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

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KEY WORDS: Inclined Orbit, Ground Station Network, Latency

ABSTRACT: For regions like South East Asia that are situated close to the equator it makes sense to build and exploit inclined satellites that only monitor areas near the equator. The orbit inclination results in a trade of between the size of the area monitored and the frequency of monitoring this area. A satellite with 0 degrees inclination will monitor each point in the satellites swath near the equator up to 14 times per day but the area covered will be limited to the satellites swath along the equator. The higher the inclination, the larger the area being monitored will be and the more seldom the satellite covers the same area. In this sense the polar orbit is the orbit that monitors an equatorial area with the lowest temporal resolution over the equator, but the only one covering the entire globe. The area where the polar orbit has the highest temporal resolution is near the poles that tend to have limited interest for most applications.

This paper analyses different inclinations that are well suited for remote sensing satellites covering the equator near parts of the world and how ground stations should be located in the most efficient manner to cover all orbits and to minimize latency.

The STK analysis shows that a location on or very near the equator only needs one ground station near the equator, but in most cases with inclinations between 20-40 degrees two ground stations at the same latitude as the satellite inclination minus a few degrees north and south of the equator will ensure that almost all passes are received. The paper covers the cases for 0-40 degrees inclination and points out the importance of selecting a good ground station network of these orbits.

1. INTRODUCTION

The typical Low Earth Orbit (LEO) 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 ensures that the illumination for optical remote sensing satellite images is comparable in a time series 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. Was 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.

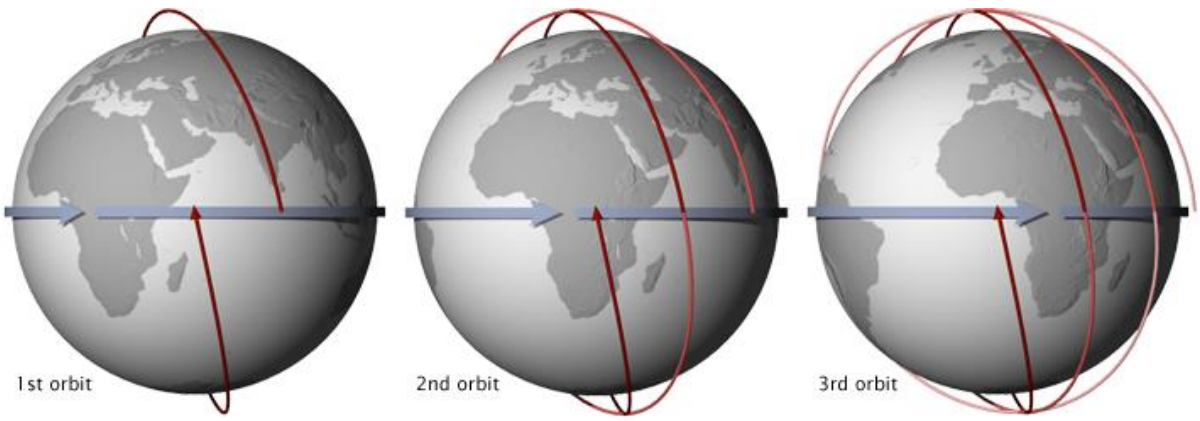

Figure 1: Sun-synchronous Orbit (Image courtesy: NASA illustration by Robert Simmon)

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 the maximum four passes over the equator normally only the one or two descending passes are used for acquiring optical remote sensing 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 considering orbits that allow more frequent revisit times and promise higher data yields and hence better exploitation of the satellites over their region.

The most famous equatorial orbit is the geostationary orbit (GEO) with zero degrees inclination. Given its distance of 35786 kilometer to the ground and the fact that it has one revolution per day makes it geosynchronous. The meteorology community is utilizing geostationary satellites for frequent weather coverage, but the spatial resolution offered from a GEO orbit still makes it not usable for high resolution 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 LEO orbits remain best suited for effective high resolution Remote Sensing applications.

2. INCLINED ORBITS

A zero degree LEO orbit will limit the satellites' Earth coverage to its swath (depending on the satellites agility) over the equator. Therefore an inclined orbit usually is chosen to widen the coverage of the satellite. 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). Most 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 28° for Burma.

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 called TeLEOS-1 in 2015 on a commercial basis. The planned inclination will be between 10-15 degrees. The market prospects for inclined satellites are one of the challenges, as the global coverage that a polar orbit delivers always will address a far bigger market. Given the large areas over the world that often are 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 clearly lack of frequent coverage of the equatorial region, which cannot be satisfied with today's polar orbiting satellites. Such equatorial coverage will 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 LEO Satellites 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 in orbit have no inclination.

