SMALL SATELLITE ACCESS OF THE SPACE NETWORK

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ABSTRACT

Small satellites have been perceived as having limited access to NASA's Space Network consisting of the TDR satellites and associated ground terminals. This paper presents the potential for access of the space network using basic small satellite design constraints and a simple helical antenna for the communications links. From the analysis derived through simulation of the orbit of both satellites, small satellites can be shown to have up to 30 minutes per orbit of single-TDRS access. Data rates on the order of 100 kbps are possible in this configuration with total daily data volumes in excess of 100 Mbits being achievable. Design parameters are given for a variety of orbital inclination angles and spacecraft transmission powers to illustrate the expected available contact time for such small satellites to the Space Network. This is compared with typical access time through a fixed ground station.

KEY WORDS

Space Communications, Satellite Design, Simulation

INTRODUCTION

There is considerable interest at this time in developing small satellites for quick turnaround missions to investigate near-earth phenomena from space; see, for example [1]. One drawback in the mission planning is the ease of communications between the earth control infrastructure and the small satellite. The nominal mission design includes a dedicated ground station for telemetry, tracking, and command support. For larger missions, the Space Network (SN) has been used to transmit data to and from orbit using the Tracking and Data Relay Satellites (TDRS) in space and interfacing to the White Sands Complex in New Mexico as the ground entry point. The advantage to the SN is that most orbits will have at least one opportunity for contact with a TDRS in the overall system constellation. Small satellite users have not often considered using the SN because of perceived problems in scheduling communications and the cost in weight and power to use gimballed, directional antennas for the communications support. Mission design tradeoffs include the required power to transmit to a relay satellite at geostationary orbit versus a ground station at the earth's surface. An additional tradeoff is the amount of on-board storage required for once-per-orbit data dumps versus storage for data dumps once or twice per day. This paper addresses the potential for SN access using non-gimballed antennas and modest transmission power.

For the small satellite system, we make the following assumptions:

a) the communications subsystem is able to supply a minimum of 10 W of output power,
b) the antenna system can provide a minimum gain of 5 dB
c) the antenna system is surface mounted along a radial vector connecting the satellite with the center of the earth and pointing away from the center of the earth
d) the small satellite is spin stabilized with a nadir orientation, that is, the long axis of the spacecraft is along the above radial vector
e) satellite contact between the small satellite and the SN can be initiated as the small satellite sweeps past the TDRS position in its orbit
f) a SN S-Band single-access service can be used for the communications link; this implies that the TDRS antenna is capable of open-loop tracking at a minimum, and
g) only the two-TDRS minimal constellation (41° W and 171° W longitude) is assumed in the SN and both TDRS are potentially available to the small satellite user.

The choice of which TDRS the small satellite uses depends upon its relative orbital position with respect to the earth and each TDRS. The SN is unable to support satellites in the zone of exclusion over the Indian ocean; however, at other times, the contact can be scheduled for when the TDRS is within the small satellite's field of view. This investigation looks at two possible SN access modes: a single TDRS is available to support access and the possibility of using the full constellation of two operational spacecraft.

In this study, we used the necessary equations of motion to solve for the small satellite and TDRS orbital motion and then determine the pointing potential. Associated with the pointing information is the determination of the slant path between the satellite and the TDRS. This information will be used to determine the data rate that can be supported given the transmitted power assumptions presented above.

FIXED GROUND STATION ACCESS

In providing low-earth orbiting satellites with telemetry, tracking, and command support, the designed often plans for support through a dedicated ground station network at a fixed location. Typically, there are two or three access times per day separated by several orbits when the contact can be initiated and meaningful data transmission can occur. The duration and timing of the contacts depend upon the orbital period, orbital inclination, minimum elevation above the horizon allowed, and ground station location. A single fixed ground station can be expected to give two to four meaningful contacts per day with up to 5 minutes per contact for 90-minute orbits with minimum elevation angles of 10°.

