LEO SATELLITES: ORBIT CALCULATIONS AND DETERMINATION OF COMPLETE COVERAGE INTERVALS FOR TURKEY

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Approval of the Graduate School of Natural and Applied Sciences

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ABSTRACT

LEO SATELLITES:

ORBIT CALCULATIONS AND DETERMINATION OF COMPLETE COVERAGE INTERVALS FOR TURKEY

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In this thesis, some orbital parameters of LEO (Low Earth Orbit) satellites that can cover the geographical area of Turkey have been calculated. For simplicity, circular orbits were assumed and calculations were done for such orbits at altitudes ranging from 650 km to 1500 km. Possible scenarios were produced for a single satellite as well as for groups of satellites known as Walker Delta Constellations.

Inclination angles of orbits at which the highest complete geographical coverage occurred during a day are determined. It has been found that the maximum coverage occurred at an inclination angle of about 52^0. To obtain 100 % coverage of Turkey in a day it was found that 30 satellites were required when an altitude of 650 km was considered. Access duration calculations have been extended to a single sun synchronous satellite for various elevation angles and have been found that no access was obtained from satellite to earth station at Ankara at an elevation angle of 45^0.

Keywords: Coverage Area, Satellite Access, Walker Delta Constellation, Mobile Satellite System (MSS), Low Earth Orbit (LEO), Orbit Simulation.

ÖZ

LEO UYDULARI:

YÖRÜNGE HESAPLAMALARI VE TÜRKİYE İÇİN TAM KAPSAMA SÜRELERİNİN BELİRLENMESİ

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Bu tezde, Türkiye'nin coğrafi alanını kapsayabilecek olan Yer'e yakın yörünge (LEO) uydularının bazı yörüngesel parametreleri hesaplanmıştır. Kolaylık sağlanması açısından dairesel yörüngeler varsayılarak yükseklikleri 650 ile 1500 km arasında değişen yörüngeler için hesaplamalar yapılmıştır. Tek uydu ve çoklu LEO uydularının oluşturduğu Walker Delta uydu takımları için muhtemel senaryolar üretilmiştir. Maksimum coğrafi kapsamanın oluştuğu yörünge eğim açısı belirlenmiştir.

En yüksek kapsamayı sağlayan eğim açısının 52^0 civarında olduğu bulunmuştur. Türkiye'nin, bir günlük süre içerisinde % 100 kapsanması için 650 km irtifada 30 uydunun gerektiği bulunmuştur. Erişim süresi hesaplamaları çeşitli yükseklik açıları için güneş eş zamanlı tek bir uyduya genişletilmiş ve 45^0 yükseklik açısı için uydudan Ankara'daki yer istasyonuna herhangi bir erişimin sağlanmadığı belirlenmiştir.

Anahtar Kelimeler: Kapsama Alanı, Uydu Erişimi, Walker Delta Uydu Takımı, Mobil Haberleşme Sistemi, Yer'e Yakın Yörünge, Yörünge Benzetimi

To My Parents

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ACRONYMS AND ABBREVIATIONS

ATM	Asynchronous Transfer Mode
B-ISDN	Broadband ISDN
CDMA	Code Division Multiple Access, a digital phone service based on spread spectrum technology
CEPT	Conference of Postal and Telecommunications Administrators
DECT	Digital European Cordless Telephone
EDGE	Enhanced Datarates for GSM Evolution
ETSI	European Telecommunications Standard Institute
EU	European Union
FCC	US Federal Communications Commission
FDMA	Frequency Division Multiple Access
GEO	Geostationary Earth Orbit (at 35,786km altitude)
GPRS	General Packet Radio Switching
GPS	Global Positioning System
GSM	Global System for Mobile communications (European second generation TDMA cellular system)
HEO	Highly Elliptical Orbit
IMT-2000	International Mobile Telecommunications System 2000
ISDN	Integrated Services Digital Network
ITU	International Telecommunications Union
LAN	Local Area Network
LEO	Low Earth Orbit (altitudes around 1,000km)
MEO	Medium Earth Orbit (altitudes around 10,000km)
MPEG	Moving Pictures Expert Group
MSS	Mobile Satellite System
PLMN	Public Land Mobile Network

PCM	Pulse Code Modulation
PSTN	Public Switched Telephone Network (traditional, wired telephone access)
RF	Radio Frequency
SAR	Specific Absorption Rate
S-PCN	Satellite Personal Communication Network
S-UMTS	Satellite UMTS
3G	Third Generation (of wireless systems)
T-UMTS	Terrestrial UMTS
UMTS	Universal Mobile Telecommunications Systems
UTRAN	UMTS Terrestrial Radio Access Network
WCDMA	Wideband Code Division Multiple Access

CHAPTER 1

INTRODUCTION

1.1. Description of the Project

In space age, Turkey also plans to involve in more space studies using her own initiatives. In this context, it is seen that TUBITAK BILTEN (Information Technology and Electronic Research Institute) has signed a major contract with Surrey Satellite Technology Limited (SSTL) on a project which involves in development of a sun synchronous microsatellite with a mass of 100 kg which is planned to be launched to an orbit at an altitude of 650 km [1].

With the existence of such a project, some orbital calculations that may contribute to the effort has mentioned above were done. That is how this work was started as a MSc. thesis.

Basically, it is aimed at calculating some of the orbital parameters of a satellite which could cover the geographical area of Turkey. To achieve this a package program called "Satellite Tool Kit 4.1.1b was used [2]. Using the software's coverage module, complete coverage intervals for Turkey were calculated by simulation.

LEO (Low Earth Orbit) satellites are placed on circular or elliptical orbits, at an altitude ranging from 500 to 1500 km, below the radiation belts. Calculations were carried out for a LEO satellite at an altitude of 650 km, having the same mass as BILTEN's microsatellite (BILTENSAT).

1.2.General approach to the project

For simplicity and demonstrative purposes the orbits were chosen circular, and inclination angles were ranged from 20^0 to 90^0. This was to find out the effect of inclination angle on the complete coverage. Coverage intervals, including pass number, pass duration and percentage coverage during a day were calculated. Besides, ground tracks of satellites have also been mapped.

It is obvious that a single satellite can only provide a limited coverage area. To extend the coverage more than one satellite may be used. Such a system is called a constellation. When such a constellation of satellite is used, the resulting total coverage area is the union set of the coverage areas of all individual satellites in the constellation.

Coverage analyses are based on the accessibility of objects that provide coverage which are called as assets and geographical areas. For analyses purposes, the geographical areas of interest are further refined using closed boundaries that called as regions consisting of points which have specific geographical locations and are used in the computation of asset availability. Accessibility to a region is computed based on accessibility to the points within that region. The combination of the geographical area, the regions within that area, and the points within each region is called coverage grid.

However, due to overlapping, the total coverage area is, in general, smaller than the sum of the coverage areas of all satellite's coverage areas. Non-Geostationary (NGSO) satellites move with respect to a point on the Earth. Thus a satellite constellation is necessary to serve all the Earth. The Moreover, the constellation coverage area may vary with time when the satellites are non-geostationary. Then, the coverage can be described by the instantaneous coverage areas which are given by the current position of the satellites. J.G. Walker developed constellations for global coverage using N satellites in inclined circular LEOs with equal period. A Walker Constellation consists of P equally inclined orbit planes with their ascending nodes being equally spaced along the equator [3].

In Chapter 2 a general review of celestial mechanics is given.

In Chapter 3, satellites are described in general terms.

In Chapter 4 complete coverage intervals for Turkey were determined by using LEO satellite constellations.

In section 4.2, Walker Delta Constellations that consist of N Planes- N Satellites per Plane where N ranges from 2 to 6 were created. For each constellation, calculations for complete coverage intervals, including pass number, pass duration and percentage coverages during a day were done for inclination angles varying from 20^0 to 90^0.

In section 4.3, scenarios were created for Walker Delta Constellations that consist of *N* Planes- *S* Satellites per Plane where *S* and *N* ranges from 1 to 6 and percentages coverage during a day were calculated for some inclination angles varying from 20^0 to 80^0 .

In section 4.4, In order to find effect of altitude over coverage altitude was changed from 650 to 1500 km for a Walker Delta Constellation, 3 Planes-3 Satellites, with 52^0 inclination. Then complete coverage intervals for Turkey were calculated.

In a Sun-synchronous or helio-synchronous orbit, the angle between the orbital plane of satellite and Sun remains constant, which results in convenient light conditions for the satellite. The angle between the orbital plane of satellite and Sun can be kept constant by a careful selection of orbital altitude, eccentricity and inclination, producing a precession of the orbit (node rotation) approximately by 1 degree eastward each day. That is equal to the apparent motion of the Sun. This condition can be achieved only for a satellite in a retrograde orbit. A satellite in the Sun-synchronous orbit crosses the equator and latitude at the same time each day. This type of orbit is therefore advantageous for an Earth observation satellite, since it provides constant lighting conditions [3].

In section 4.5 first, the LEO satellite's orbit was chosen as sun-synchronous and all of the orbital parameters were set the same as BILTEN's micro satellite's. By using the Satellite Tool Kit 4.1.1b software's coverage module, complete coverage intervals for Turkey were calculated and ground tracks of LEO satellites were mapped. Then, Walker Delta Constellations that consist of *N* Planes- *N* Satellites per Plane where *N* ranges from 2 to 6 with an were created. For each constellation, calculations for complete coverage intervals, including pass number, pass duration and percentage coverage during a day were done for some inclination angles varying from 20^0 to 90^0. Finally, for the same sun-synchronous LEO satellite a ground station is defined at Ankara and by changing the elevation angle, complete coverage intervals of the satellite were calculated.

In Chapter 5 of the thesis regulatory and organizational aspects of S-PCNs (Satellite Personal Communications Networks) systems were discussed.

CHAPTER 2

CELESTIAL MECHANICS

The motion of a spacecraft in space is specified by its position, velocity, attitude and attitude motion. The first two quantities describe the translational motion of the centre of mass of the spacecraft and are the subjects of what is variously called celestial mechanics, orbit determination, or space navigation [4]. The latter two describe the rotational motion of the body of the spacecraft about its centre of mass and are subject of attitude determination [5].

The foundation of celestial mechanics is simply the set of Newton's Laws of motion, plus his Universal Law of Gravitational Attraction and with addition set of empirical laws of Kepler which describe the planetary motion.

2.1 Kepler's Laws of Planetary Motion

In the early 17th century Johannes Kepler discovered the important properties of planetary motion that we now call as Kepler's laws:

i. The Conic Section Law: A planet's path is a conic section with the sun at one focus.

ii. The Law of Areas: The vector from the sun to the planet sweeps equal areas in equal times.

iii. The Harmonic Law: The ratio of the square of the period T of a revolution of a planet around the sun to the cube of the semi-major axis of the ellipse is the same for all planets.

$$P^2 = (\frac{2\pi}{k})^2 a^3$$

where P is period, a is the mean distance and k^2 is the gravitational constant generally expressed as G.

Kepler's laws were explained later in the 17th century by Newton's Law of gravitation.

2.2 Newton's Law of Gravitational Attraction

Isaac Newton extended the work of Kepler and in the year 1667. He discovered the Law of Universal Gravitation. The Law of Universal Gravitation stated as follows:

> Every particle of matter M in the Universe attracts every other particle of matter m with a force $\vec{F}$ directly proportional to the product of their masses and inversely proportional to the square of the distance r between them.

2.3 The Two Body Problem

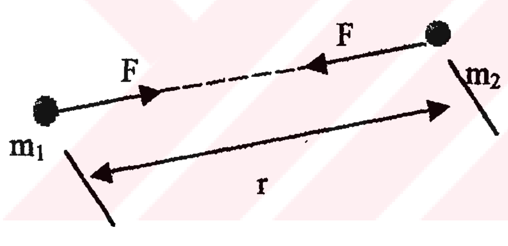

Figure 2.1 Two Body Problem

A classical problem that can be solved using Newton's law of gravitation is the two body problem [5], in which an object of a certain mass orbits another object of a much larger mass. Like in the case of a planet around the Sun.

In order to try to formulate a solution it is assumed that the two bodies are spherically symmetric so that their masses can be concentrated as a single point at the center of the sphere. Our reference frame will stay with the larger object and we will take its mass to be much larger than that of the orbiting object.

If the two masses m_1 and m_2 are separated by a distance r, Newton's Law of Gravitational Attraction for the force exerted on m_2 by m_1, can be expressed as

$$F = -\frac{k^2 m_1 m_2}{r^2}$$

or

$$F = -\frac{\mu m_2}{r^2}$$

where μ is gravitational parameter. The minus sign denotes an attractive force. This force may vectorally be written as

$$\vec{F} = -\frac{\mu m_2}{r^3}\vec{r} \qquad (2.1)$$

2.4 Conic Sections

In this section, we will find the polar equation for a conic section by deriving Kepler's first Law of planetary motion from Newton's Law of Gravitational Attraction in order to prove that a planet moves along a conic section with one focus as its sun.[5].

The central force also equals to the mass times the acceleration of the body m_2 according to the Newton's second Law of Motion. Therefore,

$$-\frac{\mu m_2}{r^3}\vec{r} = m_2 \ddot{\vec{r}}$$

giving

$$\ddot{\vec{r}} + \frac{\mu}{r^3}\vec{r} = 0 \qquad (2.2)$$

The vector product of both sides of (2.2) by $\vec{r}$ yields

$$\vec{r} \times \frac{d^2\vec{r}}{dt^2} = 0$$

This equation can be written as

$$\frac{d}{dt}\left[\vec{r} \times \frac{d\vec{r}}{dt}\right] = 0 \qquad (2.3)$$

Defining angular momentum per unit mass as

$$\vec{h} = \vec{r} \times \frac{d\vec{r}}{dt} \qquad (2.4)$$

leads to the conclusion that the angular momentum is conserved and $\vec{h}$ is a constant vector. Since $\vec{h}$ is normal to both $\vec{r}$ and $\frac{d\vec{r}}{dt}$ it must be normal to the plane of motion. Additionally, since $\vec{h}$ is constant, this plane must be inertially fixed.

Cross product of equation (2.2) with $\vec{h}$ leads to

$$\frac{d^2\vec{r}}{dt^2} \times \vec{h} = \mu \frac{d}{dt}\left[\frac{\vec{r}}{r}\right] \qquad (2.5)$$

Since $\vec{h}$ is constant, the first integral of equation (2.5) gives

$$\frac{d\vec{r}}{dt} \times \vec{h} = \frac{\mu}{r}(\vec{r} + r\vec{e}) \qquad (2.6)$$

where e is a constant of integration and called the eccentricity vector. This provides three more integrals of motion.

Taking the dot product of equation (2.6) with $\vec{h}$,

$$\left[\frac{d\vec{r}}{dt}\times\vec{h}\right]\cdot\vec{h}=\frac{\mu}{r}(\vec{r}+r\vec{e})\cdot\vec{h}$$

since $\frac{d\vec{r}}{dt}\times\vec{h}$ is orthogonal to $\vec{h}$, the left-hand-side of this equation is zero, leading to

$$\vec{e}\cdot\vec{h}=0 \tag{2.7}$$

This means, eccentricity vector, $\vec{e}$, lies in the orbit plane. The orientation of $\vec{e}$ in this plane can be taken as the reference direction.

In polar coordinates,

$$\frac{d\vec{r}}{dt}=\frac{dr}{dt}\vec{e}_r+r\dot{\theta}\vec{e}_\theta$$

The scalar product of equation (2.6) with $\vec{r}$ gives

$$r^4\dot{\theta}^2=\mu r(1+eCos\theta) \tag{2.8}$$

To convert the magnitude of the angular momentum to the polar coordinates

$$\left|\vec{h}\right|=h=\left|\vec{r}\times\frac{d\vec{r}}{dt}\right|=\left|r\vec{e}_r\times\left(\frac{dr}{dt}\vec{e}_r+r\dot{\theta}\vec{e}_\theta\right)\right|=\left|r^2\dot{\theta}\vec{e}_z\right|,$$

thus the magnitude of the angular momentum is,

$$h=r^2\dot{\theta} \tag{2.9}$$

The equation (2.8) then yields to be

$$h^2=\mu r(1+eCos\theta)$$

Solving for *r*, yields

$$r=\frac{h^2/2}{1+eCos\theta}$$

Letting $p = h^2/\mu$ which is called semilatus rectum. Then

$$r = \frac{p}{1 + eCos\theta} \tag{2.10}$$

where

$$Cos\theta = \frac{\vec{r} \cdot \vec{e}}{re}$$

that is, θ is the angle between the eccentricity vector and the position vector or true anomaly.

Equation (2.10) is the polar equation for a conic section with origin at one focus. If $\theta=0$, r is minimum and thus, eccentricity vector is parallel to the minimum r direction; and θ, the true anomaly, is measured from this point to the position in the orbit.

Equation (2.10) describes all possible conic geometries by changing p and e. Parameters the semilatus rectum, p, determines the size, and the *eccentricity*, e , determines the shape of the conic

We distinguish 3 types of conics as follows (Fig. 2.2):

$e>1$: hyperbola

$e=1$: parabola

$0<e<1$: ellipse

$e=0$: circle

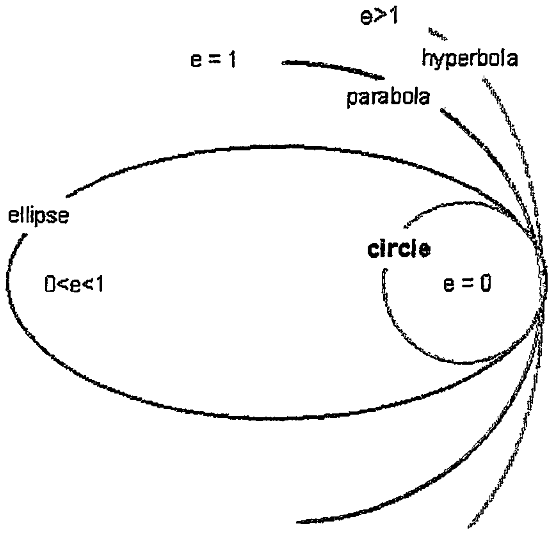

Figure 2.2 Conic Sections

Since the ellipse is the most important one in the orbit theory we will consider this case in some detail. Figure 2.3 illustrates the geometry of the ellipse.

