An FSS (VSAT) arrangement offers a much wider bandwidth but may require a few days to activate owing to the installation effort and sometimes the need to obtain a regulatory clearance. In developed regions such as the United States, disaster and emergency management vehicles and systems replenished with a variety of fixed and mobile satellite communications units are finding favour with the welfare and disaster management agencies.

Figure 1.8 shows a personal Emergency Position Indication Radio Locator (EPIRB), which operates via a low-orbit satellite distress and safety system known as COSPAS-SARSAT (Cosmicheskaya Sistyema Poiska Avariynich Sudov or Space System for the Search of Vessels in Distress – Search and Rescue Satellite-Aided Tracking) (Cospas-Sarsat, 2010).

1.3.2.8 Radio Amateurs

Radio amateurs are an active group, establishing contacts with each other through the Orbiting Satellites Carrying Amateur Radio (OSCAR) satellites since 1961. The OSCAR series was originally

Figure 1.8 An EPIRB for personal maritime distress. When activated, signals are transmitted to a registered maritime agency for search and rescue. Reproduced by permission of © ACR.

Figure 1.9 A ham radio transreceiver. Reproduced courtesy of NASA.

meant for amateurs to experience satellite tracking and participate in radio propagation experiments; however, these satellites have become increasingly advanced over the years. They are often used to support school science groups, provide emergency communications for disaster relief and serve as technology demonstrators. The first slow-scan TV reception in space was demonstrated aboard the Challenger STS-51 mission through an amateur transmission. The first satellite voice transponder and some advanced digital ‘store-and-forward’ messaging transponder techniques are also accredited to this group.

Figure 1.9 (Peck and White, 1998) illustrates radio amateur equipment during a school experiment. The Space Amateur Radio EXperiment (SAREX) is a notable example of youth participation. It facilitates communication between astronauts and school students. Through SAREX, astronauts make both scheduled and unscheduled amateur radio contacts from the Shuttle orbiter with schools selected through a proposal process. These contacts serve to enthuse students and families about science, technology and learning (Peck and White, 1998).

1.3.2.9 Military

Satellites are today indispensable to the military throughout the world, during peace, war or the reconstruction phase at the end of a war. The military of many advanced countries have dedicated military satellite systems for both strategic and tactical purposes. Indeed, such is the demand for such services that the military tend to utilize the communication capacity available on civilian satellite systems in order to satisfy their total requirements. In addition, the introduction of assured *service-based* military satellite provision (for example, Skynet 5 and Xtar) has allowed other nations to benefit from satellite capability without the associated expense of asset purchase.

During periods of peace, satellites assist in reconnaissance, communication between headquarters, logistics, welfare, etc. Military navigation systems have become indispensable at every phase of military operations. Both GPS and GLONASS are military systems. During a war, satellites play an indispensable part in tactical communication, surveillance and navigation. During the reconstruction phase, satellites can be used for communications between the military and other government and non-government organizations, and for distance learning to impart training in the affected regions and auxiliary services such as asset tracking and management (Mitsis, 2004).

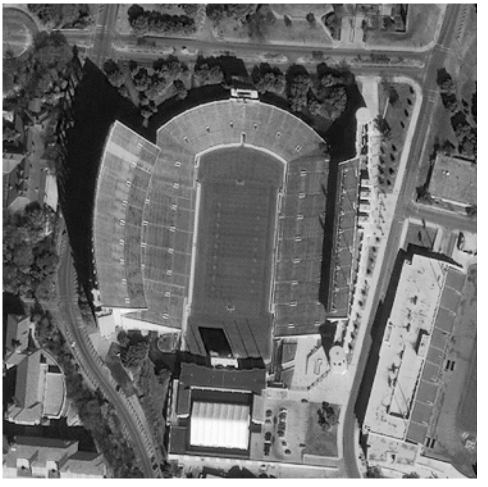

Figure 1.10 Satellite imagery showing the stadium at the University of Texas. Reproduced by permission of © GeoEye Inc.

1.3.2.10 Earth Observation

Earth observation satellites, also referred to as remote sensing satellites, are attractive to assist in weather forecasts, agriculture yield estimates, forest management, commercial fishing, urban planning, etc. Such activities are normally associated with governments, welfare agencies, etc. Significantly, in recent years the data gathered by Earth observation satellites have become available to the general public and businesses.

Weather forecasts based on remote sensing satellite data embellished with satellite pictures are a regular part of television transmissions. Satellite imagery superimposed on route maps is quite a powerful route and location guidance tool for the general public. High-quality satellite images are widely available commercially. As an illustration, Figure 1.10 shows an image of the stadium at the University of Texas taken by a GeoEye satellite.