PROPOSED ANTENNA SYSTEM

In order for this concept to work, we are assuming that sufficient power can be obtained from an antenna without steering. The only way that this can be done is to have a fairly non-directional antenna system, i.e., one with a large Half-Power Beam Width (HPBW). The tradeoff with a large HPBW is a low gain for the system thereby giving a low Effective Isotropic Radiated Power (EIRP). In this study, we are assuming that a helix antenna is available to supply all of the transmission and reception gain. For typical helical antennas, the HPBW and directivity, D, may be computed from [2]. Table 1 lists available HPBW and gains for helix antennas expected to be appropriate for small satellites at the available Space Network S-Band return frequencies. Based on the results listed in Table 1, our assumed minimum EIRP for the study should be achievable with this technology.

Table 1. Helix Antenna Performance

Number of Turns	Gain (dB)	HPBW (degrees)
5	11.3	54.8
10	14.3	38.8
21	17.5	26.8

DETERMINING ORBITAL ACCESS

To determine if using the Space Network can be an effective alternative to the fixed-ground-station model, we first need to determine the access potential for a simple satellite communications system. For the purposes of this study, access to the SN is determined based on visibility by the user satellite of at least one of the two TDRS composing the minimum SN constellation. In this study, pure Keplerian mechanics [3] are used to predict the three-dimensional positions for both the TDRS spacecraft within the SN and a test satellite using the SN. The orbital elements for the TDRS positions were taken from [4] while the small satellite was started at a random position. The satellite and TDRS equations of motion and relative pointing angle computations were entered into the MATHCAD analysis package to form a document containing the analysis, the expected contact minutes per orbit, and the associated worst-case slant path. The orbital computations for the small satellite was varied from 14 through 16 orbits over one full day at a resolution of 100 points per orbit. The orbital inclination angle for the small satellite was varied from 0° through 110°. Three threshold angles for the pointing angle were considered: 20°, 40°, and 60° to account for narrow, medium, and wide beam antennas and to include the pointing that the TDR satellites are capable of in single access mode. The threshold angle corresponds to one-half of the antenna's HPBW. If the pointing angle was within the threshold, then the TDR satellite was considered to be visible from the small satellite. The MATHCAD simulation recorded the following data:

a) access time per day (minimum, maximum, and average) to both SN satellites individually,
b) access time per day when both satellites were simultaneously visible to the small satellite,
c) access time per day of the whole SN satellites (time when either or both TDRSS satellites was visible to the small satellite), and
d) access time to each TDRS satellite and the constellation on a per-orbit basis.

The following sections discuss the results obtained by this analysis.

ORBITAL ANGULAR COVERAGE

Using the position vectors for the satellites, we can investigate when there is a possibility for SN coverage under the constraint that the small satellite has no active positioning mechanism for antenna pointing and relays on the communications antenna sweeping past the TDR satellites. Given that standard microstrip patch antennas can have half-power beamwidths of 90° while helical antennas can have HPBW up 50°, we investigate three cases of the pointing angle between the SN satellites and the small satellite expected to be typical: the cases of the pointing being within 20°, 40°, and 60°. We then find the minimum, maximum, and average number of minutes per orbit that the satellite is within this angle. This was done for small satellites having mean motions of 14, 15, and 16 orbits per day which corresponds to orbital periods of 102.9, 96, and 90 minutes, respectively and at orbital inclination angles of 0° through 110°. The computations were made between both the east and the west TDR satellite locations and the test satellite. It was found that with this set of parameters, there was no time when both TDR satellite locations were simultaneously visible from the test satellite location. It was also found that both TDRS locations had similar results when averaged over one day. Figure 1 presents this information in the form of a plot of the number of orbits per day whose contact time through a single TDR satellite exceeds the given ordinate value in minutes. This is shown for a satellite with a mean motion of 15 revolutions per day (similar results hold for 14 and 16 revolutions per day) and the pointing constraint was to be within 20° of the TDRS. Figure 2 illustrates this same information through the constellation of both TDR satellites. As can be seen in both graphs, the number of contact minutes is highly dependent upon orbital inclination angle. Generally, small inclination angles are needed to have large numbers of contact minutes per orbit. Also, the penalty for not having a steerable antenna is seen here as well because some orbits have no contact time, even if the small satellite is not within the SN zone of exclusion.