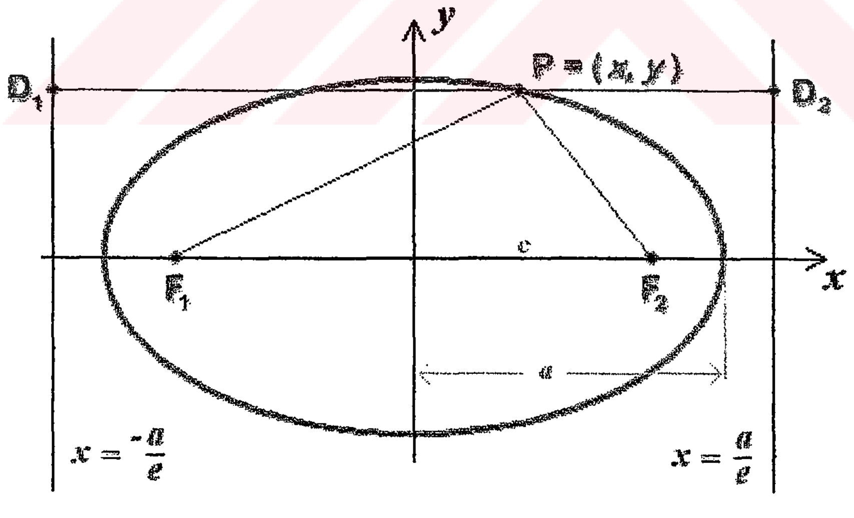

Figure 2.3 Geometry of ellipse

a) Focal length (c): the distance from the centre to each focus is *c*.
b) Major Axis (2a): The line segment connecting the vertices is called as the major axis.

c) Semi Major Axis (a): Half the length of the major axis, from the centre to the vertex, is called as the semimajor axis.

d) X is called as Directrix

e) Eccentricity (e): The circularity of the orbit.

2.5 Satellite's Velocity and its Orbital Period:

The law of gravity states that two bodies with mass *m* and *M* separated with a distance *r* attract each other with the gravitational force [6].

$$F_g = G\frac{mM}{r^2}$$

Here, G= 6.6732 x 10^{-11} Nm^2/kg^2 is the universal gravitational constant.

For a satellite orbiting around the earth with the mass of earth $M=M_{\oplus}=5.9733 \times 10^{24}$ kg and *m* represents the satellite's mass. The total mechanical energy consisting of the potential energy and the kinetic energy is constant:

$$\frac{mv^2}{2} - \frac{\mu m}{r} = -\frac{\mu m}{2a}$$

where $\mu=Gm_{\oplus}=398\ 600.5\ km^3/s^2$. Thus, the velocity *v* of a satellite in an elliptic orbit is

$$v = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}.$$

This can be simplified for circular orbits (a=r) to

$$v = \sqrt{\frac{\mu}{r}} \qquad (2.11)$$

Equation (2.11) states that the velocities of satellites in circular orbits are constant, coinciding with Kepler's second law. The orbital period can now be derived as

$$T = \frac{2\pi r}{v} = 2\pi\sqrt{\frac{r^3}{\mu}}$$

This can further be generalized for elliptical orbits

$$T = 2\pi\sqrt{\frac{a^3}{\mu}} \tag{2.12}$$

according to Kepler's third law.

2.5 General Orbital Parameters

The position of the satellite is completely determined by a set of six orbital parameters which are given in Table 2.1 [7].

Table 2.1 The summary of the six classical orbital elements

Name	Symbol	Describes
Semimajor axis	a	Size (and energy)
Eccentricity	e	Shape (e = 0 for circle, 0is greater than e is greater than 1 for ellipse, e = 1 for parabola, e is greater than 1 for hyperbola)
Inclination	i	Tilt of orbit plane with respect to the equator
Longitude of ascending node	Ω	Twist of orbit with respect to the ascending node location
Argument of perigee	ω	Location of perigee with respect to the ascending node
True anomaly	υ	Location of satellite with respect to perigee

These parameters are often referred to as the Kepler elements. The Kepler elements of satellites will change during a satellite's lifetime due to the orbital perturbations. Classical elements are shown in Figure 2.4 and Figure 2.5 [7].

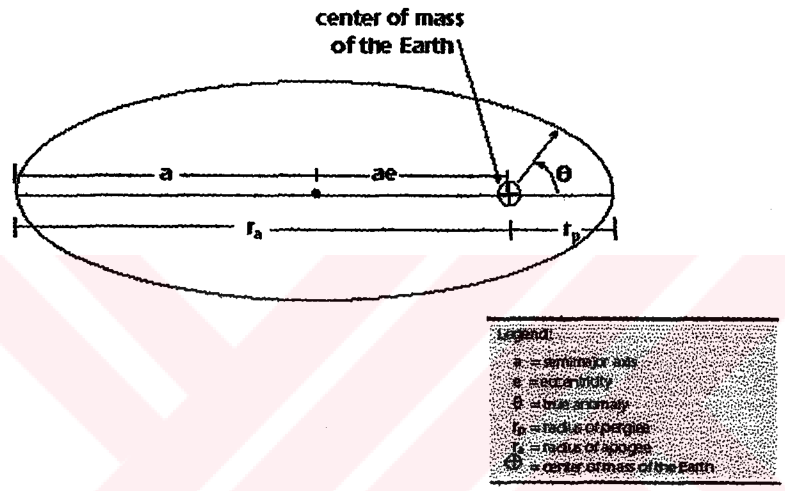

Figure 2.4 Classical elements in the orbit plane

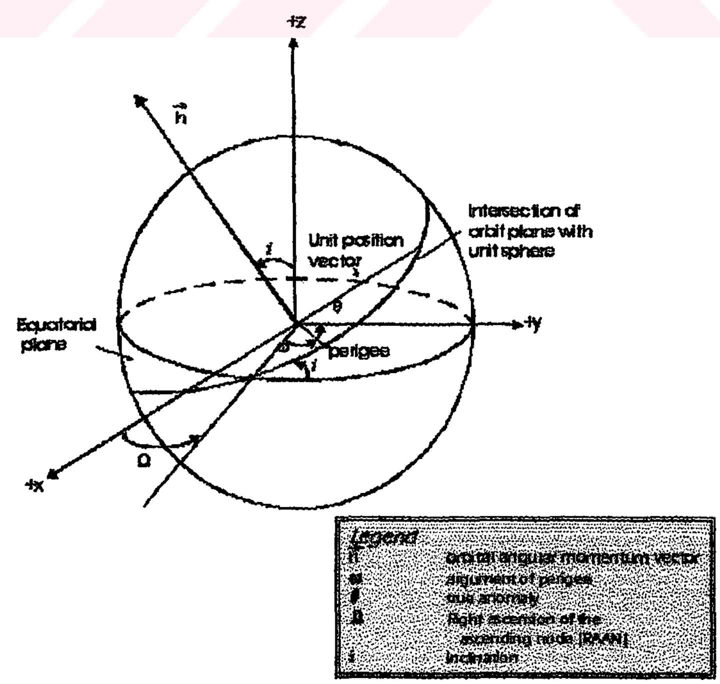

Figure 2.5 Classical coordinate relationships

The general parameters of the satellite orbit and the brief definitions of the main orbital parameters are given below [7]:

1. Semi Major Axis (a):

Half the length of the major axis, from the centre to the vertex, is called as the semimajor axis.

2. Eccentricity (e):

The second important orbital parameter is the eccentricity, which determines the orbit's shape. For circular orbits, the eccentricity is zero and the satellite moves at uniform speed. For elliptical orbits, however, the eccentricity is between 0 and 1. The satellite moves fastest at perigee, or the point closest to the Earth, and slowest at apogee, or the point farthest from the Earth. By adjusting the position of the apogee, the dwell time of the satellite [Appendix A] can be maximized over the region of interest [8].

Eccentricity is given as

$$e = [1-(b/a)^2]^{\frac{1}{2}} = c/a$$

and if e=0 then the orbit is a circle.

3. Inclination (i)

The third fundamental orbital parameter of a satellite is its orbital inclination. It is defined as the angle between the orbit plane and the Earth's equatorial plane. It is counted positively with respect to the ascending satellite orbit track. The intersection between the two planes is called the line of nodes. The ascending node is passed when the satellite enters the northern hemisphere.

The inclination ranges from 0 to 180 degrees. An orbit that stays directly over the equator has an inclination of 0 degrees and is called as an *equatorial orbit.* An orbit that goes directly over the north and south poles must have an inclination of exactly 90 degrees and is called as a *polar orbit.* An inclination of 180 degrees indicates a retrograde equatorial orbit.

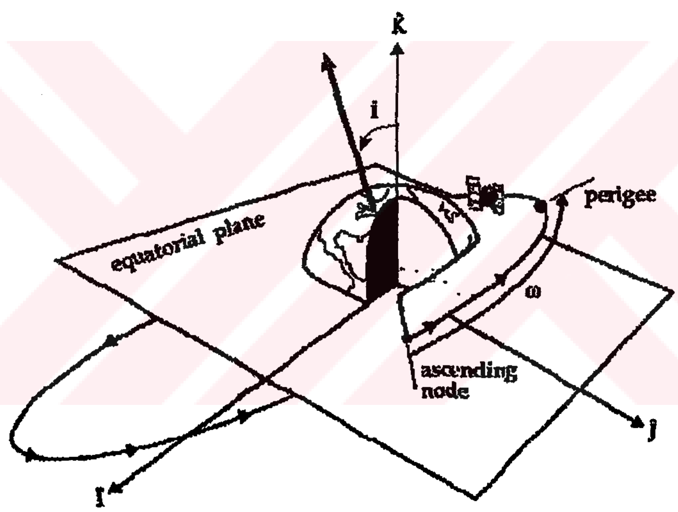

Figure 2.6 Inclination, *i*

4.The Right Ascension of Ascending Node (RAAN) (Ω):

The angle in the Earth's equatorial plane measured eastward from the vernal equinox to the ascending node of the orbit is defined as The Right Ascension of Ascending Node (RAAN) which determines the angle between a reference direction and the line of nodes. The reference direction is given by the direction from the Earth's centre to the sun at vernal equinox. Equivalently, this direction corresponds to the intersection between the equatorial plane and the plane of the ecliptic. The reference direction remains fixed in space.

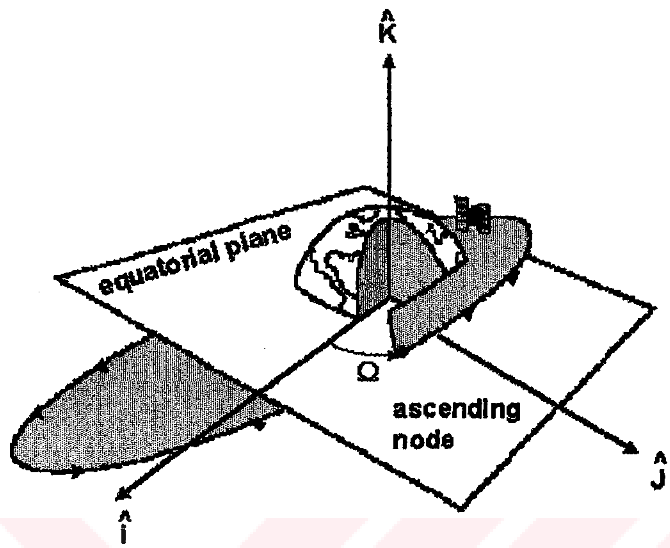

Figure 2.7 Right Ascension of the ascending node, (Ω)

5. The argument of perigee (w):

The argument of perigee, w, is the angular distance between the ascending node and perigee. Since an orbit usually has an elliptical shape, the satellite will be closer to the Earth at one point than at another. The point where the satellite is the closest to the Earth is called the "perigee". The point where the satellite is the furthest from the Earth is called the "apogee". The argument of perigee is the angle formed between the perigee and the ascending node. If the perigee would occur at the ascending node, the argument of perigee would be 0. This parameter is relevant only for elliptical orbits.

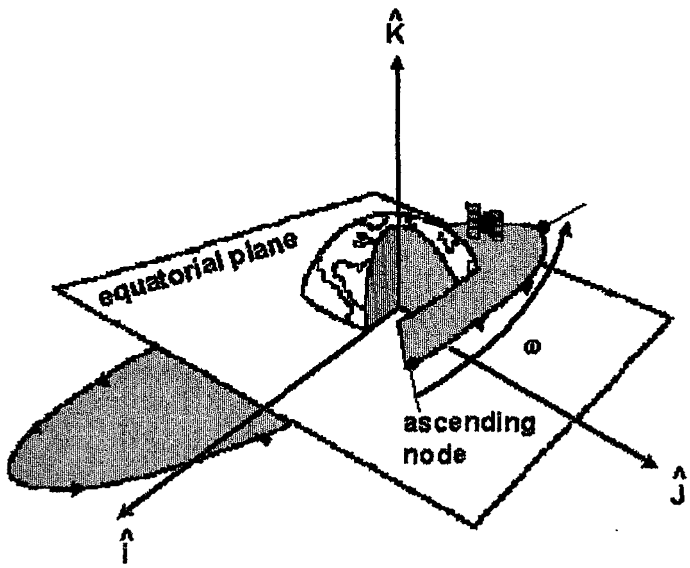

Figure 2.8 Argument of perigee, *w*

6. True Anomaly, (υ)

The angle from the eccentricity vector (points toward perigee) to the satellite position vector, measured in the direction of satellite position vector, measured in the direction of satellite motion and in the orbit plane. It is the angle, measured positive in the direction of motion, between perigee and the satellite's position. Of the six orbital elements, only true anomaly changes continually (ignoring perturbations).

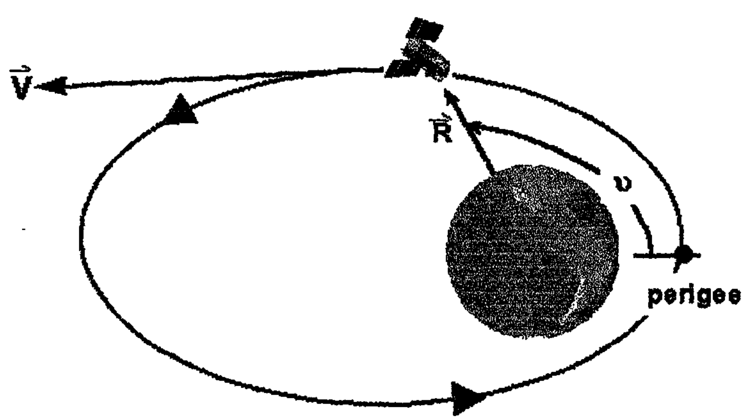

Figure 2.9 True anomaly υ,

CHAPTER 3

SATELLITES IN GENERAL

3.1 What is a satellite?

A satellite can be described as a body which revolves around another body of preponderant mass and which has a motion primarily and permanently determined by the force of attraction of that other body. Satellites can be classified into two categories:

a) Natural satellite: A relatively small celestial body that orbits another celestial body is called a natural satellite. For example, the earth's only natural satellite is the moon.

b) Artificial satellite: A human-made spacecraft that orbits the earth, moon, sun or a planet is called an artificial satellite. Artificial satellites are used for a variety of purposes. Communication satellites are used for relaying telephone, radio and television signals round the curved surface of the earth. They are of two types: passive satellites reflect signals from one point on the earth's surface to another; active satellites are able to amplify and retransmit the signals they pick up. Astronomical satellites are equipped to gather and transmit to the Earth astronomical information from space, including conditions in the Earth's atmosphere, which is of great value in weather forecasting.

3.2 Satellite Elements:

A communication satellite essentially consists of two main functional units payload and bus [6].

3.2.1 PAYLOAD

The payload comprises repeater and antenna sub-systems and performs the primary function of communication.

Repeater

The function of a repeater is to receive the uplink RF signals, and covert these signals to the appropriate downlink frequency and power for transmission toward the service area.

Antenna

The function of the antenna is to transmit signals and to receive signals from ground stations located within the coverage area of the satellite. The choice of the antenna system is therefore governed by the size and the shape of the coverage area.

3.2.2 BUS

The bus provides all the necessary electrical and mechanical support to the payload. The bus consists of several sub-systems.

a) The attitude and orbit control system (AOCS)

AOCS stabilizes the spacecraft and controls its orbit. A satellite maintains the desired orientation and orbital position through its attitude control sub-system.

b) The propulsion system

The propulsion system provides the necessary velocity increments and torques to the AOCS. The function of the propulsion system is to generate the thrust required for the attitude and orbit corrections. The thrust requirement for orbit control is generally large. Mono- or bi- propellant fuels are commonly used for this purpose.

c) The thermal control system

The thermal control system maintains the temprature of various sub-sytems within tolerable limits. The structure provides the necessary mechanical support during all the phases of misssion.

d) The telemetry, tracking and command (TT&C) sub-system

TT&C support the function of spacecraft management. These functions are vital for succesful operation of all satellites and they are treated separately from communication management.

The main functions of a TT&C system are to:

- monitor the performance of all satellite sub-systems and transmit the monitored data to the satellite control centre;
- support the determination of orbital parameters;
- provide a source to earth stations for tracking ;

- receive commands from from the control centre for performing various functions the satellite.

e) The electrical power supply system

The function of the power sub-system is to provide DC power to all sub-systems throught the life of a spacecraft.

The main demands on a satellite bus are as follows:

1. Maintain the position and orientation of a satellite at any specified orbital location and keep the antennas correctly pointed towards the service area; this function is performed by the attitude and orbit control system.

2. (a) Provide data to the ground control centre for monitoring the performance of the various spacecraft sub-systems.

   (b) Accept commands from the ground control centre for altering spacecraft configurations and performing vital manoeuvres.

   (c) Support ground station tracking requirements. The functions are performed by telemetry, tracking and command subsystem.

3. Provide DC power to all active components of a spacecraft; this function is performed by the power sub-system.

4. Maintain the temprature of the various spacecraft sub-systems within the specified limits.; this function is performed by the thermal sub-systems

3.3 Satellite System Architecture

Satellite System Architecture is aimed to define the space segment of a satellite based mobile system to be integrated with future terrestrial cellular system(s). To achieve this goal, four working areas have been identified as follows [9]:

Orbit Selection, with the aim of recognizing suitable orbital configurations for the applications.

Satellite Payload, aimed to identify favorable payload configurations (mainly in terms of processing capacity to be installed on-board), according to the system architectural assumptions and the user requirements.

Type of Coverage, whose purpose is to identify suitable coverage models (i.e. number of spot-beams constituting the satellite antenna footprint) according to the considered orbital configurations and other system architectural assumptions.

Frequency Band, intended to suggest the most suitable frequencies for Mobile Satellite Systems (MSSs).

3.3.1 Orbit selection

A preliminary classification of the satellite orbital configurations is characterized by the two following broad categories:

3.3.1.1 GEostationary Orbit (GEO)

Geostationary satellites are fixed with respect to a terrestrial observer and they are on an equatorial circular orbit at about 36,000 km altitude. Theoretically, only three GEO satellites are sufficient to serve all the earth.

Unfortunately, this type of coverage is not reliable for areas at North or South latitudes greater than approximately 70°, because the elevation angle falls below the minimum acceptable (considered here to be in the region of 10°) and, therefore, the link is not reliable [9].

For many years, the dominant platform for space-based communications has been the GEO satellite. Due to the distance between the Earth's surface and the GEO satellite, highly specialized end user terminals are required. For example, accurate alignment of the user terminal antenna is critical to the performance of the product. Furthermore large distance also requires significant Radio Frequency (RF) energy to overcome the path loss. This has size implications for both battery life and product packaging [10].

