

STUDY OF A DATA COLLECTING SATELLITE CONSTELLATION

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ABSTRACT

The Brazilian Environmental Data Collection System, currently operated by INPE, is constituted by three satellites (SCD1, SCD2 and CBERS2), two data receiving stations (Cuiaba and Alcantara), more than 600 Data Collecting Platforms (DCPs) installed over Brazil, and a data collection mission center (Cachoeira Paulista). The system enjoys a growing interest in the user's community as can be seen by the steady growth in number of the DCPs deployed over Brazil. However, the current system cannot assure fully satisfactory time regularity of the collected data for new applications. In addition, SCD1 and SCD2, although presenting a very good functional performance, have exceeded their nominal lifetime. In order to improve this system, a low cost constellation of 3 small spin stabilized satellites was proposed in a previous work. It considered 3 orbital planes separated by 120 degrees in the right ascension of the ascending node (RAAN), with only one satellite per orbit plane and 30 degrees inclination. In order to improve the system performance and to extend the system use for new real time applications such as warning systems, this paper presents proposals to reduce the revisit time to around 16 minutes, for any single DCP installed in the Brazilian territory, by using a satellite constellation with four satellites per plane, providing almost continuous coverage.

1 INTRODUCTION

The space segment of the Brazilian Environmental Data Collection System is composed of two dedicated small data collecting satellites (SCD1 and SCD2), and a remote sensing one (CBERS2). Since the launch, in 1993, of the first satellite SCD1 (Rozenfeld et al., 1994), the system user community presented a very important growth, both in terms of number of users as well as of applications diversity. The importance gained by the system, reflected by the growing user community and increasing interest in the system services, imposes the need for replacement of the current satellites.

An overview of the INPE's existing data collection system (Teracini et al., 2000) is presented in the section 2. Following, a brief description of a previously developed study of a new data collecting satellite constellation is presented (Rozenfeld et al., 2003). This study was directed toward the definition of an improved system, regarding data collecting temporal distribution, and valid message reception rate, considering as a constraint that the average revisit time should be in the order of one orbital period (about 100 minutes). Starting from the results of this study, an analysis

of new possible constellations is presented in order to reduce the average revisit time to the order of 16 minutes (approximately the maximum pass duration of a data collecting satellite over a ground receiving station). The inclusion of new orbital planes and more than one satellite per plane is considered. Section 5 presents some final comments and conclusions.

2 EXISTING DATA COLLECTING SYSTEM

Nowadays, the Brazilian Data Collection System is composed of two small data collecting satellites SCD1 and SCD2; the China-Brazil Earth Resources Satellite CBERS2 (which, in addition to the remote sensing cameras, carries on-board a data collecting transponder); two data receiving stations located at Cuiaba and Alcântara; 600 DCPs (installed over Brazil); and a data collection mission center (CMCD) located at Cachoeira Paulista for message processing, archiving and distribution. Each DCP transmits to the satellite in UHF-band and the satellite retransmits the data back to ground receiving stations in S-band (SCD1, SCD2 and CBERS2) and in UHF-band (CBERS2). The DCP messages are stored in receiving stations. After a satellite pass, the stored messages are transferred to the CMCD, where they are processed and distributed to the users via Internet. The satellites retransmit the received DCP signals to ground in S-Band (2.267,52 MHz). In the case of CBERS2, the DCP messages are down linked additionally in UHF-band (462,5 MHz). This feature is very convenient, since working in UHF band makes easier the use of a low cost reception station. A UHF station prototype is currently being tested at INPE with promising results. A low cost receiving station operating in S-band is also under development.

