Journal of Advanced Engineering Research
ISSN: 2393-8447
Volume 4, Issue 1, 2017, pp.51-58

Proposal for an Interplanetary CubeSat Data Relay Constellation

Aditya Sunil*, L. Anantha Raman

Department of Aeronautical Engineering, Rajadhani Institute of Engineering and Technology, Thiruvananthapuram, India – 695001

*Corresponding author email: adityasunil@me.com, Tel.: +91 9048351279

ABSTRACT

Interplanetary and deep space missions that use satellite probes are heavily reliant on line of sight and high gain antennas for data communications over long distances. These missions rely on the Deep Space Network of Earth ground stations located all around the globe to communicate with the satellite or probe for transferring data such as imagery or scientific measurements, and also sending commands to control the craft. Several satellites have become unusable due to the very long data transmission times needed for communicating with them from the earth ground station. There are also time periods where data transmission cannot occur due to the spacecraft being in a 'blind spot'. To overcome the communication problem, this paper proposes having a series of small 'Cube Satellites' to act as data relay satellites to increase the time scientists at ground stations are able to remain in contact with deep space crafts. The proposal is also key to improving the data connectivity between Earth and Mars for uninterrupted future interplanetary data links.

Keywords – Communications, CubeSat, Data Relay, Interplanetary, Spacecraft

1. INTRODUCTION

All spacecraft, including atmospheric probes, flyby spacecraft, interplanetary spacecraft, landers, orbiters, satellites, and space stations require radio waves to communicate between them and the Earth ground stations located all around the world. The ground stations then capture the signals and relay them to control rooms where engineers and scientists collect, process, interpret and analyse the data. The data downlink from the spacecraft to the ground stations can include scientific data such as images and measurements taken by instruments mounted on the spacecraft, system information for monitoring the health of the spacecraft's system, and information about the spacecraft's current position in space. A data uplink is often used to send commands to the spacecraft, and often these commands include course corrections, and small changes to the operation of hardware and scientific instruments.

2. DEEP SPACE NETWORKS

Six launch capable countries each have their own network of deep space antennas and communications facilities to support their launch and interplanetary space missions.
~ NASA Deep Space Network (DSN)
~ European Space Tracking (ESTRACK) Network
~ Indian Deep Space Network (IDSN)
~ Soviet Deep Space Network
~ Usuda Deep Space Network
~ Chinese Deep Space Network
Each country operates its own communications network to support their deep space missions, and use large parabolic dish antennas that vary in size, with some up to 70m in diameter.

2.1 NASA Deep Space Network

The NASA Deep Space Network began when the Jet Propulsion Laboratory (JPL) developed radio tracking stations for the US Army to be installed at locations in Nigeria, Singapore, and California to help the Army with telemetry, and to plot the orbit during the launch of Explorer-1 in January 1958. The National Aeronautics and Space Administration (NASA) was established on October 1st 1958 to consolidate the space exploration programs of the United States Army, Navy, and Air Force into a single organisation. JPL was transferred from the US Army to NASA on December 3rd 1958, and the responsibility for space programs using remotely controlled spacecraft. NASA soon began to develop the concept of the Deep Space Network as a separate communications system that could be used for all deep space missions, reducing the need for separate systems on individual spacecraft. The Deep Space

Network started its own research, development, and operations, and has now become one of the largest, and most reliable entities, designing its own parabolic dish antennas, tracking, telemetry, and command systems.

JPL designs most of its spacecraft to operate with the smaller dish antennas of the Deep Space Network, but the larger antennas are often used during emergency situations where the spacecraft may be lost. Under normal operations, the spacecraft will be able to use its regular power source to maintain a communications link, but during emergency situations, the spacecraft may only be able to provide nominal power to communications equipment to keep mission critical systems such as guidance and attitude control systems operational. System malfunctions may inhibit the use of attitude control systems, and the high gain antennas may not be in the optimum orientation, so using the larger dish antennas allows for the maximum telemetry data to be recovered, which may be critical in assessing the health of the spacecraft and providing correctional commands.
NASA's Deep Space Network consists of both parabolic dish reflector antennas as well as beam waveguide antennas. NASA's three main stations for Deep Space Communications are located in California, Madrid, and Canberra[1].