GEO satellites are typically used for fixed-site and bandwidth intensive applications such as leased lines, international PSTN connections, television programming, and video feeds. Other applications, such as mobile telephony, are also used but they are often expensive and typically used by a small number of specialized users [10].

The drawbacks of using a GEO satellite include the terminal cost, service price, regional coverage, and line of sight from the terminal to the satellite. Each terminal must have a clear south-facing view in the Northern Hemisphere and a north-facing view in the Southern Hemisphere [10].

Additionally, for two-way voice communications, the propagation delay is significant and this has restricted widespread use of GEO satellites for this application [10].

Some examples of GEO-based satellite systems include those operated by Inmarsat, AMSC, PanAmSat, GE Spacenet Turksat 1-B and Turksat1-C.

Turkey uses two telecomunications satellites; Turksat 1-B and Turksat1-C.

Turksat 1-B, weighing 1,779 kg it has been placed on a geostationnary orbit at an altitude of 35,800 km, carries 16 Ku-band transponders.

Turksat 1-C, weighing 2,100 kg, it has been placed on a geostationnary orbit at an altitude of 35,800 km, provides radio and TV communications to Turkey and the neighbouring areas.

The main aspects that characterize this orbital configuration (GEO systems) are summarized below [6,9]:

- The simplest space configuration;
- Well developed and proved technology;
- Good system modularity (one satellite to cover regional areas, three satellites to provide global coverage);
- Coverage available to most populated areas of world;
- Signal strength sytable owing to constant ground-satellite range;

- The spot-beam footprints on the Earth are fixed (due to the stationary of satellites) and they are so wide that we can consider that a Mobile Subscriber does not change the spot-beam during the call lifetime (i.e.no handover procedure);
- Simple space control system;
- No tracking system at the earth stations;
- Interference effects are easy to predict owing to stable geometric relationship;
- Minimal Doppler effect;
- No variation of propagation delay and elevation angle;
- Relatively lower number of Sun eclipses and hence battery charge/discharge cycle low giving long battery lifetime
- Time between launch and deployment/operation is relatively small, of the order of weeks
- Several new technological advantaces likely to improve performance and cost-effectiveness of geostationary systems

Disadvantages

- Coverage not available beyond $\sim \pm 76^0$ latitude
- Poor link reliability at mid to high latitude for mobile communications
- Relatively large propagation delay; affects voice and time-sensitive data protocols
- Relatively larger path loss
- Spectrum efficiency relatively low through advances in spot beam technology are improving efficiency

- Very few sun eclipses
- Relatively high launch cost
- Increasing thread of space debris
- If in-orbit back-up satellite used then system cost increases disproportionately.
- problematic links feasibility due to the long satellite-user distance (prohibitive power levels and/or too large on-board antennas could be required if low power hand-held user terminals are considered);

3.3.1.2 Non-GeoStationary Orbit (NGSO)

NGSO satellites move with respect to a point on the Earth; therefore, a group of co-planar satellites is required in order to cover a given region of the Earth diurnally; a satellite constellation is necessary to serve all the Earth. The satellite constellation size increases if the satellite altitude decreases [9].

MEO (Medium Earth Orbit), LEO (Low Earth Orbit) are the types of the NGSO which are the fundamental orbits for satellite communication purposes.

3.3.1.2.1 Medium Earth Orbit (MEO)

MEO is also known as Intermediate Circular Orbit (ICO). MEOs combine the advantages of both GEOs and LEOs. MEO satellites are placed on circular inclined orbits at altitudes ranging from 5 000 to 10 000 km between the two radiation belts.

The satellite constellation size for a global coverage is typically 10-15 satellites. The satellites visibility time is about 1-2 hours. An ICO solution is an intermediate solution between GEO and LEO configurations, not only as far as the orbit altitude is concerned, but also from an architectural point of view. MEO satellite technology can best be described as a hybrid version of GEO and LEO technology. It combines the advantages of both to provide a system with fewer satellites than a LEO system, but more than a GEO [11]. The main aspects that characterize the MEO system are summarized below [6,9].

Advantages :

- Can provide true global coverage;
- Lower path loss makes it possible to use small terminals;
- Medium propagation delay (~30 ~100ms from transmitter to receiver);
- Efficient use of spectrum;

Disadvantages:

- Large number of satellites necessary;
- Doppler effects must be considered;
- Complex network architecture: e.g. handover mechanism, inter-satellite link, dynamic satellite resource management, routing mechanism;
- Satellite visibility is in the order of 50 minutes to 180 minutes and necessitates satellite-satellite and beam-beam handover, but handover rate is lower; low probability of handover during a typical telephonic conversation;

- Technology yet to be established and hence an element of risk involved;
- Relatively large number of eclipses which increases charge/discharge cycle of batteries reducing their lifetime
- MEO systems increase orbital debris because they require quite large number of satellites per system but this is less than a LEO system
- Relatively long time required to deploy a full constellation
- Need to replace failed satellites regularly because of their lower lifetime and larger numbers (replacement rate is more than GEO but less than LEO)

3.3.1.2.2 Low Earth Orbit (LEO)

LEO satellites are placed on circular or elliptical orbits, at an altitude ranging from 500 to 1500 km, below the radiation belts and high enough to avoid atmospheric drag. Many LEO satellites are needed to guarantee the coverage of the whole earth diurnally. These constellations are composed of several tens of satellites with their size increasing with decreasing altitude, and with increasing the minimum acceptable elevation angle. Satellites are visible for a short period of time (few minutes), and this implies frequent handover from satellite to satellite, and sometimes it is even more [6].

There are currently a lot of satellites in LEOs and plans for huge constellations to cover the entire globe .A global communication system needs 48 or more satellites to achieve near global coverage [11].

Table 3.1 LEO System Overview

System type	**Frequency bands**	**Applications**	**Terminal type/size**	**Examples**
Little LEO	P and below	Position location, tracking, messaging	"As small as a packet of cigarettes" and omnidirectional	OrbComm, E-SAT
Big LEO	L and S	Cellular telephony, data, paging	Cellular phone and pagers; fixed phone booth	Iridium, GlobalStar,
Broadband LEO	Ka and Ku	Internet access, voice, video, data, videoconferencing	Dual 20-cm tracking antennas, fixed	Teledesic, Celestri

Table 3.2 Band Names

Band Name	**Frequency Range**
HF-band	1.8-30 MHz
VHF-band	50-146 MHz
P-band	**0.230-1.000 GHz**
UHF-band	0.430-1.300 GHz
L-band	**1.530-2.700 GHz**
S-band	**2.700-3.500 GHz**
C-band	Downlink: 3.700-4.200 GHz Uplink: 5.925-6.425 GHz
X-band	Downlink: 7.250-7.745 GHz Uplink: 7.900-8.395 GHz
Ku-band (Europe)	**Downlink: FSS: 10.700-11.700 GHz DBS: 11.700-12.500 GHz Telecom: 12.500-12.750 GHz Uplink: FSS and Telecom: 14.000-14.800 GHz; DBS: 17.300-18.100 GHz**
Ku-band (America)	**Downlink: FSS: 11.700-12.200 GHz DBS: 12.200-12.700 GHz Uplink: FSS: 14.000-14.500 GHz DBS: 17.300-17.800 GHz**
Ka-band	**Roughly 18-31 GHz**

There are three types of LEOs, these are classified by the bandwidth of the information they can carry [11]:

Table 3.3 Classification of LEO systems by the bandwidth of the information they can carry

Name	Frequency
Little LEOs	800MHz
Big LEOs	> 2GHz
Mega (Broadband) LEOs	20-30GHz

a) Little LEO Satellite Systems

Low-Earth orbit satellites, called "Little LEO" satellites, provide commercial radiolocation and two-way data messaging services that include e-mail, facsimile, remote meter reading, vehicle tracking, security alerts and other two-way data messaging services to customers anywhere around the world [12].

Little LEO systems are designed to send and receive digital packets of information. The ground-based counterpart of Little LEO services is traditional paging services.

Little LEO satellite systems are non-geostationary (NGSO), low-Earth orbit satellite systems that provide non-voice, data-only services. In fact, these services are called "NV, NG" because they are non-voice and non-geostationary. The proposed commercial Little LEO satellite systems range in size from 6 to 48 satellites and operate under 1 GHz. Each system is comprised of portable, mobile user terminals on Earth that communicate directly with low-earth orbit satellites or indirectly through gateway earth stations and feeder links.

A current commercial or near commercial example of Little-LEOs is ORBCOMM. The final analysis for the purpose of transmitting data from pipeline field operations to pipeline control centers the ORBCOMM Little-LEO system has been selected.

b) Big LEO Satellite Systems

Big low Earth orbit satellites, known as "Big LEO" satellites, are slated to provide global telephones that will work anywhere in the world. The proposals for these services using these satellites include mobile voice, data, paging, and fax. In addition to a mobile handset that can be used around the world, these satellites may allow services in rural areas and in countries lacking extensive wireline networks [13].

A Big LEO service links customers on the ground to other services through Fixed Satellite Service (FSS) feeder links to gateways on the ground.

Iridium and Globalstar are the examples of companies for Big LEO satellites.

IRIDIUM

Iridium is the first of a group of new companies that use a global network of satellites to provide worldwide mobile service (cellular, messaging, and data) from a single company.

Therefore, a single standard eliminates the need to arrange for roaming agreements or changes in the handsets (or other terminal equipment) as the customer travels.

Iridium has a network of 66 LEO satellites plus six spares. Iridium has contracted with cellular companies to provide services such as roaming in areas beyond the urban centers and the highways and backup facilities for the current cellular networks [12].

Table 3.4 The main features of Iridium

Services	Voice (2.4 kb/s), real-time data (2.4 kb/s), fax short messaging, paging
Constellation	66 LEO satellites in six polar orbits, altitude 680 km, 86.4^0 inclination
Coverage	Global, 48 spot beams per satellite, 8.2^0 minimum elevation
Ground Segment	12 Gateway stations

GLOBALSTAR

The LEO Global system represents a relatively simple LEO system concept to extend terrestial cellular networks. The system has been operating since November 1999. Dual-mode handsets support terrestial and satellite services for voice, paging and real time data. Globalstar utilizes 48 satellites in inclined orbits. The constellation provides seamless global coverage with the exception of polar regions. The constellation was designed to provide good visibility for the temperate climate zones with main business relevance [12].

Table 3.5 The main features of Globalstar

Services	Voice (1.2 - 4.8 kb/s), real-time data (9.6 kb/s), fax paging, position determination using GPS
Constellation	48 LEOs in eight circular orbits, 1414 km altitude 52^0 inclination, Walker Constellation, eight orbital planes of six satellites
Coverage	Global, up to $\pm 70^0$ latitude, 16 spot beams per satellite, 10^0 minimum elevation
Ground Segment	50 Gateway stations

c) Broadband LEO Satellite Systems

Broadband low-Earth orbit (LEO) satellite systems are slated to provide fixed, broadband connections that are comparable to ground-based fiber services. Broadband LEO systems can be seen as an "Internet in the sky" satellite systems linking computers around the world with high-speed connections. These networks would also offer other information services, from high-quality voice channels to broadband channels supporting videoconferencing, interactive multimedia, and real-time two-way digital data [14].

Broadband LEO systems are similar to Big LEO systems in their location on the spectrum and in their use of low-Earth orbits for their satellites (non-Geostationary, or NGSO).

Broadband LEO services are potential competitors to ground-based fiber technologies. However, just as current telephone networks make use of both wireline and wireless technologies depending on the situation, in the future, service providers may use both their broadband equivalents.

Teledesic and Celestri are the examples of companies for Big LEO satellites.

TELEDESIC

The first proposed broadband LEO service by Teledesic has a system that consists of 288 NGSO satellites that surround the globe in low-Earth orbit. There are four bands, two for service links and two feeders for "gigalink" gateway terminals. Inter-satellite links connect each satellite with eight other satellites in the same and adjacent planes approximately 435 miles above the earth. Teledesic provides domestic and international Fixed Satellite Service (FSS) in the "Ka-band [12].

Teledesic plans to provide an open network through ground-based gateways and feeder links to service providers who, in turn, will sell products and services to consumers and to other companies. Teledesic's network would provide twenty-four hour seamless coverage to over 95% of the Earth's surface and almost 100% of the Earth's population. On September 18, 1998, the FCC initiated a proceeding to set rules for spectrum sharing among terrestrial services and FSS in the Broadband LEO bands. This sharing may create interference problems.

CELESTRI

Motorola's first satellite business, Iridium, is a voice and paging system. The second system, M-Star3, is a high-bandwidth system that will provide data to corporations. The Celestri system is the third major satellite venture for Motorola. The latter is expected to offer a wide range of real-time broadband communication services by the year 2002 [14].

The Celestri System will combine geosynchronous high-earth orbit satellites (Millenium4). and low-earth orbit satellites with earth-based control equipments and interfaces. The GEO satellite constellation orbiting at 36000km above the earth, would provide broadcast services such as television. A constellation of 63 LEO satellites, orbiting at 1450km above the earth, would provide telecommunications carriers, businesses and consumer customers instant access to a broadband network infrastructure and true bandwidth-on-demand throughout the world [15].

Each LEO satellite would contain all of the hardware necessary to route communications traffic through the network, including Earth-to-space, space-to-Earth and space-to-space connections. Earth-based control equipment would include terrestrial-based network interfaces to telecommunications infrastructures, the Internet, corporate and personal networks, entertainment networks and residences. This equipment will seamlessly interface to existing computers, television (HDTV), and Local Area Networks (LANs) and Wide Area Networks (WANs).

The main aspects that characterize a LEO system orbital configuration are listed below [6]:

Advantages:

- excellent links feasibility, due to the low orbit altitude;
- low propagation delays;
- launch flexibility, due to the small size of the spacecrafts;
- better subscriber coverage;

- high elevation at higher latitudes;
- small coverage areas;
- lower capacity per satellite;
- smaller satellites;
- low launch cost per satellite;
- low free space propagation loss;
- low transmit power;
- Handheld terminal easily achievable;

Disadvantages:

- full constellation needed for operation
- complex satellite control
- short satellite lifetime (fuel, battery)
- earth stations need fast steerable ant.
- propagation delay variations
- high Doppler shifts and variations
- short satellite visibility
- long satellite constellation construction process, due to the high number of spacecrafts;
- frequent handovers (more or less every 10 minutes between satellites and even every 1-2 minutes or less between beams);
- multiple antenna gateways with fast tracking mechanisms to accommodate handovers procedures;
- zooming effect;
- low minimum elevation angles (about 10°);

- variable propagation conditions due to variations of elevation angles;
- lack of system modularity (the number of satellites for a regional or a global coverage are comparable);
- high system costs.

Satellite systems can also be categorized according to the data type they transmit: voice, data, or multimedia, for example. The following list represents major satellite technologies in LEO, MEO and GEO business.

LEOS Technology:	MEOS Technology:	GEOS Technology:
Iridium(VD)	Agos (VO)	AMSC (VD)
Globalstar (VO)	Inmarsat C, D(VO)	Inmarsat A, B, M, H, I (VD)
Orbcomm (DO)	Boatracs (VO)	Millenium (M)
VITAsat (DO)	Ellipso(VO)	SkyBridge (M)
LEO one (DO)	ICO(VD)	KaStar (M)
Final Analysis (DO)		Spaceaway (M)
		GE Star (M)
		Astrolink (M)
		Cyberstar (M)
		Celestri (M)

VD: Voice and Data
VO: Voice Only
DO: Data Only
M: Multimedia

3.3.2 Satellite Payload

The objective of this working area is to identify favorable payload configurations (mainly in terms of processing capacity to be installed on-board), according to the system architectural assumptions and the user requirements [14].

3.3.3 Type of coverage

The objective of this working area is to define the coverage model to be utilized for the satellite system we are going to design. The problem is that a model suitable for all the possible alternative solutions of the candidate orbital configurations, and satisfying in the meanwhile the system and user requirements, does not exist, because there are a lot of system parameters involved (first of all, frequency and orbital characteristics) [6].

During the comparative analysis of the proposed orbital solutions, different multi-beam coverage models have been considered. The major critical point arising during such activity is the relationship among orbital altitude and frequency band versus size (hence number) of spot-beams: due to the fact that the beamwidth decreases when the frequency increases and, once the frequency is fixed the beam coverage becomes smaller, decreasing the orbit altitude, it is clear that the definition of the coverage model is conditioned by the orbit selection [12].

3.4.4 Frequency band

The radio spectrum is a limited natural resource which should be shared by all types of radio services, terrestial or via satellites. To avoid interference between the various radio systems, The International Telecommunication Union (ITU) allocates frequencies for each service on a global and regional basis. The use of frequencies for domestic applications is regulated by individual countries who assign frequencies according to radio regulations and ensure that radio transmissions originating in their respective countries do not cause interference either to domestic or international networks [16].

The ITU has categorized radio services according to their broad functions. Frequency allocations are made for each service. At present 36 radio services have been defined by the ITU. We are concerned here with the Fixed Satellite Service (FSS), the Broadcast Satellite Service (BSS) and the Mobile Satellite Service (MSS). The FSS applies to systems which interconnect fixed points such as international telephone exchanges. The BSS refers to broadcast by satellite of television or radio programmes directly to the public. Finally, MSS networks provide communication to mobile terminals and individuals [16].

The ITU has divided into three regions for the purpose of frequency allocation. These regions are:

Region 1: Europe, Africa, the Middle East and the Asian Regions of the Former USSR

Region 2: The Americas,

Region 3: The remainder of Asia, plus Australasia

A frequency band can be allocated to one or more service either globally or by region. The allocations can have different several types of status. Each allocation type is governed by a specific set of regulations. The majority of allocations have a primary or secondary status.

As any kind of radiocommunications, satellite communications depend on the availability of radio spectrum, a limited precious resource. At a series ITU World Radio Conferences frequency bands were allocated for the communication between satellites and users (user link or service link) [16].

Non-geostationary satellite systems for data transmission ("little –LEOs) are allowed to use VHF and UHF frequencies around 150 and 400 MHz. Non-geostationary voice systems ("big-LEOs, such as Iridium and Globalstar) can use L and S band frequencies in the ranges 1.610-1.6265 GHz and 2.4835-2.500 GHz for the mobile up – and down link. The band 1.6138-1.6265 GHz is allocated for both directions and it is used by Iridium in time-division duplex (TDD) [12].

CHAPTER 4

DETERMINATION OF THE COMPLETE COVERAGE INTERVALS FOR TURKEY BY USING LEO SATELLITE CONSTELLATIONS

The ultimate goal of coverage is to analyze accesses to an area. Coverage area was chosen as Turkey in this thesis, by using LEO satellites. Surrey Satellite Technology Ltd (SSTL) have signed a major contract for a 100 kg enhanced microsatellite, sun synchronous, 650 km altitude, with a know-how transfer and training, to BILTEN TUBITAK Information Technology and Electronic Research Institute .