Taking a five-minute contact time as being the minimum useful contact time, we can see how many orbits give useful contacts per day as well as the total contact duration conditioned on a minimum contact time of five minutes. This also gives a basis for comparison against fixed ground stations. Figure 3 shows the contact minutes per day on all orbits having contact times longer than five minutes through a single TDRS and through the TDRS constellation. As before, this is shown for a satellite with a mean motion of 15 revolutions per day (similar results hold for 14 and 16 revolutions per day) and the pointing constraint was to be within 20° of the TDRS. The orbits can have times where no TDRS access are possible due to large angle between the test satellite position and the TDRS. The effect is least at lower inclination angels and is worst at 90°-inclination angles. At high orbital inclination angles, this modulation of the coverage pattern reaches its maximum. As expected with these narrow pointing restrictions, there are no orbits where both TDR satellites are visible simultaneously. For the 40-degree and 60-degree pointing cases, there are many instances where on a given orbit only one of the two TDR satellites is visible on a given orbit while on the next orbit, the other is visible. Therefore, there are relatively few orbits when at least one of the two TDRS cannot be scheduled from a visibility restriction.

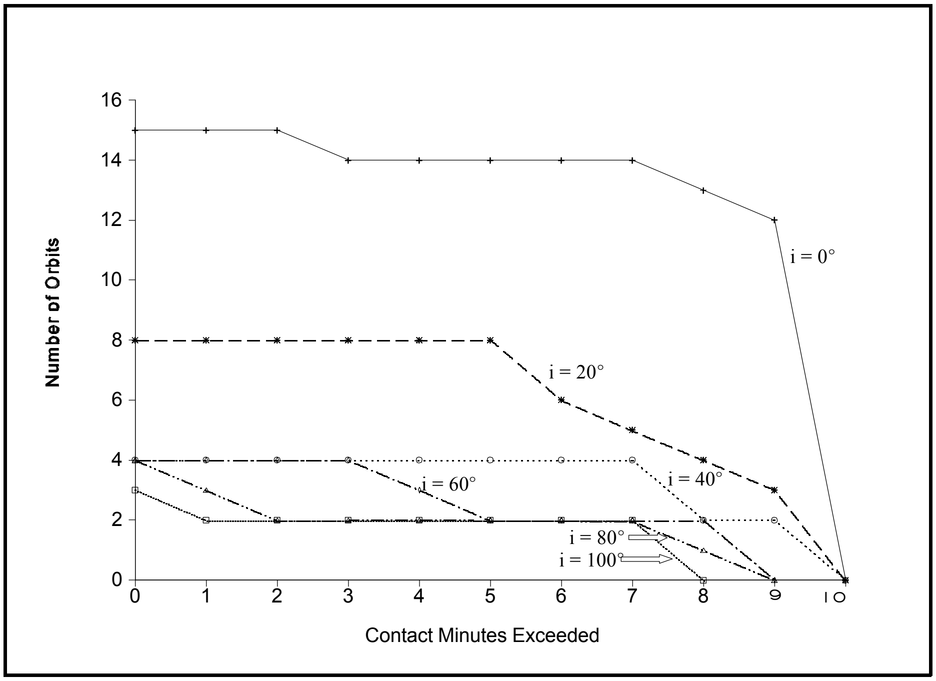

Figure 1 - Single TDRS Contact Minutes within 20° Pointing for 15 Orbits per Day.

