Analysis and Animation of Satellite Communication Constellations

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Preface

Only 15 years ago the future of satellite communications systems for applications other than TV broadcasting was considered very uncertain.
The satellite industry was in fact seriously endangered, given the parallel crisis of military applications and the shrinkage of government budgets for scientific and earth – observation missions all over the Western world.
Today's space industry is living a very exciting and promising phase of its history, triggered on one side by the enormous success of wireless cellular telephony and on the other side by the worldwide diffusion of internet and its related services.
Despite the shy start and uncertain success of Second Generation Satellite Personal Communication Systems, S-UMTS systems are likely to benefit from the parallel exponential growth of terrestrial UMTS networks.
Third generation mobile communications systems (S-UMTS) will extend capabilities of present mobile technologies, providing a single integrated network in which the user can access a wide range of telecommunications services, in an easy to use and uniform way, in all environments, "any where and at any time".

1. Introduction

What is a satellite?
A satellite is a specialized wireless receiver/transmitter — essentially a radio-frequency repeater — that is launched by a rocket and placed in orbit around the earth. Today, there are literally hundreds of commercial satellites in operation around the world. These satellites are used for such diverse purposes as wide-area network communication, weather forecasting, television broadcasting, amateur radio communications, Internet access, and the Global Positioning System.
The first man-made satellite, which was about the size of a basketball, was launched by the Soviet Union in the late 1950s. It did nothing but repeatedly transmit a simple Morse code signal back to earth.
In 1962, the American telecommunications giant AT&T launched the world's first true communications satellite, called Telstar. Since then, countless communications satellites have been placed into earth orbit, and the technology being applied to them is forever growing in sophistication.
Since that time, satellites have become much more powerful.

1.1 Basic Elements

Satellite communications are comprised of 2 main components:

- **The Satellite**

The satellite itself is also known as the space segment, and is composed of three separate units, namely the fuel system, the satellite and telemetry controls, and the transponder. The transponder includes the receiving antenna to pick-up signals from the ground station, a broad band receiver, an input multiplexer, and a frequency converter which is used to reroute the received signals through a high powered amplifier for downlink. The primary role of a satellite is to reflect electronic signals. In the case of a telecom satellite, the primary task is to receive signals from a ground station and send them down to another ground station located a considerable distance away from the first. This relay action can be two-way, as in the case of a long distance phone call. Another use of the satellite is when, as is the case with television broadcasts, the ground station's uplink is then downlinked over a wide region, so that it may be received by many different customers possessing compatible equipment. Still another use for satellites is observation, wherein the satellite is equipped with cameras or various sensors, and it merely downlinks any information it picks up from its vantagepoint.

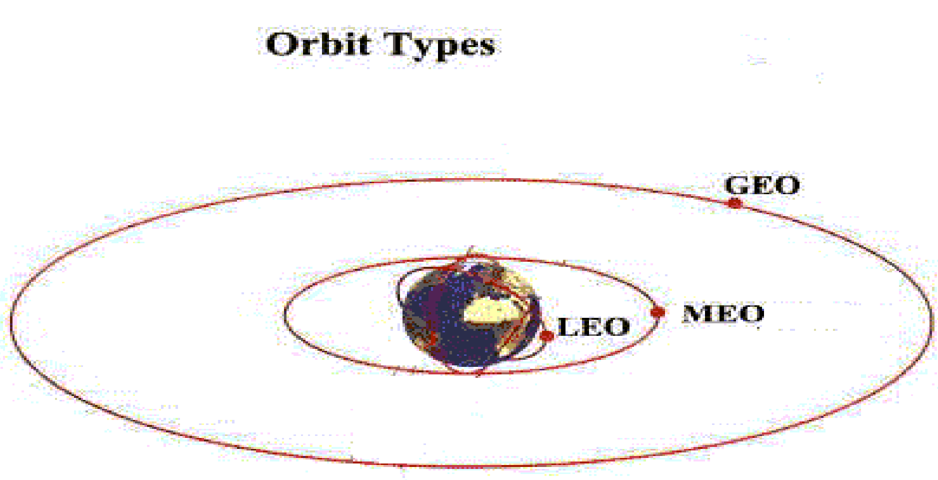
- **The Ground Station.**

This is the earth segment. The ground station's job is two-fold. In the case of an uplink, or transmitting station, terrestrial data in the form of baseband signals, is passed through a baseband processor, an up converter, a high powered amplifier, and through a parabolic dish antenna up to an orbiting satellite. In the case of a downlink, or receiving station, works in the reverse fashion as the uplink, ultimately converting signals received through the parabolic antenna to base band signal.