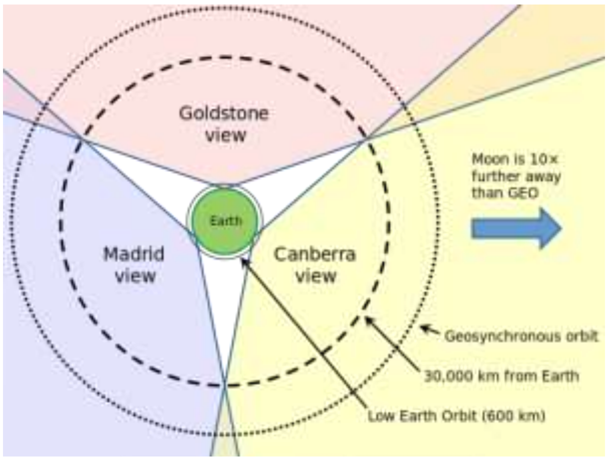

Fig. 1 The field of view of the main DSN antenna locations

2.2 European Space Tracking Network

The European Space Tracking (ESTRACK) network was first established in Villafranca Del Castillo, in Spain and used a 15m diameter parabolic dish antenna to support the International Ultraviolet Explorer mission. ESTRACK is a combination of several spacecraft tracking stations operated on behalf of the European Space Agency (ESA) and the operations are headquartered by the European Space Operations Centre (ESOC) in Darmstadt, Germany. The ESTRACK network is used to communicate between the mission controllers and ESA spacecraft as well as to command, monitor, and control them during launch, and their subsequent orbit. Each ESTRACK centre has different capabilities and supports different missions. The ESTRACK station in Santa-Maria is used to track Ariane launches and has capabilities to track Vega and Soyuz launches from the ESA launch pad in French Guiana [2].

Fig. 2 ESA's 35m DSA-2, located at Cebreros, Spain

2.3 Indian Deep Space Network

The Indian Deep Space Network (IDSN) complex is located near Bangalore, and was commissioned to provide telemetry and communications for India's first lunar mission, Chandrayaan-1 in October 2008. The IDSN has two primary antennas that work alongside the Indian Space Research Organisation (ISRO) Telemetry, Tracking, and Command Network (ISTRAC). The ISTRAC system is used to support launch facilities, low earth orbiting spacecraft, and deep space missions of ISRO, and operates several ground stations around the world to accomplish this.

The IDSN currently functions to support the Mars Orbiter Mission, and the Indian Regional Navigation Satellite System which has been indigenously developed to provide global positioning services for the nation [3].

2.4 Soviet Deep Space Network

The first Soviet Space Network was used to track earth orbiting satellites during the space race. The Soviet Deep Space Network was started in the late 1950s to support deep space missions to Venus and Mars in 1960. The Pluton antenna design had three sets of eight 16m dishes mounted on hulls of diesel submarines, and supported by railway bridge trusses and were mounted on large bearings from gun turrets. Two set of dishes were used for receiving the signals and the third was modified for data transmission [4].

Fig. 3 A Pluton receiver antenna with eight 16m duralumin parabolic dishes

2.5 Usuda Deep Space Network

The Usuda Deep Space Centre is a facility operated by the Japan Aerospace Exploration Agency (JAXA). Situated in Usuda, the centre houses a 64m beam waveguide antenna which has been operational since the facility opened in late 1984. The Usuda centre is used to primarily to track spacecraft, as well as transmitting commands to deep space probes and receiving scientific data from them as they reach their mission destinations. Usuda was the first deep space antenna constructed to use beam waveguide antenna technology [5].

2.6 Chinese Deep Space Network

The Chinese Deep Space Network has several large antennas and communications facilities to support the China National Space Administration (CNSA) and the lunar and interplanetary spacecraft that have been launched [6].

