Orbits, Services and Systems

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Satellite Orbits

In the 17th century Galileo Galilei (1564-1642) first observed the moons of Jupiter through his handcrafted telescope. These observations ultimately led to his realization that not only did planets encircle the Sun, but that moons could and indeed did encircle planets. To the moon of Jupiter he applied the Latin word *satelles*, which means "servant." He concluded that somehow a planet 'commanded' its moons to remain in their constant orbits just as a master or mistress commanded the actions of a servant. Today this remains an apt term in that artificial satellites do the bidding of the scientists and engineers that design satellites for telecommunications, broadcasting, remote sensing, space navigation, meteorology, geodetics or scientific exploration.[1]

A century later Sir Isaac Newton not only discovered gravity but understood how gravity commanded the orbits of satellites. In his book *Philosophiae Natralis Principia Mathematica*, and known as simply the *Principia*, Newton explains the workings of gravity in terms of the "falling" of objects but also applied it to the planetary motions described by Johannes Kepler some years before. Newton's famous book even included an iconic illustration that showed how a cannon that shot high enough and fast enough could hurl an object into Earth orbit. Thus we have known for three centuries how artificial satellites could be launched into orbit to carry out various tasks.[2]

Ironically, it was the world of early science fiction that gave us our first vision of how various types of application satellites might be launched into Earth orbit and then carry out various missions. Although there are many examples from

[1] Joseph N. Pelton and Scott Madry, "Satellites in the Service of Humanity," Chapter 6, in Joseph N. Pelton and Angela Bukley, editors, *The Farthest Shore: A 2lst Century Guide to Space* (2009) Apogee Books, Burlington, Ontario, Canada. p. 181–82.

[2] *Ibid*, Angie Bukley et al, "Space Missions and Programs: Why and How We Go to Space," Chapter 8, p. 259–60

J.N. Pelton, *Satellite Communications*, SpringerBriefs in Space Development,
DOI 10.1007/978-1-4614-1994-5_2, © Joseph N. Pelton 2012

H. G. Wells, Jules Verne and others, one of the most striking first such images was provide by Edward Everett Hale in his book *The Brick Moon* (1869). Hale foresaw an artificial moon being launched into polar orbit to carry out weather and Earth observation and to act as a communications device. This turned out to be an amazing precursor prediction of what would happen more than a century later. Of course the artificial satellites of today are not built of bricks. Neither do polar orbiting satellites have a crew of 17 men and two women on board nor do they use Morse code to transmit messages. Still Hale's book was a remarkably innovative concept that helped to lead the way forward.[3]

The key to all communications satellites being able to operate successfully is to place them in an appropriate orbit targeted to providing one or more useful services. Today there are three main groups of orbits used by telecommunications. These are the geosynchronous Earth orbit, or GEO (also known as the Clarke orbit in honor of Arthur C. Clarke, who first wrote about using this unique orbit for satellite communications in 1945); medium Earth orbit, or MEO; and low Earth orbit, or LEO. Although there are other orbits that can be used for satellite applications that will be described briefly, most communications satellites are in GEO. There are, however, also a number of LEO and MEO constellations that are used for communications as well as other practical purposes such as space navigation, remote sensing, and meteorological observation.

When satellites are launched from Earth they tend to go initially into an elliptical orbit. These are just like the elliptical orbits the planets follow around the Sun when one charts the geography of our Solar System. The Sun, as explained by Kepler, is not found at the center of a series of concentric orbital circles. Rather the Sun can be found in one of the two foci found in every ellipse because a circular orbit is a very unique and special case of an ellipse when the two foci exactly overlap. A satellite launch thus typically sends the spacecraft into such an orbit with an apogee (or high point) and a perigee (or low point). This is shown in Fig. 2.1 below.

The initial launch will send the spacecraft into an elliptical orbit. Some of these orbits can be suitable for LEO or MEO constellations. If the launch, however, is for a satellite intended for GEO then the initial orbit will be a very highly elliptical orbit, called a transfer orbit, with an appropriate very high apogee (35,780 km) so that the spacecraft can later be pushed into a circular GEO. In the early days what was called an apogee kick motor would be fired at apogee to circularize the orbit. Today, a last stage rocket firing or on-board thrusters will divert the satellite to a circular GEO.