In this thesis coverage calculations of LEO satellites which have similar characteristics as BILTEN's microsatellite was made for Turkey. Simulation studies were done for a Leo satellite and Walker Delta constellations of LEO satellites by using the Satellite Tool Kit (STK) software. Effects of inclination angle on access times and durations, and percentages of coverages were studied.

Simulations were made basically at 5 steps:

4.1 Coverage of a LEO satellite over Turkey

The appropriate orbital elements for the LEO satellite was chosen as below:

Propagator : Two body

Apogee Altitude : 650 km

Perigee Altitude : 650 km

Coordinate Type : Classical

Coordinate System : J2000.0

Inclination Angles : 20^0, 30^0, 35, 40^0, 45^0, 50^0, 52^0, 54^0, 56^0, 58^0, 60^0, 65^0, 70^0, 80^0, 90^0

Argument of Perigee : 0.0^0

Mass : 100 kg

In order to make coverage analyses of LEO satellites over Turkey, STK Software's coverage module was used. In order to make a coverage definition in these created scenarios, a data file [Appendix B] was written to set the boundries of the coverage area, custom regions of Turkey, for the Leo satellite's access as an input of this software.

Durations of complete coverage intervals, percent of coverage of a LEO satellite were calculated for the same orbital elements for different inclination angles of 20^0, 30^0, 35, 40^0, 45^0, 50^0, 52^0, 54^0, 56^0, 58^0, 60^0, 65^0, 70^0, 80^0, 90^0 . These LEO satellite scenarios were simulated over 24-hour period.

Table 4.1 Simulation results for a LEO satellite in an orbit of altitude 650 km and with inclination angles varying from 10^0 - 90^0

Inclination Angle (deg)	Total Duration of coverage (min)	Total percent of Coverage (%)	Figure Number	
			Ground Tracks of the satellite	Access of the satellite to Turkey
10	0.0	0.0		
20	7.7	0.5	4.2	4.3
30	39.2	2.7	4.4	4.5
35	47.7	3.3		
40	58.7	4.1	4.6	4.7
45	62.8	4.4		
50	68.9	4.8		
52	69.2	4.8	4.8	4.9
54	68.5	4.7		
56	66.8	4.6		
58	64.1	4.4		
60	60.1	4.2	4.10	4.11
70	44.4	3.1	4.12	4.13
80	39.2	2.7	4.14	4.15
90	37.2	2.6	4.16	4.17

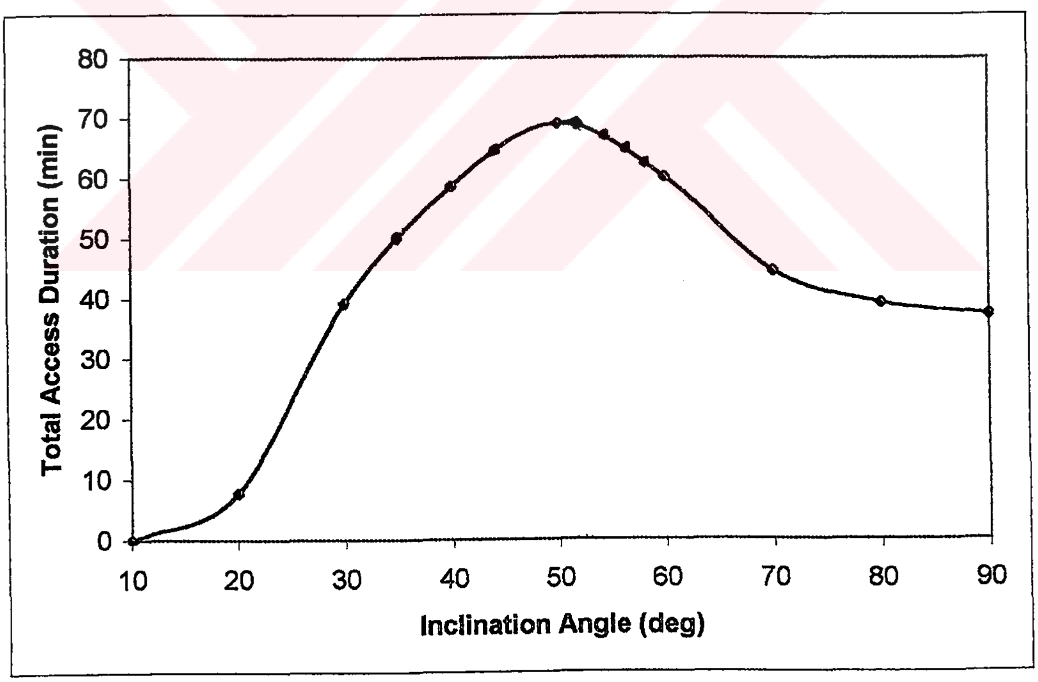

Figure 4.1 Total Access Duration of a LEO satellite in an orbit of altitude 650 km and with inclination angles varying from 10^0 - 90^0

LEO satellite with an inclination of 52^0 gives best result that covers 4.8 % of Turkey and its total duration of coverage of Turkey is 69.2 minute during a day.

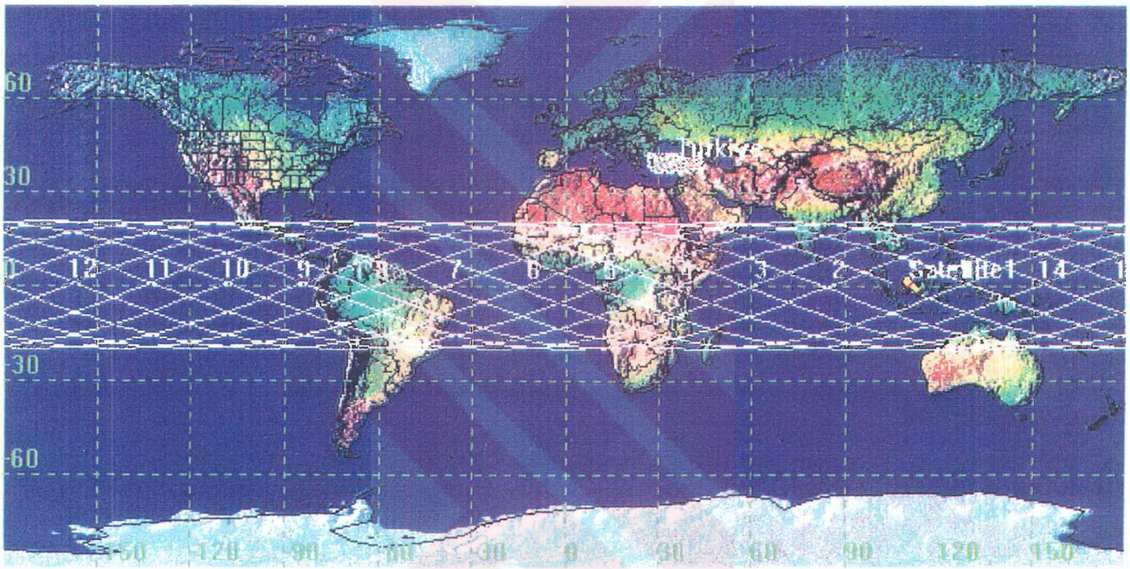

Figure 4.2 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 20^0

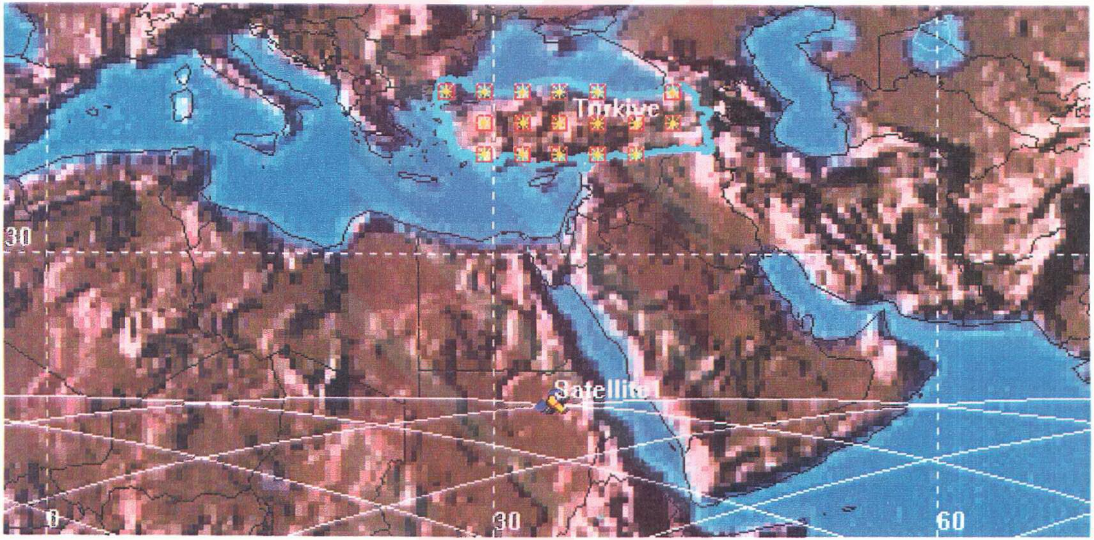

Figure 4.3 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 20° to Turkey


With no passage

With passage

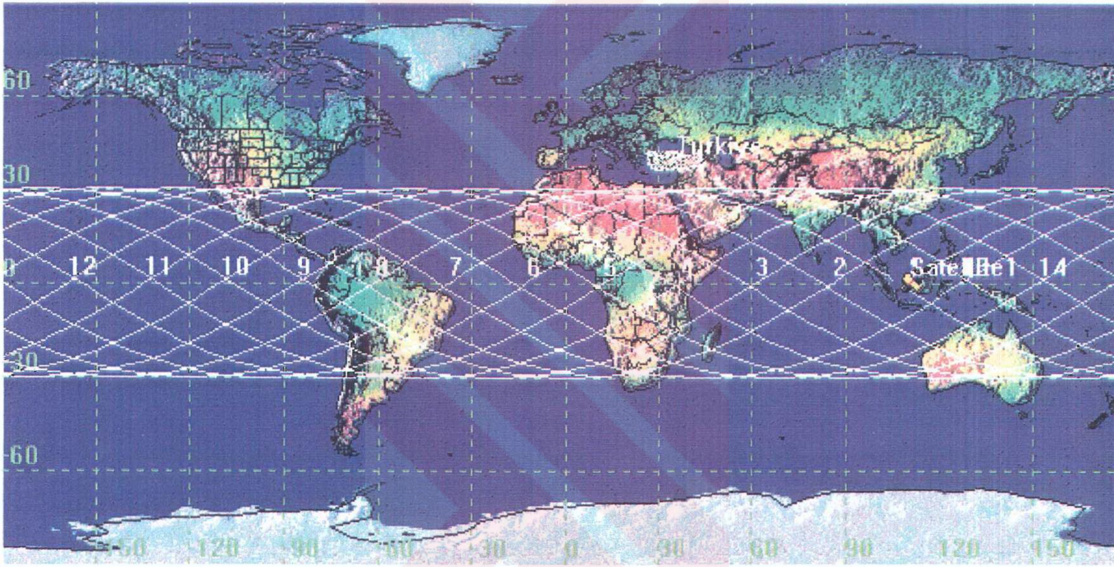

Figure 4.4 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 30^0

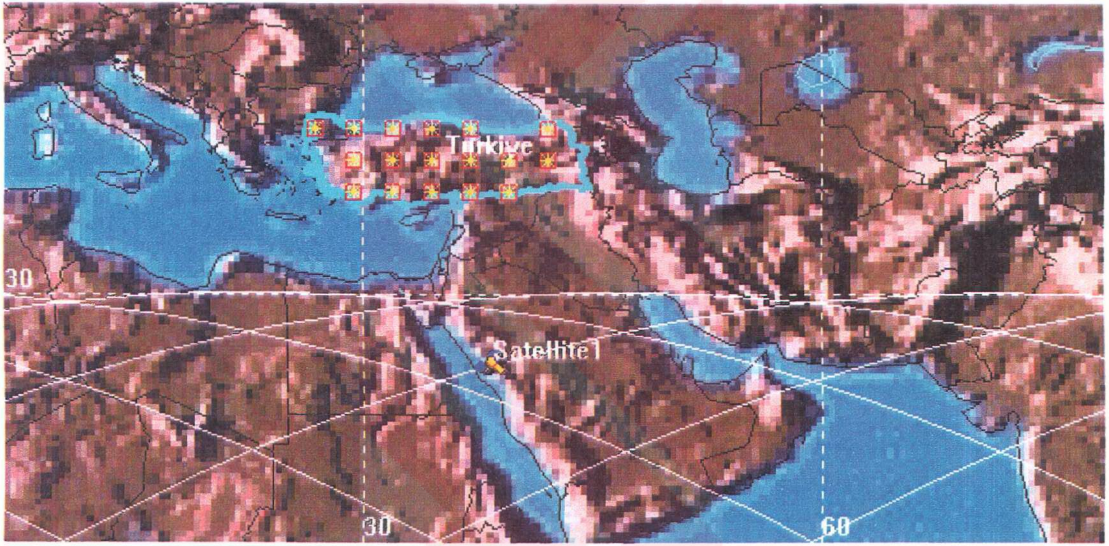

Figure 4.5 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 30° to Turkey

With no passage

With passage

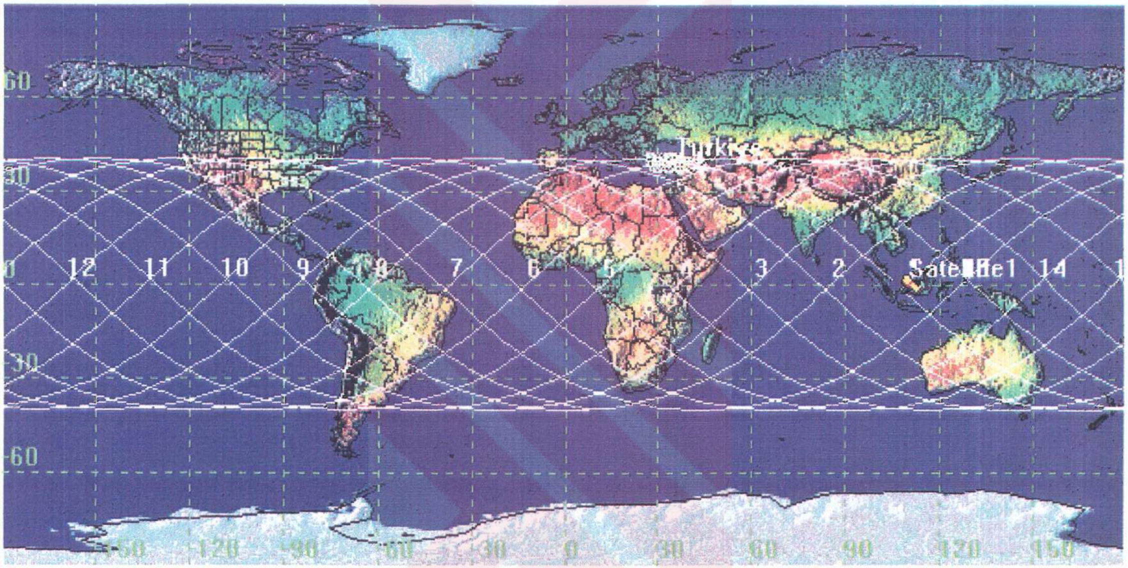

Figure 4.6 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 40^0

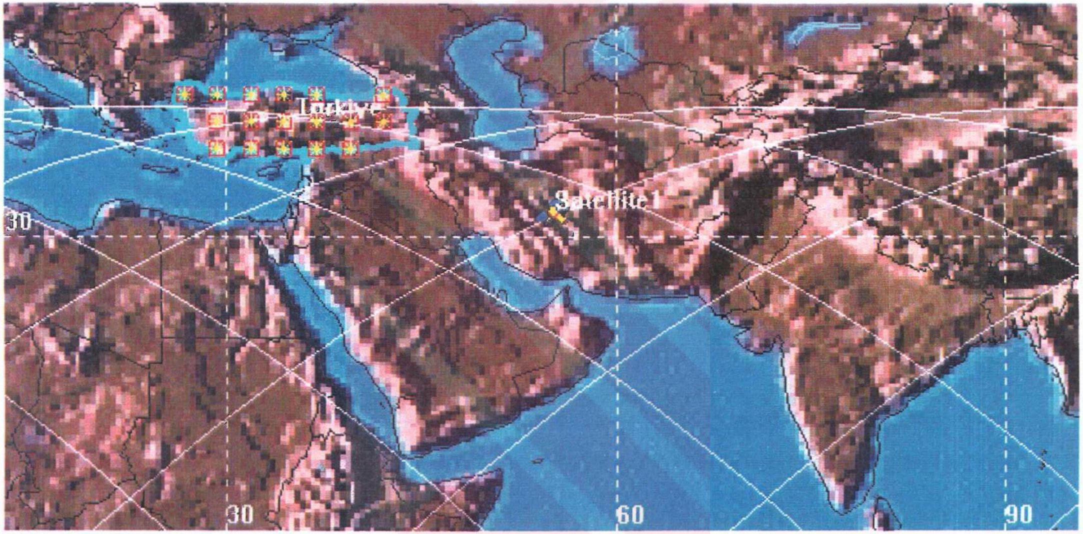

Figure 4.7 Access of a LEO Satellite in an Orbit of Altitude 650-km, and with an inclination of 40^0 to Turkey