2.7 Deep Space Network Functions

Each Deep Space Network site has an array of large antennas, including large parabolic dish antennas. These are designed to enable continuous radio communications between various spacecraft and Earth. The large antennas work to focus the faint radio signals from distant spacecraft, and then amplify the signal whilst also removing as much background 'noise' as possible. The antennas are operated remotely from a control centre located nearby, to eliminate as much electronic interference as possible, and the data from the antennas is sent to the control centre for further processing.

The various Deep Space Networks have more functionality than just being a series of large antennas. These networks are large scale systems capable of communicating with, tracking, monitoring, and commanding the many spacecraft en-route to, or orbiting other distant planetary bodies.

Telemetry data is a collection of scientific and engineering data sets sent from the spacecraft to the ground station on a regular basis. The telemetry data includes information about the spacecraft's various on-board systems and is used to continually monitor the health and condition of the spacecraft. The Deep Space Network acts to capture the radio signals containing telemetry data, and then transfer the information to the ground control stations for each individual mission.

The Deep Space Networks also work to continually track the various satellites and probes that are launched into space. This is done with different types of radio antennas mounted on the spacecraft to provide a two-way data link between the spacecraft and the Earth station to make regular measurements to allow mission controllers to determine the position and velocity of the spacecraft with high precision.

Mission controllers use the tracking and telemetry data to compare the mission simulation to the actual mission status, and then can create commands to control and correct the spacecraft's trajectory if required, and commands to sequence various activities such as making scientific probes operational, starting imaging systems, and eventually shutting down the craft at the end of its mission.

The Deep Space Network of antennas is also used for performing scientific research experiments which use radio signals being sent and received. The signal variations, and frequency change due to the Doppler shift can provide insight about places in deep space, and other solar systems. This information can be used to research the structure of far off planets and their moons, and various other astrophysical phenomena.

3. TRACKING AND DATA RELAY

NASA currently uses a constellation of nine communications satellites in a geosynchronous orbit (GSO), called a Tracking and Data Relay Satellites (TDRS). These satellites as a series of repeater stations in connection with NASA's Near Earth Network (NEN) ground stations to provide near continuous space communications and increases the data transfer between NASA's satellites in low Earth orbits (LEO), as well as the Hubble Space Telescope and the International Space Station (ISS). The satellites are placed approximately 120 degrees apart to provide maximum coverage over the earth, for the longest possible continuous time. Three generations of the TDRS project have been made operational with the key differences between the generations being the communications technology being used. This TDRS system has been designed to enable increased communication between satellites in LEO and MEO, but does not provide any data link to those in GEO or other higher orbits. Each of NASA's TDRS satellites cost between $250 million and $300 million to build, not including the launch costs. The total cost of building and launching the TDRS constellation is upwards of $7 billion USD [7, 8].

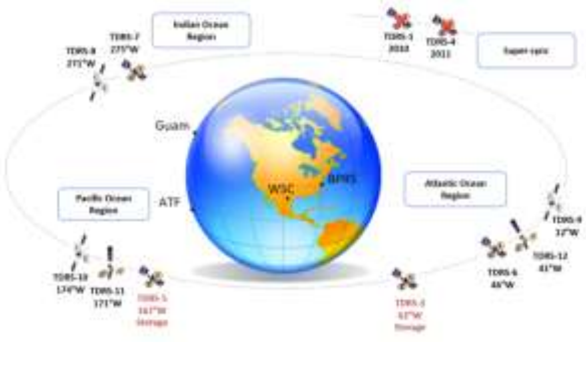

Fig. 4 NASA's TDRS satellite network

4. DATA RELAY SATELLITES

The primary use of a data relay satellite system is to provide a near continuous data link through line of sight from all types of spacecraft in different orbits to the ground station. Traditional systems using direct ground links to the satellite generally have a communications window that lasts approximately 10 minutes and repeats a few times per day. To provide the desired continuous communications support would require a vast number of ground stations, and several stations would need to be located on floating platforms in the middle of the ocean. By using two data relay satellites placed 180° apart in geosynchronous orbits (GSO), and locating them within sight of a ground station, we are able to maintain continuous communications with the majority of satellites in low Earth orbit (LEO) and medium Earth orbits (MEO).

