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Design of a Peruvian Small Satellite Network

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A national concept for the implementation of a network of ground stations for small satellite missions is being designed. This network shall support the newly conceived small satellite program in Peru. Currently Peruvian engineers conduct investigations on how to carry out this challenging project, which is expected to gain not only Peru but also the Peruvian industry. The proposed network shall be supported not only by Peruvian government institutions, but also by national and international universities. The establishment of such a program has already been started and a couple of European entities and universities are interested in becoming co-partner within the project. The ground stations will be located in remote places in Peru thus providing wide communication coverage, permitting longer contact capabilities between the satellite and the ground, and creating a complex space and ground based system. A network including these places will cover a landscape area larger than one million km^2. In general small satellites use a low data rate downlink. Due to less number of access and low power capacity the usage of an UHF transmitter is the only possibility. This network will widen the contact capability with the satellites and consequently there will be more opportunity to dump a higher amount of data. Since the communication system for small satellites is developing in a rapid pace, this network would be beneficial to dump data faster than before allowing the collection and distribution of data in an effective manner for the users. This will permit generating more accurate data generation from the instruments or from the spacecraft itself. At a first level the network will be implemented with UHF band antennas, which in the future will be expanded with S-band antennas. This Peruvian network will be functional for our national small satellite program and also for all the satellite missions that currently operate on radio amateur frequencies.

I. Introduction

THE number of small satellites that have been largely developed for education, earth observation and constellation operations have increased during the last decade. Due to the restricted opportunities in launching, small satellites are usually launched as secondary payloads through a piggy-back manner. As a result, during the early orbit phase, it is likely that several small satellites may be clustered in space and frequency. Moreover, the contact time may be very limited due to the ambiguity in orbit prediction at this phase. As a result, the workload at the ground station for the tracking of a satellite in early orbit phase is often overwhelming.

A huge amount of academic small satellites, like nano and pico satellites, have been developed and intended to be launched supporting a wide variety of missions including Earth observation which can be realized through their design and constellation. The advantages of these small satellites are the short development time, miniature devices, standard launcher interfaces, and piggy-back launch opportunities saving launch costs. However, a problem associated with pico satellites operations is that the communication frequencies, typically in the UHF/VHF band, are very close between two different satellites.

As many pico satellites are usually released in one launch, the proximity in spatial and spectral separation between those may render problems for ground stations in satellite tracking, especially in the early orbit phase. Even when there is a contact, it may be difficult for a ground station to know which satellite is actually pointed at by the ground station antenna. The station may have to resolve the desired signal out of a class of near-by interferences. Also, the frequency overlap due to doppler shift, clock drift and operation error aggravate the tracking problem. If a

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contact with the satellite fails and the station wants to search the signal again, it often needs to wait for the next contact. And the gap between two contacts is usually several hours, even one day long.

Taking the above mentioned topics into consideration Peruvian engineers have attempted to design a ground station network, which is called the Peruvian Satellite Network (PSN), dedicated at a first stage to support small satellite missions. In this paper, six ground station installations across Peru has been taken into consideration and the authors have analyzed the possibilities of overcoming different issues with regard to small satellites. Considering the magnitude and importance of this challenging project, especially for educational purposes, we envisage the involvement of a couple of Peruvian universities to join and be part of the network. Also the economics behind the development of such infrastructure and thoughts about future work is presented in this paper.

II. Network Description

The Peruvian Satellite Network will consist of six (6) selected ground stations located in strategic places around the Peruvian territory. A network including these places will cover a landscape area larger than one million km^2. The cities where the ground stations will be situated are listed in Table 1 and shown in Fig. 1. The coordinates of the stations are as shown below.

Ground Stations/ City	Location in Peru	Latitude	Longitude
Iquitos	North East	3° 45' 0" S	73° 15' 0" W
Lima	Central West (Pacific Coast)	12° 2' 36" S	77° 1' 42" W
Piura	North West (Pacific Coast)	5°12' 0" S	80° 38' 0" W
Pucallpa	Central East	8° 23' 0" S	74° 33' 0" W
Puerto Maldonado	South East	12°36' 0" S	69°11' 0" W
Tacna	South West (Pacific Coast)	18°3' 20" S	70° 14' 54" W

Table 1: Location of the Ground Stations in Peru

A. Privileged Location

The first ground station which is currently being implemented at the premises of the National University of Engineering (UNI) is located in the Peruvian capitol, Lima. One very important aspect of the ground station in Lima is that it is geographically well placed. There will be no other academic ground station in the Central-Western part of the South Pacific region. Furthermore any satellite crossing the South American continent will be passing over the first ground station of the PSN network.