LEO Constellations

LEO altitudes are typically in the range of about 500 to 1,200 km. These orbital altitudes are essentially below the lowest of the Van Allen high radiation belts and

[3]Ibid, Peter Diamandis, Robert Richards and Joseph Pelton, "The Future of Space," Chapter 4, p. 118.

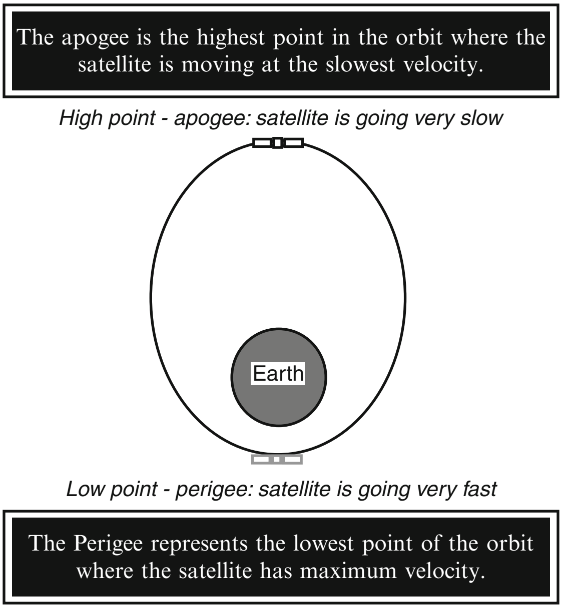

Fig. 2.1 Natural elliptical orbital characteristics with a typical satellite launch

require a constellation of satellites of between 40 and 80 spacecraft in order to provide global coverage. One can also design an LEO system to provide coverage for only a portion of the globe such as between 65 degrees latitude North and 65 degrees latitude South. Such a constellation can "see" 99% of the world's population. (Penguins do not represent a useful client base.) If one looks at Fig. 2.3, which shows an MEO constellation, it should be clear that quite a few more satellites located at much lower altitudes would be needed to achieve complete coverage of Earth. If this is not clear shine a flashlight on a globe and see how the illumination area grows or shrinks as you move the light away from the globe or bring it back much closer.

In essence, the lower the low Earth orbit, the more satellites are needed to complete the constellations' total coverage. If you are in a balloon, for instance, the higher you are the farther you can see in all directions.

The positive tradeoff is that the flux density (or irradiated power) is higher within the much smaller viewing or "catchment area" on Earth's surface. Obviously if the satellite transmission path is much shorter the so-called path loss, or spreading out of the transmitted power, is also much less. Clearly one needs a larger "swarm" (or more precisely a constellation) of satellites to truly cover Earth's surface completely, since each LEO satellite can only illuminate a much smaller area. Enthusiasm for low Earth orbit satellite constellations for mobile communications and data relay services diminished after the bankruptcies of the Iridium, Globalstar and ICO global mobile satellite systems in the 1990s. This was further compounded by the later financial difficulties with the Orbcomm data relay system. After financial restructure,

Fig. 2.2 One of the Orbcomm satellites launched into a low Earth orbit constellation. (Graphic courtesy of Orbcomm.)

Fig. 2.3 The NAVSTAR GPS satellite constellation for space navigation

however, all of these systems except ICO are now operating successfully and are technically and operationally viable. (See Fig. 2.2.)

MEO Constellations

In the case of MEO satellites the constellation of from 8 to about 24 satellites is configured in orbits that are typically 10,000 to 20,000 km above Earth's surface. Because the satellites are higher, fewer satellites are need to cover Earth, but the path loss due to the spreading of the antenna beams means the flux density of the beams is less when they reach the ground. The number of satellites in the constellation depends on not only the altitude but also the particular mission the satellites are designed to perform. Space navigation satellites such as the NAVSTAR Global Positioning Systems (GPS) for instance requires that a user accesses four or more satellites to get an accurate fix on location. Thus this constellation, although in a relatively high orbit, still has some 24 to 27 operational satellites in order that multiple satellites can be seen at the same time. (See Fig. 2.3.)