During SCD1 mission exploitation phase, the DCP network (Magina, 2001) experienced a very significant increase, not only in quantity, but also in applications diversity. The DCP network (Yamaguti et al., 1994; Teracine et al., 2000) started with 60 platforms when SCD1 was launched. This number remained stationary until 1996. Then a remarkable growth of the DCP number has been verified, with the acquisition of 200 platforms (176 hydrological and 24 meteorological) by the Brazilian National Agency for Electric Power. At the same time, initiatives as the one of the Time, Climate and Hydrological Resources Program of the Ministry of Science and Technology made the number of platforms experience a considerable growth. Nowadays more than 600 DCPs are installed, comprising a wide field of applications. There are hydro-meteorological DCPs collecting data on air temperature, precipitation level, wind direction and speed, and river and reservoir water level. Others collect data on atmospheric pressure, CO₂ and O₃ concentration and air temperature, allowing studies in the field of environmental science and atmospheric chemistry. The usefulness of DCPs collecting river and reservoir water level has been prominently displayed during the last drought in Brazil (October 2001 - March 2002). The drought has caused electric power shortage in the country. DCP data are also used to monitor the water levels, in order to estimate the remaining power generation potential of the hydroelectric power plants. Some DCPs, located over the Brazilian coast, perform measurements of submarine pressure, water temperature, water salinity and atmospheric pressure. Still others installed on fixed and drifting buoys, collect data required to investigate oceanic surface circulation and buoy location experiments. The data collected is being used in several fields such as climatology, agricultural planning, meteorological and environmental control, geomagnetism, hydrologic resources prediction, etc.

The SCD1 satellite (Lopes et al., 1994) was launched on 1993 at about 14:42:20 GMT by the North American Pegasus launcher. Its expected lifetime was estimated, before launch, to be one year. Nowadays, almost 12 years after the end of the expected lifetime, the functional performance of SCD1 in terms of data collection can be considered quite nominal. The SCD2 (Rozenfeld et al., 1999) was launched on October 22, 1998, also by the Pegasus launcher. It is still presenting a

satisfactory performance, after more than six years in orbit, exceeding the initial two years lifetime. SCD2 was placed, like SCD1, in an orbit with approximately 750 km of altitude, at 25 degrees inclination, allowing a reasonable coverage of the whole Brazilian territory. Each satellite completes 14 orbits a day, 8 of which are visible by the Cuiaba ground receiving station (main station). SCD2 and SCD1 orbital planes are separated by 180 degrees in RAAN. Due to this fact, SCD2 passes, always cover existing gaps of the SCD1 passes over a given ground station or DCP.

SCD2 has a more adequate payload antenna design and pointing, in relation to the ground stations and DCPs. As a consequence, its rate of valid retransmitted DCP messages (about 76%) is higher than that of SCD1 (about 59%).

CBERS2, developed and manufactured in cooperation by Brazil and China, was launched on 21 October 2003, with an expected lifetime of two years.. It is operated on a time shared basis by the two countries. In terms of valid DCP message rate, CBERS2 presents a performance just a little bit better than SCD2: 77%.

Fig. 1 shows the visibility regions of DCPs located at the extreme north (Oiapoque), at the extreme south (Chui), and at the center (Cuiaba) of Brazil, considering 10 degrees minimum elevation.

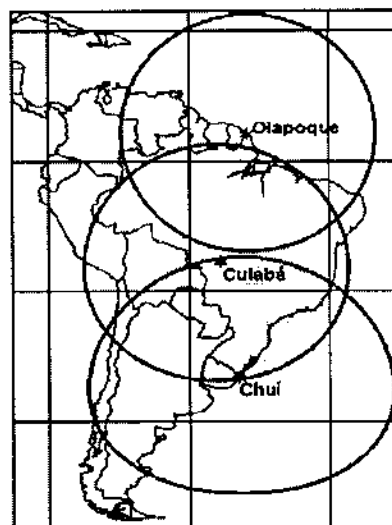


Fig. 1. Visibility Regions for Oiapoque, Cuiaba and Chui locations

CBERS2 is in a polar sun-synchronous orbit, with local time of equatorial plane crossing at 10:30 AM. This orbit is adequate for its earth observation mission, but not for data collection, since there are only about three CBERS2 daily passes over Brazilian territory. For this reason, the temporal distribution of CBERS2 passes are worse than those of SCD1 and SCD2. This can be observed in Fig.2, which graphically shows the passes of the three satellites over Cuiaba station. While SCD1 and SCD2 present about 7 visible passes a day over Cuiaba, CBERS2 presents 3 passes per day. However, CBERS2 three-axis autonomous attitude stabilization results in a more adequate antenna pointing. As a consequence, the percentage of valid messages during satellite passes is, for CBERS, a little bit better than for SCD2. Another important characteristic of SCD1 and SCD2, displayed on Fig. 2, is that they are in complementary orbits. The daily periods, which are not covered by SCD1, are covered by SCD2 and vice versa.

