WHATEVER!!!!

IRNSS

Analysis of Opportunities and Challenges

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Hello World,

I am very happy to learn that India has initiated the implementation of a dedicated navigational system of satellites to enable civilians and military establishments with navigation in and around India. IRNSS, as the Indian space program calls it, is a regional navigational system, meaning it would only cover India and surrounding regions. This system is quite different from the global navigational systems that are capable of locating any point on planet earth. Having sat through the orbital mechanics, attitude dynamics, space propulsion and spacecraft design classes at Mississippi State University, I am more than eager to analyze the IRNSS based on what I've learned and make an attempt to look into the possible opportunities that the IRNSS may provide along with the challenges it may face.

The first of the 7 satellites of IRNSS, namely the IRNSS-1A was launched on July 1st, 2013. According to the official releases, the satellites are supposed to be lined along 34^o, 55^o, 83^o, 111.5^o and 131.5^o East longitudes. 4 of the7 satellites would be in geosynchronous orbits while the remaining three would be geostationary. The inclination for the geosynchronous orbits as per official release is 29^o. Base on the basic information we have so far, it becomes easy to draft the ground track of the IRNSS satellites with a little wiggle room for satellite positioning that we would be discussing further in this article. Given below is Fig.1 which is my conception of how IRNSS would be (This is a Ground Track or 2D plot of Path traced by the satellites as per the information given above, simulated using STK):

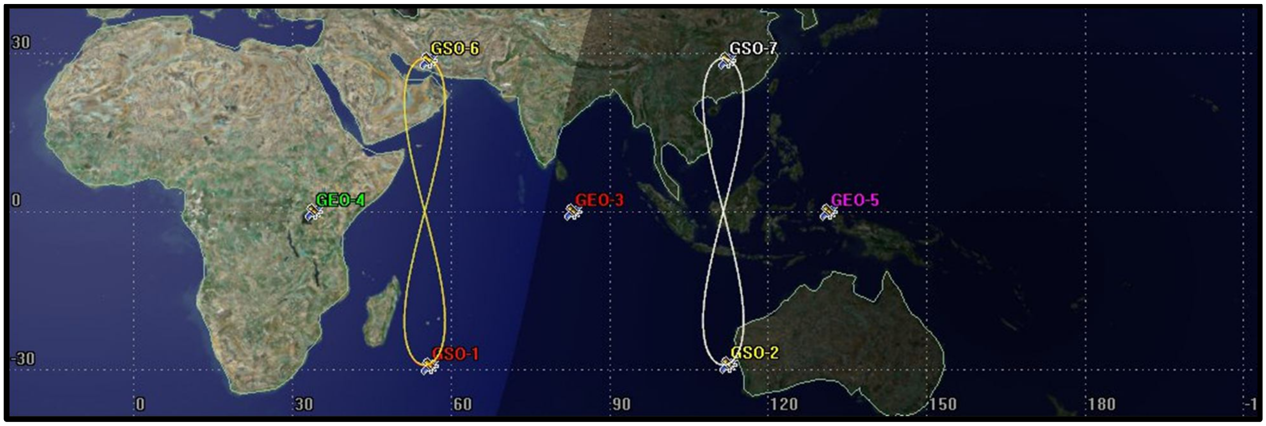

Fig 1 Indian Regional Navigation Satellite System Schematic (Conceptual)

Fig.1 given above has 3 satellites along the equator and 4 satellites located at either end of the 8-shaped loop. The 3 satellites (titled GEO-#) without a visible trajectory-plot are geo-stationary satellites that are supposed to be above a specific location on earth at all times. In other words, they tend to revolve around the earth in a heavily synchronized manner that for the observer on earth, these satellites are just stationary objects in the sky. Therefore the 2D-Plot above has no visible path traced on the map. The other 4 satellites (titled GSO-#) are geosynchronous satellites that are in orbits inclined with the earth's equator. The extent of the 8-shaped loop on either side of the equator indicates the inclination of the geosynchronous orbit. As per official release, the inclination of the geosynchronous satellite orbits is 29^o and you can see that the 8-shaped loop extends until 29 degrees on either side of the equator. This orbit has a trajectory traced on the map, making the geosynchronous satellites visible over a "specific region" on earth. The position of the geosynchronous satellites, at either ends of the 8-shaped trajectory are a result of a basic assumption and in reality, their position with respect to their complimentary geosynchronous satellites may be different depending upon the orbital design which in turn would depend on the IRNSS strategic requirements that we will discuss as we proceed further.

