The Deep Space Network - A Technology Case Study and What Improvements to the Deep Space Network are Needed to Support Crewed Missions to Mars?

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By
Prasad Falke
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Declaration

I declare that this project is my own work and has not been submitted in any form for another degree or diploma at any university of other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

Prasad Falke
05-28-2017

SUNY Polytechnic Institute

Department of Telecommunications

Approved and recommended for acceptance as a thesis in partial fulfillment of the requirements for the degree of Master of Science in Telecommunications.

May 19, 2017

Date:

Approved by:

Dr. Larry Hash
Thesis Advisor

Dr. John Marsh

Dr. Joshua White

Prof. David Climek

Dr. Kevin Kwiat

Abstract

The purpose of this thesis research is to find out what experts and interested people think about Deep Space Network (DSN) technology for the crewed Mars mission in the future. The research document also addresses possible limitations which need to be fix before any critical missions. The paper discusses issues such as: data rate, hardware upgrade and new install requirement and a budget required for that, propagation delay, need of dedicated antenna support for the mission and security constraints.

The Technology Case Study (TCS) and focused discussion help to know the possible solutions and what everyone things about the DSN technology. The public platforms like Quora, Reddit, StackExchange, and Facebook Mars Society group assisted in gathering technical answers from the experts and individuals interested in this research.

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As the thesis research was challenging and based on the output of the experts and interested people in this field, I would like to express my gratitude and appreciation to all the participants.

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1. **Introduction**

The deep space network (DSN) was introduced in the year of 1963 by Jet Propulsion Laboratory (JPL) under the contract for US Army and then transferred to National Aeronautics and Space Administration (NASA) for deep space exploration [1]. From that time till now, the DSN technology has helped the scientist to investigate deeper into the space to send the radio signals and know about some other facts about the life on Earth. Information about asteroids and the possibility of its collision with the Earth in the future helped to know about atmospheric changes in anticipation, the environmental movement, and in medical science to scan the body parts like brain [2].

The DSN helps to keep track of spacecraft by transmitting the command signals to it and receiving the critical information about different planets, galaxies and their surface [4]. It also monitors the health and safety of the spacecraft for achieving the results. The numbers of other functions are telemetry, science, and radio science with the help of which the scientists can study the behavior of the elements on the Earth, when they formed, how they evolved, and what are the characteristics. This approach helps them to compare the studies they have done in the past with the research they did on another planet by sending the rovers, spacecraft [5].

As the Earth is round and continuously moving, there is a necessity to maintain the reliable communication with the planet Mars (and other planets in the solar system). The DSN is an interplanetary communications system where the redundancy supported by three different sites which reside at an angle of 120 degrees to each other. The sites located in Barstow (California, USA), Madrid (Spain), and Canberra (Australia), help to maintain the connectivity with the satellites around the Earth which are communicating with satellites revolving around the Mars and with the satellites which were sent far in our galaxy to investigate about our solar system. The interplanetary communication system provides an uninterrupted connectivity (with some delay) with other satellites which are in the deep space and maintains it throughout the year irrespective of any issues and hence it is used to communicate with the satellites which are revolving around the planet Mars. The interplanetary communication system consists of an array of antennas which exist at sites mentioned above. Each location has one 70m antenna and 2 to

many 34 diameter antennas (secondary antennas) which help the communication to take place. The primary antenna or 70m antenna used for sending the radio/radar waves to the satellites around the planet Mars and to different other spacecraft/satellites which were sent in early years to study about life on another planet (if there is any) [6].

As per the papers discussed in the literature review, there are multiple issues with DSN technology. The research performed here tried addressing all the possible problems and provide a solution if there is any.

The cost of the hardware required for DSN set up and its maintenance [13], bandwidth limitation, frequency limitation (transmitting and receiving frequency noise), other noise sources in the space which affect the signal quality (gravitational waves, high-frequency noise, cosmic noise, radiations). Also, the power requirement and noise (thermal noise because of high power), data rate, propagation delay, endless and uniform connectivity, DSN Scheduling [8] are few of the well-known issues now.