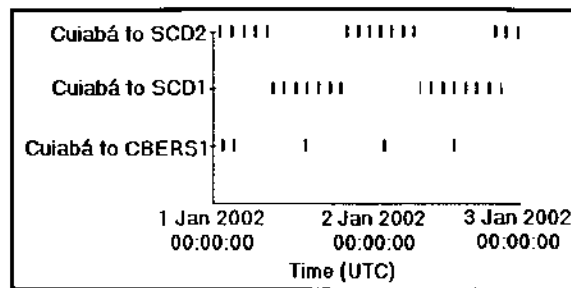


Fig. 2. Satellite Passes over Cuiaba Station (Center of Brazil)

As far as the Brazilian northern region is concerned, the existing satellites cannot assure a good satellite pass distribution. There are visibility gaps with duration of up to 3 hours, twice a day. If CBERS2 were not considered, the revisit time would increase up to 5 hours. The current system shows poor characteristics in terms of temporal regularity of environmental data collection, for the northern region. In the case of the southern region, CBERS2 does not fill the gaps in which there are no SCD1 and SCD2 passes. Due to this fact, for this region, the revisit time can reach values up to 6 hours.

3 PREVIOUS STUDY RESULTS

A previous study (Rozenfeld et al., 2003) proposes an improved new system to replace the existing one, not only to assure its continuity, but also to increase its reliability and performance. The analysis of the existing system has shown that it has no satisfactory temporal regularity of the data collection service, for both the northern and southern regions. In order to cover the existing gaps between access periods for these regions, it was proposed the use of a constellation with three small satellites, similar to SCD2, with orbital planes separated by a 120 degrees angle in RAAN. In order to obtain a better coverage of the Brazilian southern region (whose latitude goes down to -33 degrees) it was analyzed the effect of increasing orbit plane inclination, starting with 25 degrees (the current inclination of SCD1 and SCD2). The analysis leads to a compromise solution, since increasing the orbit inclination angle the coverage become better for the southern region but, at the same time, worsening for the northern one. In conclusion, it was proposed to consider 30-degree inclination angle for the data collecting satellites. The considered constraint in terms of data collection regularity was to have at any Brazilian region at least one satellite pass each orbital period (about 100 minutes).

In spite of its simple attitude control system, SCD2 presents the same percentage of valid message as CBERS2 (about 77%), which is equipped with an expensive three-axis stabilized attitude control system. It was suggested that a SCD2-like attitude system should be adopted for the proposed constellation (spin stabilization, autonomous spin rate control, and spin-axis directed around the ecliptic normal, based on magnetic control). Since only one satellite per orbit plane was considered, there is no need of phasing maneuvers and, owing to this reason, spin stabilization was suggested.

4 STUDY OF A NEW DATA COLLECTING SATELLITE CONSTELLATION

In order to improve the system performance and to extend the system use for new real time applications such as a warning system, the objective is to reduce the revisit time to around 16 minutes for any DCP installed in the Brazilian territory. Starting from the previous work results, the idea is to allow the placement of more than one satellite per orbital plane to meet the new goal. This revisit time is of the order of the maximum pass duration over a ground receiving station. By imposing this magnitude for revisit time, one will have an almost continuous data collecting system

operation, since only few time intervals with no satellite access will occur. It was considered, like in the previous analysis, the existence of only three orbital planes, which are separated by 120 degrees in RAAN and orbit inclination of 30 degrees. The satellites sharing each orbital plane are regularly distributed in the orbit, that is, the phase angle between any two consecutive satellites is considered as a constant. The number of orbit planes will be fixed to three, in order to minimize the number of launches, which would be needed to place all satellites in orbit. The idea is that all satellites, which will share the same orbit plane, could be placed in orbit simultaneously, by a single launch. The existence of more than one satellite sharing the same orbit plane imposes the need of maintaining an adequate relative phasing between the satellites. This requires the capability of performing orbit maneuvers, in order to control the satellite relative phasing in each constellation orbit plane. Therefore, an adequate solution in terms of attitude stabilization system is to adopt a three-axis stabilization system to enable the satellite thruster pointing during orbit maneuvers.