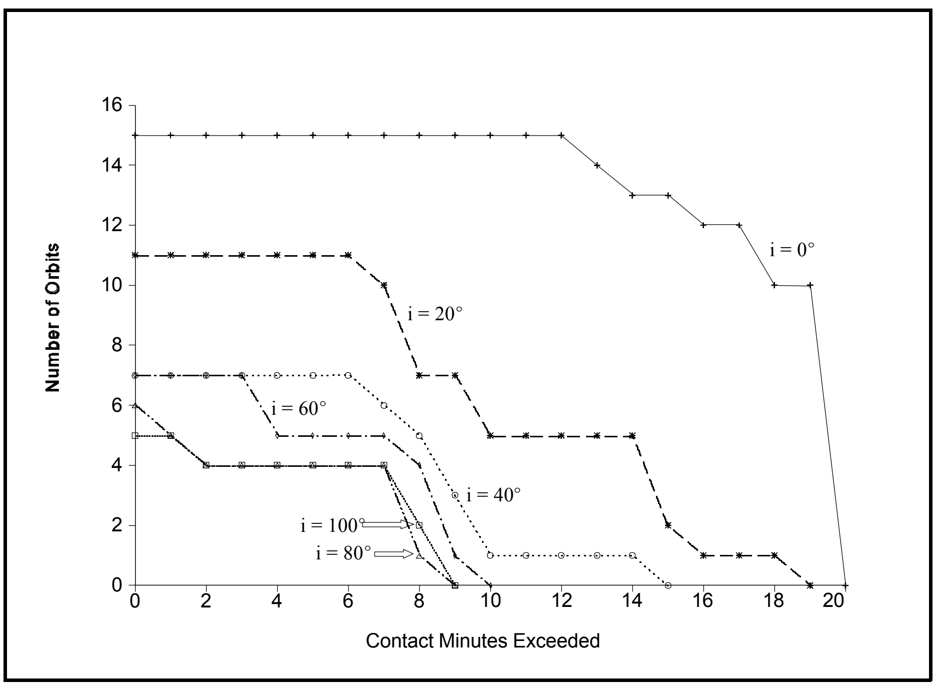

Figure 2 - Constellation Contact Minutes within 20° Pointing at 15 Orbits per Day.

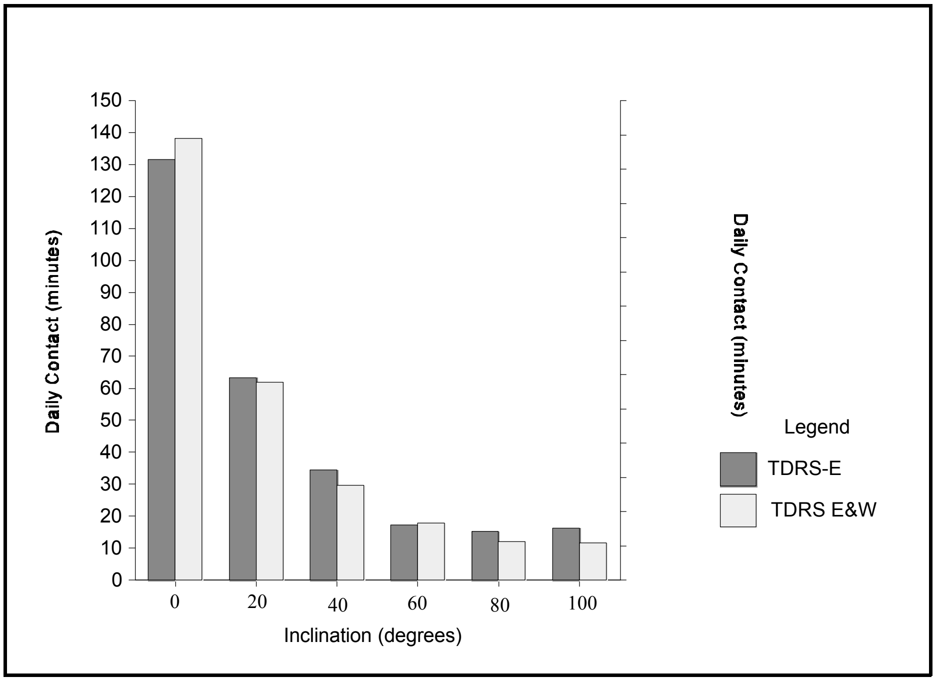

Figure 3 - Daily Useful Contact Minutes within 20° Pointing at 15 Orbits per Day for a Single TDRS and the TDRS Constellation