Satellite Owner	Mission	Inclination	Launch
NASA	SORCE	40°	2013
CNES	Diademe 1 &2	40°	1967
NASA/JAXA	TRMM	35°	2001
KARI	Kompsat 1&2	28°	1999 2006
INPE	SCD 1&2	25°	1993 1998
CNES/ISRO	Megha-Tropique	20°	2011
ANGKASA/ATSB	RazakSAT	9°	2009
INPE	SSR 1&2	0°	2007 2012

Table 1. Satellites with inclinations of 40° or less

3. KSAT GROUND STATION NETWORK

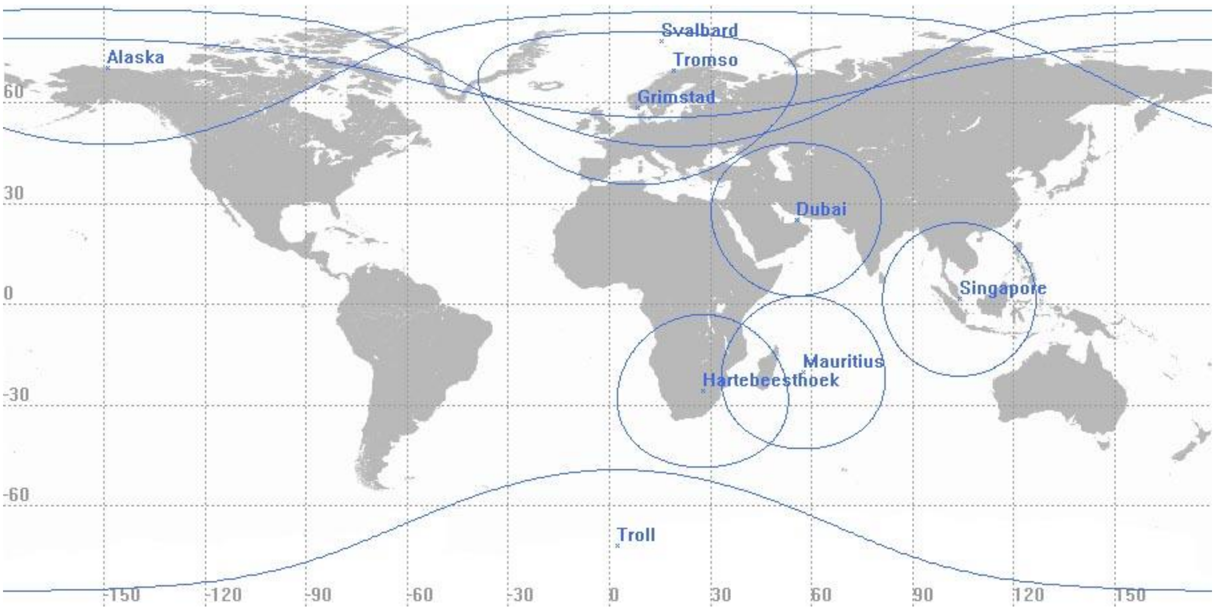

Figure 2: KSAT global ground station network

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 part of orbits – hence flying southwards from the North Pole. 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 down link the data near the Southern fringe of the continents.

All KSAT stations have both S- and X-band capabilities which means that they can be used for down linking payload data, as well as for TT&C to send up new commands while receiving data at the same time. These stations are also suited for the Launch and Early Orbit Phase (LEOP). The stations are all operated remotely and controlled from the Tromsø Network Operations Centre (TNOC) – located at 70° north. The location of a Network Operations Centre is with today's communication infrastructure not important as fiber connectivity allows for delays globally measured in milliseconds. The remotely controlled stations are connected through 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 up 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. It also offers unique locations otherwise unavailable to satellite owners in the Arctic and Antarctica, giving access to 26 of 28 possible contacts per day.

As the KSAT 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 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 best be served with different combinations of ground stations. It should be mentioned that the KSAT network is developing steadily and new locations are under investigation.

4. INCLINED ORBITS ANALYSIS WITH KSAT GROUND STATIONS

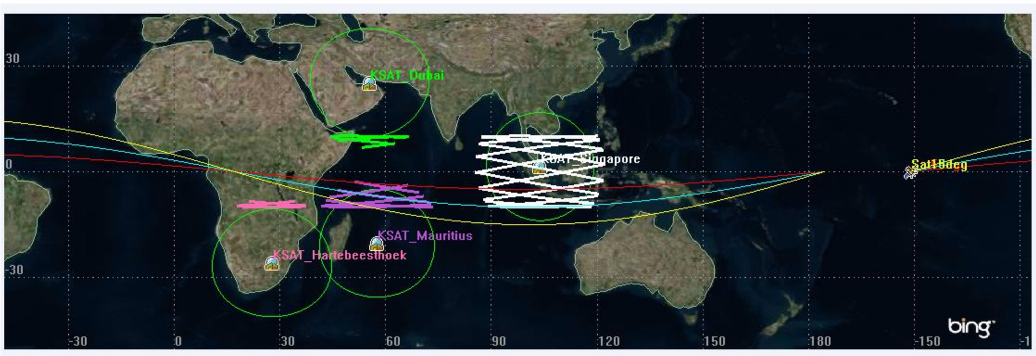

Figure 3: Ground Station Coverage of KSAT mid latitude network at an inclination of 10°