With an increased number of satellites positioned at smaller intervals, and with the use of satellite interconnects, it is possible to have continuous data streams passed from satellites in Earth orbits, to a single ground station. The ability to transfer data will not be compromised due to poor weather conditions or cloud formations, since the satellite interlinks will allow data to be handed off to an adjacent satellite and passed around to a point where the data can successfully transmit down to a ground station.

For deep space, and interplanetary missions, it is highly desirable to have communications with the satellite for as long as possible, to allow for higher data transfers and thus sending back more information from the spacecraft including data about its health, raw data from scientific probes, imaging sensors, and other on board equipment. Current technology and methods limit the data transfer window to about 10 minutes per day for Mars missions and the windows is as small as ninety seconds for probes that have gone past Pluto. A main cause of this limited access is due to the heliocentric orbits of planetary bodies being different to that of Earth, and thus being out of alignment.

5. SATELLITE COMMUNICATIONS

The majority of satellites communicate with other stations using low frequency radio waves. During the second World War, frequency bands were given non-sequential identifier codes. These identifier codes were later published by the Institute of Electrical and Electronics Engineers (IEEE), and now are the worldwide standard for terrestrial, radar, and satellite communications.

Each frequency band is subdivided into smaller bandwidths, and communications systems can only operate in a specified bandwidth. The difference between narrowband and broadband is the difference in allocated bandwidth, and this limits functionality. Most modern systems use broadband to communicate with satellites and this supports the transfer of more data such as high resolution images and video, whereas older narrowband systems only allow the transfer of small data sets.

Table 1 IEEE frequency standard

Frequency Band	Frequency	Wavelength
HF	3-30 MHz	100-10 m
VHF	30-300 MHz	10-1 m
ULF	300-1000 MHz	100-30 cm
L	1-2 GHz	30-15 cm
S	2-4 GHz	30-15 cm
C	4-8 GHz	15-7.5 cm
X	8-12 GHz	7.5-3.75 cm
Ku	12-18 GHz	3.75-2.5 cm
K	18-27 GHz	1.67-1.11 cm
Ka	27-40 GHz	1.11-7.5 mm
V	40-75 GHz	7.5-4 mm
W	75-110 GHz	4-2.73 mm

The majority of satellites use frequencies above 1 GHz for their communication needs to send and receive data. Signals in the low frequency range; L-band, S-band, and C-band require larger antennas to receive the signals to the lower power of transmission signals. Signals in the higher frequencies; X-band, Ku-band, K-band, Ka-band, and V-band require much smaller antennas due to the increased power of transmitted signals. This allows satellites being launched today to use the X-band and Ku-band and have antennas that are less than 50cm in diameter. This is why most home broadband applications such as internet and satellite television provides use the Ku-band and Ka-band spectrum to connect users to their services [9].

6. CUBESATS

The Cube Satellite, or CubeSat, is an international standard for a small nanosatellite that has exoskeleton body measuring 10x10x10cm, and weighs up to 1.33kg called a 1U CubeSat. Multiple units can be combined to make 2U, 3U, 4U, and 6U CubeSats, with corresponding mass increments. Although their dimensions are fixed for uniformity during launch and deployment, many utilise folding solar arrays which extend and provide the satellite with extended power generation capabilities for the duration of its mission. These small satellites utilise off the shelf components thus reducing the costs, and complexity. The standards for CubeSats are very simple to understand and has led to several high schools, universities, and other institutions using the standard to launch research satellites.

It has been shown that these low cost CubeSats are not only a viable option, but provide functionality that is very close to conventional satellites that are much larger and cost millions of dollars. Several small companies have managed to successfully raise seed funding for large scale CubeSat deployments, where they would have unable to raise the same capital if they had proposed for a handful of large satellites. This has proven to key aerospace solutions providers that it companies are willing to develop their own satellites using readily available materials and launch research payloads on their own. This has been made even more accessible with NASA offering funding and free launches for research and technology demonstrator CubeSats.

