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COMMUNICATIONS DURATION WITH LOW EARTH ORBITING SATELLITES

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ABSTRACT
Communication via satellite begins when the satellite is positioned in the desired orbital position. The satellite's coverage area on the Earth depends on orbital parameters. Ground stations can communicate with LEO (Low Earth Orbiting) satellites only when the satellite is in their visibility region. The duration of the visibility and so the communication duration varies for each satellite pass at the ground station. For low cost LEO satellite ground stations in urban environment it will be a big challenge to ensure communication down to the horizon. The communication at low elevation angles can be hindered through natural barriers or will be interfered by man made noise. This paper discusses the variations of the communication duration between the ground station and LEO satellites and investigates if it is useful to support low elevation passes. For this paper data recorded at the Vienna satellite ground station within the Canadian space observation project "MOST" (Micro variability and Oscillations of Stars) are applied.

KEY WORDS
LEO, satellite, coverage, duration

1. Introduction

A typical satellite communication system comprises a ground segment and a space segment. Basic parameters of communication satellites are communication frequency and orbit. Frequency allocations are treated by international agreements. The orbit is the trajectory followed by the satellite. Several types of orbits are possible, each suitable for a specific application or mission. Generally, the orbits of communication satellites are ellipses within the orbital plane defined by orbital parameters. Orbits with zero eccentricity are called *circular orbits*. The circularity of the orbit simplifies the analysis. The movement of the satellite within its circular orbit is represented by *orbital time, radius, altitude* and *velocity*. Circular orbits are mainly categorized as GEO (Geosynchronous Earth Orbits), MEO (Medium Earth Orbits) and LEO (Low Earth Orbits).

2. Space Orbital Parameters

In order to completely describe the movement of the satellite in space only a few parameters are required to be defined. These are known as space orbital parameters which schematically are presented in Fig. 1 and defined under items a), b), c) and d).

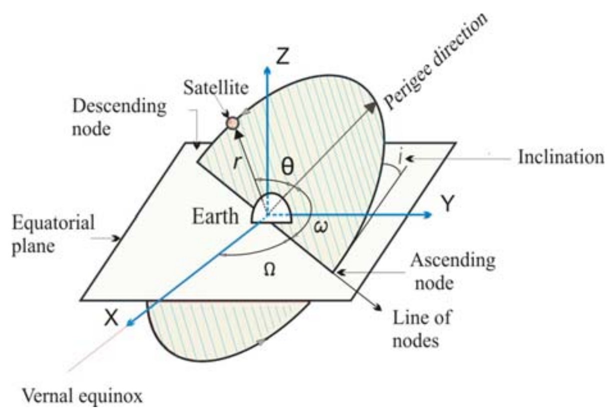


Fig. 1. Space orbital parameters.

a) The position of the orbital plane in space.
This is specified by means of two parameters - the *inclination i* and the *right ascension of the ascending node Ω*. Inclination *i* represents the angle of the orbital plane with respect to the Earth's equator. The right ascension of the ascending node *Ω* defines the location of the ascending and descending orbital crossing points (these two nodes make a *line of nodes*) with respect to a fixed direction in space. The fixed direction is Vernal equinox. Vernal equinox is direction of line joining the Earth's center and the Sun on the first day of spring [2].
b) Location of the orbit in orbital plane.
Normally an infinite number of orbits can be laid within an orbital plane. So, the orientation of the orbit in its plane is defined by the *argument of perigee ω*. This is the angle, taken positively from 0º to 360º in the direction of the satellite's motion, between the direction of the ascending node and the direction of perigee.

c) Position of the satellite in the orbit.
The position of the satellite in orbit is determined by the angle υ called the *true anomaly,* which is the angle measured positively in the direction of satellite's movement from 0º to 360º, between the direction of perigee and the position of the satellite.
d) The shape of orbit.
The shape of orbit is presented by the *semi-major axis a* which defines the size of orbit and the *eccentricity e* which defines the shape of the orbit (These two parameters are not explicitly seen in the Fig.1).

3. The Coverage Area

The position of the satellite within its orbit considered from the ground station point of view can be defined by *Azimuth* and *Elevation* angles. The *coverage area* can be defined as a region of the Earth where the satellite is seen with a minimum predefined elevation angle. The concept of azimuth and elevation is presented in Fig. 2. The ellipse in Fig. 2 is the horizon plane.