1.4 Trends

The topic of technology forecasting interests academics, researchers, strategists and planners and commercial companies, although each for different reasons. On one hand the likes of academics, the government and intergovernment bodies aim to further the frontiers of knowledge to pave the way for long-term economic and social benefit, while on the other hand a commercial company judges the short-to-medium trends in targeted areas to develop its business. Satellite manufacturers are interested in the medium-to-long term (5–15 years), and satellite carriers, service providers, application developers, etc., have a short-to-medium-term interest. We have seen the disastrous consequence of incorrect market forecasts in the MSS sector towards the end of the last century, when several operators had to file for bankruptcy owing to misreading the market trend in the early 1990s.

This section outlines the general trends in the topics discussed so far without trying to project a synthesized scenario of the future. The reader is referred to Chapter 17 for a more detailed exposition. Suffice to mention here that, with the steady convergence of telecommunication, broadcast, position location systems and computing and an increasing integration of functionality in personal devices, the information society will expect a wider accessibility to information (anywhere), greater mobility (everywhere), large bandwidth (broadband) and 'converged' personal devices – all at a lower cost. Judging from the present situation, it is evident that satellite systems will have a fair role but will have to evolve rapidly to be in step.

Handheld

A notable trend in recent years is the integration of an increasing number of functionalities in the personal handheld, facilitated by user demand and the refinements of low-cost semiconductor processes such as CMOS and SiGe Bi-CMOS. The enormous processing capability of modern programmable chips enables a variety of embedded functionality on the same platform. From the user's perspective, it is convenient to have a unified package of multimedia, communications and computation. Thus, a handheld device may potentially incorporate some or all of the following units – a camera, a multiple standard cellular/satellite phone, a mobile TV, a satellite positioning device, a Wireless Local Area Network (WLAN) interface, personal music/video systems, gaming, etc. Consumer demands for data *pushed* to a handheld device are on the rise. Examples are satellite imagery and maps, GPS coordinates, location-specific and general news, sports results, etc. Wireless technologies of interest here are satellite, cellular, WLAN and WiMAX (Worldwide Interoperability for Microwave Access). Using GPS as the location detection engine, handheld location-based services are gaining in popularity, riding on applications such as fleet management and proof-of-delivery signatures.

Owing to the availability of satellite imagery through Internet search engines and thereon to handheld devices, this type of data is whetting the appetite for more advanced remote imaging applications. Specialist companies are gearing up their space segment to provide higher-resolution imagery. These data, combined with local information, provide effective applications. For example, location knowledge can enable the downloading of desired location-specific traffic or weather conditions.

An interesting example of a future personal application (Sharples, 2000), in line with the UK government's Green Paper on life-long learning (Secretary of State, 1998) is the concept of a framework of educational technology constituting a personal handheld (or wearable) computer system that supports learning from any location throughout a lifetime. Such a concept would require an all-encompassing wireless network covering the majority, if not all, of the populated area, consisting of a hybrid, terrestrial–satellite architecture.

VSAT

It is recognized that personal VSAT systems benefit from high bandwidth and smaller terminal size. VSAT migration to Ka band provides a much larger available bandwidth ($\sim$1 GHz) and enables a smaller terminal size through the use of a greater number of smaller high power beams. It is therefore anticipated that Ka-band VSAT systems will be more attractive for many applications. Other notable areas of interest are as follows:

- Considerable effort is under way to maximize spectral efficiency and enhance transport protocol robustness to the inherent signal latency of satellite systems.
- Several operators offer a mobile VSAT solution for moving platforms such as ships. One limitation of a VSAT, when considered in a mobile application, is that, because it belongs to the fixed satellite service, there are mobility restrictions on these services in various parts of the world.

MSS

A major limitation of MSS systems is their relatively poor coverage in shadowed (especially, urban) areas. Following a liberalization of the spectrum regulations, the Auxiliary Terrestrial Component (ATC), also known as the complementary terrestrial component, has drawn considerable interest in the MSS and satellite radio broadcast communities, where satellite signals are rebroadcast terrestrially in difficult coverage areas to fill in such gaps (see S-DMB and DVB-SH above). In effect, the satellite spectrum is made available to terrestrial transmissions. The potential of a massive increase in the user mobile satellite base with consequent revenue gains and the possibility of a lucrative collaboration with terrestrial operators are strong incentives to the satellite operators.

The majority of modern MSS systems deploy an integrated architecture. Users can thus roam between these networks, identified by their subscriber identity module (SIM) card. This feature, along with a multimode receiver software-defined architecture, will allow a seamless connectivity while roaming across multiple services.