2. Satellite Classifications

Satellite systems are classified according to the height of their orbits.

Practically, there are 3 satellite orbits: GEO, MEO and LEO



2.1 GEO

GEO stands for Geostationary or Geo synchronous earth orbits.
Most communication satellites in use today are geostationary. They orbit the earth directly over the equator, approximately 22,000 miles up. At this altitude, one complete trip around the earth (relative to the sun) takes 24 hours. Thus, the satellite remains over the same spot on the earth's surface at all times, and stays fixed in the sky from any point on the surface from which it can be "seen." A single geostationary satellite can "see" approximately 40 percent of the earth's surface. Three such satellites, spaced at equal intervals (120 angular degrees apart), can provide coverage of the entire civilized world.

A single transponder on one of these satellites (the part of the satellite that transmits signals back to Earth, of which a typical satellite has 32) is capable of handling approximately 100 million bits of information per second. This means that if the transponder is accessed for only 90 seconds per day, close to 1 billion bytes of data would be transferred — the equivalent of 865,000 double-spaced pages. With this immense capacity, today's communication satellites are an ideal medium for transmitting and receiving almost any kind of content, from simple data to the most complex and bandwidth-intensive video, audio and data content.

2.2 MEO

MEO stands for Medium Earth Orbit
In this case, the orbit altitude is about 10 000 km.

2.3 LEO

LEO stands for Low Earth Orbit.
The orbit altitude is between 160 and 1500 km.
Since they orbit so close to Earth, they must travel very fast so gravity won't pull them back into the atmosphere. Satellites in LEO speed along at 17,000 miles per hour (27,359 kilometers per hour)! They can circle Earth in about 90 minutes.

2.4 Some Satellite Communication Systems

2.4.1 Inmarsat (GEO)

Inmarset have 4 geostationary satellites in orbit. These satellites cover the entire Earth's surface excluding the regions above 75° north and below 75° south. The main use of these satellites are for non-realtime communications as the latency associated with GEO links is approximately 250ms excluding latency associated with the necessary terrestrial links. The progress of Inmarsat over the years demonstrates the movement of GEO satellite technology from emphasis on global coverage to spot beam technology that increases capacity in high usage regions. The next generation Inmarset satellites, INMARSET-4, will support the new Broadband Global-Area-Network (B-GAN) offering the typical internet services at speeds up to 432kbit/s to almost the entire world.

2.4.2 Teledesic (MEO)

The Teledesic project is a project that is attempting to shift the focus of broadband internet from terrestrial links to "internet-in-the-sky" using MEO satellites. The benefit of MEO is the reduced latency compared to GEO satellites which allows for the use of realtime applications such as video conferencing but with reduced costs compared to LEO. Teledesic previously planned to use 840 active satellites in 21 orbits with an additional 4 satellites in each of these orbits. This was found to be very cost ineffective and a change in the constellation design using 30 MEO satellites was found to be more cost effective. Teledesic MEO satellites will operate in the Ka-band and will have the capability of several spot beams in its footprint allowing for efficient use of its capacity. The benefits associated with the reduced latency of MEO satellites has already won it many customers who wish to use these satellites to offer commercial services such as cable TV and internet. The Teledesic project plans to launch its first satellite in 2004.

2.4.3 IRIDIUM (LEO)

The IRIDIUM is one of the major consortiums working on global voice communications via satellite. The constellation consists of 66 LEO satellites at approximately 680km above the Earth. The IRIDIUM satellites use the Ka-Band (19.4-19.6Ghz for the downlink and 29.1-29.3Ghz for the uplink) to link with earth stations. It will utilize the L-band (1616-1626.5MHz) for telephone services and Ka-band (23.18 – 23.38GHz) for inter-satellite links.

The focus of IRIDIUM is on the rural and maritime markets when communication links are scarce or non-existent. It also focuses on the lost cost associated with the technology therefore making it affordable to people traveling to rural areas or boats. This technology also allows for the virtual private networks and flat-rate charges with no distance or roaming charges. Also due to its LEO, latency for services such as voice is insignificant. The downside to the IRIDIUM technology however is the low bandwidth available making its primary use telephony or very very slow internet access with a compressed data transfer rate of only 10kbps and uncompressed data rate of 2.4kbps.