Orbit Altitudes and Impacts

The IRNSS satellites are, based on the minimal details we have so far, are designated into orbits that are rather located at very high altitudes. The IRNSS-1A satellite has been launched into an orbit with an apogee of 35874.6 km, which is around the standard GSO/GEO orbit parameters (altitude wise). This altitude also marks the end of Middle Earth Orbits (MEO) and the beginning of High Earth Orbits (HEO). The GPS satellites are located at an altitude of approximately 20000 km, which is in the mid-region of the MEO band. Fig.2 given below is something I found online that I think gives a good pictorial view of orbit altitudes.

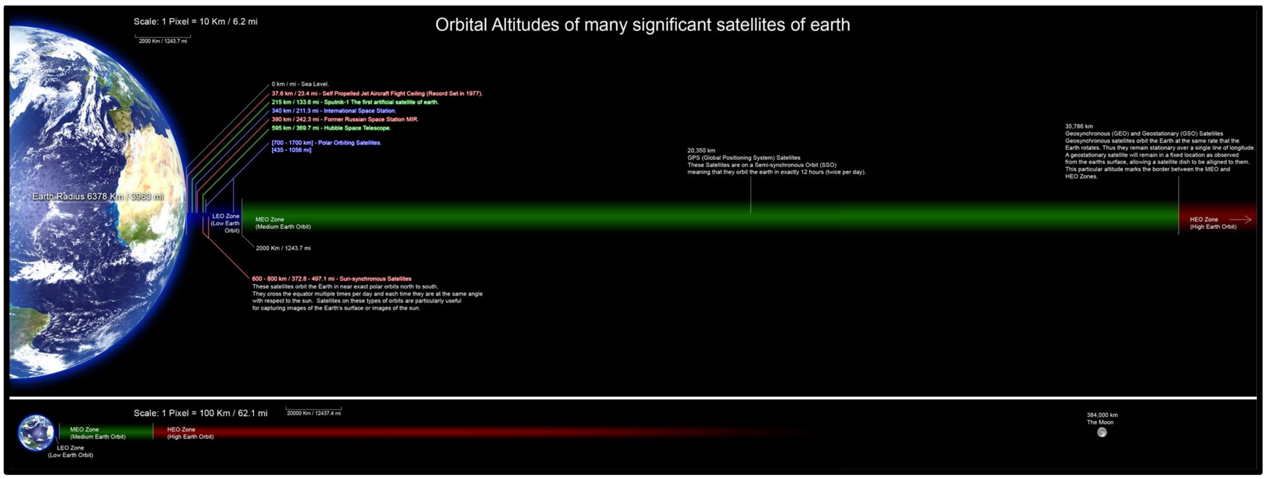

Fig 2 Orbital Altitudes (http://commons.wikimedia.org/wiki/File:Orbitalaltitudes.jpg)

The orbit altitude marked first from the right on Fig.2, is the end of MEO's and beginning of HEO's and the IRNSS-1A has been launched into an orbit at this altitude. The altitude marked in the middle of the image in that of the GPS satellites. With the IRNSS navigational satellites located at least 12000km (approx.) beyond the GPS satellites; the IRNSS has a tougher job to do with respect to accuracy in positioning, which would mean a stronger methodology for error correction in force, in comparison to that used by the GPS Program.