After performing a preliminary analysis it can be indicated that the coverage area of the Peruvian satellite network will correspond to an approximately of 50 million square kilometers. As shown in Fig. 2 the network will cover South America and part of Central America and the Caribbean.

Figure 1: Location of the Ground Stations

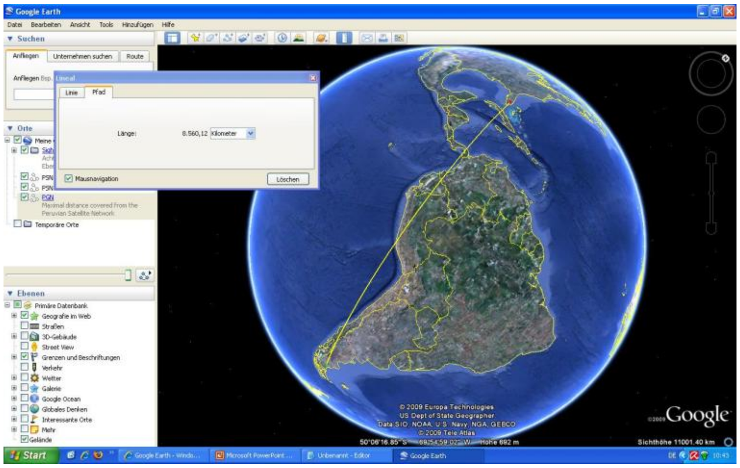

Figure 2: PSN Coverage Area (using Google Earth)

B. Network Topology

The preferred network topology selected in our case is the so called Bus topology. With this topology it is possible to guarantee the functionality of the network in case of one or more stations might fail. Furthermore the bus topology is more economical and efficient than other kind of network topologies.

At the first stage of the project the connection between all the stations or nodes will be supported through the internet. All the nodes will have a wide band internet connection. Using this nowadays available infrastructure it is possible to implement the PSN network without extra high costs for the connectivity between the stations. At an advanced stage a dedicated and faster connection will be implemented to have a very efficient and secure system. The ground stations should be able to work independent from each other and there will be no prime station. All of them will have the same characteristics and importance. The system must be transparent, by doing the handover from one station to the other or when one of the stations fails. Each station stores the collected data. After a contact all the stations exchange the data from each other and merge this, so that each node is able to archive the whole amount of data for further analysis and documentation.

III. Access Times and Duration

After choosing the above mentioned ground stations and its locations, in order to have a complete analysis and database, the access time which is the time of communication between the spacecraft and the ground has been calculated. For the study purpose, the software Satellite Tool Kit (STK) was used to simulate different combinations to calculate the number of access times and access duration. It is necessary to be able to have an effective way to share the data from the ground stations and also to have redundant backup downlink.

As mentioned earlier, the PSN network consists of the stations located in Lima, Iquitos, Piura, Pucallpa, Puerto Maldonado, and Tacna. The chosen locations of the ground stations are from all corners of Peru. The STK tool was used to perform the calculations of access times between the satellite and the ground stations for different orbits and inclinations considering that the satellite cannot communicate with the ground during eclipse and elevation angle below 10◦. The results have been recorded by month over a period of one year and all these access times have been plotted in order to easily determine effectiveness of this network. Figure

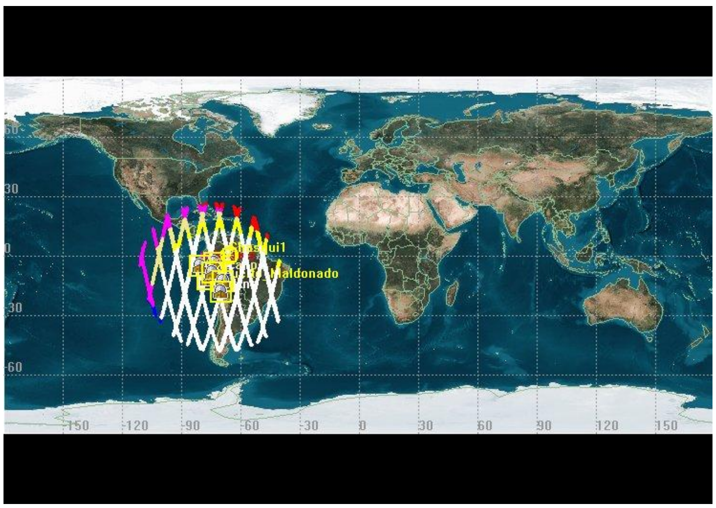

Figure 3: Ground Station Coverage (using STK)

3 shows again the PSN coverage area but this time as reproduced using STK.