2.5 Satellite Communication Systems Technical Parameters

SYSTEM	Iridium	Globalstar	ICO	Thuraya
Orbit	LEO	LEO	MEO	GEO
Service Life	5 years	7.5 years	12 years	12 years
Spot Beams per Satellite	48	16	163	250 - 300
User Link Frequency (Up/Down), GHz	1.621 – 1.626	1.610 – 1.621 / 2.483 – 2.495	1.980 – 2.010 / 2.170 – 2.200	1.525 – 1.559 / 1.626 – 1.660
Feeder Link Frequency (Up/Down), GHz	30 / 20	5.1 / 6.9	5.2 / 6.9	14 / 12
Multiple Access	TDMA / FDMA	CDMA / FDMA	TDMA / FDMA	TDMA / FDMA
Nominal Capacity per Satellite	1,100	2,400	4,500	16,000
Nr. Of Gateways	12	38	12	variable
Reported Cost ($Billion)	4.7	3.5	4.8	1

3. Satellite Constellations

For studying and simulating satellite systems constellations an existing free open source program was used. It is Called SaVi

3.1 SaVi

SaVi is the Satellite Visualization Software, it allows to simulate satellite orbits and coverage, in two and three dimensions. *SaVi* is particularly useful for simulating satellite constellations.

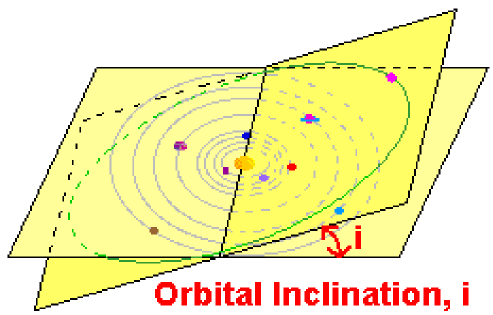
SaVi was developed at SourceForge, the latest version so far is SaVi 1.2.1a.
SaVi is a free Software and can be downloaded from:
http://www.ee.surrey.ac.uk/Personal/L.Wood/software/SaVi/src/releases/

For a complete manual for installing and using SaVi, please refer to Appendix A.

3.1.1 SaVi Constellation Parameters

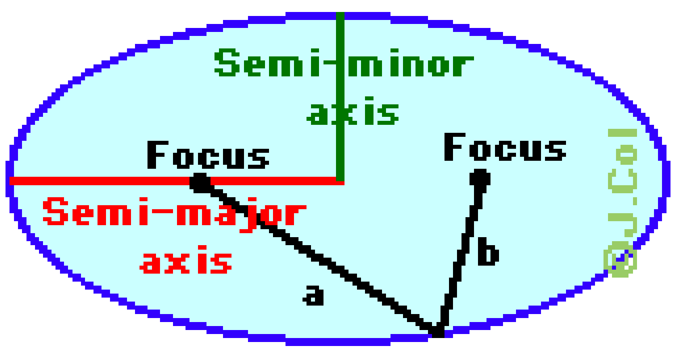
3.1.1.1 Inclination

is the angle between the plane of an orbit and the plane of the ecliptic.



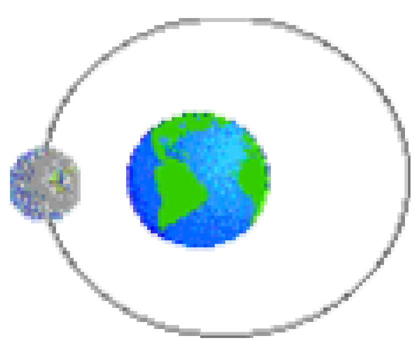
3.1.1.2 Semi-major axis

of an ellipse is half the length of the line segment across the longest part of the ellipse



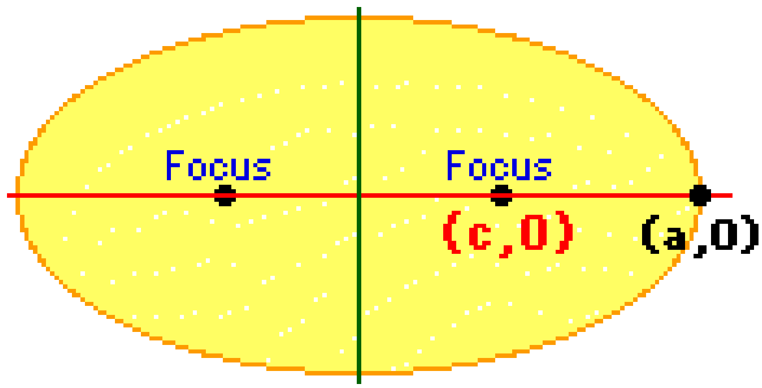
3.1.1.3 Perigee (periapsis)

is the point in each orbit which is closest to the Earth.