Currently, one of the biggest limitations to current CubeSat technology is their limited access to ground stations for sending and receiving data. Most CubeSats are placed in a very low Earth Orbit, often in orbital planes that are not as high as the ISS. This limits their field of view to downlink data and in the event that a CubeSat does not pass over its home ground station, the data transfer from a receiving station to the home ground station may be very time consuming. This may not be much of an issue for non-critical data transfers, but it makes it almost impossible to send commands up to the CubeSat. Some CubeSats will only be in orbit collecting data for a few days before the drag induced by the upper atmosphere will cause them to de-orbit and fall back down to earth. Not all CubeSats have a large amount of on-board storage available, and even those that have on-board storage require the CubeSat to be retrieved once it de-orbits and falls to earth.

Most CubeSat missions have a total hardware cost that is less than $100,000 which includes the structure, and all electronic components for the mission. The biggest expense is to actually launch the payload, and small research satellites can reduce this cost by ‘piggybacking’ on other payload launches, but this reduces the orbit possibilities as the orbit is dependent upon the primary payload [10].

7. MARS CUBE ONE

The Mars Cube One (MarCO) satellites are technology demonstrators being launched with NASA’s InSight Mars Lander Mission. These two 6U CubeSats are being deployed whilst en route to Mars, with the intention of using them as a communications link between the InSight Mars Lander and Earth during mission critical stages of entry, descent, and landing as the lander will not be capable of line of sight communications with Earth Stations. The two identical spacecraft will be equipped with both a UHF antenna to receive data from InSight, and an X Band antenna to relay the data to NASA's DSN sites on Earth with an 8kbit/s data transfer rate.[11]

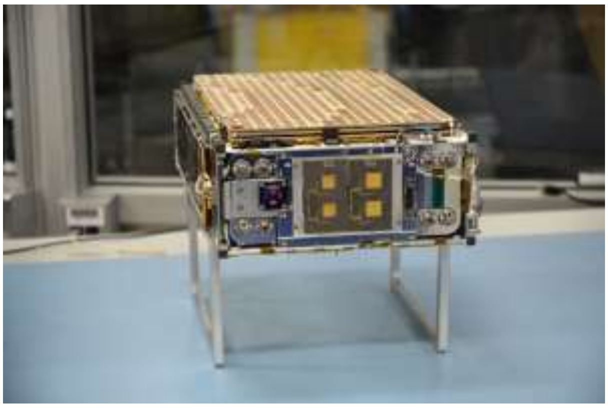

Fig. 5 – MarCO 6U CubeSat model

8. PROPOSED CUBESAT CONSTELLATION

The proposal calls for three sets of CubeSats in different orbits to act as intermediary data relay stations to support future interplanetary missions to Mars. The required constellations would need to be placed in orbits around Earth, Mars, and the Sun to achieve the continuous data transfer.

The CubeSat constellation would ideally be placed in either a Geostationary Orbit or a High Earth Orbit, with arrangement such that at least two CubeSats each have a direct line of sight to one of the ground stations with several satellites in between them to enhance coverage between them and provide redundancy with satellite interlinks. A similar constellation would be placed in an Areostationary Orbit around Mars, with two CubeSats having line of sight communications with a Martian ground station, and more satellites to act as satellite interlinks. The final part of the Interplanetary CubeSat Data Relay Constellation is a number of CubeSats placed in a Heliocentric orbit between the orbital planes of Earth and Mars. These will act to relay the data between the CubeSats in Earth and Martian orbits when the orbital periods result in a loss of line of sight communications between the two CubeSat constellations.

A fully redundant system would have thirty-six CubeSats positioned 10° apart at minimum, to provide total coverage around the equator in both geostationary orbit, and areo stationary orbit. The Heliocentric Constellation would need four times as many CubeSats to cover the orbital plane due to the drastically increased orbital radius.