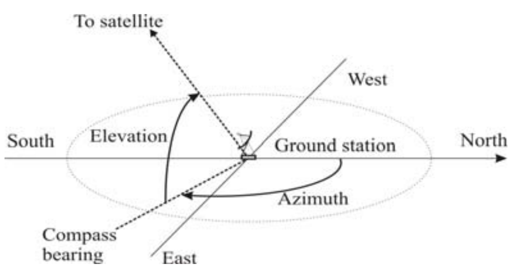
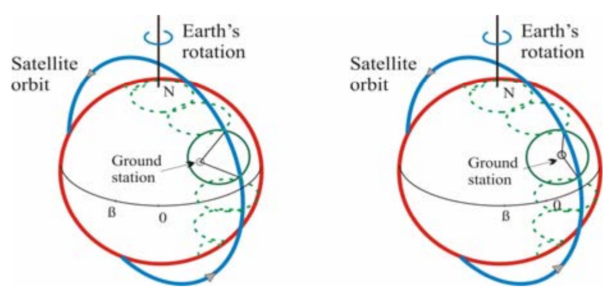


Fig. 2. Azimuth and elevation.

Because of the Earth's motion around its North-South axis the satellite passes at the ground station change from pass to pass. This is presented in the Fig. 3.



a) b)

Fig. 3. Satellite pass for an Earth rotation angle of β per orbit a) first pass and b) second pass.

The orbital plane is in principle fixed and defined by orbital parameters (see Fig. 1). Because of Earth's rotation around its N-S axis for angle β (see Fig. 3), the ground station changes the position relatively to orbital plane, so the pointing (azimuth and elevation) from the ground station to the satellite is not identical for the both satellite passes (see a) and b) in Fig. 3) [3]. Hence the communication duration between the satellite and the ground station is not constant and varies for each orbit path. This leads to the fact that there will be many passes with maximum elevation angles below 5°. The communication efficiency due to the time variations as well as the usefulness of low elevation passes will be analyzed for the Vienna satellite ground station.

4. MOST Satellite and Vienna Ground Station

The project "MOST" is a Canadian micro satellite space telescope mission. The size of the satellite is 65cm x 65cm x 30cm and the mass is about 65kg. The goals of the mission are: to analyze the inner structure of stars, set a lower limit to the age of the universe and to search for Exoplanets, by picking up tiny light variations of stars. The project "MOST" consists of a Low Earth Orbiting (LEO) Satellite and three Ground Stations, one of them in Vienna [4]. The idea of "MOST" satellite is depicted in Fig. 4.

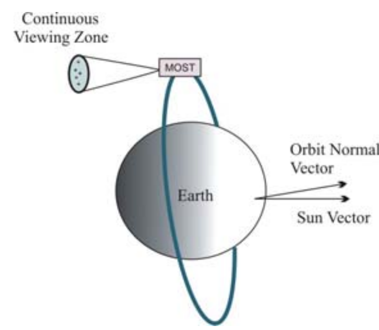


Fig. 4. MOST satellite idea.

The baseline orbit of MOST is a sun-synchronous orbit, with 98º inclination and an altitude of around 820 km. The Vienna ground station system was set up at the Institute for Astronomy of the University of Vienna in cooperation with the Institute of Communications and Radio-Frequency Engineering of the Vienna University of Technology. The ground station must track the satellite during its flyover keeping a pointing accuracy of 0.5º [4]. The ground station can interact with the satellite only if it is visible above the horizon and therefore for a fraction of few orbits per day [5]. The visibility region of the Vienna satellite ground station is shown in Fig. 5.

Fig. 5. Visibility region of Vienna ground station for elevation angle of 0° [6].

The MOST satellite has a line of sight radio contact with the Vienna ground station 6-8 times per day. The communication duration time of each satellite pass will last between 5-15 minutes.