3.1.1.4 **Eccentricity**

is a measure of how an orbit deviates from circular $0<e<1$



3.1.1.5 **Longitude of the ascending node**

is the node's celestial longitude

3.2 Geomview

SaVi as a stand alone program is capable of simulating Satellite Constellations in 2-Dimensions only, for 3D simuation; Geomview is needed.

Geomview is an interactive 3D viewing program for Unix. It lets you view and manipulate 3D objects: you use the mouse to rotate, translate, zoom in and out, etc. It can be used as a standalone viewer for static objects or as a display engine for other programs which produce dynamically changing geometry. It can display objects described in a variety of file formats. It comes with a wide selection of example objects, and you can create your own objects too.

Geomview was written at the Geometry Center at the University of Minnesota between 1992 and 1996. Although the Geometry Center closed in 1998, Geomview is still used by thousands of people around the world. Through the volunteer work of the original authors and other volunteers, Geomview continues to evolve.

Geomview runs on most Unix platforms, including GNU/Linux. It is free software.

4. Savi Simulation Environment

The Problem we had with SaVi was finding the specific constellation parameters required by this software to run the simulation.

Trying to find these parameters on the websites of the Satellite Communication Systems companies was useless since only commercial non technical data were found there.

To solve this problem, two scenarios of solutions were found.

4.1 Space Geometry

The first approach was to calculate the parameters from the space geometry of the Satellite systems which includes satellite height, inclination, number of orbits and number of satellite.

By the help of TCL programming language, a script was created and embedded wihin SaVi capable of calculating the needed parameters from the given space geometry.

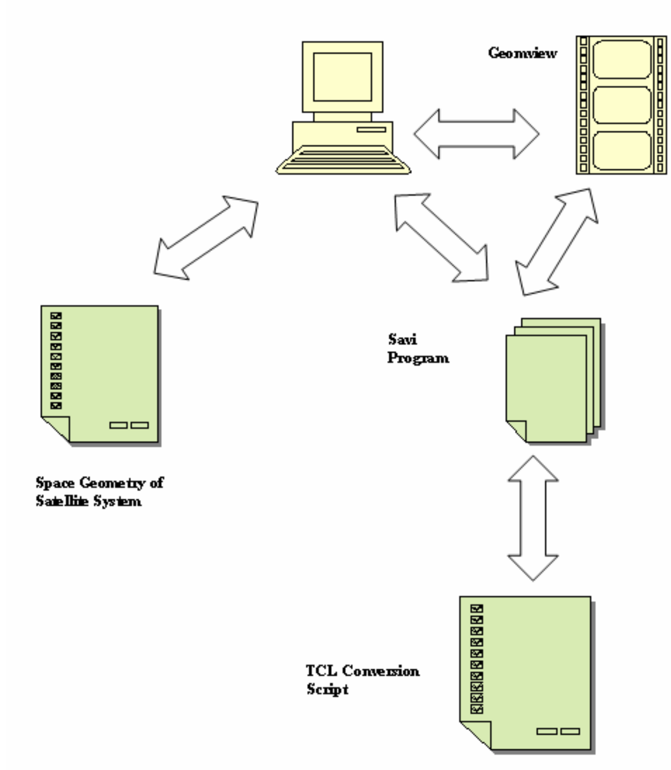
We take GPS as an example:

```
# GPS
set PI 3.14159
set MU 398601.2
set RADIUS_OF_EARTH 6378.14

set SATS_PER_PLANE 4
set NUM_PLANES 6

upvar #0 coverage_angle angle
set angle 0

# setup orbital elements
set a [expr 20200.0+$RADIUS_OF_EARTH]
set e 0.0
set inc 55.0
set omega 0.0

# GPS period is approximately 12 hours.
set T_per [expr 2 * $PI * pow($a,1.5) / sqrt($MU)]
```

```
satellites GV_BEGIN

for {set j 0} {$j < $NUM_PLANES} {incr j} {
        set Omega [expr $j * 360.0 / $NUM_PLANES + 17 ]
        for {set i 0} {$i < $SATS_PER_PLANE} {incr i} {
#B1-4
            if { $j == 0 } {
              if { $i == 0 } {
                set plane_offset 339.7
              }
              if { $i == 1 } {
                set plane_offset 81.9
              }
              if { $i == 2 } {
                set plane_offset 115.0
              }
                if { $i == 3 } {
                set plane_offset 213.9
              }
            }
# C1-4
                if { $j == 1 } {
              if { $i == 0 } {
                set plane_offset 16.0
              }
              if { $i == 1 } {
                set plane_offset 138.7
              }
              if { $i == 2 } {
                set plane_offset 244.9
              }
                if { $i == 3 } {
                set plane_offset 273.5
              }
            }
# D1-4
                if { $j == 2 } {
              if { $i == 0 } {
                set plane_offset 42.1
              }
              if { $i == 1 } {
                set plane_offset 70.7
              }
              if { $i == 2 } {
                set plane_offset 176.8
              }
                if { $i == 3 } {
                set plane_offset 299.6
              }
            }
# E1-4
                if { $j == 3 } {
              if { $i == 0 } {
                set plane_offset 101.7
              }
              if { $i == 1 } {
```

```
                set plane_offset 200.5
            }
            if { $i == 2 } {
                set plane_offset 233.7
            }
                if { $i == 3 } {
                set plane_offset 335.9
            }
        }
# F1-4
              if { $j == 4 } {
            if { $i == 0 } {
                set plane_offset 142.2
            }
            if { $i == 1 } {
                set plane_offset 255.6
            }
            if { $i == 2 } {
                set plane_offset 5.3
            }
                if { $i == 3 } {
                set plane_offset 34.5
            }
        }
# A1-4
              if { $j == 5 } {
            if { $i == 0 } {
                set plane_offset 280.7
            }
            if { $i == 1 } {
                set plane_offset 310.3
            }
            if { $i == 2 } {
                set plane_offset 60.0
            }
                if { $i == 3 } {
                set plane_offset 173.4
            }
        }

        if { $plane_offset > 180 } {
            set plane_offset [expr $plane_offset - 360]
        }

              set T [expr $T_per * $plane_offset / 360 ]
              satellites LOAD $a $e $inc $Omega $omega $T
    }
}
satellites GV_END
```