As per the NASA's audit in October 2016 [13], the DSN is currently meeting its operational commitments but not going to help for the future missions because of the budget issue which leads to insufficient (or not at all) funding for the maintenance and upgradations of the hardware. The hardware used old and will not be able to support more missions. As discussed in the literature review paper 1, the scheduling itself is a big issue which is happening because of the limited capacity of the DSN for more than 200 missions. So, to make it useful, the NASA has proposed some solutions which will help for more missions along with added security, effectiveness, and more channel capacity (with increasing antennas) [12] [13] [14].

As mentioned in one of the NASA's audit book that DSN will handle more than 400 missions by 2020 and as it is already having issues like deteriorating infrastructure, power failure to few antennas in the Goldstone and Madrid complexes. It also has a limited capacity and maintenance issues which likely to result in loss of critical scientific data in the future, and eventually, it is directly affecting the other things like signal strength, receiving sensitivity.

The data rate achieved by existing technology (DSN) is 500 bits to 32,000 bits per second, and the propagation delay is up to 21 minutes when the both planets are at the maximum distance, and it is 3 minutes when they are close [7]. So, the point is, to send the scientists on the Mars and form colonies for the people in the future, there is a need of very strong communication technology (the signal data rate should be very high), and that should be stable too. As per the NASA's deep space network technology, at this moment, the X-band frequencies are being used for communication between ground-based antennas and the satellites orbiting around Mars. The frequency range for X-band is 8 to 12 GHz and the data rate achieved is 500 bits to 32 kbps which are very less and as per the telecommunication study, "the more the frequency of a signal, more is the achievable data rate or information transfer rate [4]". However, that is not true in this case because of the significant distance and other limitations like noise, power, technology. As discussed, there are limitations to using more power to communicate with the help of operating frequencies and the sources of the noise (Sun, pulsars, quasars, radio galaxies, and nebulas) in the space is another thing [9]. The DSN scheduling problem listed in above paragraph is also a major issue currently NASA is facing, and it also needs to be addressed either by providing a solution or by replacing the DSN by any alternative technology. As per the research paper from the year 2005 submitted by two JPL scientists, there were 150 missions listed under DSN technology program, and 20 space crafts were using the four months' schedule [8]. If it was the situation 11 years back, then it should be reviewed one more time by the researchers, year by year it is going to make the things complex because of many satellites in the space.

To know more about the existing research and what needs to be done to provide a possible solution(s); the study divided into two parts. The first part will be a technological case study (TCS) of Deep Space Network (DSN) explaining the background, introduction, working, limitations and delimitations, advantages and disadvantages, and applications. The study will help to focus more on the research field, contribute to addressing any unknown issues and provide a feasible solution for it if there is any.

The second part of the paper suggests the solution to the problems discussed in the first part and analyze it with the help of experts working in this field. It is important to have an expert opinion on this matter because there will be lot many things to consider before making the conclusion for

this paper. For this, the researcher will have the free flow discussion which will help to initiate the topic, and both researcher and the expert can present their opinions. The researcher will post few questions from above issues on the public platforms like ResearchGate, Reddit, Quora, Google Groups, and StackExchange and will try to get answers from the experts. The collected answers from different people with divergent views can then be analyzed before making the conclusion.

2. Thesis Statement

The Deep Space Network - A Technology Case Study and What Improvements to the Deep Space Network are Needed to Support Crewed Missions to Mars?

3. **Uniqueness Claim**

The research performed here is entirely based on the Deep Space Network (DSN) managed by Jet Propulsion Laboratory (JPL) NASA. The DSN was formed in 1963 to explore space and perform research beyond Earth. As a result, there have been research papers, documents and several other missions since 1963.

When this began last year, there was a need to gather all the possible details regarding the DSN from a variety of resources into one report. Which led to the arduous task of reading all the possible resources, deciding what was important and needed to be documented into one paper. The reason behind this task was to help the research thesis in the second part, which dealt with asking questions. As stated earlier, the job was challenging due to the constantly evolving technology and their subsequent changes in research techniques.