EXPECTED DATA RATE SUPPORT

Once the slant path is computed, the expected maximum data rate that can be supported can be determined. To determine the expected maximum data rate through the SN, a standard link budget design table [5] is used with the worst-case slant paths derived for the orbital viewing angles. This design table is configured for the various SN service modes at both K-Band and S-Band with only the latter being considered here. From the link budget design table, the data rates listed in Table 2 are expected to be supported using a SN data group 2 (DG2) transmission mode, QPSK modulation, and a minimum channel error rate of 10^{-5}. The data rate listed is the minimum that can be supported, namely, the data rate at the start or stop of the contact time when the slant path is the longest. In principle, the data rate can be increased as the contact slant path decreases through the contact time and with sufficient control, can be varied through the contact time. As can be seen, wide pointing angles result in a longer slant path and lowers the maximum data rate.

In order to estimate the usefulness of these contacts, we can estimate the total daily data volume to be transmitted through the space-to-ground link from considering that at the 50th percentile, mission models across a range of small payloads require that an average daily data transport volume corresponding to a continuous production rate of 10 kbps [6] be delivered to the ground. This corresponds to a total production of 864,000,000 bits per day. The required minimum data rate necessary is a function of the contact duration per day and the supported data rate for the communications system. Using the available data rates given in Table 2 and the total orbital time when the orbital contact time exceeds five minutes per orbit, we can compute the daily data volume that potentially be transmitted through the SN satellites. Table 3 illustrates the contact statistics in the form of millions of bits per day for the case of a single-TDRS access as well as a full-constellation (two TDRS) access. The cases of the 20° and 40° pointing correspond to configurations like the helical antenna considered earlier. As can be seen, the 50th percentile payload requirements can be supported most easily with an EIRP of 15 dBW with dual-TDRS support. It can also be obtained with the 60° pointing despite the low data rate; however, it is problematic if the required

Table 2. Space Network Slant Path and Data Rate Support

EIRP (dbW)	Pointing Angle	Max. Slant Path (km)	Data Rate (kbps)
15	20	36000	169
	40	37000	160
	60	38500	148
10	20	36000	53.5
	40	37000	50.5
	60	38500	46.5

Table 3. Space Network Potential Daily Transmission Data Volume

EIRP (dBW)	Pointing Angle (deg)	Data Rate (kbps)	Single TDRS Contact (min)	Dual TDRS Contact (min)	Single TDRS (Mb/day)	Dual TDRS (Mb/day)
15	20	169	17.28	32.64	175.2	331
	40	160	87.36	169.92	838.7	1631.2
	60	148	191.04	383.04	1696.4	3401.4
10	20	53.5	17.28	32.64	55.5	104.4
	40	50.5	87.36	169.92	264.7	514.9
	60	46.5	191.04	383.04	533.0	1068.7

number of contact minutes can be obtained with actual operational network support. In the other cases, the 50th percentile cannot be achieved but a substantial data volume can be supported.

CONCLUSIONS

The orbital analysis shown here indicates that there is a reasonable expectation that accessing the Space Network for space-to-ground communications from a small satellite with a fixed antenna is not only possible but makes operations sense. The advantage to the Space Network is that orbital access can occur several times per day for durations that can greatly exceed that found with fixed ground stations. The link margin penalty still exists but is overcome by allowing a greater volume per day through the space link that possible through the fixed ground station link. There is also the advantage of the space network not causing a major data backup is a fixed access time is missed. The next orbit, or one shortly thereafter, an access time will occur. Total access times through the Space Network can be considerably more than that through a single ground station. With this configuration, sufficient data volume can be transported through the space network to support the 50th percentile of required data support for small payloads given sufficient antenna gain and transmission power to reach an EIRP of 15 dBW.

ACKNOWLEDGEMENT

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