So after calling the script called GPS.tcl from SaVi, the simulation will be ready within 1 second.



At the beginning, this solution sounded perfect to us, but the problem we faced was finding the space geometry of some satellite communication systems.
So without knowing the space geometry, the script is useless.

Our more convenient solution was using the NORAD 2-line format.

4.2 NORAD Two-Line Format

What is the format for the two-line element sets?
A NORAD two-line element set consists of two 69-character lines of data which can be used together with NORAD's SGP4/SDP4 orbital model to determine the position and velocity of the associated satellite. The only valid characters in a two-line element set are the numbers 0-9, the capital letters A-Z, the period, the space, and the plus and minus signs—no other characters are valid.
Of course, not all valid characters can be used in all columns within the element set. Figure 4.2.1 shows what type of character is valid for each column. Columns with a space or period can have no other character. Columns with an 'N' can have any number 0-9 or, in some cases, a space. Columns with an 'A' can have any character A-Z or a space. The column with a 'C' can only have a character representing the classification of the element set—normally either a 'U' for unclassified data or an 'S' for secret data (of course, only unclassified data are publicly available). Columns with a '+' can have either a plus sign, a minus sign, or a space and columns with a '-' can have either a plus or minus sign (if the rest of the field is not blank).

1 NNNNNC NNNNNAAA NNNNN.NNNNNNNN +.NNNNNNNN +NNNNN-N +NNNNN-N N NNNNN
2 NNNNN NNN.NNNN NNN.NNNN NNNNNNN NNN.NNNN NNN.NNNN NN.NNNNNNNNNNNNNN

Figure 4.2.1. Two-Line Element Set Format

Further restrictions are placed upon the values in each column as the individual fields of data are defined. Tables 4.2.1 and 4.2.2 define each of the individual fields for lines 1 and 2, respectively. Many of these bear additional explanation.