IRNSS Life Expectancy

Any constellation of satellites tends to have a definite life expectancy with respect to their primary mission objectives. Apart from the primary mission objectives, the satellites individually have a definite operational life depending on various factors. Now the life of a constellation is the minimum life of the constituting satellites, orbit wise or operation wise. In other words, the constellation is said to be alive as long as the satellites are alive and looking at where they are supposed to be looking at. With one of the satellites dead (system failure), the constellation is useless. If all the satellites are alive and working but deviate away from their designated orbits and don't look at where they are supposed to be looking at, the constellation is rendered useless. The reality of natural forces such as the earth not being a perfect sphere, the earth's gravitational sphere of influence being non-uniform and constant movement of earth's neighboring bodies(moon, planets and so on) tend to impart a condition on any satellite that is otherwise called orbital-decay.

Orbital Decay may result in the reduction in orbit altitude, satellites swaying away from their target locations or any other orbital transformation that may be beyond the scope of orbital corrections or station-keeping. Estimating such orbital decay would give us an approximate timeline of the viability of the satellites, with respect to their mission objectives.

I wanted to see how long the IRNSS would last mission-objective wise and used STK to estimate the orbital decay of IRNSS constellation. Given below is the video of IRNSS constellation's operation for a time period of 10 years:

Youtube Video.1: http://youtu.be/rRmMmIEz-ys

The video above is a capture of simulation done on STK with the basic details of IRNSS constellation design details that are publicly available so far and my assumptions as to what may contribute to the primary mission objectives of such a constellation of satellites. The orbit perturbation captured in the video above is based on the application of J4 Orbit Propagator, a very basic second-order orbit propagator that accounts for the secular variations (short-term oscillatory variation) of orbit properties due to oblateness of earth. The solar and lunar gravitational forces are not included since we do not have the accurate orbit details of all the 7 satellites yet. The atmospheric drag element is insignificant as the satellites of IRNSS are way above the atmosphere of earth.

As you can see in the video, the geostationary satellites oscillate (very minutely) in the north-south direction and the geosynchronous satellites make a longitudinal shift towards the left by approximately 40^o that may otherwise be a distance of approximately 4500 km on the surface of the earth. This is a considerable shift that clearly indicates that at least 2 of the 4 geosynchronous satellites would go out of range from the target area. The leftward shift may not necessarily be a unidirectional shift as the simulation is based on orbit parameters that include my assumptions and the perturbation component is J4 which is quite discreet in its own way. More than the direction of the shift made by the ground-track, it the amplitude that seems interesting to note. If such a large variation is set to occur with very few disturbances included, the real time decay of the orbits may be much beyond what this simple simulation has captured.

To get a more realistic view of the orbit decay, I used the option in STK that enables the program to take the Two Line Element sets of the concerned satellite and use the real time data observed as the basis for simulation of the orbit perturbation. For this case however, I prefer to see just the one satellite that has been launched (IRNSS-1A). This is to ensure that we do not mix a lot of assumptions with a small amount of real time data. Find below the video of the simulation of Orbit Perturbation of IRNSS-1A for a period of 10 years:

YouTube Video.2: http://youtu.be/GokNArLBtYA

This video tends to capture the periodic variation in orbit parameters that is indicated by the left-right oscillation of the ground track of IRNSS-1A. Again, this simulation is not an exact match with the real time perturbations that IRNSS-1A would face but it is more precise than the one shown in the previous video (of the IRNSS constellation). The propagator used for this simulation is called Simplified Perturbations Propagator (SPG4) and this methodology uses the TLE data of the satellite for the respective parameters of the simulation. Technically, this propagator considers secular (short-term) and periodic (long-term) variations due to oblateness, solar & lunar gravitational effects, gravitational resonance effects and also incorporates a simple drag model. The drag model however is insignificant in this case as the orbit altitude is very high.

This simulation's significant feature is the "swaying" of the geosynchronous orbit, measuring little over 40^{o} in longitude or a surface distance of 4500-5000km. This is quite similar to the "swaying" captured in the previous simulation shown in Video.1.

The "swaying" of the geosynchronous orbit of IRNSS-1A indicates that a steady station-keeping responsibility is to be shouldered in order to keep the tracking/positioning process with minimum error propagation. This really matters because the error propagation in the tracking/positioning process would directly impact the direction shown on a display device on earth (the GPS unit that we use). The more the error, the higher will the pointing errors in the device, ultimately confusing the user. The error correction does involve a considerable amount of signal processing from the ground-based segments of IRNSS but it is always better to avoid as much error as possible so as to keep the error-correction minimal and accurate.