With the users' insatiable desire for larger bandwidth, the MSS industry is striving hard to provide higher throughput in spite of the harshness of the propagation channel, cost constraints and meagre spectrum availability in the favoured L and S bands. In the area of the L-band broadband MSS arena, 0.5 Mb/s portable mobile technology was introduced by Inmarsat in 2005, and the service was extended to all types of mobile environment by the year 2008. However, the scarcity of the L and S-band spectrum has prompted the industry to investigate higher-frequency bands – the Ka band to an extent but the Ku band in particular – where adequate bandwidth exists in spite of the problems of rain attenuation, stringent antenna pointing needs and low coverage of sea and air corridors. (Arcidiacono, Finocchiaro and Grazzini, 2010). High data rates of up to 2 Mb/s are available to ships in Ku band via Eutlesat satellites, while in the aeronautical sector Boeing Service Company provides a Ku-band broadband network service comprising high-speed Internet communications and direct broadcast television to the US Air Force Air Mobility Command following the closure of its commercial operations called Connexion to civil airlines. The forward link to the aircraft provides 20–40 Mb/s of shared capacity. Mobile platforms may transmit at up to 1.5 Mb/s (Jones and de la Chapelle, 2001). A number of commercial aeronautical Ku band services also exist.

Broadcast

Satellite radio technology has reached a mature stage within a rather short timespan, riding on the back of the most rapid service uptake of all the satellite products to date. Companies in the United States, in particular, have been at the forefront of its commercial introduction. The user base in the United States and other parts of the world is growing steadily despite competition from terrestrial and Internet radio, indicating the long-term commercial viability of the technology, particularly following a consolidation between US operators in order to achieve a critical mass, and introduction of novel commercial applications.

Terrestrial mobile TV systems are being promoted as the next commercial broadcasting success. By the same criteria, satellite mobile TV technology also holds promise. Handheld simulated-satellite TV trials are under way in Europe based on the DVB-SH technology. An operational system will use high-power spot-beam satellites and Orthogonal Frequency Division Multiplexing (OFDM) and will be compatible with DVB-H and 3G mobile standard. A similar system resident on another technology platform was in service for a while in Japan via MBSat since 2004, offering eight channels along with 30 audio channels. It also broadcasted maritime data such as sea currents and sea surface heights. Korea launched a similar service in 2005, and China intended to introduce the service prior to the 2008 Olympics, while India plans to deploy a multimedia mobile satellite for S-DMB IP-based services to individuals and vehicles.

High-Altitude Platforms

High-Altitude Platforms (HAPs) have been studied as surrogate satellites for well over a decade. They potentially offer an effective alternative to ground base stations by eliminating the logistics and costs associated with the installation of terrestrial base stations. Being closer to the Earth than satellites, they do not require an expensive launch, and nor do they need space-qualified hardware; their equipment can be readily repaired; they can provide considerably higher downlink received powers and uplink sensitivity than satellites and a smaller coverage area for a given antenna size owing to their proximity to the Earth (<60 km) and hence can support a variety of wireless technologies, for example, mobile and fixed broadband, WiMax, etc. Use of HAPs as ATC platforms is also an interesting concept. A number of initiatives are being pursued actively, and a commercial launch is awaited.

Network
Following the introduction of the 3G systems, the focus of the research community is towards the next generation of mobile system, 4G and beyond. While the specific details are under active research, some of the requirements have become reasonably well entrenched. It is believed that the 4G network will comprise a multitude of interoperable wireless technologies and interfaces. It is also clear that satellites will be one of the constituents of such an all-encompassing network. Techniques under investigation include software-defined radio, which should permit users to migrate across a heterogeneous mixture of air interfaces and protocols, an ad hoc network to facilitate mobility and allow formation of decentralized network management, efficient resource management techniques, handover between heterogeneous networks, etc.

Region
The United States continues to lead in the exploitation of personal satellite services, but there are indications that consumer demand for satellite communications products will increase considerably in the Middle East, the Far-East, India and South Asia. The areas of expected growth there include IP-based VSAT services, Virtual Private Network (VPN) services, combined data/video/voice services and robust handheld MSS solutions.

1.5 Overview of this Book

This chapter has provided a sample of the use of satellite technology for personal applications. The remainder of this book is divided into two parts. Part I, comprising Chapters 2 to 8, introduces fundamental principles and concepts of the applicable satellite systems, including some novel concepts of future interest. While some of the concepts presented in Part I are also documented elsewhere, it is the intention here that these topics be treated specifically in the context at hand. This material is therefore presented somewhat succinctly except where the subject is relatively new or, in the authors' view, has not received adequate attention in other texts. Part II, comprising the remaining chapters, introduces practical system techniques and architectures, with illustrative examples, concluding with a chapter on trends and evolution. For use with relevant educational courses, or to assist home study, each chapter includes a set of revision questions.