With no passage

With passage

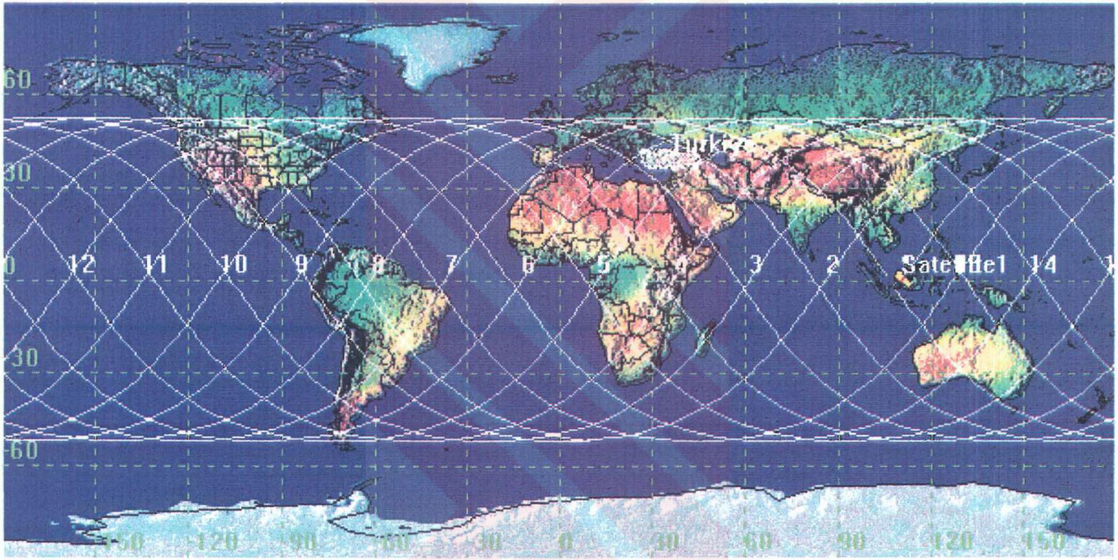

Figure 4.8 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 52^0

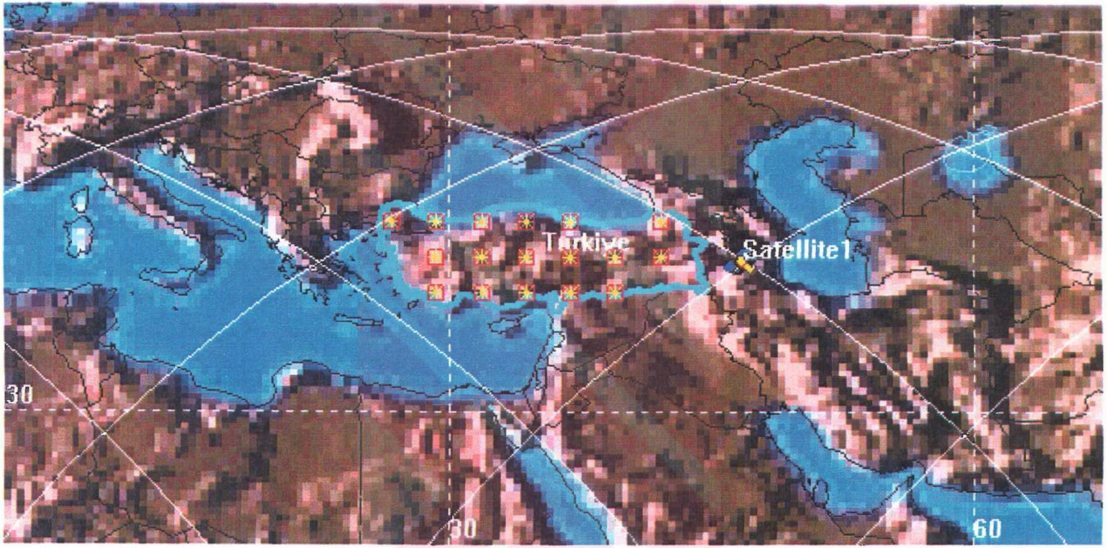

Figure 4.9 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 52^0 to Turkey

With no passage

With passage

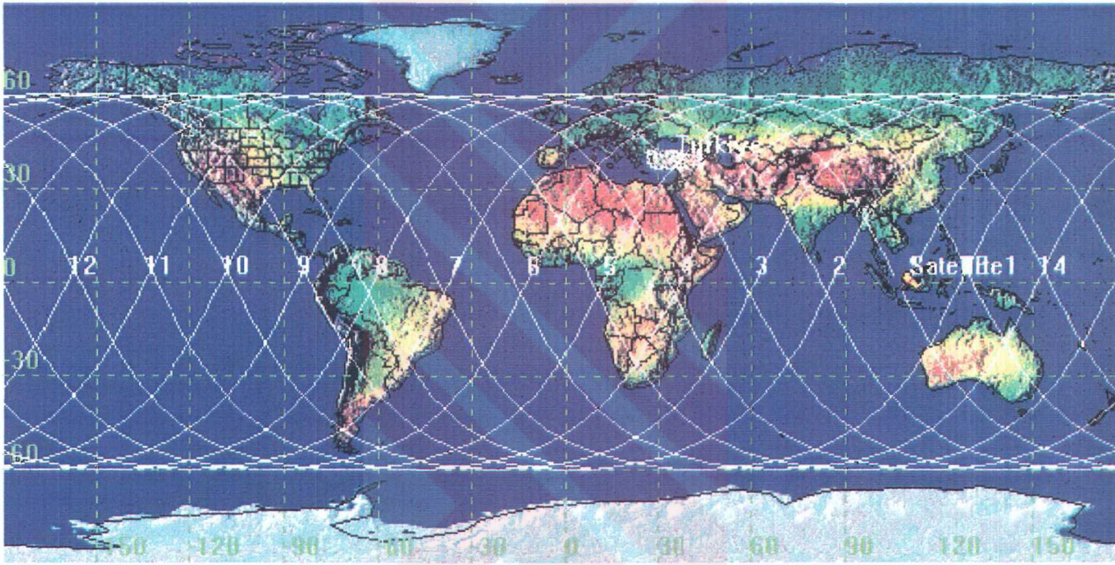

Figure 4.10 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 60^0

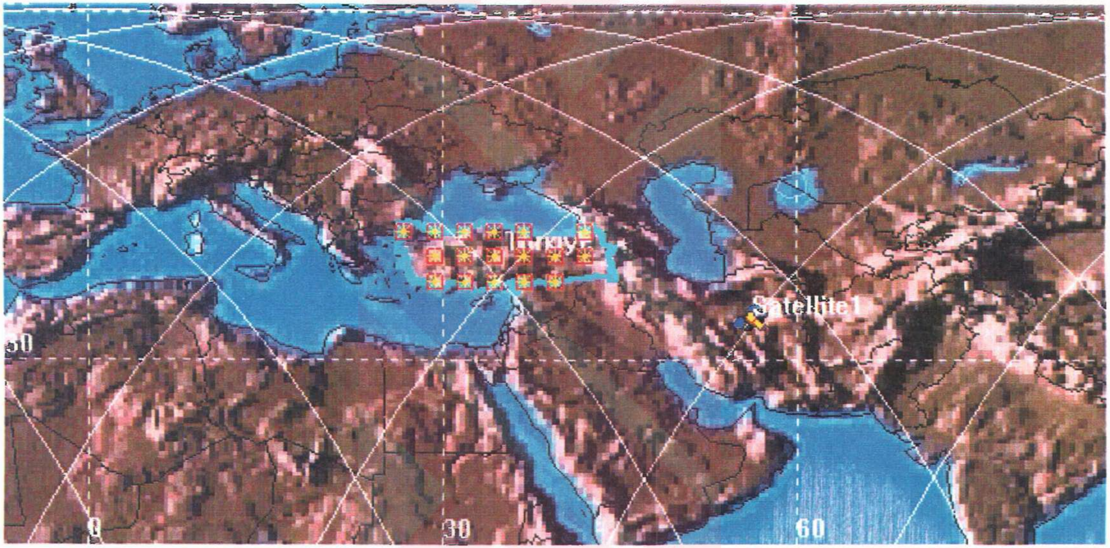

Figure 4.11 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 60^0 to Turkey

With no passage

With passage

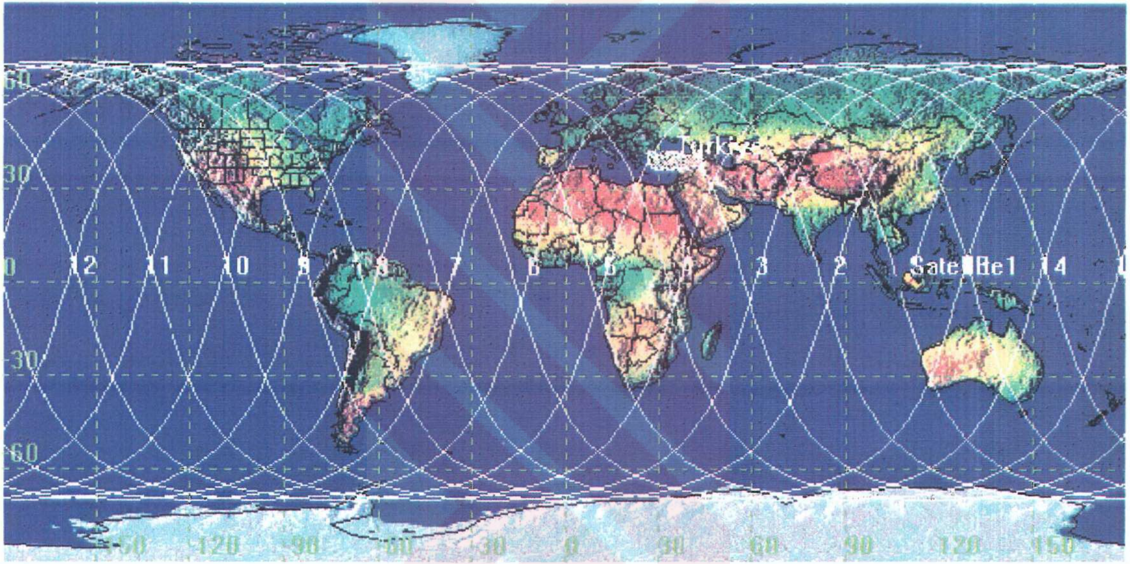

Figure 4.12 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 70^0

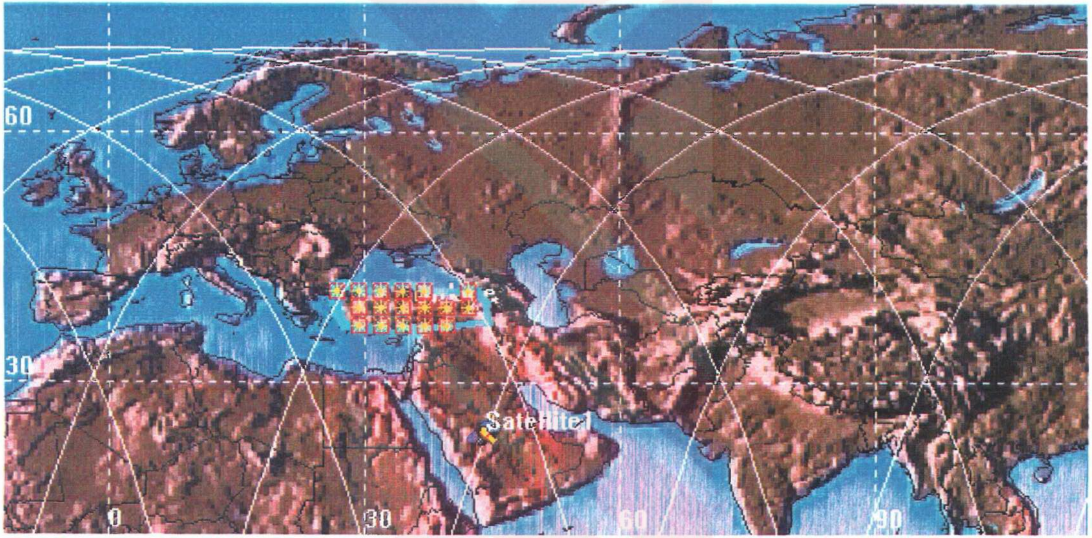

Figure 4.13 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 70^0 to Turkey

With no passage

With passage

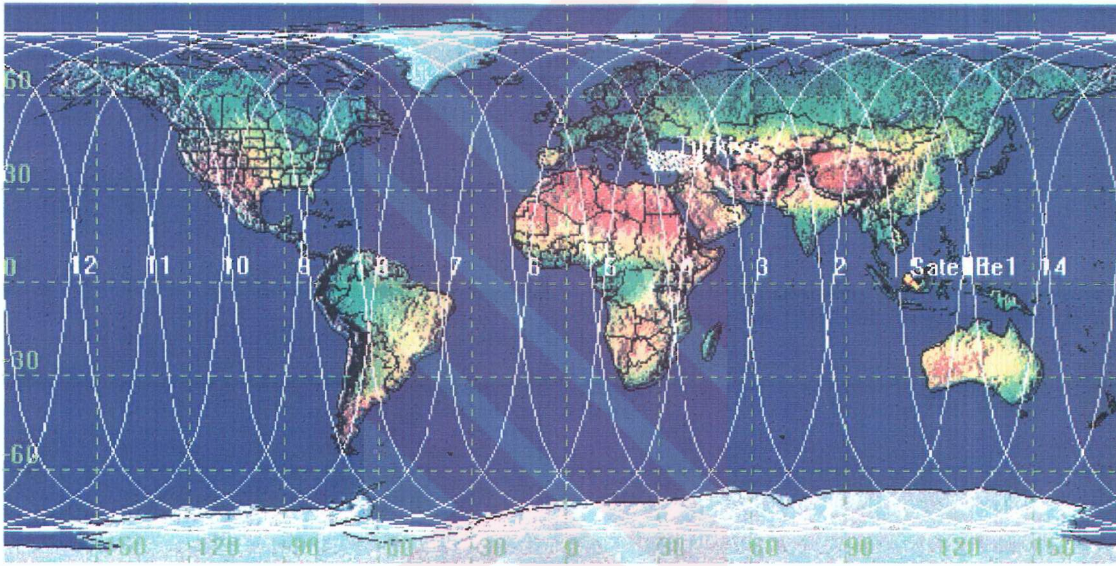

Figure 4.14 Ground tracks of a Leo satellite in an orbit of altitude 650 km, and with an inclination of 80^0

Figure 4.15 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 80^0 to Turkey

☐ With no passage

☐ With passage

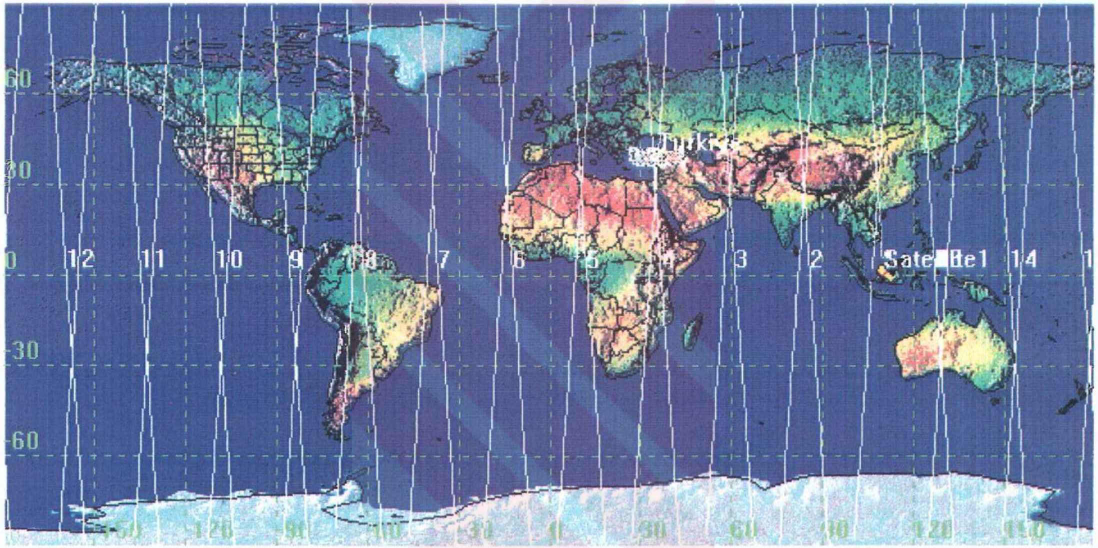

Figure 4.16 Ground tracks of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 90^0

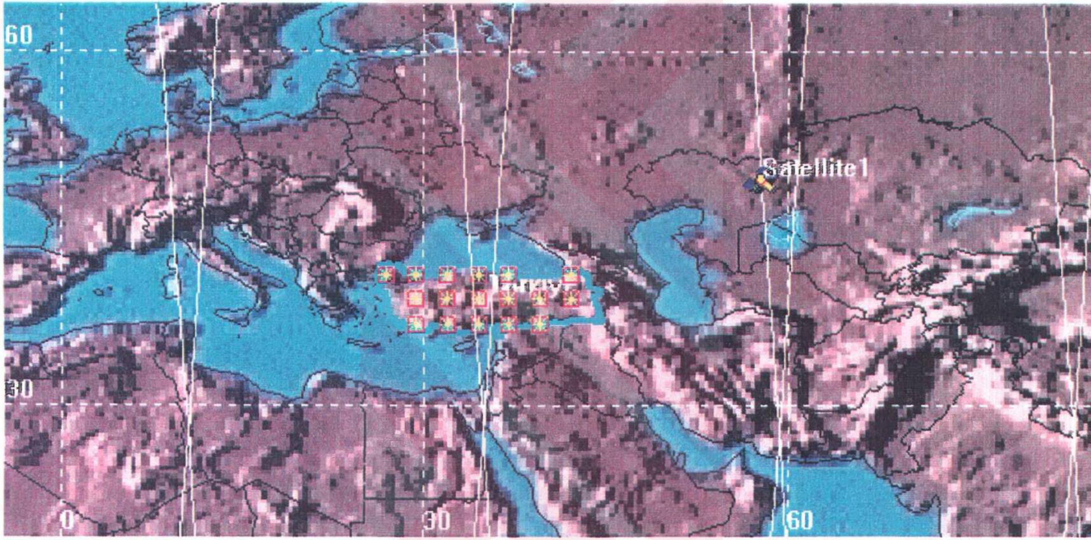

Figure 4.17 Access of a Leo satellite in an orbit of altitude 650-km, and with an inclination of 90^0 to Turkey

With no passage

With passage

4.2 Walker Delta constellations of LEO satellites for N planes – N Satellites per Plane

A Walker constellation [3] consists of a group of satellites (*t*) that are in circular orbits and have the same period and inclination. The pattern of the constellation consists of evenly spaced satellites (*s*) in each of the orbital planes (*p*) specified so that $t=sp$. The ascending nodes of the orbital planes are also evenly spaced over a range of right ascensions (RAAN).

The way in which spacing between the ascending nodes that define the orbital planes is calculated depends on the type of Walker constellation that is chosen. In addition to specifying the number of satellites in each plane, it is necessary to specify the location of the first satellite in each plane relative to the first satellite in adjacent planes. The way to specify the position of the first satellite depends on the type of Walker constellation that is chosen.

Defining a Walker Delta Constellation

For a Walker Delta constellation type, the relative along-track position of two satellites in adjacent planes is determined by a phase parameter (*f*) where *f* is an integer from 0 to *p-1*. The value of *f* represents the number of slots of angular measure (*360 degrees/t*) by which the more easterly satellite leads the more westerly satellite.

When a Walker constellation is created, the original (seed) satellite is duplicated as part of the constellation. The new satellites are considered as children of the seed.

When a Walker constellation is defined as having 2 Planes, 2 Satellites per plane, an Interplane Spacing of 1 and a RAAN spread of 360 degrees, the Map window would look similar to that in following.