GEO Communications Satellites

In the case of GEO, the satellite is first launched into a highly elliptical (cigar-shaped) transfer orbit where the perigee (low point) is only a few hundred km in altitude, but the apogee (high point) is nearly 36,000 km. The satellite remains in this transfer orbit until an appropriate apogee is close to the desired longitudinal location with respect to Earth's equator. At this stage either an "apogee kick motor"(in the early days) or the last stage engine of the launch system or apogee motor pushes the satellite from transfer orbit into a new perfectly shaped circular orbit that allows the satellite to move around the planet exactly once every 23 hours and 56 minutes. In this very special orbit the satellite appears to remain exactly stationary with regard to Earth below. (Note: What seems to be the "missing 4 minutes in a day" actually is not missing at all. Earth travels around the Sun every 365.25 days, and this means it travels 4 minutes worth of its annual revolution around the Sun every day).

Again there are tradeoffs to consider. Only three GEO satellites are needed to cover the planet except for the most extreme polar cap regions. The great altitude means that the flux density of the beams is much less than for LEO or MEO systems because the "path loss" (i.e., the loss of signal strength equivalent to the spreading of the beam from the satellite's antenna in its journey back to Earth) is much greater for the GEO than for the lower orbits. In the case of the GEO satellite, the spacecraft is almost one-tenth of the way to the Moon. Even with a very highly focused beam, the signal spreads out greatly by the time it reaches Earth. This spreading out of the beam over its transmission distance is called "path loss."

The enormously important advantage of the GEO or Clarke orbit satellite is that ground Earth stations, very small aperture terminals (VSATs) and various forms of antennas, from larger Tracking, Telemetry and Command (TT&C) units to small micro-terminals, do not have to "track" or continuously move to keep connected. Once one orients a ground station, particularly a small aperture VSAT or a direct broadcast receiving station, it stays continuously connected because the satellite appears to remain constantly fixed overhead.

There are two terms often used with regard to a GEO satellite – one is "geostationary" and the other is "geosynchronous." A geostationary satellite would be one that remains constantly at the same longitude all the time and also remains exactly in the equatorial plane at 0 degrees latitude. Such a perfectly geostationary orbit is, in fact, almost impossible to achieve in the real world because of Earth's orbital mechanics. This is because Earth is first of all not a perfect and homogenously composed sphere of constant density. An even more important factor is that the gravitational pulls of the Moon and Sun are constantly changing forces, tugging at GEO satellites pulling them either east or west in longitude or even more strongly dragging them north or south to higher "inclination." Inclination means the degree of elevation above or below the equatorial plane.

The north and south gravitational pulls of the Sun and Moon are the strongest and indeed are ten times greater than the east and west longitudinal forces. The satellite thus has to be managed through "station-keeping" to keep it inside of a box

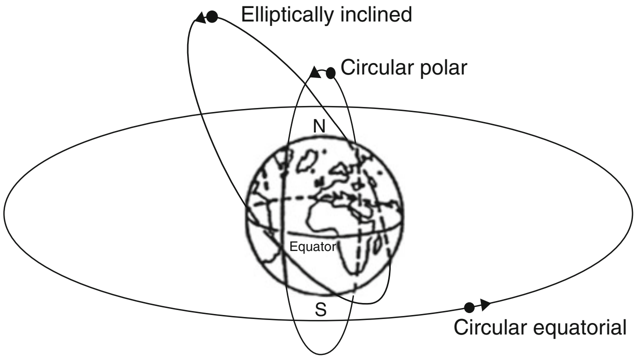

Fig. 2.4 Comparing satellite orbits (not to scale). (Graphic courtesy of author.)

by the firing of rocket thrusters to keep it "geosynchronous" or at the right speed to complete the one complete revolution per sidereal or "solar" day. Most geosynchronous satellites have some inclination build up and go up and down a small bit from the equator each day and thus are not truly geostationary, especially in terms of north and south latitude excursions. Unless you are an astrodynamics engineer you can forget about the distinction.