Table 4.2.1. Two-Line Element Set Format Definition, Line 1

Field	*Column*	*Description*
1.1	01	Line Number of Element Data
1.2	03-07	Satellite Number
1.3	08	Classification
1.4	10-11	International Designator (Last two digits of launch year)
1.5	12-14	International Designator (Launch number of the year)
1.6	15-17	International Designator (Piece of the launch)
1.7	19-20	Epoch Year (Last two digits of year)
1.8	21-32	Epoch (Day of the year and fractional portion of the day)
1.9	34-43	First Time Derivative of the Mean Motion
1.10	45-52	Second Time Derivative of Mean Motion (decimal point assumed)
1.11	54-61	BSTAR drag term (decimal point assumed)
1.12	63	Ephemeris type
1.13	65-68	Element number
1.14	69	Checksum (Modulo 10) (Letters, blanks, periods, plus signs = 0; minus signs = 1)

Column 1 of each line of the two-line element set indicates the line number (and hence the format) for that line. The next field on each line (fields 1.2 and 2.2) indicates the satellite number—actually, the NORAD Catalog Number—of the object the data is for. The NORAD Catalog Number is a unique identifier assigned by NORAD for each earth-orbiting artificial satellite in their SATCAT (Satellite Catalog). For a valid two-line element set, fields 1.2 and 2.2 must be identical. As mentioned above, field 1.3 indicates the security classification of the data—all publicly available data will have a 'U' in this field to indicate unclassified data.

The next three fields—fields 1.4 through 1.6—define the International Designator of the object. This identifier is an additional unique designation assigned by the *World Data Center-A for Rockets and Satellites* (WDC-A-R&S) in accordance with international treaty (1975 Convention on Registration of Objects Launched into Outer Space). The WDC-A-R&S works together with NORAD and NASA's National Space Science Data Center (NSSDC) in maintaining this registry. Although there have been some changes in format since it was first used back in the late1950s, the International Designator indicates the year of the launch (field 1.4 only gives the last two digits), the launch of that year (field 1.5), and the piece of that launch (field 1.6) for each object. These three fields can be left blank, but all must be present if any is. Finally, field 1.6 can be either right or left justified—the latter is preferred.

The next two fields (fields 1.7 and 1.8) together define the reference time for the element set and are jointly referred to as the epoch. Field 1.7 is the two-digit year (more on this later) and field 1.8 is the day of that year. The epoch defines the time to which all of the time-varying fields in the element set are referenced.

Field 1.9 represents the first derivative of the mean motion divided by two, in units of revolutions per day^2, and field 1.10 represents the second derivative of the mean motion divided by six, in units of revolutions per day^3. Together, these two fields give a second-order picture of how the mean motion is changing with time. However, these two fields are not used by the SGP4/SDP4 orbital models (only by the simpler SGP model) and, therefore, serve no real purpose.

Field 1.11 represents something called *B** (BSTAR), which is an SGP4-type drag coefficient. In aerodynamic theory, every object has a ballistic coefficient, *B*, that is the product of its coefficient of drag, C_D, and its cross-sectional area, *A*, divided by its mass, *m*.

$$B = C_D A/m$$

The ballistic coefficient represents how susceptible an object is to drag—the higher the number, the more susceptible. *B** is an adjusted value of *B* using the reference value of atmospheric density, ρ_o.

$$B^* = B \rho_o/2$$

B^* has units of (earth radii)$^{-1}$.

Fields 1.10 and 1.11 have a somewhat different format that the other fields. In particular, they use a modified exponential notation with an implied leading decimal point. This convention is inherited from FORTRAN where all such numbers range from 0 to less than 1. The first six columns of each field represent the mantissa and the last two represent the exponent. For example, the value -12345-6 corresponds to -0.12345×10^{-6}. Each of these two fields can be blank, corresponding to a value of zero.

Field 1.12 represents the ephemeris type (i.e., orbital model) used to generate the data. *Spacetrack Report Number 3* suggests the following assignments: 1=SGP, 2=SGP4, 3=SDP4, 4=SGP8, 5=SDP8. However, this value is used for internal analysis only—all distributed element sets have a value of zero and are generated using the SGP4/SDP4 orbital model (as appropriate).

Field 1.13 represents the element set number. Normally, this number is incremented each time a new element set is generated. In practice, however, this doesn't always happen. When operations switch between the primary and backup Space Control Centers, sometimes the element set numbers get out of sync, with some numbers being reused and others skipped. Unfortunately, this makes it difficult to tell if you have all the element sets for a particular object.
The last column on each line (fields 1.14 and 2.10) represents a modulo-10 checksum of the data on that line. To calculate the checksum, simply add the values of all the numbers on each line—ignoring all letters, spaces, periods, and plus signs—and assigning a value of 1 to all minus signs. The checksum is the last digit of that sum. Although this is a very simple error-checking procedure, it should catch 90 percent of all errors. However, many errors can still sneak through.