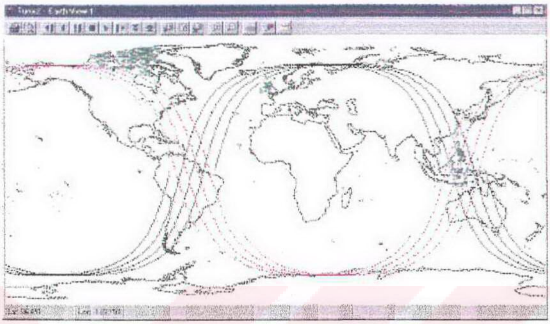

Figure 4.18 The Map window showing a Walker seed satellite and its children (two planes each with two satellites)

Figure 4.19 more clearly shows the configuration and spacing of the satellites.

Figure 4.19 Walker constellation illustrating the satellite configuration clearly

The following table describes the spacing between satellites in more detail.

Satellites	RAAN	Argument of Perigee	True Anomaly
Seed Satellite	0 degrees	0 degrees	0 degrees
Satellite11	0 degrees	0 degrees	0 degrees
Satellite12	0 degrees	0 degrees	180 degrees
Satellite21	180 degrees	0 degrees	90 degrees
Satellite22	180 degrees	0 degrees	270 degrees

Table 4.2 Satellite spacing for sample Walker satellites

In this section, Walker Delta constellations of LEO satellites which have the same orbital elements were created for N Planes – N Satellites per plane where N ranges from 2 to 6 with an interplane spacing of 1 were created. Inclinations were chosen as 20^0, 52^0, 60^0, 70^0, 80^0, 90^0 for each of the Walker constellation.

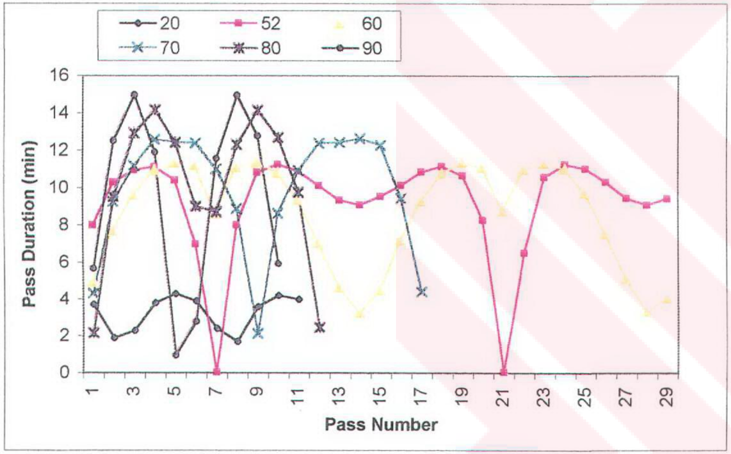

Figure 4. 20 Access times for a Walker Delta Constellation that consists of 2 planes-2 satellites, for inclination angles varying from 20^0 - 90^0

Table 4.3 Summary of how orbital inclination effects on the coverage of Turkey for a Walker Delta Constellation that consists of 2 planes- 2 satellites per plane

Orbital Inclination (deg)	Total Duration of coverage (min)	Total percent of Coverage (%)	Figure Number of Ground Tracks of the Constellation
20	36.5	2.5	4.21
52	264.5	18.4	4.22
60	247.3	17.2	4.23
70	165.9	11.5	4.24
80	120.3	8.3	4.25
90	94.1	6.5	4.26

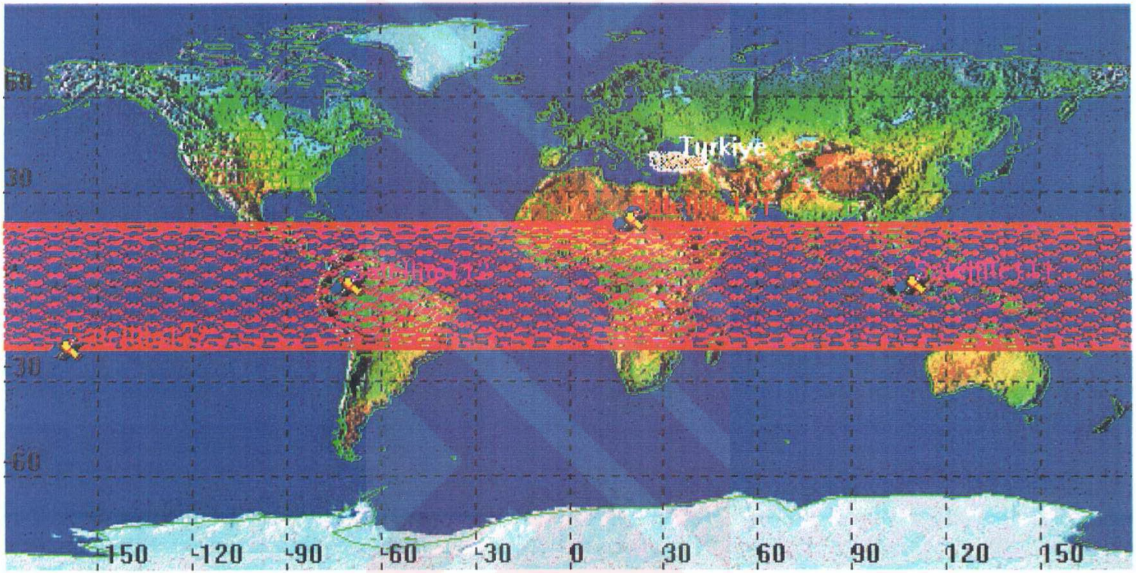

Figure 4.2.1 Walker Delta Constellation 2 Planes – 2 Satellites, for an angle of inclination of 20^0

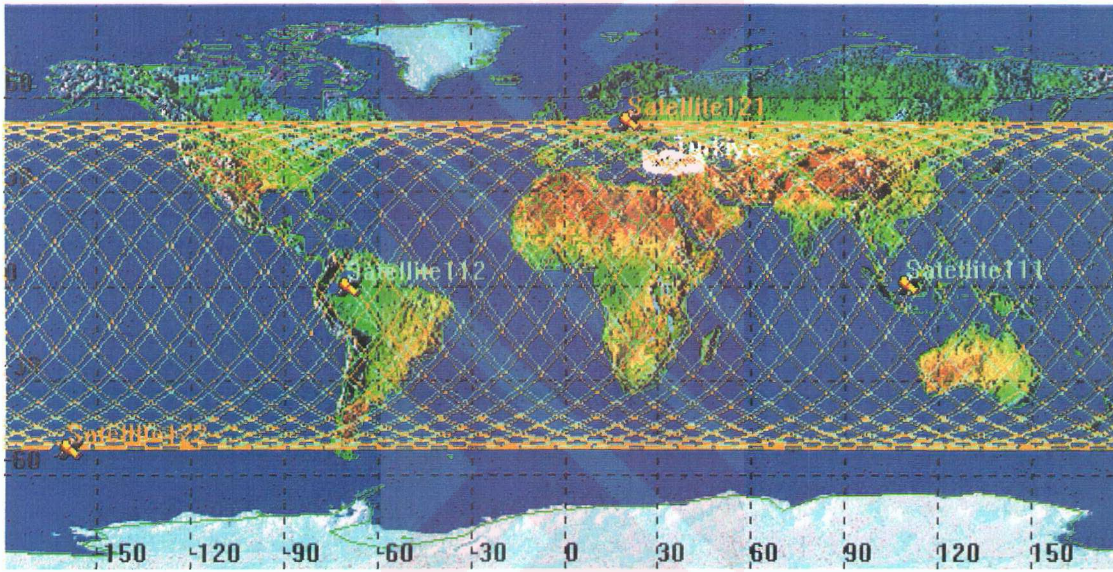

Figure 4.22 Ground tracks of a Walker Delta Constellation 2 planes-2 satellites, for angle of inclination 52^0

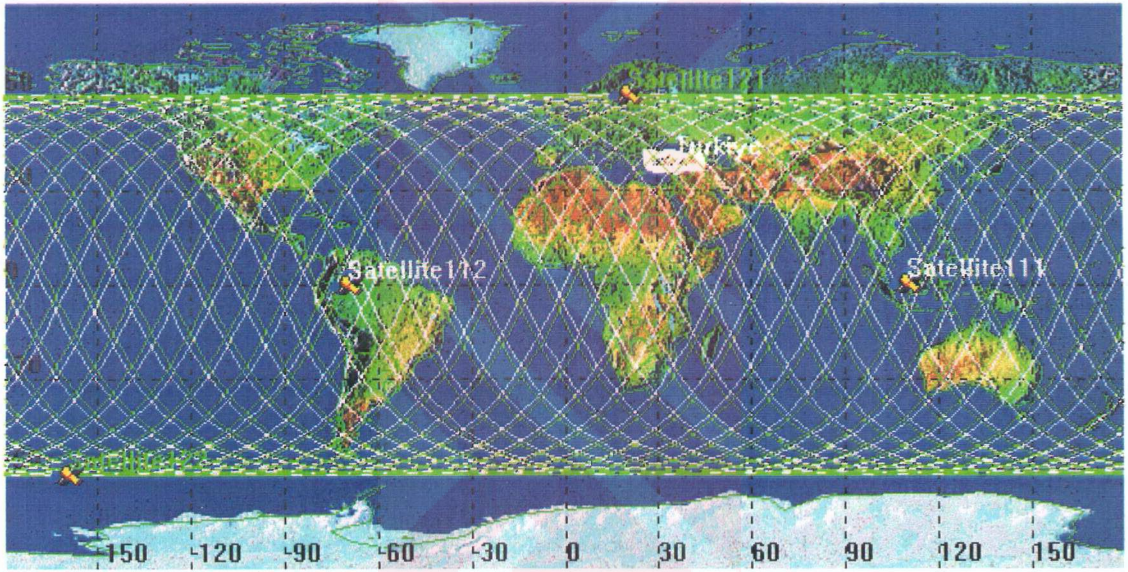

Figure 4.23 Ground tracks of a Walker Delta Constellation 2 planes-2 satellites, for angle of inclination 60^0

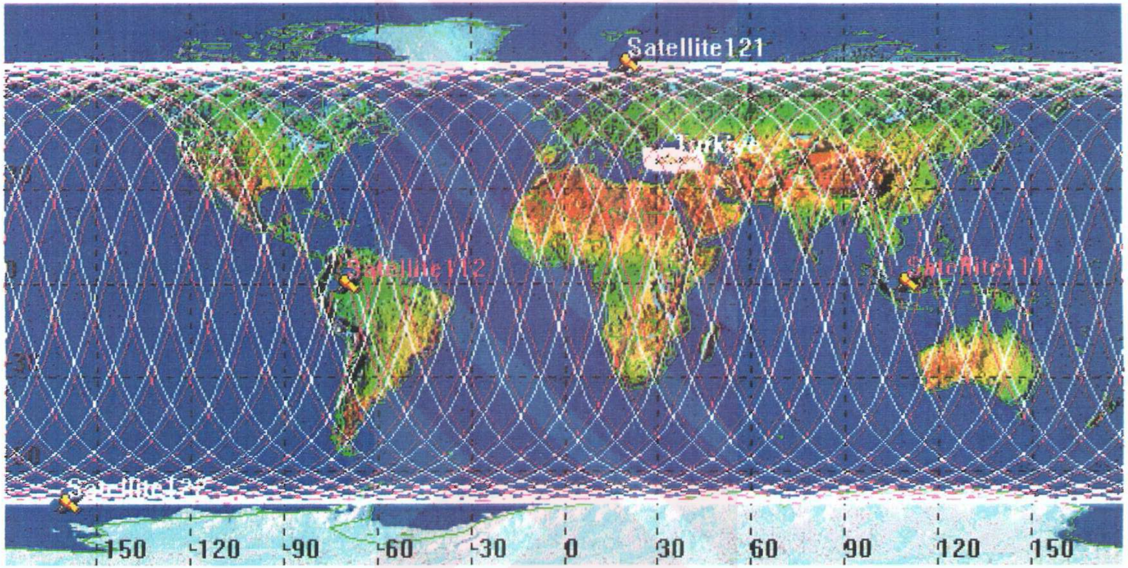

Figure 4.24 Ground tracks of a Walker Delta Constellation 2 planes - 2 satellites, for angle of inclination 70^0

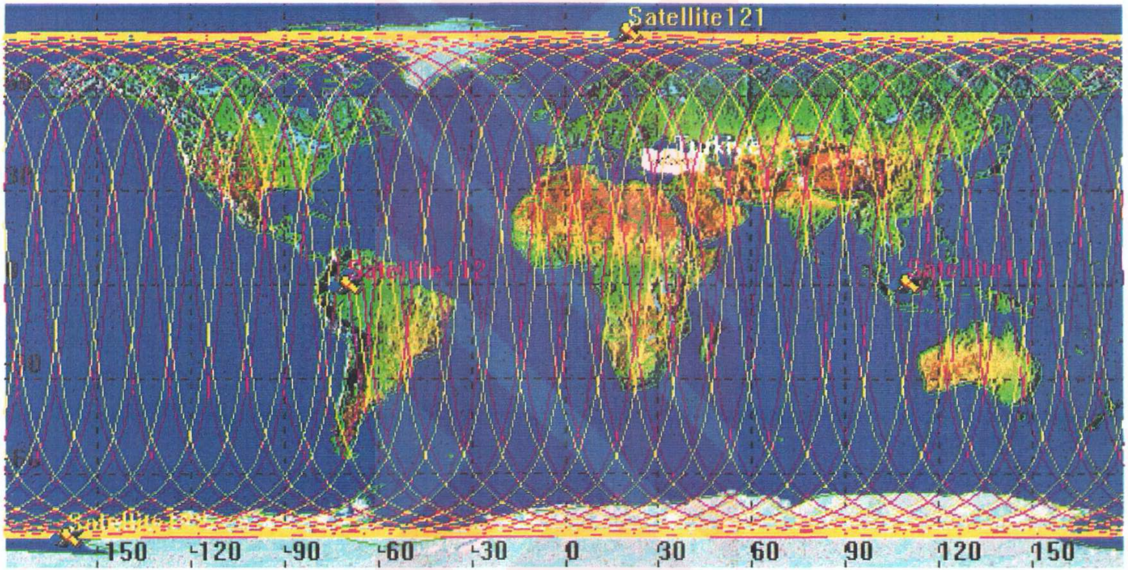

Figure4.25 Ground tracks of a Walker Delta Constellation 2 planes-2 satellites, for angle of inclination 80^0

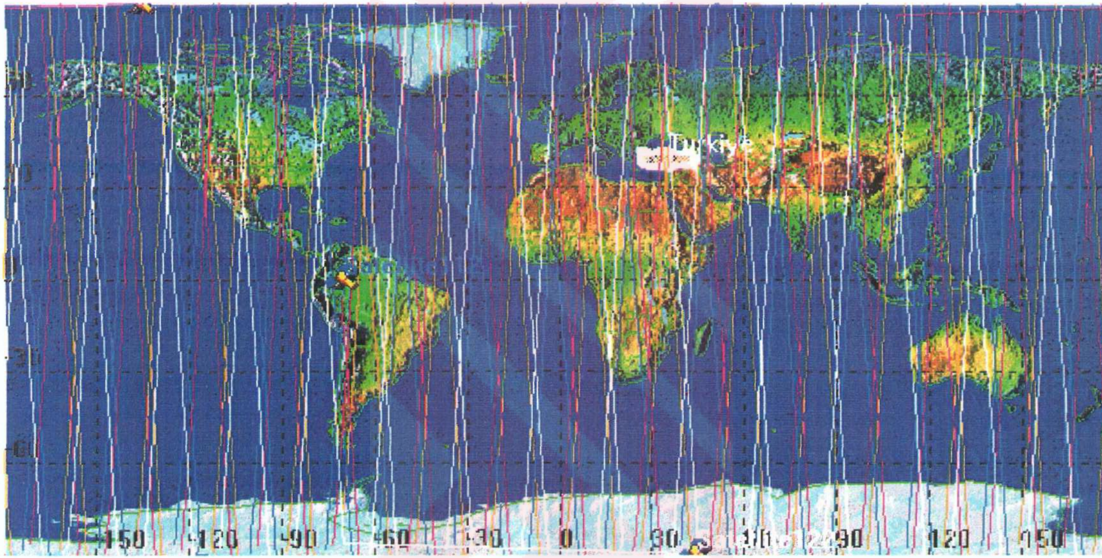

Figure 4.26 Ground tracks of a Walker Delta Constellation 2 planes - 2 satellites, for angle of inclination 90^0

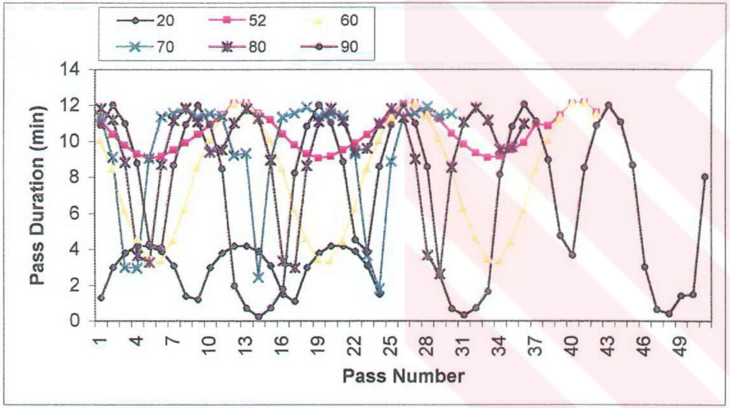

Figure 4. 27 Access times for a Walker Delta Constellation that consists of 3 planes-3 satellites, for inclination angles varying from 20^0 - 90^0

Table 4.4 Summary of how orbital inclination effects on the coverage of Turkey for a Walker Delta Constellation that consists of 3 planes- 3 satellites per plane

Orbital Inclination (deg)	Total Duration of coverage (min)	Total percent of Covarage (%)
20	74.8	5.2
52	439.9	30.5
60	337.6	23.4
70	279.0	19.4
80	333.6	23.2
90	349.1	24.2

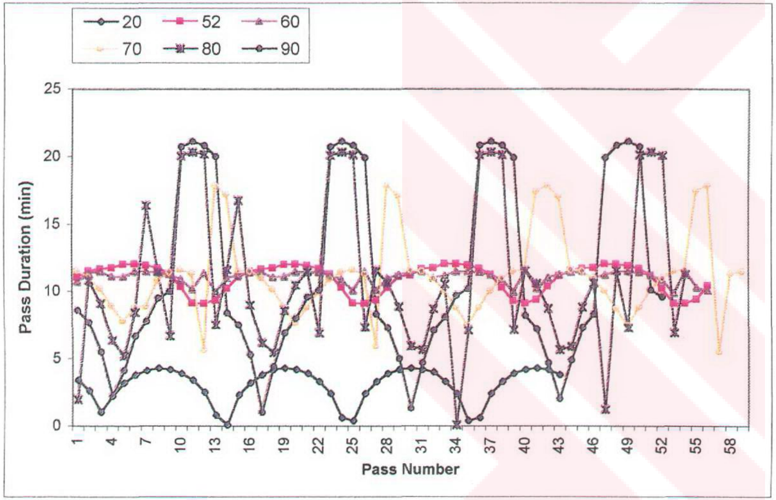

Figure 4. 28 Access times for a Walker Delta Constellation that consists of 4 planes-4 satellites, for inclination angles varying from $20^0 - 90^0$