What's important to visualize is the extent of the major geographic separation in altitudes that the various orbits represent. A GEO satellite is about 3 times further out from Earth than a MEO. The GEO (which is the outer orbit shown below) is, in fact, about one-tenth of the way to the Moon. A GEO can be up to 40 times further away than a LEO satellite. Figure 2.4 below is an artist representation, in cartoon fashion, of various types of orbits. One should recognize that this graphic is not to scale, since the GEO satellite would be well off the page. This "compressed cartoon" is necessary since the GEO and even MEO satellites are, in fact, much, much further away and thus cannot easily be shown accurately in Fig. 2.4.

In sum there are a lot of different tradeoffs that can and indeed are made to determine what kind of satellite orbit is used to provide satellite communications services. These advantages and disadvantages are summarized in Table 2.1 below. One of the easiest choices is in the case of a domestic or regional satellite covering only a specific geographical area. Here a GEO satellite is clearly indicated.

The choice of a GEO satellite for domestic or even regional service is simply because a single satellite (plus a backup spare) can provide total coverage. Further, ground Earth stations can be pointed to the satellite and perform with high efficiency with no need for constant tracking systems, which increases cost and complexity as well as reliability issues. In short, LEO or MEO constellations, if they are indeed employed by a satellite operator, are designed and deployed for global type services.

GEO systems, which are by far the most numerous, can be used for domestic, regional or global systems alike. The following issues are typically considered in

Table 2.1 Advantages and disadvantages of various satellite orbits. (Chart supplied by author.)

Advantages of Low-Earth Orbit Systems
• Low latency or transmission delay
• Higher look angle (especially in high-latitude regions)
• Less path loss or beam spreading
• Easier to achieve high levels of frequency re-use
• Easier to operate to low-power/low-gain ground antennas
Disadvantages of Low-Earth Orbit Systems
• Larger number of satellites to build and operate
• Coverage of areas of minimal traffic (oceans, deserts, jungles, and polar caps
• Higher launch costs
• More complicated to deploy and operate – also more expensive TTC&M
• Much shorter in-orbit lifetime due to orbital degradation
Advantages of Medium-Earth Orbit Systems
• Less latency and delay than GEO (but greater than LEO)
• Improved look angle to ground receivers
• Improved opportunity for frequency re-use as compared to GEO (but less than LEO)
• Fewer satellites to deploy and operate and cheaper TTC&M systems than LEO (but more expensive than with GEO systems)
• Longer in-orbit lifetime than LEO systems
• Increased exposure to Van Allen Belt radiation
Disadvantages of Medium-Earth Orbit Systems
• More satellites to deploy than GEO
• More expensive launch costs than GEO
• Ground antennas are generally more expensive and complex than with true LEO systems
• Coverage of low traffic areas (i.e., oceans deserts, jungles, etc.)

choosing the right type of satellite orbit. As can be seen in Table 2.1 below, there are a number of factors to be considered such as launch costs, path loss, number of satellites and spares to be manufactured, operational and control complexities and perhaps most importantly the type of ground system to be utilized. (Note: Mobile systems are different from broadcast and fixed telecommunications satellite systems, because the antennas employed by users of the system are moving around rather than remaining stable and fixed at one point with an unobstructed and constantly clear view of the satellite above.)

The first choice in terms of choosing an ideal satellite orbit or constellation, however, may simply not be available. The lack of choice is constrained by orbital crowding. There are already over 300 communications satellites in operation, with most of these in the crowded GEO or Clarke orbit. Sometimes one must choose an orbit or constellation configuration that is not ideal. The decision thus becomes the challenge of finding a satellite location or constellation design for multiple satellites that can meet projected needs. The satellite system designer is charged with achieving a cost-effective design that provides the best solution after considering all the factors in Table 2.1 and more.

GEO, MEO and LEO are the prime configurations for satellite communications systems. There are hundreds of GEO satellites for global, regional, and domestic satellite communications systems as well as to serve military or defense communications purposes. There are also a growing number of MEO and LEO constellations. Although there are far fewer of these types of networks they require many more satellites to populate such a network and achieve global coverage. For instance the Globalstar mobile satellite system requires 48 operational LEO satellites plus spares, and the Iridium mobile satellite system requires 66 operational LEO satellites plus spares.

Beyond GEO, MEO and LEO systems, there are still some other orbits that have been proposed or actually used for special communications purposes. These are briefly listed and defined here.