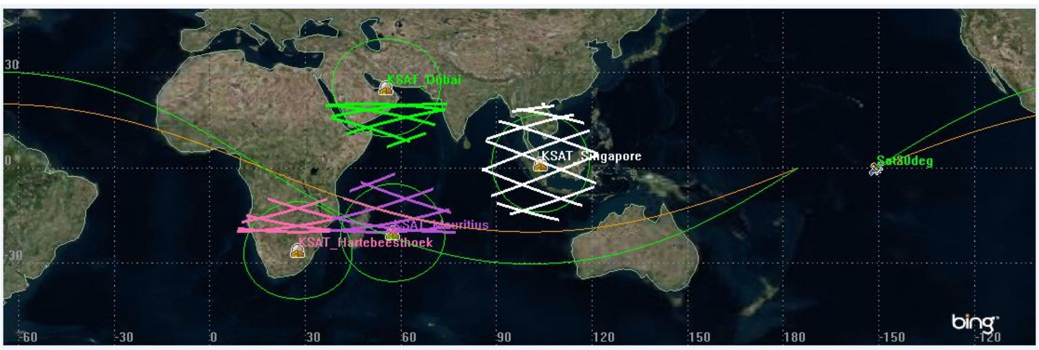

Figure 4: Ground Station Coverage of KSAT mid latitude network at an inclination of 20°

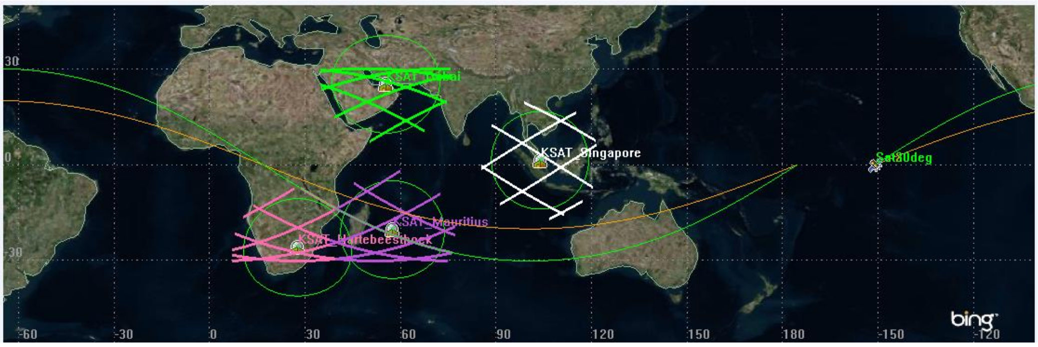

Figure 5: Ground Station Coverage of KSAT mid latitude network at an inclination of 30°

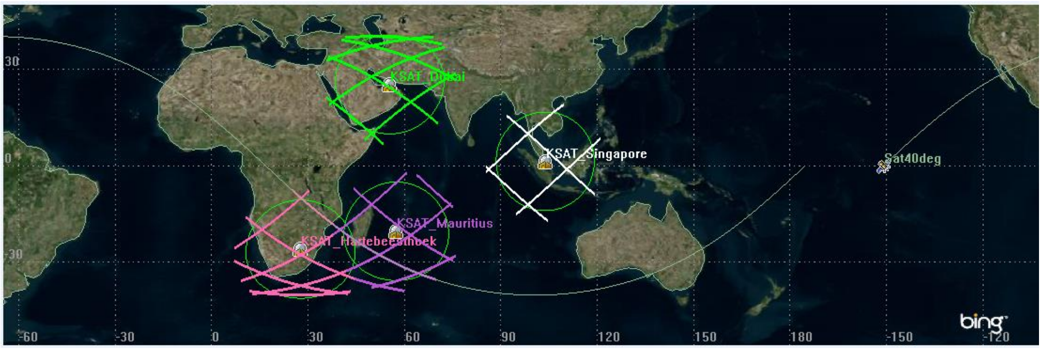

Figure 6: Ground Station Coverage of KSAT mid latitude network at an inclination of 40°

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 would give 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 trend 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 out of 14 passes. The additional combination of Hartebeesthoek delivers a few very long passes which could prove beneficial, especially during a LEOP.

5. 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). The KSAT mid-latitude station network offers tailored solutions for any kind of inclination, complementing its polar network capabilities. In addition investments and risks are lowered for the satellite owner and the long time experience and efficiency of KSAT ground station network operations is another important bonus.