Although the videos shown above are a result of orbit propagation, a technique based on mathematical methods, it is just a math-based attempt to model real events in the real world and there is no guarantee that the variation of orbit parameters as predicted will happen in real time. For those who are wondering about the background of such predictive methods, the dark lords of Runge-Kutta Methods, the Lagrange and Euler conspiracies and the evil forces of Gaussian Quadrature Formulas, (as most techies feel during college days) are part of the basics of such orbit propagation techniques. Unfortunately, not a lot of us got access to such service-minded teaching in the Indian engineering colleges, where we could have been told the real life applications of such mathematical techniques.

IRNSS Constellation Configurations and Impact

I used an attitude constraint for all the satellites where the nadir is aligned with the earth-centered inertial velocity constraint but had the constraint offset at 0. The orbital design for the constellation is slightly different from that shown in Fig.1. The geosynchronous satellites (GSS's), in my view, are supposed to be covering the entire target region (India and regions around, say about 1500 km beyond the borders). When I tried simulating the IRNSS constellation having the GSS's 180^{o} apart from each other in their respective orbits, they positioned themselves at the upper and lower extremes of the geosynchronous orbits (as shown in Fig.1). But such a positioning would mean that both the GSS's would not be exactly viewing the target areas, at least not at the same time.

I decided to play around with the Argument of Perigee of the GSS's and realized that setting them apart by 90^o in one orbit and by 270^o in the other orbit, we would have a constellation, where at any given time, two of the GSS's would be traveling in parallel, while the other two would have a complimentary trajectory covering the northern and southern half of the geosynchronous orbit. Unlike the previous set-up as shown in Fig.1, this offset-positioning of geosynchronous satellites enables IRNSS to have at least one satellite in both the northern and southern sections of its target area and also avoids the situation where all the 4 satellites tend to "crowd-over" the equator, when they are set symmetrically 180^o apart. Fig.3 given below shows the "crowding" aspect that I think would hamper the IRNSS's objective of reducing Dilution of Precision:

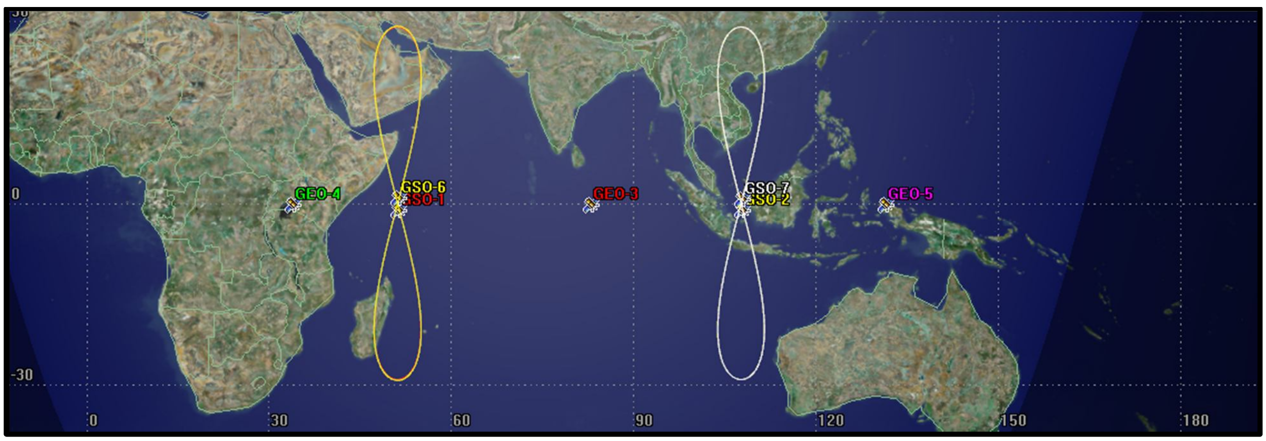

Fig 3 "Satellite Crowding" over the equator (when set apart by 180^o)