Equatorial Circular Orbit (ECO)

This orbit, also known as the "string of pearls," is a circular orbit in the equatorial plane but deployed in MEO rather than GEO. Six to eight of these satellites with similar communications capability could continuously provide service to equatorial countries where some 2 billion people live. One satellite would continuously move into position to provide service as another satellite would rotate away from the current service area. This type of system has been proposed by the Brazilian space agency but not actually deployed. There have been proposals from Japan to create an extremely high-speed orbital network via a ring of satellites that are linked together via laser-based inter-satellite connections to achieve global interconnectivity.

Highly Elliptical Orbits (HEO), Extremely Elliptical Orbits (EEO), Molniya Orbits and Loopus Orbits

These are all very long elliptical orbits that have very long "hang times" above Earth's surface. These satellites can appear to be essentially in the same location for 8 to 12 hours at a time, especially at locations that are near the polar extremes. In short, this type of configuration can work particularly well for countries located at high latitudes such as Russia or New Zealand. Three satellites in this type of orbit can provide continuous world coverage.

The truth of the matter is that this type of orbital system works only for high-latitude countries because the satellites are very hard to track as they move back closer to the equator. When these satellites are at perigee they are zooming very fast indeed. The original Russian satellite system named "Molniya" used this type of orbit. The most exotic orbit of this kind is what is called the Loopus Orbit, which can serve different parts of the Northern Hemisphere with very long "hang times" to provide telecommunications or direct broadcast type services. There could also be an "inverse Loopus" geared to serve the southern latitudes. (See Fig. 2.5.)

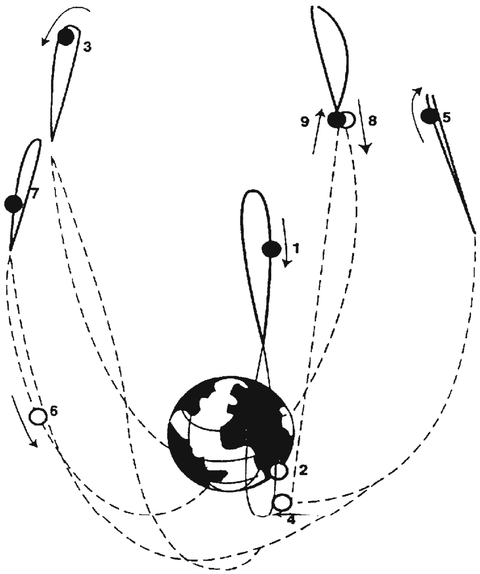

Fig. 2.5 The Loopus-type orbit to serve northern latitudes. (Graphic supplied by author.)

Quazi-Zenith or "Figure 8" Orbit

This is essentially a GEO that is inclined some 45 degrees. Three satellites in this orbit provide excellent high-look angles to countries located at 45 degrees latitude. This orbit is being used by Japan for mobile satellite communications and to provide supplemental space navigation services.

Super Synchronous Orbits

This is an orbit that is very difficult to track and would be used mostly for defense or military purposes.

Satellite Services and Applications

The types of services and applications that can be provided from an artificial satellite are continuously expanding. In terms of revenues, the most important communications satellite services are known by definitions provided by the International Telecommunication Union (ITU). These key ITU defined services are: Fixed Satellite Services (FSS), Broadcast Satellite Services (BSS) and Mobile Satellite Services (MSS). As one can see in Table 2.2 below there are also many other ITU-defined satellite services

Table 2.2 Officially defined satellite services of the ITU

ITU Defined Satellite Services[4]
Fixed Satellite Services (FSS)
Inter-Satellite Services (ISS)
Broadcast Satellite Services (BSS)
Broadcast Satellite Services for Radio (BSSR)
Radio Determination Satellite Services (RDSS)
Radio Navigation Satellite Services (RNSS)
Mobile Satellite Services (MSS)
Aeronautical Mobile Satellite Services (AMSS)
Maritime Mobile Satellite Services (MMSS)
Maritime Radio Navigation Satellite Services (MRNSS)
Land Mobile Satellite Services (LMSS)
Space Operations Satellite Services (SOSS)
Space Research Satellite Services (SRSS)
Earth Exploration Satellite Services (EESS)
Amateur Satellite Services (ASS)
Radio Astronomy Satellite Services (RASS)
Standard Frequency Satellite Services (SFSS)
Time Signal Satellite Services (TSSS)