The access duration depends on the altitude of the satellite and elevation of the ground station. The table below gives the results of the performed analysis. It lists the maximum and the average access time each ground station could provide per pass. The altitude of the satellite (here as Sat 1 to 4) considered for the analysis varies between 400 and 1000 km (Low Earth Orbit) with a scale of 200 km.

Access Duration - Max/Avg (sec)				
Station	**Sat 1 (400Km)**	**Sat 2 (600Km)**	**Sat 3 (800Km)**	**Sat 4 (1000Km)**
Iquitos	602/487	761/603	906/674	1045/845
Lima	600/433	762/575	907/667	1044/817
Piura	602/445	761/602	907/681	1043/829
Pucallpa	603/445	762/587	905/650	1041/786
Puerto Maldonado	602/445	762/589	906/696	1043/762
Tacna	603/435	763/580	907/673	1045/829

Table 2: Access Duration Calculation

The analysis shows the maximum and the average time to be the same for all the stations irrespective of the ground stations location. The number of effective contacts per day will make the difference in a ground station network. This kind of network will reduce the amount of data lost during the contact.

IV. Number of Access

The number of access is the effective number of entries into the coverage area of the ground station. Similar conditions were considered for the simulation of the effective number of contacts per day. Table 3 illustrates the access events per day over the individual ground stations in Peru.

Number of contacts				
Station	**Sat 1 (400Km)**	**Sat 2 (600Km)**	**Sat 3 (800Km)**	**Sat 4 (1000Km)**
Iquitos	4	4	4	5
Lima	4	4	5	6
Piura	4	4	4	5
Pucallpa	4	5	5	6
Puerto Maldonado	4	5	4	6
Tacna	4	5	5	5

Table 3: Average number of access per day

The number of access varies as well based on the altitude and the inclination of the satellite. Since small satellites are most predominantly launched in a sun synchronous orbit hence an inclination of between 95◦ to 105◦ has been assumed for this investigation. Taking into account the eclipse period and the sun period, the number of access reduces effectively between 2 to 4 passes a day in view of an individual ground station.

The plot depicted in the next page (Fig. 4) gives a scheme of the average number of passes taking place over each ground station. Considering the ISS orbital elements in the analysis the number of access varies between 3 to 6 contacts per day with contact duration between 490 and 540 sec.

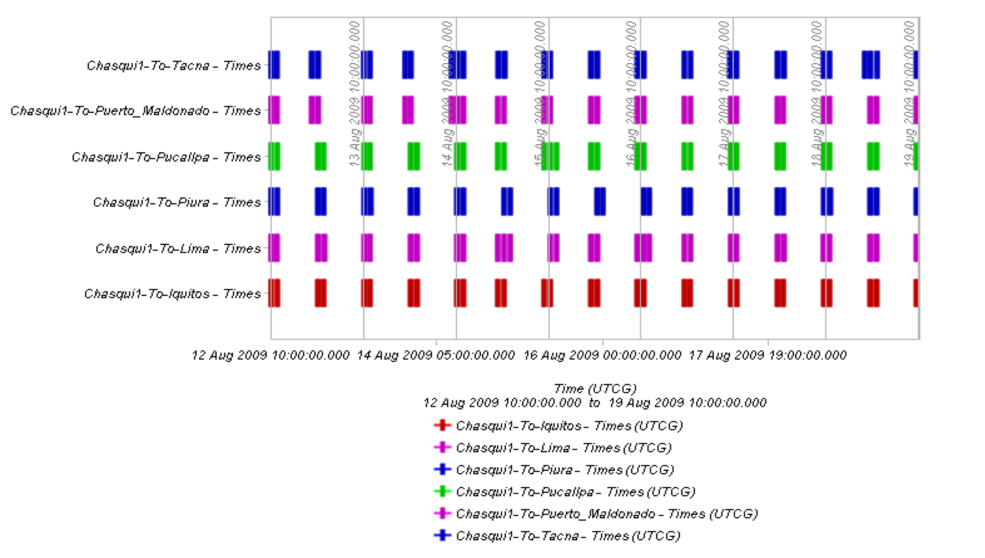

Figure 4: Daily planning of contacts (elevation >10°)