Chapter 2 describes the main attributes of satellite and high-altitude systems. Topics include satellite orbits, geometrical relationships and characteristics of high-altitude platforms. Chapter 3 introduces relevant aspects of spectrum regulation and electromagnetic wave propagation, including the effects of the atmosphere and the operational environment, as well as remote sensing windows. An understanding of system aspects of antennas, the transmission equation and the origins and characteristics of noise is fundamental to a radio communication system. Chapter 4 introduces these concepts. Next, Chapter 5 discusses the related topics of modulation and error control coding, including highly efficient modulation schemes. Coding topics include various block and convolution codes as well as newer turbo and LDPC codes. This leads to Chapter 6, which covers link budget and satellite access methods – particularly multiple access – and generic aspects of satellite networking. Chapter 7 covers the concepts of Doppler and ranging-based navigation systems, which are widely used in contemporary satellite navigation systems. In the final chapter of Part I, we discuss information entropy and concepts of data compression as well as speech, audio and video encoding.

With the reader thus prepared, the second part of the book goes on to discuss techniques and architectures – illustrating them with selected case studies and examples. Such system concepts are best dealt with in conjunction with the overall architecture, and hence these concepts are included in this part rather than in Part I. In Chapter 9, we address digital broadcasting techniques and architectures, including a review of MPEG multimedia standards, the concept of multiplexing and transporting, direct-to-home broadcast system architectures and prevalent transmission standards. In the next chapter, we introduce numerous contemporary state-of-the-art broadcast systems of each category – satellite radio, direct multimedia broadcasts, direct-to-home satellite television systems used in various parts of the world (with a focus on Europe and the United States). In the final section we introduce a multimedia broadcast system used by the US military. In Chapter 11 we address various types of network topology and connectivity, illustrating them with typical satellite and tentative HAP systems. In particular, we use network concepts for a hypothetical mobile satellite network as a baseline. These topics prepare us for chapter 12, where we present examples and case studies of various types of satellite communication system (mobile, fixed, amateur and portable military systems) including a few prominent HAP communications research initiatives undertaken in Europe. The next chapter, Chapter 13, introduces the techniques prevalent in navigation systems, including system aspects of Doppler and ranging navigation, the satellite augmentation system and hybrid communication–navigation system architecture, including issues related to navigation receivers. In the final part of the chapter we introduce the concepts of distress, safety and location-based services. Chapter 14 follows with examples of prominent global and regional navigation systems, satellite augmentation systems and distress and safety systems, concluding with an example of a system to provide a location-based service. Chapters 15 and 16 respectively introduce system-level remote sensing techniques/architectures, and prominent remote sensing systems and optical imaging systems.

What of the future? In the final chapter we address the evolution of personal satellite applications and systems, taking into consideration trends in user expectations, technology, regulatory and standardization efforts and the inherent strengths and limitations of satellite systems.

The authors hope that the reader will find this book to be a useful reference. They firmly believe that, with the passage of time, satellite systems will enrich the quality of people's lives far more than is visualized today.

References

Arcidiacono, A., Finocchiaro, D. and Grazzini, S. (2010) *Broadband Mobile Satellite Services: the Ku-Band Revolution*. Available: http://www.eutelsat.com/products/pdf/broadbandMSS.pdf [accessed January 2010].

Cospasat-Sarsat (2010) http://www.cospas-sarsat.org/ [accessed February 2010].

Global VSAT Forum (2009) http://www.gvf.org [accessed February 2009].

Jones, W.H. and de la Chapelle, M. (2001) Connexion by Boeing/sup SM/-broadband satellite communication system for mobile platforms. MILCOM 2001. Communications for Network-Centric Operations: Creating the Information Force, 28–31 October, Washington, DC, IEEE, Vol. 2, pp. 755–758.

Mitsis, N. (2004) Rebuilding Iraq: Satellite-enabled Opportunities. *Via Satellite*, April, S6–S8.

Peck, S. and White, R. (1998) *Amateur Radio in Space – A Teacher's Guide with activities in science, Mathematics and Technology*. NASA, Office of Human Resources and Education Division.

Raman, B. and Chebrolu, K. (2007) Experience in using W-Fi for rural Internet in India. *IEEE Communications Magazine*, **45**(1), 104–110.

Robson, D. (2006/2007) The need for space. *IET Communications Engineer*, **4**, (December/January), 26–29.

Secretary of State (1998) Secretary of State for Education and Employment, Green Paper on lifelong learning, UK Government.

Sharples, M. (2000) The design of personal mobile technologies for lifelong learning, *Computers and Education*, **34**, 177–193. Available: http://www.elsevier.com/locate/compedu [accessed May 2007].