The focus of this book is on commercial satellite communications technology and services, and a review of Fig. 2.6 below reveals the broad range of commercial satellite applications now provided around the world. The satellite communications industry in 2010 achieved total annual revenues of some $170 billion (U. S. dollars). (This total includes military and defense satellite operations, plus all types of communications satellite services, satellite manufacture, launch services, Earth station manufacture, and launch insurance.) The communications satellite industry is clearly by far the largest. Fig. 2.6 clearly indicates that there are continually expanding satellite applications markets. Space applications today include space navigation, remote sensing, surveillance and meteorological observation. There is speculation that there will be, within the next decade, new offerings in solar power satellites as well as travel to in-orbit space habitats.

The following "official" definitions are provided for the "Big Three" in satellite communications services, which are Fixed Satellite Services (FSS), Broadcast Satellite Services (BSS), and Mobile Satellite Services (MSS).

The *Fixed Satellite Service (FSS)* is defined as follows: "A radio-communication service between Earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within

[4]Joseph N. Pelton, *The Satellite Revolution: The Shift to Direct Consumer Access and Mass Markets*, (1998), International Engineering Consortium, Chicago Illinois.

Fig. 2.6 The broad range of expanding global satellite applications.[5] (Used with copyright permission by author.)

specified areas; the fixed-satellite service may also include feeder links for other space radio-communication services."[6]

The ITU definition for *Broadcast Satellite Service (BSS)* is as follows: "A radio-communication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-satellite service, the term "direct reception" shall encompass both individual reception and community reception."[7] Closely related to the BSS service is the more recently defined *Broadcast Satellite Service Radio (BSSR)*. This involves a new

[5] Op cit, Joseph N. Pelton and Scott Madry, p. 182.

[6] ITU Radio Regulations, Article 1, Definition of Radio Service, Section 1.21, http://www.ictregulationtoolkit.org/en"practiceNote.aspx?id=2824

[7] ITU Radio Regulations, Article 1, Definition of Radio Service, Section 1.25, http://www.ictregulationtoolkit.org/en"practiceNote.aspx?id=2824

Table 2.3 Annual services revenues for satellite communications and space applications. (Chart prepared by author. Figures derived from report by the Futron Corporation on behalf of the Satellite Industry Association.)

REVENUES FOR YEARS 2004-2009 IN SATELLITE SERVICES[8] (In billions of (U.S.) dollars per year)						
Type of Satellite Service	2004	2005	2006	2007	2008	2009
Direct to Consumer	$35.8 B	$41.3 B	$48.9 B	$57.9 B	$68.1 B	$75.3 B
DBS Television	$35.8 B	$40.2 B	$46.9 B	$55.4 B	$64.9 B	$71.8 B
DBS Radio	$0.3 B	$0.8 B	$1.6 B	$2.1 B	$2.5 B	$2.5 B
Broadband Internet	$0.2 B	$0.3 B	$0.3 B	$0.4 B	$0.8 B	$1.0 B
Fixed Satellite Services	$8.9 B	$9.3 B	$10.7 B	$12.2 B	$13.0 B	$14.4 B
Transponder Lease	$7.0 B	$7.3 B	$8.5 B	$9.5 B	$10.2 B	$11.0 B
Managed Networks	$1.9 B	$2.0 B	$2.2 B	$2.6 B	$2.8 B	$3.4 B
Mobile Services	$1.8 B	$1.7 B	$2.0 B	$2.1 B	$2.2 B	$2.2 B
Remote Sensing	$ 0.4 B	$ 0.6 B	$0.4 B	$0.4 B	$0. B	$1.0 B
TOTAL	$46.9 B	$62.8 B	$62.0 B	$72.6 B	$84.0 B	$93.0 B

radio frequency allocation that is used for audio broadcasting services. Today Sirius XM Radio (representing the merger of XM Radio and Sirius Radio) plus Worldspace both provide this type of satellite service. These systems provide audio-only broadcast satellite service either to automobile-based radios or handsets capable of direct reception from high-powered satellites. (This service is also called Satellite Digital Audio Radio Services (SDARS) by the U. S. regulatory authority, the Federal Communications Commission.)