5. Tracking of the Satellite

For tracking the satellite a tracking mechanism and software is used. The tracking software used for “MOST” is called *Nova* [6]. As inputs Keplerian elements are used calculating the actual position of the satellite. The respective software provides real-time tracking information. The display mode “radar map” includes the stars with accurate position on the sky with the ground station at the center. The perimeter of the circle is the horizon plane, with the North on the top (Az = 0º), then at the East (Az = 90º), South (Az = 180º) and West (Az = 270º). Three circles represent different elevation 0º, 30º and 60º. At the center the elevation is El=90º (see Fig. 6, 7). Software parameters which define the movement of the satellite related to the ground station are: AOS_{time} – Acquisition of the satellite (time), LOS_{time} – Loss of the satellite (time), AOS_{Az}– Acquisition of the satellite (azimuth), LOS_{Az} – Loss of the satellite (azimuth), *Max El*- Maximal Elevation and *Orbit* – Orbit number.
The communication duration is defined as:

$$Duration = AOS_{time} – LOS_{time} \tag{1}$$

and represents the maximum theoretical time duration of the communication between the satellite and ground station. In Fig. 6 and Fig. 7 two different MOST satellite passes are presented. These passes are recorded on 18 January 2004 in Vienna and presents the satellite passes in the radar map. The satellite movement in these figures is indicated as “MOST path”. During the first pass shown in Fig. 6 contact between the satellite and ground station was established.

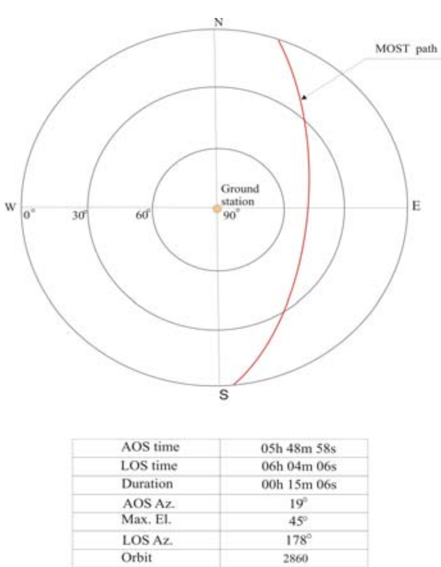


Fig. 6. MOST path (1).

At the second pass shown in Fig. 7 no contact to the satellite could be established because of natural barriers at this low elevation.

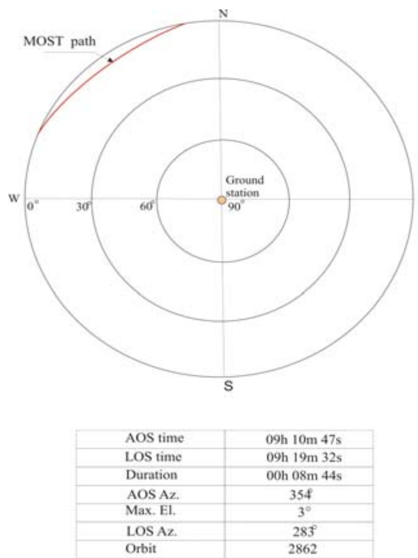


Fig. 7. MOST path (2).

So, the communication time depends on one hand on the maximum elevation and on the other hand on the practical radio horizon. The duration time of communication expressed in Eqn. 2 is based on Kepler’s law and represents the theoretical time duration, which practically is always shorter because of natural barriers, misspointing or any other interference. Table 1, shows examples for the *AOStime, LOStime and MaxEl* taken from MOST passes at the Vienna ground station.

Table 1. Expected orbital data.

Date	*Orbit number*	*AOStime*	*LOStime*	*Duration*	*MaxEl*
dd:mm:yy		hh:mm:ss	hh:mm:ss	mm:ss	º
05.12.03	2235	5:31:39	5:47:10	15: 21	84.0
15.12.03	2378	7:21:05	7:33:23	12: 18	14.0
21.12.03	2467	13:36:00	13:45:38	9: 38	6.0
13.01.04	2795	16:11:18	16:26:47	15: 29	86.0
20.01.04	2893	14:00:22	14:11:27	11: 05	11.0
25.01.04	2965	15:41:33	15:56:47	15: 14	56.0
28.01.04	3007	14:45:14	14:58:50	13: 36	22.0
28.01.04	3009	18:07:10	18:18:41	11: 31	9.0
03.02.04	3093	16:09:01	16:24:30	15: 29	90.0
08.02.04	3160	8:08:24	8:17:27	9: 03	8.0
15.02.04	3263	14:02:10	14:13:25	9: 15	10.0
18.02.04	3302	8:17:03	8:25:20	8: 17	5.0
20.02.04	3336	18:24:34	18:38:41	14: 07	23.0
27.02.04	3427	3:43:08	3:55:43	12 : 35	13.0