Table 4.5 Summary of how orbital inclination effects on the coverage of Turkey for a Walker Delta Constellation that consists of 4 planes- 4 satellites per plane

Orbital Inclination (deg)	Total Duration of coverage (min)	Total percent of Covarage (%)
20	131.1	9.1
52	610.2	42.4
60	619.7	43.0
70	660.7	45.9
80	595.3	41.3
90	577.7	40.1

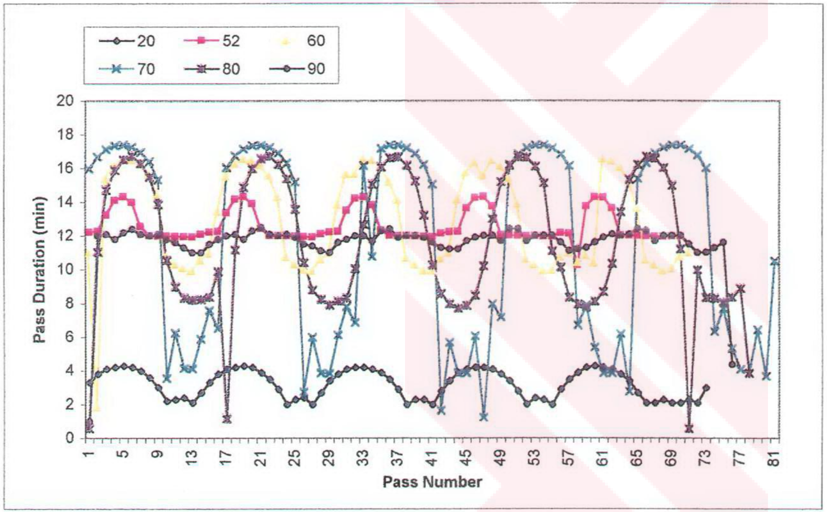

Figure 4. 29 Access times for a Walker Delta Constellation that consists of 5 planes-5 satellites, for inclination angles varying from 20^0 - 90^0

Table 4.6 Summary of how orbital inclination effects on the coverage of Turkey for a Walker Delta Constellation that consists of 5 planes- 5 satellites per plane

Orbital Inclination (deg)	Total Duration of coverage (min)	Total percent of Covarage (%)
20^0	229.1	15.9
52^0	882.0	61.2
60^0	934.0	64.9
70^0	932.7	64.8
80^0	908.7	63.1
90^0	878.7	61.0

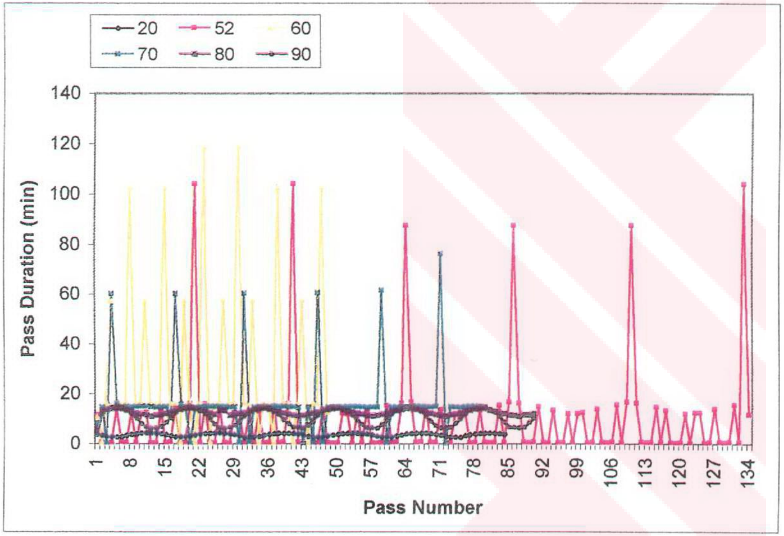

Figure 4. 30 Access times for a Walker Delta Constellation that consists of 6 planes-6 satellites, for inclination angles varying from 20^0 - 90^0

Table 4.7 Summary of how orbital inclination effects on the coverage of Turkey for a Walker Delta Constellation that consists of 6 planes- 6 satellites per plane

Orbital Inclination (deg)	Total Duration of coverage (min)	Total percent of Covarage (%)
20	299.0	20.8
52	1283.0	89.1
60	1434.6	99.6
70	1343.1	93.3
80	1127.1	78.3
90	952.8	66.2

4.3 In this part scenarios were created for Walker Delta Constellations that consists of *N* Planes-*S* satellites per plane where *S* and *N* range from 1 to 6 and percentages coverage during a day were calculated for some inclination angles varying from 20^0 to 80^0.

Table 4.8 Summary of total percentages of coverage for Walker Delta Constellations that consists of *N* Planes-*S* satellites per plane where *S* and *N* range from 1 to 6

	Number of Planes						
Number of Satellites	1p (%)	2p (%)	3p (%)	4p (%)	5p (%)	6p (%)	Inclination (deg)
1s	0.5	0.8	1.6	1.9	2.9	3.1	20
	4.8	7.9	14.0	16.5	21.9	27.0	52
	4.0	8.0	12.4	16.4	19.5	24.7	60
	2.9	5.8	9.1	12.1	14.6	17.7	70
	2.8	5.4	8.6	11.1	14.2	16.7	80
2s	1.2	2.5	3.4	4.7	5.7	7.14	20
	9.0	18.4	26.6	36.1	40.9	53.7	52
	8.2	17.2	23.6	34.3	34.2	50.7	60
	5.8	11.5	18.2	23.3	22.5	35.2	70
	5.4	8.3	17.5	17.1	22.6	27.3	80
3s	1.7	3.4	5.2	6.79	8.7	10.2	20
	13.5	26.9	30.5	47.0	72.9	61.2	52
	12.2	24.4	23.4	45.3	62.0	47.0	60
	9.0	18.0	19.4	38.6	35.8	38.7	70
	8.3	16.5	23.2	32.8	35.0	46.9	80
4s	2.2	4.6	6.8	9.1	11.3	13.6	20
	17.9	36.0	50.6	42.4	71.0	96.2	52
	16.3	33.2	42.6	43.0	76.1	98.4	60
	12.0	23.8	31.4	45.9	63.7	62.4	70
	10.6	20.5	32.1	41.3	56.5	62.4	80
5s	2.8	5.6	8.5	11.3	15.9	17.0	20
	22.2	46.6	68.5	60.9	61.2	100.0	52
	20.4	41.4	60.5	55.7	64.9	100.0	60
	14.8	27.4	45.6	52.6	64.8	84.34	70
	13.6	20.3	43.1	40.5	3.1	67.6	80
6s	3.4	7.0	10.2	13.8	23. 2	20.8	20
	26.8	53.9	71.5	90.5	66.9	89.1	52
	24.4	51.3	61.7	87.5	64.3	99.6	60
	18.0	34.7	46.2	73.9	56.0	93.3	70
	16.3	25.6	49. 6	51.3	62.7	78.3	80

4.4 Effect of Altitude on Total Percentage of Coverage of Turkey

In this part, we changed altitude from 650 to 1500 km for a Walker Delta Constellation,3 Planes- 3 Satellites, 52^0 inclination, and complete coverage intervals including pass number, pass duration and percentage of coverage during a day for Turkey calculated.

Table 4.9 Simulation results of the Walker Delta Constellation that consists of 3 planes-3 satellites, for 650 km altitude

Altitude (km)	Total Duration of coverage (min)	Total percent of Covarage
650	439.9	30.5
700	459.6	31.9
800	502.6	34.9
900	543.1	37.7
1000	578.2	40.1
1100	608.9	42.3
1200	635.8	44.1
1300	665.2	48.2
1400	696.8	48.4
1500	721.5	50.1

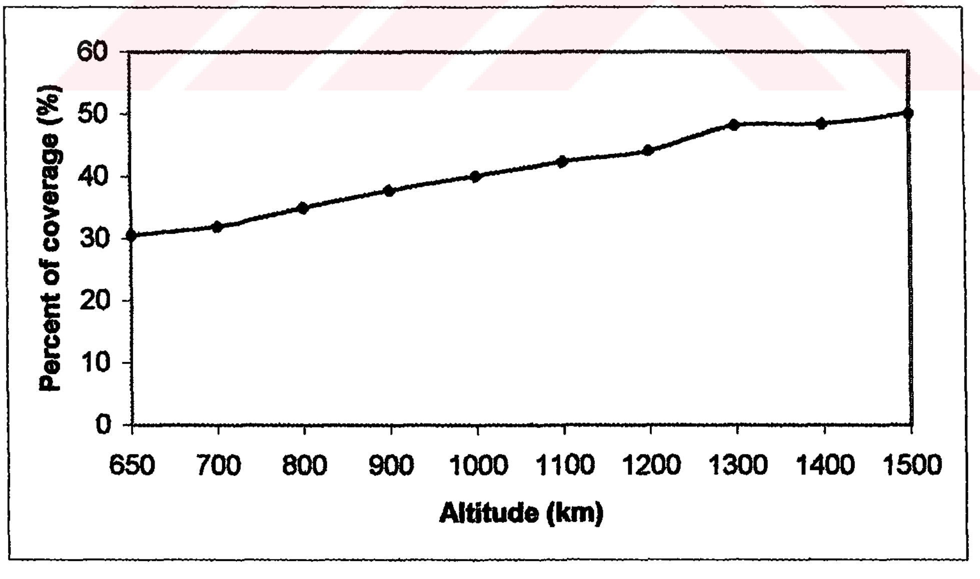

Figure 4.31 Variation of total percent of coverage with altitude for the Walker Delta Constellation that consists of 3 Planes- 3 Satellites per plane, with an inclination of 52^0.

4.5. Coverage of Sun-Synchronous LEO Satellite over Turkey

4.5.1 In this part LEO satellite's orbit is chosen as sun-synchronous and all the parameters same as BILTEN's micro satellite. Scenarios were created for Walker Delta Constellations that consists of *N* Planes-*S* satellites per plane where *S* and *N* range from 1 to 6 and percentages coverage during a day were calculated.

Table 4.10 Summary of total percentages of coverage for Walker Delta Constellations that consists of *N* Planes-*S* satellites per plane where *S* and *N* range from 1 to 6

	Number of Planes					
Number of Satellites	1p (%)	2p (%)	3p (%)	4p (%)	5p (%)	6p (%)
1s	2.7	5.5	8.8	11.1	13.3	17. 8
2s	5.4	7.9	15.9	15.8	24.8	24.7
3s	8.0	16.0	24.0	32.3	40.5	53.8
4s	10.7	20.5	34.2	39.9	52.4	73.2
5s	13.4	19.3	40.9	38.3	56.7	61.0
6s	16.0	24.0	47.6	48.1	66.9	66.2

4.5.2 In this part, for the same satellite a ground station is identified at Ankara and by changing the elevation angle complete coverage intervals of the sun-synchronous satellite was calculated.

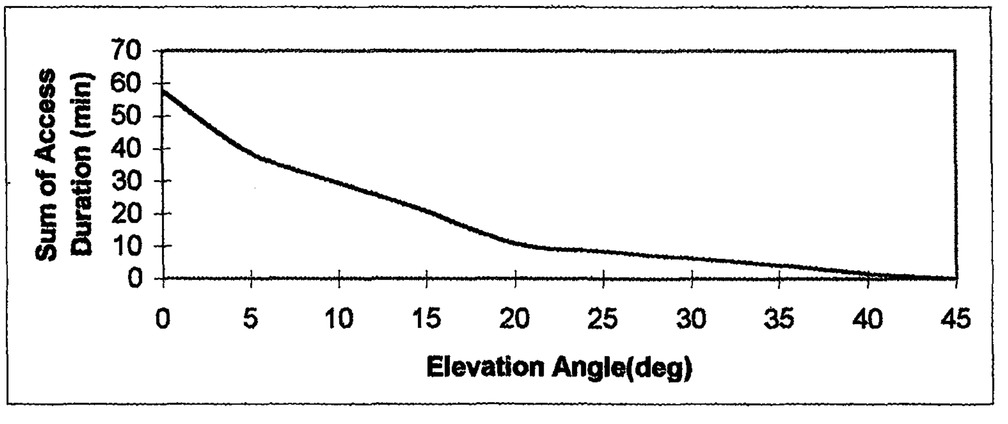

Figure 4.32 Access duration change with elevation angle

CHAPTER 5

REGULATORY AND ORGANIZATIONAL ASPECTS OF S-PCNs (Satellite Personal Communications Networks) SYSTEMS

5.1 Personal Satellite Communications

The central idea of personal communications is the ability of a mobile subscriber to set up and to receive a call at any place and time, using his or her own (personal and typically handheld) terminal. In this context, satellite personal communications networks should provide a range of services with acceptable quality and affordable costs [12]:

- Mobile telephony, typically with net bit rates of 4.8 kb/s
- Mobile real-time data communications, typically 2.4 or 4.8 kb/s
- Store-and-forward data communications (e-mail, voice-mail, still pictures, control and measurement data, etc.)
- Paging/messaging (with or without acknowledgement)
- Position determination and reporting (e.g. to dispatch center, for fleet management)
- Supplementary services (call forwarding, etc.)
- Value-added services (online services, data retrieval, etc)

Global personal communications is implemented by a number of terrestrial personal communications networks (PCNs) being supplemented by satellite personal communications networks (S-PCNs) [12].

Global S-PCNs are based on constellations of NGSOs in LEOs or MEOs. Typical examples are the Iridium system with 66 LEO satellites in 6 polar orbits at an altitude of 780 km, Globalstar with 48 LEO satellites in 8 inclined orbits at 1414 km, and ICO with 10 MEO satellites at an altitude of 10 390 km. Orbcomm with 36 satellites at 825 km is an example of a LEO dedicated to data communications.

Regional S-PCNs use Geostationary satellites because the coverage area of a GEO satellite is fixed and can be efficiently tailored to the intended service area of the system. The high signal attenuation must be compensated by a very high-gain satellite antenna which results in large antenna dimensions. Due to the narrow beam of such satellite antenna, a large number of spot beams are necessary to fill the coverage area of the satellite and further more increases antenna complexity. An example of a regional GEO S-PCN is the Asian Cellular Satellite (AceS) systems with a satellite antenna diameter of 12 m and 140 satellite spot beams.

Apart from the technical aspects, there are a number of other issues related to S-PCN systems which have to be solved before a system can successfully be operated [12]:

Frequency bands for the mobile and feeder links have to be allocated. For each system, a licence must be granted for implementation and operation of the space segment. Further, a licence establishing a gateway station is required by the gateway operator from the respective country. A licence for providing the service must be granted to the service provider by respective country. Connection agreements with terrestrial fixed networks, and roaming agreements with terrestrial mobile networks, must be set up.

A number of political issues between system proponents and various countries must be cleared up concerning the cost of licences and airtime, ownership of gateways, type approval and free circulation of terminals, and service accessibility .

Finally, a huge amount of costs must be financed during construction. The service charging policy is an important instrument to penetrate the markets in developed and less developed countries.

5.2 Allocation of Frequency Bands

The ITU (International Telecommunication Union) is an organization associated to the United Nations. The radio communication sector of ITU (ITU-R) performs the following tasks [16]:

- Global assignment of frequency bands. Frequencies are allocated to types of services, not to systems.
- Establishment of technical rules for the efficient and economic use of the spectrum. Such radio regulations have the status of a treaty and represent international law.
- Coordination of orbital slots in GEO arc.

The radio regulations are reviewed and updated approximately every other year in the frame of World Radiocommunication Conferences (WRCs), e.g. WRC-97 and WRC-2000 that was held in Istanbul last year.

5.3 Licensing/Regulation

Various licences must be obtained before a satellite system can be operated [12]:

- System licence: For each system, a licence must be granted for the implementation and operation of the space segment (satellite constellation) and for the frequency allocation for the system. This license is filled for by the system proponent and is granted by a regulatory authority of one country in coordination with the ITU.
- A licence for establishing and operating a gateway station is required by the gateway operator from the respective country.
- A licence for providing the service must be granted to the service provider by the respective country. Also, the respective frequency band must be allocated for the system in each country.

- The terminal supplier or the service provider must achieve a type approval of the terminals for each country.
- Mutual acknowledgement of national licenses is required.
- Interconnection agreements with terrestrial fixed networks must be established.
- Roaming agreements with terrestrial mobile networks must be set up, allowing cellular users to roam into the satellite network and vice versa.

The regulation of satellite services is handled very differently around the world, representing a difficulty for global satellite systems. Establishing a global regulatory framework is a very important aspect for such systems.

5.3.1 Granting a System License

In order to receive a system license, a detailed procedure must be followed [12]:

- Advanced publication and detailed publication of the planned system. These procedures are required for filling with the ITU (through a national regulatory authority) and are used to inform other authorities and system operators.
- Publication in the Weekly circular of the ITU with the possibility to comment.
- Clearing of objections and coordination with other system operators. In this respect, systems which were applied for earlier have a higher priority.

- Entry into the Master International Frequency Register and frequency allocation Entry into the Master International Frequency Register and frequency allocation.

In the last few years, a common problem was the filling of "paper satellites" which were used only to gain orbital positions. As a counter-measure, the Administrative Due Diligence has been introduced, which is a procedure controlling the actual usage of an allocation. This procedure requests the periodical publication of information concerning the system, the operator, and a time schedule.

5.3.2 Licensing in the USA

In the USA, the Federal Communications Commission (FCC)) is responsible for licensing. The FCC is concerned with system licenses as well as with service licences and established the following requirements for obtaining a big-LEO system license [12]:

- Global continuous coverage with voice service (except poles) for 75% of the time
- Continuous coverage of the USA with voice services 100% of the time.
- Guaranteed financing
- Cooperation with radio astronomy
- Ka band feeder links

In January 1995, three "big-LEO" systems were licensed by the FCC:

- Globalstar

- Iridium
- Odyssey (subsequently abandoned).

In July 1997, two more "big-LEO" systems were licensed by the FCC:

- Ellipso
- Constellation.

Also, a number of "little-LEO" systems (data systems) were licenced:

- Orbcomm
- VITA
- E-Sat
- Final Analysis
- Leo One USA.

The license for a little-LEO system requires that the system uses the frequency bands 137-138 MHz, 148-149 MHz, and 400.15-401 MHz in time-sharing mode. This means that the satellites are periodically switched off when the overlap with existing satellites of ground stations.

In order to prevent the operation of terminals in countries where the MSS service is not licensed, the USA intends to license only (handheld or mobile) terminals with position determination capability.

In May 1997 a number of Ka band GEO systems received a license from the FCC. Among them were Spaceway, Orion Network, Echostar, and Ka-Star. In 1997 the Ka band LEO system Teledesic also received a licence from the FCC.