We can notice that the geosynchronous satellites (titled GSO-#) are "crowded" near the equator and the northern/southern regions of the target are does not have even one satellite looking over them. From the "Possibility" standpoint, satellites, while at the equator can look or can be made to look at the northern/southern ends of the target area but from the "Feasibility" standpoint, it would call for a frequently changing heavily demanding attitude maneuvers, complicating station-keeping efforts. Moreover a straight view from the point above is more precise than the inclined view from a far off distance, meaning, the error-correction challenges would be greater in magnitude and intensity. Spatial configuration of constellation does impact the accuracy of navigation and in space-terms, it is often denoted by the Position Dilution of Precision Factor (PDOP factor). It is true that error-correction to great extents is possible in today's world, but that would make the cost of positioning service higher than the estimated amount, leading to unavailability and inaccessibility due to monetary and administrative reasons, in whichever order they may impact.

I personally feel, with the offset-positioning of geosynchronous satellites, the IRNSS would have a constant view of its target region with a minimized attitude correction executed on the GSS's in a cyclical fashion. I always prioritize "comfortable station-keeping" over anything else when it comes to preserving primary mission objectives. The Fig.4 given below shows how I expect the IRNSS satellites to be placed, if the idea is to have at least one satellite look over both the northern and southern regions respectively:

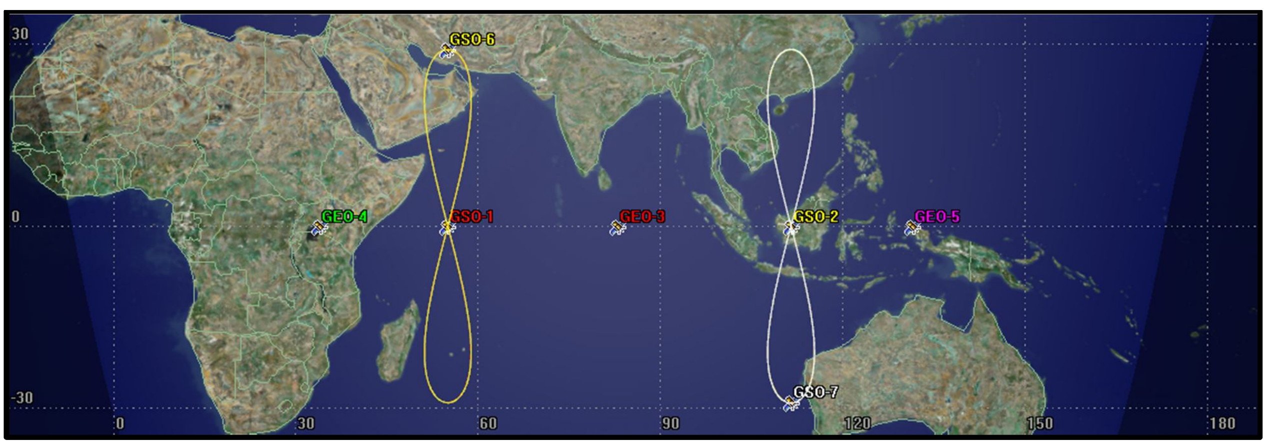

Fig 4 Geosynchronous satellites positioned for maximum coverage and continuous visibility (north/south of target area)

It has to be noted that, for two satellites to be above and below the equator at the same time looking over India, the two geosynchronous orbits need to be inclined to the equator such that one of them should be indicated with a negative angle for inclination (for the sake of symmetry) such as 29^o and -29^o. Now negative inclination is just a mathematical indication of the downward inclination the orbit might have with respect to the equator. In real terms the inclinations of the orbits may be 29^o and 151^o. The launch costs may increase but if the cost of positioning service at the error-correction/ground-based processing stage is reduced with expensive launches (lift-off and ΔV burns), then I would consider that a valuable and sensible investment as the whole purpose of the program is to create an effective positioning service to be used by the military and civilian population of India and possibly by those in the surrounding regions. Also largely varying elevation and azimuth angles of satellites would mandate a strongly regulated ground-based tracking system that has the flexibility and economic frugality to accommodate the data coming in from far away directions at the same time. I would suggest deploying separate ground stations dedicated for the IRNSS so as to avoid over-use of available resources and also keep the positioning service devoid of complications that may arise out of sharing transceiver resources.