The different time duration for each orbit in Table 1, based on Eqn. 1 confirms the explanation by the Fig. 3. For practical reasons and in order to have real view on communication time, the *LOCKtime* (time when communication was established) and the *UNLOCKtime* (time when communication was lost) with its respective Acquisition Elevation (*AEl*) and Lost Elevation (*LEl*) was recorded and is presented in Table 2.

Table 2. Real orbital data.

Date	*Orbit number*	*LOCK time*	*UNLOCK time*	*AEl*	*LEl*
dd:mm:y		hh:mm:s	hh:mm:s	º	º
05.12.03	2235	5:32:32	5:47:00	3.0	2.0
15.12.03	2378	7:22:45	7:32:43	4.0	2.5
21.12.03	2467	13:38:20	13:43:20	4.0	4.0
13.01.04	2795	16:11:20	16:26:00	2.0	2.0
20.01.04	2893	14:01:00	14:10:00	2.0	3.5
25.01.04	2965	15:42:00	15:56:00	2.0	2.0
28.01.04	3007	14:46:00	14:57:00	3.0	4.5
28.01.04	3009	18:08:00	18:17:00	3.5	4.0
03.02.04	3093	16:10:00	16:25:00	2.0	2.5
08.02.04	3160	8:10:00	8:16:00	3.5	2.5
15.02.04	3263	14:03:00	14:12:00	3.0	3.5
18.02.04	3302	8:20:00	8:23:00	4.0	3.0
20.02.04	3336	18:25:00	18:37:00	3.0	2.5
27.02.04	3427	3:44:00	3:54:00	3.0	3.0

Usually the lock is established and lost in average at elevation angles of 1º – 4º. In order to quantify these variations in communication duration (comparing ideal and real communication time), a parameter called *Time Efficiency Factor* (T_{eff}) was defined:

$$T_{eff} = \frac{LOCK_{time} - UNLOCK_{time}}{AOS_{time} - LOS_{time}} \qquad (2)$$

The *Time Efficiency Factor* represents the ratio of the real communication duration to the theoretical communication duration. Fig. 8 shows T_{eff} in percentage as function of *MaxEl* by using the data from Table 1 and Table 2.

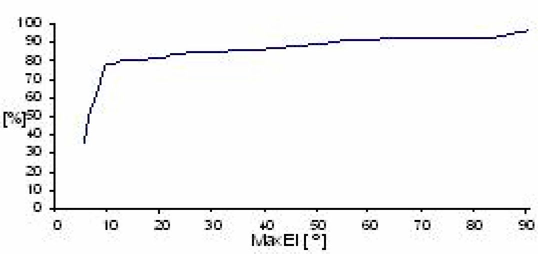


Fig. 8. Time efficiency factor dependency on maximal elevation angle.

From the Fig. 8 it is obvious, that for *MaxEl* higher than 10º it is the time variance which is keeping a trend of linearity starting at 80% toward 100%, but for *MaxEl* lower than 10º T_{eff} rapidly falls causing high time variance. Assuming a pass with an elevation of 5° with practical time duration of 3 min. and a data rate of 38.4 kbit/s, the amount of data (including the protocol) which can be downloaded during this pass is 863 kByte. Further assuming a protocol overhead of about 15% the data amount downloaded during this pass is about 735 kByte. This is worth amount of data collected by the satellite during low elevation.

6. Conclusion

During communication with LEO satellites it is obvious that at elevation angles below 10º the time efficiency falls, because of natural barriers and interference, thus not the whole pass can be used. This leads to a decreased data flow compared to the theoretical case. The analysis of the data amount at a low elevation pass has shown that it is worth to dimension the ground station also for low elevation passes, because an important part of the stored data at the satellite can be downloaded at such passes. Finally, Time Efficiency Factor could be considered as a QoS element on communication duration between a satellite and a ground station.

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