INCLINED SATELLITE ORBITS AND RESULTING GROUND STATION NETWORK SOLUTIONS FOR NEAR EQUATORIAL AREAS

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ABSTRACT

For countries like Indonesia, situated along equator it makes sense to build and exploit inclined satellites that only monitor a strip above and below the equator. The inclination is directly proportional to the area monitored. The larger the area being is monitored, the higher is the inclination and the more seldom the satellite comes over same area. In this sense the polar orbit is the orbit that monitors an area with the lowest temporal resolution possible but the only one covering the entire globe. The only area where the polar orbit has the highest possible resolution is near the poles that tend to have limited interest for most applications (except polar research applications).

This paper analyses which inclination is best suited for a remote sensing satellite covering the tropical parts of the world and how ground stations should be located in the most efficient manner to see all orbits and minimize latency.

The STK analysis shows that a location on or very near the equator is not ideal, except for very low inclinations. Instead two ground stations at the same latitude as the satellite inclination north and south of the equator will ensure that all passes are received. In addition an off-set in longitude that is dependent of the satellite inclination is needed. The paper covers the cases for 0-25 degrees inclination and points out the tradeoffs of these orbits with special focus on ground station locations for the different inclinations.

Keywords: inclined orbit, ground stations, station networks
INTRODUCTION

The typical Low Earth Orbit is a polar orbit. These orbits pass nearby both poles on each revolution. The inclination is close to 90 degrees to the equator. Most polar orbits are sun-synchronous which assures that each successive orbital pass occurs at the same local time of day. This enables that the illumination for optical remote sensing satellites is comparable and applications like classification and change detection can (partly) be automated.

To retain the sun-synchronous orbit as the Earth revolves around the sun during the year, the orbit of the satellite must change at the same rate. Were the satellite to pass directly over the pole, this would not happen. Due to the Earth's equatorial bulge, an orbit inclined at a slight angle is subject to a torque which causes precession; it turns out that an angle of about 8 degrees from the pole produces the desired precession in a 100 minute orbit.

Figure 1: Sun-synchronous Orbit (Image courtesy: NASA illustration by Robert Simmon)

The result is an orbit that continuously covers the entire globe. However, the Polar Regions are covered far better (14/14 passes) than equatorial regions (max 4/14 passes). Of these four passes normally only the one-two descending passes are used for acquiring data. Given the high probability of cloud coverage in equatorial regions the data yield over the equatorial regions is likely to become unsatisfactory.

It is therefore not surprising that countries on or close to the equator have been analyzing orbits that allow more frequent revisit times and promise higher data yields and hence better exploitation of the satellites over their countries. The most famous equatorial orbit is the geostationary orbit (GEO). Given its distance of 35786 kilometer to the ground and the fact that it has one revolution per day like the Earth it is mostly used for Communication applications. The meteorology community is also utilizing geostationary satellites for frequent weather coverage, but the spatial resolution offered from a GEO orbit still makes it not usable for normal Remote Sensing applications. Future instruments with much higher resolution may change this, which would also allow taking advantage of the ideal temporal resolution that the GEO orbit offers, thus opening for continuous monitoring.
However, until these technical hurdles (based on physics) are not solved only LEO orbits can be used for effective Remote Sensing applications.

INCLINED ORBITS

A zero degree LEO orbit will limit the satellites’ Earth coverage to its swath (and depending on the satellites’ agility) over the equator. Therefore a slightly inclined orbit usually is chosen. In comparison with the polar LEO orbits the trade-off is between temporal resolution (how often passes the satellite over a given area) and geographic resolution (how large is the total area that can be covered). Any near equatorial country will choose the inclination in a way that the entire country will be covered. This for example is 10° for Indonesia, 7° for Malaysia, 32° for Brazil and 16° for Nigeria.

Singapore Technology (AgilSpace) has developed a concept that uses an inclined near equatorial orbit and addresses this region – where many countries cannot afford their own satellites – as a market. It plans to launch a satellite TeLEOS-1 in 2015 on a commercial basis. The planned inclination is between 10-15 degrees (TBC). The market prospects for inclined satellites are one of the challenges, as the global coverage a polar orbit delivers always will address a far bigger market. Given the large areas over the world that often is cloud free (such as e.g. the Gulf region), this will result in a more stable business plan for financing a polar satellite. On the other hand there is a clear lack of coverage of the equatorial region, which cannot be satisfied with polar orbiting satellites today. Such equatorial coverage would be a welcome complementary data source to the polar orbiting satellites.

Analyzing the Committee on Earth Observation Satellites (CEOS) handbook on past and flying missions shows that approximately 80 percent of all Low Earth Orbiting Satellites (LEO) are polar sun-synchronous; 10 percent polar non sun-synchronous; 7 percent inclined between 40-80 degrees and only 3 percent have an inclination of 40 degrees or less. Only two satellites have no inclination.