Line 2 consists primarily of mean elements calculated using the SGP4/SDP4 orbital model. The definitions for fields 2.3 through 2.8 can be seen in table 4.2.2 below. Fields 2.3, 2.4, 2.6, and 2.7 all have units of degrees and can range from 0 up to 360 degrees—field 2.3 (inclination) only goes up to 180 degrees. The eccentricity (field 2.5) is a unitless value with an assumed leading decimal point. For example, a value of 1234567 corresponds to an eccentricity of 0.1234567. The mean motion (field 2.8) is measured in revolutions per day.

Table 4.2.2. Two-Line Element Set Format Definition, Line 2

Field	***Column***	***Description***
2.1	01	Line Number of Element Data
2.2	03-07	Satellite Number
2.3	09-16	Inclination [Degrees]
2.4	18-25	Right Ascension of the Ascending Node [Degrees]
2.5	27-33	Eccentricity (decimal point assumed)
2.6	35-42	Argument of Perigee [Degrees]
2.7	44-51	Mean Anomaly [Degrees]
2.8	53-63	Mean Motion [Revs per day]
2.9	64-68	Revolution number at epoch [Revs]
2.10	69	Checksum (Modulo 10)

The final field on line 2, prior to the checksum, is the rev number. Since there are several conventions for determining rev numbers, this field also bears some clarification. In NORAD's convention, a revolution begins when the satellite is at the ascending node of its orbit and a revolution is the period between successive ascending nodes. The period from launch to the first ascending node is considered to be Rev 0 and Rev 1 begins when the first ascending node is reached. Since many element sets are generated with epochs that place the satellite near its ascending node, it is important to note whether the satellite has reached the ascending node when calculating subsequent rev numbers.
In general, any number smaller than the maximum field size can be padded with either leading spaces or leading zeros. In other words, an epoch can be represented as either 98001.12345678 or 98 1.12345678 or an inclination can be represented as 28.1234 or 028.1234. Convention uses leading zeros for fields 1.5 and 1.8 and leading spaces elsewhere, but either is valid.
Updated NORAD files for almost every Satellite system are found at: http://www.celestrak.com.

An example of NORAD Format is shown below for the Glonass System:

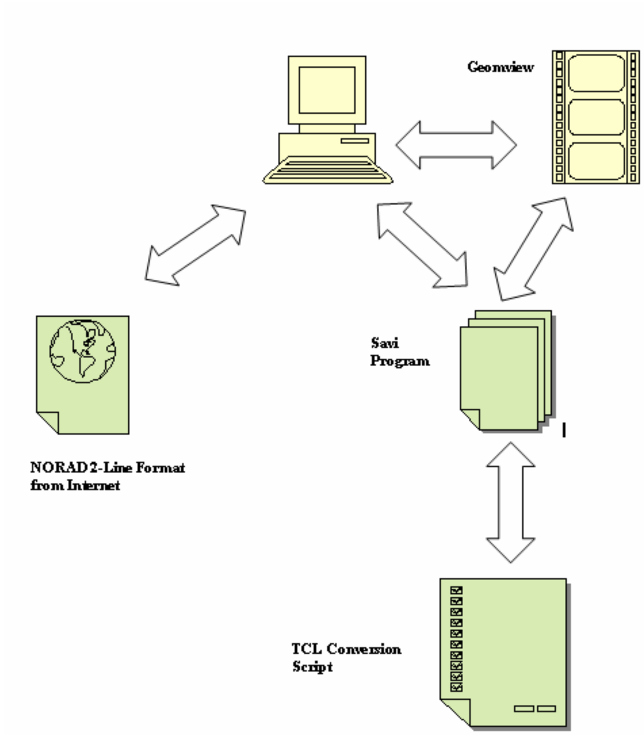
```
COSMOS 2362 (786)
1 25594U 98077B   03011.58269314 -.00000047  00000-0  00000+0 0  2106
2 25594  65.1494   2.2475 0010868  47.6937 105.8992  2.13102386 31379
COSMOS 2363 (784)
1 25595U 98077C   03010.56082131 -.00000050  00000-0  00000+0 0  1624
2 25595  65.1631   2.2784 0001396 122.0842  13.5872  2.13102735 31353
COSMOS 2374 (783)
1 26564U 00063A   03009.67609279  .00000034  00000-0  00000-0 0  6972
2 26564  64.6050 242.8722 0004767  38.4419  80.1419  2.13102169 17428
COSMOS 2375 (787)
1 26565U 00063B   03009.61450422  .00000033  00000-0  00000-0 0  6992
2 26565  64.6069 242.8654 0002051  14.5230 101.0643  2.13102383 17423
COSMOS 2376 (788)
1 26566U 00063C   03009.63445407  .00000033  00000-0  10000-3 0  7009
2 26566  64.5891 242.8158 0039592 226.6760 168.9535  2.13099905 17426
COSMOS 2382 (711)
1 26987U 01053A   03009.51502307 -.00000054  00000-0  00000-0 0  3462
2 26987  64.8480   2.8755 0005475 186.5083 319.0841  2.13102916  8608
COSMOS 2381 (789)
1 26988U 01053B   03009.77880544 -.00000053  00000-0  00000-0 0  3406
2 26988  64.8517   2.8579 0023878 216.7357 220.9242  2.13102929  8622
COSMOS 2380 (790)
1 26989U 01053C   03009.88862204 -.00000053  00000-0  00000-0 0  3480
2 26989  64.8444   2.8767 0006640  78.4890 308.4377  2.13102886  8627
```