The design of the CubeSat calls for a 6U or 12U design which incorporates several technologies using some off the shelf components as well as other specialist parts that are custom designed for the data relay CubeSat Constellation such as a cold gas attitude control system dual antennas, one for receiving and one for transmitting data through UHF and X-band whilst having a set of solar panels that can be unfurled after deployment to provide continuous power. The CubeSats would be equipped with satellite interlinks to allow for communication and data handoffs within the satellite constellation, and then transponder functionality to relay the data signals.[12] This would allow data to be continually transmitted to and from the Martian ground station to an Earth ground station via the CubeSat Data Relay Constellation, or vice versa regardless of the current position of the satellites in relation to the ground stations. The challenge of keeping the CubeSats within a small positional tolerance within its orbital plane and maintaining its position with respect to the other satellites is overcome using a star tracker for station keeping, and a cold gas attitude control system to manoeuvre the CubeSat and adjust its position.

CubeSat deployment can be done by 'dropping off' the CubeSats whilst the larger space vehicles carrying people, and equipment travel towards Mars. CubeSats can be deployed during three flight phases, Earth orbit, Hohmann Transfer, and Martian orbit. During the Earth orbit, the CubeSats destined for Geostationary orbit can be deployed, the Heliocentric CubeSats part way through the Hohmann Transfer manoeuvre, and the CubeSats for the areostationary orbit during the Martian orbit before entering the Martian atmosphere. CubeSats can be deployed on all future Mars missions to build and increase the Constellation size all whilst improving reliability, efficiency, and reducing the latency of data transfers.

One significant challenge for maintaining an areostationary orbit is the effects of Mars' two moons, Phobos, and Deimos, on the satellite's orbital trajectories.[16] The two moons will likely shift the orbit of the areostationary CubeSats and these are the ones likely to use their attitude control system the most and eventually deorbit due to propellant exhaustion. These problems can be overcome by using low altitude orbits, but this will need significantly more satellites in several orbital planes to provide the same coverage.

The greatest challenge facing this proposed CubeSat constellation is maintaining the integrity and operability of the systems whilst being developed and deployed as a viable alternative to traditional satellites. The design will approximately cost $100,000 per CubeSat although that can be drastically reduced to about $60,000 per unit if they are mass produced. The cost of launching and deploying these CubeSats will have to be borne by companies and organisations that are launching to Mars, as it is simply not viable to send a launch vehicle to Mars in order to deploy CubeSats. This allows us to have thousands of CubeSats ready for deployment, for the same cost of developing and building traditional communications satellites. This enables greater reliability, redundancy, and flexibility although the CubeSats may fail and need replacing more often. This system will supersede the communications system proposed by the Mars One venture which calls for a single satellite in orbit around Mars above the Mars One settlement and another that orbits the sun. Although their proposed system will enable communications between the settlement and Earth, the data transfer will be limited and will not have continuous, uninterrupted communications throughout the year [17].

Further development and expansion of this CubeSat Constellation is possible, and will be useful for aiding the data transfer between deep space probes and satellites that go beyond Mars. This low cost solution can be attached to the launch vehicle's upper stage as an auxiliary payload which can be deployed on the way. As the network of data relay CubeSats increase, it will allow us to go further and further into space with reduced risk of losing communications, which is the most common reason for terminating a mission.

5. CONCLUSION

Traditional satellite communications with the deep space networks has been adequate for the last several decades owing to the limited data transfer, with a relatively small number of satellites and spacecraft being launched. As the number of spacecraft increases, and the quality and resolution of data sampling, and imaging increases, there is a requirement for increased data transfer rates, and longer windows of opportunity to send the data between the ground stations and spacecraft and vice versa. The satellite data interlinks will allow a seamless data handoff to nearby satellites thus eliminating the need to rotate the receiving antenna to maintain the communications signal. This will reduce latency and maintain a continuous data uplink, as well as reducing the wear and tear of existing deep space network ground stations by allowing us to keep them in a fixed position. This proposed system will be several times cheaper than the current system for space communications with respect to the hardware cost as well as launch cost.