The study has been performed through the simulation of all suggested constellation formation, by using the "Satellite Tool Kit – STK v6.1 (copyrights by Analytical Graphics Inc). For each constellation analyzed it was computed the average revisit time and corresponding standard deviation, for the northern (Oiapoque) and southern (Chui) extreme points of the Brazilian territory, as well as for a central point (Cuiaba). A simulation period of 48 hours was considered for every case study.

The study started by considering a constellation with 2 satellites per orbit plane. In this case the obtained results, in terms of average revisit time and corresponding standard deviation, are presented in Table 1. Comparing these results with the previous study (when only one satellite per orbit is considered) one observes a significant reduction in the revisit time of more than 60%: from about 100 minutes in the previous study to about 30 minutes in the current case. This lower average revisit time, represents a good improvement in the constellation performance, related to the data collection performance. If one standard deviation shift is considered, one can have minimal revisit time of about 9.5 minutes over Cuiaba, and maximal of about 48 minutes over Oiapoque. It can be considered itself a good option in terms of enhanced data collecting constellation, although it does not present average revisit time of the order of 16 minutes.

Table 1. Average Revisit Time with 2 satellites per orbital plane

	Extreme North (Oiapoque)	Extreme South (Chui)	Center (Cuiaba)
Average Revisit Time (minutes)	32.29	36.26	22.81
Standard deviation (minutes)	15.99	10.91	13.15

Table 2 presents the obtained results when 3 satellites per orbital plane are considered showing not significant change of average revisit times; however, the standard deviation presents very reduced values, meaning that the maximum value of the revisit time is significantly lower than the one corresponding to the previous case. The maximal value presented by the average revisit time is about 40% greater than the 16 minutes average revisit time, for any Brazilian region.

Table 2. Average Revisit Time with 3 satellites per orbital plane

	Extreme North (Oiapoque)	Extreme South (Chui)	Center (Cuiaba)
Average Revisit Time (minutes)	26.09	21.74	25.25
Standard deviation (minutes)	4.04	8.49	3.80

The results obtained for the case when 4 satellites per orbit plane are considered are presented in Table 3. As one easily observes, these results are in compliance with the imposed restriction for revisit time (16 seconds), since the maximal value for the average revisit time, which is displayed by Chui location, is of only 16.49 minutes. Considering 1-sigma deviation, one can also observe that, during the simulation interval, the maximal value for the revisit time is only about 20 minutes (Oiapoque), while the minimum value is about 4.2 minutes

Table 3. Average Revisit Time: 4 satellites per orbital plane

	Extreme North (Oiapoque)	Extreme South (Chui)	Center (Cuiaba)
Average Revisit Time (minutes)	11.96	16.49	12.59
Standard deviation (minutes)	7.70	1.28	5.38

The constellation of 4 satellites per orbit plane has a satisfactory performance in terms of revisit time, with the capability to improve significantly the time distribution of the data collection services. It can operate in an almost continuous way, making possible to provide a near real time response.

Fig.3 presents a graph of the revisit time as a function of time for Chui, where one can observe that there is a periodic regularity of the revisit time variation between the successive passes over the considered location.

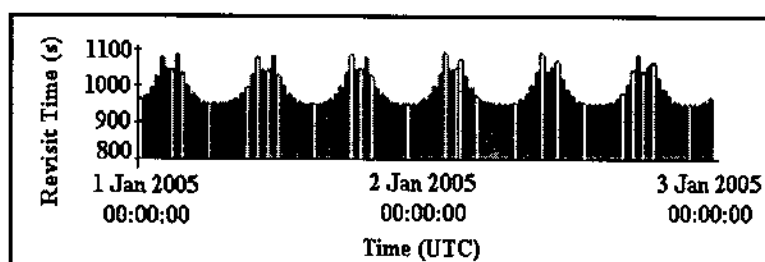


Fig. 3. Revisit Time for Chui

In order to illustrate the relative distribution of the satellite passes over a given location, it is presented in Fig. 4 a graph displaying the successive satellite passes over Chui. One can observe in this figure that there are practically no overlaps between satellite passes. There is a satisfactory matching level between a satellite pass and the gaps of the other ones.