V. Data Rate

The data rate is the number of bits transferred from one system to another system. The data rates are quantified using bits per second. For the above study work, the commonly used data rate for small satellites has been considered ranging between 1200 bps to 154000 bps. Due to power constraints the data rate of pico satellites is specified to a maximum of 9600 bps. Since this kind of satellites are restricted by their size most of the missions are realized with miniaturized equipment. Very small cameras and sensors are used as payloads. Few of the recently launched pico satellites carry equipment for attitude control but still the power consumption is one of the parameters that need to be reiterated. With the previous calculated access time and the assumed data rate, the analysis shows a maximum of 90 Kbytes that could be downloaded per contact. Scientific data may consume few megabytes of data per data-take. Using various compression techniques the data could be compressed to range of kilobytes. The major concern for the transfer is the data losses during the link and the second worry is the effective contact duration per day. Assuming two (2) data takes will probably lead to data content of 200 kbytes inclusive the house keeping data. Comparing the data accumulated with the given data rate of 1200 bps, the calculation shows a requirement of approximately 1400 sec of contact per day.

VI. Ground Network Analysis

The above study shows the individual capabilities of the ground stations. In view of all the 6 stations the network gives a considerable difference in the results of the above criterions. Similar access studies with different orbital conditions were considered. The ground station locations are wide spread across Peru hence the area of coverage gets a direct impact due to this. The increase in the coverage varies between 30 - 50% when all the ground stations work in tandem. This consequently leads to increase the time duration per access. The resulting average access time is between 60 and 140 sec higher compared to the average time covered by a single ground station.

A 21 days simulation cycle shows an increase in the number of access as soon as all the ground stations are active. The number of access increases by one extra pass on an average per day. Most important factor is the redundancy in receiving data. Most of the small satellite missions especially CubeSats work on low bit rates. The probability of receiving bad telemetry is high therefore the communication protocols do need to be well scripted to attain the telemetry data in a best possible way. The Peruvian Satellite Network cleans up all the constraints by having redundant stations for the reception of the data. The other aspect for bad telemetry is the attitude control being used for the pico satellites missions. Most of the CubeSats use the permanent magnets to control its attitude in space. The latest development in CubeSats is the use of reaction wheels or magneto- torques. Still the usage of such attitude systems is yet to be verified for full effectiveness. The attitude system plays an important role in supporting the satellite to communicate with the ground station. Even though the permanent magnets are used to drag the tumbling in 2 axes, it still tumbles in all 3 axes, which leads to loss of contact and bad telemetry.

The proposed satellite network could solve the issues discussed above by having redundant ground stations to support the contact and could also reduce the time loss caused by bad telemetry process. The minimum number of ground stations that could support the contact is two.

VII. Future Work

In general terms, a ground station is able to support parallel contacts with satellites in different ways, either using more antennas or more receivers. The most recommendable configuration for a multi-mission station is the installation of two antennas, each of these with its own receiver. The receiver can be reconfigured in a short time, and in few minutes after be switched to another frequency, the station will be ready to receive data from a second satellite, sent in a different frequency as the first supported one. With two antennas, it is possible to support parallel and also successively passes. But we need to consider that the mentioned configuration is reasonable only if the supported missions use the same Terminal Node Controller (TNC) or if the TNCs can be switched in a short time, without any influence and degradation of the whole system. To guarantee a good and permanent support to multiple satellites is very important to define some standards for all the constellation units. The most important requirements to be defined are: terminal node controller, operation system and data protocol, telemetry and telecommand software, hardware of the ground stations (if possible), network configuration, etc. These standards will help to avoid errors or to solve problems in a short period of time. In case of communication problems, the operators can help each other much efficient, if they use the same hardware and software configuration. System errors can be isolated and the system will be more reliable.

For a better tracking and identification of satellites, the definition of a dedicated beacon for the constellation is an advantage. This beacon is a data packet which contents important information about the satellite. The packet format is public hence it is effortless to decode the information inside. This method will permit tracking the satellites outside of a scheduled contact. The Automatic Identification System (AIS) is a short range tracking system for ships. Stations along the coasts can receive the beacon of the ships. With this information, it is possible to create a map with the position of all the ships near the station (harbour). This kind of automatic identification could be implemented for the satellite constellations as well.