The *Mobile Satellite Service (MSS)* is defined as follows: "A radio-communication service (a) between mobile Earth stations and one or more space stations, or between space stations used by this service; or (b) between mobile Earth stations by means of one or more space stations.This service may also include feeder links necessary for its operation."[9]

In general the trend in satellite service growth is quite positive. This is shown in the 2010 report from the Satellite Industry Association on the state of the industry as prepared by the Futron Corporation. (See Table 2.3 below.) Although there is upward growth in all the markets, what is most striking is the predominance of the direct-to-consumer services that are provided to end users. The size of revenues in what might called satellite "retail sales" that provide services directly to consumers

[8] Satellite Industry Association "Executive Summary, 2010 State of the Satellite Industry Report", Prepared by the Futron Corporation, 2010 Washington, D. C. www.sia.org/news_events/pressrelease/2010StateofSatelliteIndustryReport2010(Final).pdf NOTE: There are many reference books and almanacs that provide a guide to satellite communications systems in operation around the globe. See, for example, the appendices in Handbook of Satellite Applications by Joseph N. Pelton, Scott Madry and Sergio Camacho Lara, 2012, published by Springer in New York.

[9] ITU Radio Regulations, Article 1, Definition of Radio Service, Section 1.XX, http://www.ictregulationtoolkit.org/en"practiceNote.aspx?id=2824

totally dominate and outweigh what might be called the satellite "wholesale markets" that provide services to large telecommunications organizations that in turn resell these services to end users.

The global report prepared for the Satellite Industry Association by the Futron Corporation is the most thorough and complete report available. This report is unique in that it builds up its data from individual annual revenue reports from over seventy commercial operators.

Nevertheless, the reported revenues from this report still require some interpretation. First of all, revenues related to space navigation markets are not included. It is estimated by some that this market, in terms of direct and indirect sales of space navigation devices plus applications in map making, transport systems, law enforcement, defense and security operations, etc., could be as large as $5 or $6 billion per year.

The above figures from Futron also do not include expenditures and costs related to national space systems operated by governments nor do they include expenditures related to military or defense satellite systems operations, except in the case of "dual use" of commercial systems. Also, it should be recognized that the reported revenues differ between one satellite service and another.

The total revenues related to mobile satellite services, for instance, are more dependent on the sale of satellite handsets, consumer mobile user units, etc., than to the other satellite services in terms of "sizing the market." User transceivers tend to be updated more frequently and thus turn over more quickly in the mobile satellite industry than in the other space communication services, and the total number of units is quite large in comparison to, say, fixed satellite services.

Further, the mobile satellite industry is in the midst of a major change with the launch of new hybrid mobile satellite networks that will include the so-called "ancillary terrestrial component." This new aspect of the mobile industry will likely increase total revenues in this sector. Nevertheless, with the active combining of "terrestrial wireless and satellite" service it will be much more difficult to determine which revenues relate to space- and which relate to ground-based service. This is all to say that the mobile satellite revenues, as reported by the Satellite Industry Association, may currently give a somewhat minimized view of the total size of this part of the satellite world and that revenues in this sector can be expected to increase the most rapidly in the next five years if the new hybrid systems prove successful.

Overall, Table 2.3 above demonstrates not only the large size of the various satellite communications service sub-markets but also just how dominant this space industry is in relation to other emerging commercial space markets such as remote sensing. Today, space navigation services probably represent at least $5 billion (in U. S. dollars) in total worldwide sales of services and equipment. These services are perhaps the most rapid growing new space application market, but clearly satellite communications services are by far the largest single commercial space market. Further, it should be noted that satellite communications services are only a part of the total market. When ground systems and user equipment manufacturing, satellite spacecraft manufacturing, launch services, launch insurance and other support industries are taken into account, the satellite communications industry annual sales swell to some $170 billion (U. S, dollars) in total revenues, as will be discussed further in Chapter 6.

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