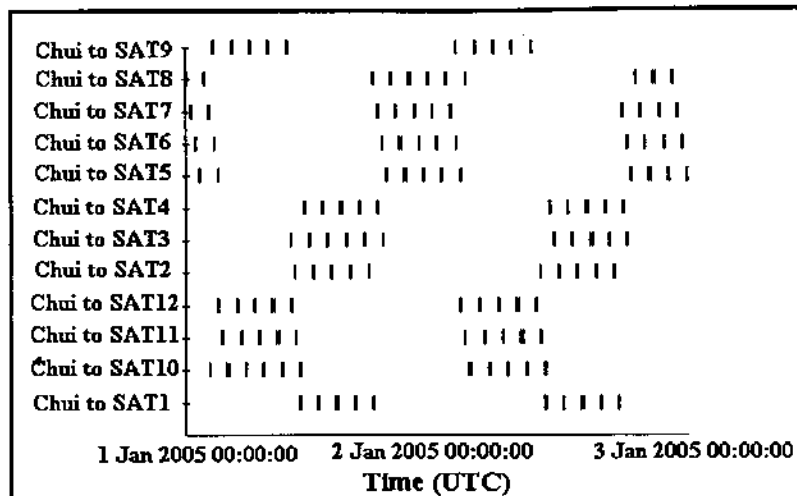


Fig. 4. Satellite Passes: Extreme South of Brazil (Chui)

Although the shown constellation with 4 satellites per orbital plane satisfactorily complies with the proposed objectives, it is presented in the table 4 the results obtained when 5 satellites per orbital plane are considered. One sees that in this case, as expected, the revisit time falls with a good margin below to the 16 minutes restriction. Considering a one-sigma deviation range, one verifies that even the maximum value, in this case displayed by Oiapoque, is less than 16 minutes.

Table 4. Average Revisit Time: 5 satellites per orbital plane

	Extreme North (Oiapoque)	Extreme South (Chui)	Center (Cuiaba)
Average Revisit Time (minutes)	10,47	9.63	5.53
Standard deviation (minutes)	4.44	2.98	5.29

As mentioned above, having more than one satellite sharing the same orbit plane restricts the use of spin stabilization for the constellation satellites. The need of maintaining the relative phase angle between the satellites that share the same orbit plane makes more adequate the use of an attitude stabilization system which have the capability of actively maintaining the thrusters pointed to adequate directions, in order to make possible the execution of relative phasing maneuvers. For this reason, a three-axis stabilization system is proposed as a suitable solution.

The availability of low cost receiving stations could extend the service area to other regions of the planet and stimulate the establishment of cooperation between INPE and foreign institutions, which demonstrated their interest in the use of the Brazilian Environmental Data Collection System.

5 CONCLUSION

The Brazilian Environmental Data Collection System, although well accepted by the user community, in the next phase could be improved in terms of temporal regularity to meet applications with real time data reception requirements.

By increasing the number of satellites sharing the same orbit plane, it was verified that it is possible to design a constellation, with three orbit planes with 30 degrees inclination, which could be the basis of a new data collecting system with an almost continuous working capability.

It was verified that a constellation with four satellites per orbit could satisfy the proposed objective. The idea of limiting the number of constellation orbit planes in three is to minimize the number of launches which would be needed to place all satellites on orbit. The satellites that share the same plane could be launched simultaneously in a single launch.

As more than one satellite will share the same orbit plane it is necessary to have the capability of applying relative phasing orbit maneuver. In order to make it easier to point the thrusters for phasing maneuvers, it is suggested to provide the satellites with a simplified three-axis attitude stabilization system.

The improved constellation would assure, not only the future continuity of the Brazilian Data Collection System, but also enable an increased quality on the provided services. Additionally, other improvements could be considered such as the use of a high stability oscillator in the DCP transponder for drift buoys and mobile platform transmitters to increase the location accuracy as well as the use of new system access protocol like platform interrogation or even on board processing.

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