The ground stations of the PSN network will be able to work remotely and automatically. The remote service permits the control of a ground station from another point connected to the network. This functionality is very useful for stations located in isolated places. The “virtual” operator will in such manner configure the station, command the satellite and transfer the received data to the end user as needed. In the automatic mode, the ground station will be programmed in advance to support passes of the selected satellite and will also send the data to the correspond users. The ground station could also send commands by itself if needed. This capability allows the station to be operational 24 hours daily without operators. This mode is also very useful for a station located in remote and inaccessible places. In order to increase the performance of the ground stations, the Peruvian satellite network shall be enhanced with a remote and automatic capability of the stations and upgraded with S-band antennas. To avoid high investment at the beginning an infrastructure of small scale antennas is sufficient. The first design will use a 3m antenna. The size of these antennas is good enough to support pico satellites missions. Later 5m antennas will be used to further enhance and improve the system. With this kind of ground stations and the network proposed in this paper it will be possible to support pico, nano and even micro satellite missions.

Microsatellites use normally S-Band transmitters (they can also use UHF depending on the mission and the budget). The Peruvian government with the support of CONIDA and Peruvian individuals envisages the acquisition of a microsatellite for Earth observation as the next step within the framework of its space program development. For this reason it is indispensable to prepare in advance the necessary equipment for that. The higher the cost the longer it takes to put together the intended infrastructure. Hence the earlier the infrastructure is available the faster we will be able to support satellite missions and compete internationally in this promising area.

GENSO, a project of the European Space Agency (ESA) and coordinated by ESA’s Education Office, aims to increase the return from educational space missions by forming a worldwide network of ground stations and spacecraft which can interact via a software standard. The proposal to join the GENSO network to support the CubeSat missions worldwide is under consideration and we are coordinating this with the respective GENSO responsibles. Moreover for supporting a Satellite Constellation like the one defined by the QB50 project, at least a ground station within the PSN network shall be able to receive signals from different satellites. In this manner the network will become a very strong infrastructure. This will permit supporting the project much better and collecting a bigger amount of data from the satellite cluster. The PSN network will end up more beneficial to the Peruvian satellite program also ultimately will have effects on the economical return.

VIII. Commercial Aspect

At a first stage, the Peruvian Satellite Network is planned to operate on radio amateur frequencies using UHF antennas. The UHF ground stations are not too expensive. To build an UHF ground station it is necessary to invest around $10,000. This price includes the receptor, the antenna itself, the motor for the antenna and the PCs to control it. Thus, for six ground stations it is necessary to invest around $60,000, which is indeed an affordable investment. We have to see that this network is a powerful tool for any university to complete its Space Engineering Faculty, as it is intended by the UNI.

The plan is to upgrade and further implement the ground stations with other antennas. The next generation will be a group of S-Band antennas. The first S-Band antenna will have a 3m dish. The cost of this kind of ground station is around $125,000. This upgraded ground station will use the same connection like the UHF ground station. For the future a wide band connection will be implemented. For the six ground stations the investment will be around $750,000. The next step will be to build a station with 5m antennas. Each ground station would cost around half a million dollars and together three million dollars. This investment seems to be very high but its implementation means to acquire a very powerful network system to offer and to support small satellites missions.

IX. Conclusions

As a result of this study work, the comparison shows an increase in the number of effective contacts per day and the contact time. Since the ground stations work in tandem, the network is beneficial due to its redundant data dumping. The possibility of using standard protocols for CubeSat missions and other small satellite missions may give the flexibility for the costumer to use the network to its full extent. Parallel passes could be supported quite easily. The greatest challenge for a pico satellite is its attitude system resulting in an unstable satellite but it could be supported by the PSN at its best. The Peruvian Satellite Network could also be used to support a global ground system network like GENSO and the QB50 constellation of CubeSat missions.

Comparing the commercial aspects, the outcome of this project will surely help the Peruvian space community to a great extent. Currently this project is proposed based on focusing pico, nano and microsatellite missions. As a future development, the S-band system could also lead to create new partner among the satellite operations community. The proposed ground station network does promise great potential in improving the operation of academic small satellites worldwide. This network is expected to be a powerful tool for those Peruvian universities which will be involved in the project allowing them to start their own space business and to compete in such a promising field like other international educational institutions already do.

All the effort to set up a Peruvian network of ground stations has been taken and our idea and dream to initiate the establishment of these ground stations involving academia becomes soon true.

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