Many people have suggested the need for interplanetary travel, and there is a general consensus that Mars is the only habitable planet that we can travel to within our lifetimes. It will take dozens of missions with thousands of people travelling to Mars to make the vision of an interplanetary species come to fruition, and one of the main challenges facing us is the limited communications between Earth and Mars. This will be of paramount importance until a truly self-sustaining community is developed. The first missions will require continuous communication with professionals in various fields as issues will almost definitely arise. By building our communications infrastructure networks between Earth and Mars as we travel there, we eliminate the need for specialist missions to launch and deploy communications satellites. Whilst it is possible to design and build large communications satellites, these will have a significant cost and will have a relatively long lead time for production. CubeSats that use commercially available products can be prototyped, tested and mass produced much quicker and more efficiently, reducing the cost to about the same as a luxury family car. The increased number will not only give greater connectivity, but will also provide redundancy in a network that can continually be expanded to support future deep space missions beyond Mars.

REFERENCE

[1] Victor A. Vilnrotter, Dennis K. Lee, Mitigation of Discrete Spectral Components in Filtered BPSK and OQPSK Signals, *IPN Progress Report*, 2017, 42-208.

[2] David D. Morabito, Daniel Kahan, Kamal Oudrhiri, Carlyn-Ann Lee, Cassini Downlink Ka-Band Carrier Signal Analysis, *IPN Progress Report*, 2017.

[3] Alish, Ritambhara Pandey, Telemetry, tracking, command and Monitoring system in geostationary Satellite, *International Journal*

of Electrical and Electronics Engineers, 6(2), 2014, 261-265.

[4] Arthur Norman Guest, *Telemetry, Tracking, and Command (TT&C)*, Springer New York.

[5] Felix N. C. Anyaegbunam, Design Elements of Satellite Telemetry, Tracking and Control Subsystems for the Proposed Nigerian Made Satellite, *International Journal of Engineering Science Invention*, 3(1), 2014, 05-13

[6] Colonel David J. Thompson, Lieutenant Colonel William R. Morris, China in Space Civilian and Military Developments, *Air War College Maxwell Paper*, Maxwell air force base, Alabama, August 2001.

[7] WU Ting-yong, WU Shi-qi, LING Xiang, A MEO Tracking and Data Relay Satellite System Constellation Scheme for China, *Journal of Electronic Science and Technology of China*, 3(4), 2005, 293-297.

[8] www.nssdc.gsfc.nasa.gov/multi/tdrs

[9] Eytan Modiano, Satellite Data Networks, *Journal of Aerospace Computing, Information, and Communication*, 1, 2004, 395-398.

[10] Jose E. Velazco, Microwave Frequency Multiplier, *IPN Progress Report*, 2017.

[11] www.jpl.nasa.gov/cubesat/missions/marco

[12] M. Cuollo, E. Ortore, F. Bunkheila, C. Ulivieri, Interlink and coverage analysis for small satellite constellations, *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, 227(7), 2013, 1201-1212.

[13] J.G. Walker, Satellite constellations, *British Interplanetary Society Journal*, 37, 1984, 559-572.

[14] www.planetary.org/blogs/guest-blogs/van-kane /20131023-the-potential-of-cubesats

[15] www.mars.jpl.nasa.gov/express/mission/ comm _summary

[16] www.planetary.org/blogs/emily-lakdawalla/2013 /stationkeeping-in-mars-orbit

[17] www.mars-one.com/technology/communications-system

[18] O. Kegege, Y.F. Wong, and S. Altunc, Advances in Ka-Band Communication System for CubeSats and SmallSats, *Proc. Aerospace Systems Conference of the National Society of Black Engineers*, Arlington, VA; United States, 24-29 August 2016.

[19] B.R. Smalarz, *CubeSat Constellation Analysis for Data Relaying*, Thesis submitted to California Polytechnic State University, San Luis Obispo, 2011

[20] Y.F. Wong, O. Kegege, S.H. Schaire, G. Bussey, S Altunc, Y. Zhang, P. Chitra, An Optimum Space-to-Ground Communication Concept for CubeSat Platform Utilizing NASA Space Network and Near Earth Network, Proc. Small Satellite Conference, Logan, Ut; United States, 6-11 August 2016.