Anomalies Noticed So Far

I am not really sure about this but from what I know the official releases have claimed that IRNSS-1A has been launched into an inclined geosynchronous orbit with an inclination of 29^o. I have been using publicly available internet resources to track IRNSS-1A and the data that I have collected do not corroborate the officially released data.

I downloaded the TLE data of IRNSS-1A, some of which is given below:

TLE downloaded sometime around the end of July, 2013:

```
1 39199U 13034A   13218.60084382  .00000094  00000-0  10000-3 0   244
2 39199 027.0423 140.5285 0019429 182.2365 263.8787 01.00275460   565
```

TLE Downloaded around middle of Aug, 2013:

```
1 39199U 13034A   13227.33681052  .00000000  00000-0  10000-3 0   327
2 39199 027.0503 140.3669 0019595 184.2844 175.6837 01.00274917   647
```

TLE Downloaded on 29th, Aug, 2013:

```
1 39199U 13034A   13240.13145032  .00000088  00000-0  10000-3 0   363
2 39199 027.0586 140.1274 0019230 182.8373 115.8814 01.00269935   774
```

For those who are new to the concept of TLE data, please click here to learn more about what this data represents.

The 9th to 16th characters in the second line of Two Line Element set, indicate the inclination of the satellite's orbit and in the case of IRNSS-1A, whose TLE data is given above, shows that as of 29th August, 2013, IRNSS-1A is in an orbit that is inclined at 27^o with the equator. This is 2 degrees lesser than that is officially released (29^o). A difference of 2 degrees in inclination seems mathematically small but in space-terms, missing the target orbit by 2 degrees is colossal mission failure that would impact the entire constellation configuration and operational effectiveness of the IRNSS.

Assuming there was no typographical error/understanding error in the official releases, IRNSS-1A's launch and orbital maneuvers might have faced anomalies that have resulted in ineffective transfer burns that resulted in the satellite's failure to find its berth in the target orbit. It is usual for satellites to take weeks before finding their berth in their target orbit owing to various factors, most of which might be natural and totally random. That is the reason I took multiple readings of the TLE data of IRNSS-1A, just to make sure, I don't catch it at the wrong time. But, two days from today, by the end of August, 2013, it would be over 60 days from the initial lift-off for IRNSS-1A. For one thing, it is yet to get into the previously declared 29^o inclined orbit and for the other, it has been officially declared that IRNSS-1A's launch is successful and that it has been placed in its target orbit with a status of good-functioning. I do not understand the contradiction of facts from complimentary credible sources. The funniest part is where the official document released contradicts itself by mentioning both the 29 and 27 degree inclinations, one in an image and the other in a specs column of the same document. Seriously, there is no such thing as security reasons or confidentiality that is required to indicate two different inclination angles for a satellite. The satellite industry is very visible in public domain and the whole world can learn about any satellite that is flying around the earth.

Opportunities provided by IRNSS

A whole world of opportunities would be open to India with the IRNSS including, elementary terrestrial, aerial and marine navigation that may be used by the defense establishments. The civil applications mean more than anything in my view. With the help of a dedicated navigational system in place, the civilian population will get a viable access to what is popularly called as vehicle tracking and fleet management. The Indian fishermen along the coast of Tamilnadu and Kerala, who are currently left vulnerable to firing and arrests by the Sri Lankan Coast Guard for crossing maritime border will get an opportunity to track their location with respect to the border that they do not want to cross. Most importantly, they will get a concrete scientific method to prove their innocence with regards to their not crossing the borders. The implementation however requires the administration to issue the tracking devices that may be installed in all the fishing boats. The tracking data will be recorded on a timely basis and the administration will have an eye on all the fishermen who go out into the waters. Anyone who is nearing the borders can we warned about it and the data can be shared with neighboring countries so that both countries would know whose boat is located how far from each other's maritime border. This way any case of arrests/firing may be dealt with the analysis of this tracking information recorded and be used to resolve conflicts. This will empower the fishermen to scientifically prove in cases where they encountered firing/arrests, without crossing the maritime borders. The administrations too cannot claim trespassing without any tracking data that may suggest fishing boats have crossed the maritime borders. One press of a button and the shore-station would get the distress call from the fisherman who is suspecting an attack or arrest from neighboring coast guard ships. One bright glow and loud alarm from the tracking device on the fishing boat can alert the fisherman if he is about to cross the maritime border. All the legitimate boats will have a designated tracking device and therefore identifying pirate vessels from harmless fishing vessels would become a reality. The solution to such sea-based border issues however require the strict implementation of such tracking information in the marine industries, especially fishing. With IRNSS in action, the administration need not view the cost of renting out other navigational systems as an administrative burden.