So to calculate the SaVi needed parameters from the NORAD format, the following script was written using TCL also and was embedded within SaVi.

```
proc tle_file_input {filename} {
   set now [split [exec date -u {+%D %T %Y %j %H %M %S}] " "]
   set date [lindex $now 0]
   set time [lindex $now 1]
   puts stderr "For all these satellites, time 0 is $date $time GMT."
   set year [string trimleft [lindex $now 2] 0]
   set day [string trimleft [lindex $now 3] 0]
   set hour [string trimleft [lindex $now 4] 0]
   set minute [string trimleft [lindex $now 5] 0]
   set second [string trimleft [lindex $now 6] 0]
   set epoch_now [expr $day+($hour+($minute+$second/60.0)/60.0)/24.0]
   set MU 398601.2
   set PI 3.14159
   set f [open $filename r]
   set line1 0
   set line2 0
   savi GV_BEGIN
   while {[gets $f line] >= 0} {
            # remove white space
            set line [string trim $line]
            if {([string length $line] == 69) &&
               ([string index $line 0] == 1)} {
               # first elements line
               set epoch_year [string range $line 18 19]
               if {$epoch_year < 50} {
                        incr epoch_year 2000
               } {
                        incr epoch_year 1900
               }
               set epoch [string range $line 20 31]
               # compute delta t
               set dt [time_difference $epoch_year $epoch $year $epoch_now ]
               set line1 1
            } elseif {([string length $line] == 69) &&
                        ([string index $line 0] == 2) && ($line1 == 1)} {
               # second elements line
               set inc [string range $line 8 16]
               set ascending_node [string range $line 17 24]
               set ecc 0.[string range $line 26 32]
               set arg_perigee [string range $line 34 41]
               set mean_anomaly [string range $line 43 50]
               set mean_motion [string range $line 52 62]
               set line2 1
            } else {
               # line with name or junk
               set line1 0
               set line2 0
            }

            # if we have everything then write out a satellite!
            if {($line1 == 1) && ($line2 == 1)} {
               # write out orbital elements
               set period [expr 86400/$mean_motion]
               set a [expr pow($period*sqrt($MU)/2.0/$PI,2.0/3.0)]
               set mean_anomaly [expr fmod($mean_anomaly + \
                                                      $dt*$mean_motion*360.0, 360.0)]
```

```
            set T [expr $period*$mean_anomaly/360.0]
            savi LOAD $a $ecc $inc $ascending_node $arg_perigee $T

            set line1 0
            set line2 0
        }
    }
    savi GV_END
}
```

So all what the user has to do now is to download the NORAD file of the specific Satellite system save it with .tle extension so that Savi can recognize it and load it in SaVi and the simulation will be running within 1 second.



5. Conclusion

Since Satellite Communication is a promising and developing field, having a reliable tool to calculate the constellations of such Satellite communication systems would be of great use.

Fortunately, by the end of our project, this tool is working with great performance and reliability.