Table 1. Satellites with inclinations of 40° or less

<table>
<thead>
<tr>
<th>Satellite Owner</th>
<th>Mission</th>
<th>Inclination</th>
<th>Launch</th>
</tr>
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<tbody>
<tr>
<td>NASA</td>
<td>SORCE</td>
<td>40°</td>
<td>2013</td>
</tr>
<tr>
<td>CNES</td>
<td>Diademe 1 &amp; 2</td>
<td>40°</td>
<td>1967</td>
</tr>
<tr>
<td>NASA/JAXA</td>
<td>TRMM</td>
<td>35°</td>
<td>2001</td>
</tr>
<tr>
<td>KARI</td>
<td>Kompsat 1&amp;2</td>
<td>28°</td>
<td>1999</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>INPE</td>
<td>SCD 1&amp;2</td>
<td>25°</td>
<td>1993</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1998</td>
</tr>
<tr>
<td>CNES/ISRO</td>
<td>Megha-Tropique</td>
<td>20°</td>
<td>2011</td>
</tr>
<tr>
<td>ANGKASA/ATSB</td>
<td>RazakSAT</td>
<td>9°</td>
<td>2009</td>
</tr>
<tr>
<td>INPE</td>
<td>SSR 1&amp;2</td>
<td>0°</td>
<td>2007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2012</td>
</tr>
</tbody>
</table>
KSAT GROUND STATION NETWORK

Figure 2: KSAT global ground station network

KSAT is the leading commercial ground station provider on a global scale and has both polar Ground stations and near equatorial stations. The main reason for the near equatorial ground stations in the KSAT network (also known as mid-latitude stations) is that optical satellites acquire their images on the descending orbits. Once the data has been acquired over the Northern hemisphere users want the data to be used as fast as possible and the most effective way to do so is to receive it near the Southern fringe of the continents.

All KSAT stations have both S- and X-band capabilities which mean that they can be used for down linking payload data, as well as for TT&C and especially for the Launch and Early Orbit Phase (LEOP). The stations are all operated and remotely controlled from the Tromsø Network Operations Centre (TNOC). They are connected to high bandwidth Internet ports with 150-400 MBits per second. This means that data can be distributed to anywhere in the world directly from any of the stations – given that the customer has a similar Internet capability installed. This results in low latency and opens for Near Real Time applications.

For a satellite owner it makes no sense to build up an entire ground segment for a single mission. The KSAT network offers a highly cost effective way to build or augment a network in a scalable manner at much lower price than building a network dedicated for one mission.

As the mid-latitude stations presently serve polar missions that only need a few passes per day in this region, capacity is available on these antenna systems for serving e.g. inclined missions.

The following analysis shows – using the KSAT network as an example with its mid-latitude stations in Singapore, Dubai, Mauritius and Hartebeesthoek (South Africa) - how different satellite inclinations can be best served with different combinations of ground stations. It should be mentioned that the KSAT network is developing steadily and new locations are under investigation.
INCLINED ORBITS ANALYSIS WITH KSAT GROUND STATIONS

Figure 3: Ground Station Coverage of KSAT mid latitude network at an inclination of 10°

Figure 4: Ground Station Coverage of KSAT mid latitude network at an inclination of 20°

Figure 5: Ground Station Coverage of KSAT mid latitude network at an inclination of 30°

Figure 6: Ground Station Coverage of KSAT mid latitude network at an inclination of 40°
It is not surprising that for inclinations of 10 degrees or less a single ground station very close to the equator, as for example Singapore gives the ideal result with coverage of all passes.

At an inclination of 20 degrees Singapore still sees the majority of passes but misses a few. A combination of two stations located approximately +10 and –10 degrees below and above the equator gives a better result.

For an inclination of 30 degrees each of the stations in Dubai and in Mauritius allow for better coverage than the station in Singapore, which is only receiving 5 out of 14 passes with satisfactory pass length. The Dubai/ Mauritius combination offers 11 of 14 passes per day, which means that the satellite can be used in a much more effective manner.

Finally, for an inclination of 40 degrees this becomes even clearer. Singapore is reduced to two ascending and two descending passes – as for polar satellites. On the other hand the combination of Dubai and Mauritius delivers now 12-13 out of 14 passes. The additional combination of Hartebeesthoek delivers a few very long passes which could prove beneficial, especially during a LEOP.

CONCLUSION

The comparison of these inclination scenarios shows that the ground station network needs to be selected according to the inclination of the satellite(s) supported. The KSAT mid-latitude stations offer tailored solutions for any kind of inclination, complementing its polar network capabilities.