The average Indian would have access to finding routes within India and traveling by self would become more safe and comfortable. The defense establishments would have accurate tracking systems to help them during military operations along the disputed borders, more importantly without having to depend on international administrations.

Challenges for IRNSS

The configuration of IRNSS calls for reliable satellites since, this constellation operates on a minimum number of satellites from the navigational standpoint. For an accurate positioning on earth, at least 4 satellites are required. With 3 geostationary and 4 geosynchronous, the constellation cannot afford to have any satellite system/sub-system failure. Losing one satellite means losing precise tracking in one region of the IRNSS target area. The IRNSS constellation, from the systems engineering point of view, is yet to add the element of redundancy for reliability. This may be due to cost restrictions but having an expensive system so vulnerable actually makes the investment very risky. In future, I would like to see more satellites operating over regions already covered by these 7 satellites, such that, if one of the satellites fails, the system’s functionality does not get compromised. The back-up satellites are an additional cost but their presence means prolonged “system-survivability” and in case of no failures, added positioning accuracy. The additional satellites may be used for military operations unless there is a need for a civilian deployment in case of a failure.

One more area to look into while considering add-on satellites is **constellation optimization methods** that can help estimate and determine satellite positions in existing and new orbits so as to enable the reliability and extended lifetime of mission objectives.

The STK simulations show that the IRNSS-1A goes through a one-hour eclipse almost every day, with the eclipse timing ranging from 0.3 to 1.3 hours. The average is around 1 hour. Now the satellite is powered with a 90 ampere-hour lithium battery and solar panels that have a capacity of 1.6 kW. Regular discharge and recharging of batteries do impact the battery lifetimes and the satellite should not be rendered useless because of a failed battery. Given that apart from the payload, other sub-systems of the satellite depend on the battery power too. The chances may be rare but when electrically operated attitude-control maneuvers and payload activity clash during an eclipse time, the satellite goes into a peak demand state and a repetitive exposure to such peak-demand situations may impact the battery negatively. The subsystem with the shortest life-span would be the life-span of the entire satellite and it definitely should not be the power system i.e., the solar panels and battery-pack.

What Else to Look For

Well, the first thing to catch my attention is the cost and reliability of the hand-held equipment that can be used as the ground-based tracking devices. This is mainly because, it is a popular trend here in India for the government issue electronics to be outdated, notoriously unreliable and clumsy in appearance and handling comfort, mostly because the government issue is either free or for a low fee. I am not entirely sure but based on the fact that the data structure of the satellite transmissions from the IRNSS satellites are very similar to that of other global navigation systems, I am inclined to believe that the currently available commercial GPS units might be able to receive IRNSS signals and provide directions. So consumers might have an option of using their GPS units to receive IRNSS signals for their tracking needs.

I had a great time looking into the details of IRNSS and its first satellite IRNSS-1A. While preparing for this post, I got an opportunity to work with Systems Took Kit (STK), previously known as Satellite Tool Kit (about 5 years back). I sincerely hope IRNSS becomes a success in terms of real-world applications in India, helping the military and civilian population alike. Thanks to whoever pitched the idea of Indian Regional Navigational Satellite System. I am sure there is so much to this system than what we have explored so far and I would look for more to learn about it as the system is realized in due course.

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Regards,