5.3.3 Licensing in Europe

Europe-wide licensing is a task of the corresponding departments of the CEPT (Conference Europeene des Administrations des Postes et Telecommunications), which is a committee of European post and telecommunication administrations. CEPT is composed of representatives from communications regulatory agencies of 44 countries all over Europe including Turkey. The major committees of CEPT are:

- The European Radiocommunication Committee (ERC)
- The European Committee of Telecommunications Regulatory Authorities (ECTRA)
- The European Radio Office (ERO)
- The European Numbering Office (ENO).

In July 1997 CEPT decided on a harmonized authorization concept and a concept of the harmonized use of the spectrum for S-PCN systems. The next step is the implementation of these decisions in the CEPT member countries.

The EC (European Commission) envisages the development of a regulatory structure for the MSS (Mobile Satellite Service), which consider the following aspects:

- Selection of satellite operators
- Frequency allocation and licensing of service providers
- Licensing of terminals
- Licensing of gateway operators

- Interworking and interoperability all over Europe
- Numbering
- Fair connection conditions to the existing terrestrial networks
- Cooperation with developing countries.

The EC does not intend to grant licenses by itself. The fulfilment of the EC requirements will, however be necessary for applying for national licences in the corresponding countries. In Germany licensing will be issued by the Regulierungsbehörde für Telekommunikation und Post (RegTP).

Standardization in Europe is overseen by the European Telecommunications Standards Institute (ETSI), which is composed of representatives from private companies and regulation authorities.

5.3.4 Global Licensing and Political Aspects for S-PCN systems

A number of global licensing aspects and political aspects are relevant for S-PCN systems are listed below [12]:

- SPCN systems need landing rights in all countries they intend to serve. These must be negotiated country by country.
- The USA has a considerable political advantage because it was the first to begin the process of licensing and frequency allocation (through the FCC). Hence, the USA has a strong influence on global regulation.

- In order to allow global use (dual-mode) of terminals, the cross-border operation of terminals has to be agreed upon, and international roaming agreements must be set up. This may be hindered by national interests.
- The licensing of patents (intellectual property rights) is another important issue.
- According to international law each country can determine its own regulation strategy. National sovereignty with respect to the licensing of a system must be maintained.
- System providers must prevent the usage of their systems in countries where the system is not licensed.
- African and Asian Countries fear that the S-PCN systems will draw-off traffic from their national telecommunication networks. To prevent unauthorized traffic and bypassing of national telecommunications networks through satellite call-back services, these countries are interested in transparent call records and reliable data on unauthorised traffic.

Some political problems have been discussed at the World Telecommunications Policy Forum (WTPF) initiated by the ITU in 1996. Here, some conflicts between system proponents and developing countries arose :

System proponents are interested in low cost of licenses, foreign ownership of gateways, type approval and free circulation of terminals, and transparent regulation. On the other hand, developing countries are interested in low cost of airtime, opportunity for domestic ownership of gateways, and unrestricted service accessibility [12].

5.3.5 Global Mobile Personal Communications by Satellite (GMPCS)

Global Mobile Personal Communications by Satellite (GMPCS) is a personal telecommunications system providing trans-national, regional or global coverage from a constellation of satellites accessible with small and easily transportable terminals. Whether the GMPCS satellite systems are geostationary or non-geostationary, fixed or mobile, broadband or narrowband, global or regional, they are capable of providing telecommunication services directly to end-users. GMPCS services include two-way voice, fax, messaging, data and even broadband multimedia [17].

GMPCS has tremendous potential for parts of the world where substantial portion of the population must rely on satellite and other wireless technologies for access to broadband services. GMPCS networks have the unique ability to provide communications capabilities that are seamlessly compatible with existing terrestrial, fire-based standards [18].

The GMPCS MoU (Global Mobile Personal Communications by Satellite Memorandum of Understanding) is a non-binding agreement of administrations, GMPCS service providers, and GMPCS terminal manufacturers to cooperate in the development of type approval and marking of terminals, licensing and free circulation of terminals, and access to traffic data. [12]

In March 1998, the ITU World Telecommunication Development Conference in Valletta approved Recommendation 8, which recommend that administrations sign the GMPCS-MoU, implement its Arrangements, and take steps to facilitate the early introduction of GMPCS. As indicated in Rec. 8, provisions of arrangements on Type Approval and Marking of Terminals, Licensing, Access to traffic data, and Custom matters have broad international consensus. Hence, Administrations, System operators and Manufacturers accrue many benefits by signing the MoU and implementing Arrangements. Turkey also signed the GMPCS MoU [18].

5.3.6 UMTS, IMT-2000

IMT-2000 are third generation mobile systems which will provide access, by means of terrestrial and/or satellite radio links., to a wide range of telecommunications services supported by the fixed telecommunication networks (e.g. PSTN/ISDN/Internet Protocol (IP)), and to other services which are specific to mobile users [12].

Within the next few years, it is expected that a paradigm shift will occur in the way people communicate [12]:

i) The number of mobile phones and other mobile or portable terminals will increase dramatically. It is expected that the growth rate of mobile phones will exceed the growth rate of fixed phones.

ii) Voice conversation will no longer be the dominating form of communications. Data traffic and multimedia traffic will become of increasing importance and will benefit from new packet-oriented or Internet-based transmission schemes.

In order to prepare for this evolution, a new (third) generation of mobile communication networks is being developed, whose central idea is to combine mobility with multimedia services. These networks will form a global family of networks, called Universal Mobile Telecommunication System (UMTS) or International Mobile Telecommunication-2000 (IMT-2000). UMTS/IMT-2000 will also include and integrated satellite component, commonly designed as Satellite- UMTS (S-UMTS). The main features of UMTS/IMT-2000 with regard to services are given below [19]:

- Higher data rates (up to 2 Mb/s indoor, 384 kb/s outdoor, and 144 kb/s for mobile applications); accordingly to ITU and ETSI, the satellite component of UMTS/IMT-2000 should support data rates up to 144 kb/s
- Time varying data rates and asymmetric data rates
- Circuit switched services, packet data, real time and non-real-time services
- Mobile multimedya services, mobile Internet access
- Improved quality of service (e.g. ISDN speech quality)
- Communications in all types of environments (indoor, urban, wide area)

- Worldwide roaming, using a unique subscriber number
- Personal communications, virtual home environment (VHE), service portability
- User controlled service profile

CHAPTER 6

CONCLUSION

The main task of this project was to calculate some orbital parameters of LEO satellites that can cover the geographical area where Turkey is located. To achieve this Software program, STK 4.1.1b, was used. Using the software's coverage module, complete coverage intervals for Turkey were calculated by simulation.

Initially the effect of inclination angle that is the angle between the orbit plane and the Earth's equatorial plane on the complete coverage was tried to find out. Calculations were carried out for LEO satellites at an altitude of 650 km, having the same as BILTEN's microsatellite. For simplicity and demonstrative purposes the orbits were chosen circular, and inclination angles were considered in the range from 20^0 to 90^0.

First, calculations were carried out for a single LEO satellite at an altitude of 650 km. Coverage intervals, including pass duration, and percentage coverage during a day were calculated.

The results obtained by these simulations are summarised below:

- Pass number and coverage percentage of the LEO satellite that can cover the geographical area where Turkey is located increases for inclination angles in the range from 20^0 to 52^0.
- There is a dramatic decrease on the pass number and total percent of coverage for inclination angles in the range from 52^0 to 90^0.
- LEO satellite with an inclination of 52^0 gives the best result that covers 4.8 % of Turkey and its total duration of coverage of Turkey is 69.2 minutes during a day (Table 4.1).

Single satellite provided only a limited coverage area. To extend the coverage, more than one satellite should be used. Thus a constellation of satellites was created. Such constellations that consist of *N* Planes- *N* Satellites per plane where *N* ranges from 2 to 6 are known as Walker Delta Constellation. For each constellation, calculations for complete coverage intervals, including pass number, pass duration and percentage coverage during a day were done for different inclination angles varying from 20^0 to 90^0.

The simulation results that we obtained and selected as the best were presented in the following Table

Walker Delta Constellation (N Planes - N Satellites)	Orbital Inclination	Total Duration of coverage (min)	Total percent of Covarage (%)
2P-2S	52^0	264.5	18.4
3P-3S	52^0	439.9	30.5
4P-4S	70^0	660.7	45.9
5P-5S	60^0	934.0	64.9
6S-6S	60^0	1434.6	99.6

Next, scenarios were created for Walker Delta Constellations that consisted of *N* Planes-*S* satellites per plane where *S* and *N* are ranging from 1 to 6, and percentage coverages during a day were calculated for inclination angles varying from 20^0 to 80^0. The results obtained by these simulations are given in Table 4.10. The results for the above scenarios are summarised as follows:

- Walker Delta Constellation that consisted of 6 Planes –5 Satellites provided continuous 24-hour-a-day 100 % coverage for Turkey, at inclination angles 52^0 and 60^0. Meaning that Turkey can be covered completely by a total 30 LEO satellites during a day.
- When a Walker Delta Constellation that consisted of 6 Planes – 4 Satellites was used it has been found that it covered 98.4 % of Turkey during a day with an inclination angle 60^0.
- For each possible constellation we determined the best inclination angle in the interval from 20^0 to 80^0 that gave the highest percentage of coverage for Turkey. The results were tabulated in the following Table (Table 4.8).

Walker Delta Constellation (N Planes - N Satellites)	Orbital Inclination (deg)
1P-1S, 1P-2S, 1P-3S, 1P-4S, 1P-5S, 1P-6S, 2P-2S, 2P-3S, 2P-4S, 2P-6S, 3P-1S, 3P-2S, 3P-3S, 3P-4S, 3P-5S, 3P-6S, 4P-1S, 4P-2S, 4P-3S, 4P-5S, 4P-6S, 5P-1S, 5P-2S, 5P-3S, 5P-6S, 6P-1S, 6P-2S, 6P-3S, 6P-5S,	52
2P-1S, 5P-4S, 5P-5S, 6P-4S, 6P-5S, 6P-6S	60
4P-4S	70

Within 36 scenarios that were created with Walker Delta Constellations that consisted of *N* Planes-*S* satellites per plane where *S* and *N* are ranging from 1 to 6, 30 have the maximum coverage percentage at an inclination angle 52^0.

The configuration of the constellation was defined by the number of orbital planes *P* and the number of satellites per plane *S*. Total number of satellites, *t*, in the constellation is given by *t=SP*. When total number of satellites, *t*, in the created scenarios of section 4.3 was considered, and the coverage percentage of these scenarios were examined, it was noted that number of planes had an important role on the percentage of coverage for some scenarios. For example; Although total number of satellites, *t*, were the same in the Walker Delta Constellations that consisted of 4 Planes-6 Satellites and 6 Planes-4 Satellites, total percentage of coverage was found to be higher for the latter. That is, the more the number of planes the larger the covered area we have, as seen in the following Table (Table 4.8).

Walker Delta Constellation (P Planes - S Satellites)	Total Number of Satellites (t) (t=SP)	Total percent of Covarage (%)
3P-5S	15	68.5
5P-3S	15	72.9
4P-5S	20	60.9
5P-4S	20	76.1
4P-6S	24	90.5
6P-4S	24	98.4

It has also been tried to find out effects of altitude for a constellation. Walker Delta Constellation with 3 Planes- 3 Satellites at an inclination of 52^0 was chosen and the complete coverage intervals of Turkey were calculated.

The variation of the total percentage of coverage with altitude for the chosen constellation has been plotted in Figure 4.31. It has been found that by changing the altitude from 650 km to 1500 km, the total coverage of Turkey increased by 64.3 % for the mentioned constellation. Thus it was concluded that altitude has an important effect on the coverage area.

As an alternative, LEO satellite's orbit was chosen as a sun-synchronous one and applied to the BILTEN's microsatellite (its parameters have been used). Similar to the previous ones, Walker Delta Constellations that consisted of *N* Planes-*S* satellites per planes where *S* and *N* ranged from 1 to 6 were created and coverage calculations were performed. It has been found that the highest coverage percentage (73.2 %) occurred in the case of 6 Planes- 4 Satellites constellation.

Finally, in order to see the effect of elevation angle at a location in Turkey, a ground station was defined at Ankara. For a single sun-synchronous satellite, total access durations have been calculated for various elevation angles. The results have been that the complete coverage intervals decreased as the elevation angle increased. Finally, it was noted that there was no access from satellite to the earth station at an elevation angle of 45^0.

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APPENDIX A

1. Access

The geometric and temporal relationships between objects that meet or exceed the constraints on the objects, so that some task requiring both objects can be performed [19].

2. Coverage

The area of the Earth's surface visible to an orbiting spacecraft during one or more orbits. A coverage pattern is the sequence of coverage over an extended period of time [19].

3 Doppler Effect

The change in frequency of a signal caused by a target moving relative to a ground transmitter and receiving stations is defined as Doppler Effect [19].

4. Drag

The force acting on a satellite due to its passage through the upper reaches of the atmosphere is defined as drag [19].

5. Dwell Time

It is the amount of time that a sensor takes to scan a given area. The longer the dwell time, the more chance the sensor has to receive a strong signal.

6. Fixed Satellite Service

The fact that satellites have a wide view of the Earth makes them useful for a variety of applications besides telecommunication. These applications are in the fields of meteorology, navigation, astronomy, management of Earth resources such as forestry and agriculture, military reconnaissance, amateur radio and others. International Telecommunication Union (ITU), has categorized these services and set guidelines for the design and operation of each satellite service. Telecommunication is provided by the Fixed Satellite service (FSS) used for communication between fixed points on Earth [6].

7. Footprint of a Satellite

The point on the surface of the Earth directly below a satellite. The footprint is the intersection of the Earth's surface and the line connecting the center of the Earth to the satellite. [19].

8. J2000 Coordinate System

J2000 Coordinate System specifies that X and Z axes point toward the mean vernal equinox and mean rotation axes of the Earth at January 1, 2000 at 12:00:00.00 UTC. J2000.0 = 2000 January 1.5 = JD 2451545.0 TDB (Barycentric Dynamic Time) [19].

9. Line of Sight

Geometric direction in which two objects have direct visibility of each other is defined as Line of Sight [19].

10. Mobile Satellite Service

Mobile Service refers to the radiocommunication service between two points, when at least one is mobile or is at an undetermined location. Mobile satellite service (MSS) used for communication with moving terminals [6].

11.Retrograde Orbit

An orbit in which the projection of the satellite's position on the Earth's equatorial plane revolves in the direction opposite to that of the rotation of the Earth. The inclination of a retrograde orbit is greater than 90 degrees [11].

12 Sensor

Any of various satellite instruments that collect electromagnetic radiation emitted or reflected from the Earth's surface or atmosphere and convert it to a signal for transmission from the satellite back to Earth in a radio wave (also called the RF carrier) where it can be processed into images or numerical data [11].

13. Walker Constellation

Group of satellites that are in circular orbits and have the same period and inclination.

14. Van Allen Belts:

There are some energetic particles emitting radiation in the magnetosphere, the particles become trapped. The motion of this particles causes to form torroidal-shaped belts of radiation around the earth- Van Ellen Belts.

Van Allen Belts are divided in two; the inner and outer belts. The inner belt extends from 300 km to 6 400 km altitude and consists of high energy protons and electrons. The outer belt extends from approximately 16 000 km to 59 000 km altitude and consists of high energy electrons. [20]

APPENDIX B

THE DATA FILE THAT WAS WRITTEN IN ORDER TO DEFINE COVERAGE AREA AS TURKEY

```
stk.v.4.1.1
Begin RegionList
Begin Region
RegionName Turkiye
Begin BoundaryPoints
40.725-26.041
41.911-26.273
41.015-26.402
41.243-26.351
41.346-26.532
41.615-26.532
41.822-26.377
41.843-26.532
41.967-26.609
41.988-26.583
41.967-26.867
42.112-27.022
42.071-27.255
41.926-27.565
42.009-27.771
41.947-27.978
41.698-28.081
41.408-28.443
41.263-28.908
41.160-29.760
41.160-30.096
41.081-30.354
41.098-30.871
41.077-31.155
41.305-31.491
41.574-31.982
41.740-32.317
41.843-32.576
41.843-32.860
42.030-33.402
41.988-34.177
```

41.967-34.771
42.030-35.081
41.760-35.262
41.678-35.546
41.678-36.063
41.408-36.192
41.284-36.347
41.346-36.760
41.139-37.122
41.036-37.612
41.077-37.793
40.953-38.413
40.911-38.465
41.015-39.085
41.056-39.446
40.974-40.092
41.284-41.203
41.533-41.564
41.450-41.848
41.533-42.003
41.429-42.494
41.595-42.571
41.595-42.856
41.450-42.804
41.470-42.907
41.305-43.166
41.181-43.243
41.181-43.424
41.015-43.553
40.746-43.734
40.539-43.708
40.497-43.553
40.104-43.656
40.000 -44.018
40.021-44.250
39.793-44.638
39.690-44.483
39.421-44.328
39.400-44.070
38.468-44.328
38.406-44.509
37.930-44.250
37.785-44.405
37.743-44.612
37.661-44.509
37.454-44.638
37.288-44.819
37.164-44.793
37.184-44.664

36.957-44.302
37.102-44.199
37.262-44.276
37.267-44.276
37.288-44.018
37.205-43.863
37.371-43.114
37.350-42.985
37.350-42.778
37.267-42.623
37.122-42.339
37.329-42.210
37.122-41.745
37.039-41.332
37.102-40.867
36.667-39.472
36.729-38.775
36.915-38.284
36.646-37.406
36.625-37.070
36.812-36.657
36.418-36.579
36.232-36.682
36.232-36.424
35.983-36.347
35.818-36.140
35.942-35.908
36.335-35.804
36.605-36.114
36.895-36.037
36.729-35.649
36.563-35.520
36.770-34.642
36.294-33.970
36.149-33.635
36.149-33.325
36.025-32.705
36.480-32.059
36.832-31.181
36.853-30.716
36.708-30.587
36.253-30.406
36.294-30.174
36.149-29.734
36.335-29.166
36.687-28.960
36.646-28.830
36.812-28.443
36.791-28.262

36.584-27.952
36.729-28.030
36.708-27.513
36.791-27.668
36.791-27.926
36.874-28.004
36.998-28.262
36.998-27.232
37.102-27.255
37.122-27.461
37.247-27.591
37.391-27.436
37.350-27.281
37.723-27.048
37.743-27.203
37.930-27.255
38.033-26.971
38.178-26.687
38.137-26.428
38.303-26.248
38.385-26.454
38.634-26.428
38.406-26.661
38.385-26.921
38.468-27.100
38.468-26.945
38.655-26.790
38.924-27.022
38.903-26.867
38.944-26.893
39.276-26.687
39.545-26.893
39.441-26.093
39.980-26.196
40.332-26.222
40.456-26.454
40.642-26.790
40.622-26.144
40.725-26.067
End BoundaryPoints
End Region
End RegionList