Each document or a research paper posted by a JPL scientist referred here gave more insight on a concept/topic but did not cover the entire DSN introduction, structure or functionality. To know the DSN well enough and ask the right questions about it, it was necessary to understand the theory behind it. Therefore, the Technology Case Study (TCS) performed here was selected. The TCS of DSN covered background, introduction, space communication and basic concepts like DSN terms which provide knowledge of RF terminologies, workings, applications and their future scope.

The TCS allowed me to ask the right questions on the problem statement designed for this paper and provided a base for the second part. The focus group discussion assisted in performing the second and most important part of the research thesis. The number of possible limitations observed and recorded in the TCS of the DSN and later used in the second part to ask the questions to the experts. The result or the response received from the experts used as a recommendation for the DSN to improve its limitations for the future missions.

As the document covers DSN technology, possible limitations, and recommendation for it, it makes the research unique and reliable. The responses come directly from the knowledge of experts and their views, which fulfills the requirements of the research paper.

4. Problem Statement

The DSN is the only technology which helps NASA, ESA, India, China, Japan, Russia, Spain and Australia with their deep space communications. As per the data studied, the current DSN structure is insufficient for the future crewed as well as robotic missions because of several possible limitations discussed in the thesis research paper.

Not all problems cause delays in the mission but addressing them make it easier to solve the issues currently facing he DSN. Furthermore, the data gathered does not imply that the there is no progress on the issues faced by the DSN team, it just refers to it as a problem and provides a feasible solution where applicable. If the issues get addressed or resolved by the next mission date (the year 2020), it fulfills the purpose of the research's short term goals. For the long-term goals, the DSN still needs to resolve the issues provided in this paper.

The paper discusses six of the problems observed while studying the DSN Technology research. There is also a possibility of further issues, and it depends on the study performed by the student. The data rate of the communication signal is one of the primary concerns observed during this time, this varies from 160 bps to 5.2 Mbps. At this speed, the future missions are doubtful. They explicitly specify the minimum requirement to be from 1 Mbps to 100 Mbps [40]. For instance, the Mars Reconnaissance Orbiter (MRO) and the Odyssey orbiter transmitted more than 304.142 Terabit of the data by May 2017 and are scheduled to send much more in the next few more years. When Earth and Mars are close, the data rate taking place reach speeds of 5.2 Mbps, but when they are farther apart, it is much lesser. It takes 7.5 hours for MRO to empty the queue which needs to be transmitted towards Earth-based stations when both the planets are close. For other planets, the case is different; The Juno, Cassini, Voyager I and II talk loudly in order to transmit the signal towards Earth with even less power which raises both hardware and data rate issues.

The DSN scheduling was an issue since 2005 when it supported 40 missions, but now supports more than 80 missions and the possibility of more than 120 by 2020 as per NASA's predictions. It raises the priority of communication traffic when scientists talk about the future missions. No

doubt the primary focus would be a Mars mission, but there is a need for dedicated communication channels when the data received gets doubled. The Curiosity II mission will be a step towards Crewed missions after the year 2025 to 2030, and hence the problem becomes critical because of the less efficient system.

As per NASA report, the crewed mission in the future would need a minimum speed of 20 Mbps up and 100 Mbps down which questions the current capability (The claim here is not to prove NASA is not working on it but just providing a recommendation from what experts think about it).

When it comes to secure communications, the sophisticated encryption techniques and algorithms make it impossible to design such a state of art technology as the signal transmitted and received by the antenna is already attenuated or contain lots of noise. As per the previous reports, there have been attempts on satellites by hacker organizations, so the security is crucial on the ground as well as in space even though it is not possible in deep space.

It is far more impractical to assume replicas of the DSN would be constructed by any other country, but the possibility can't be denied 100 years from now. Additionally, there is the possibility of a man in the middle attack (MITM) by placing a satellite between the ground station and spacecraft.

The DSN and spacecraft antenna use S-band and X-band frequencies for its communication, there is a need of upgrading it to the Ka-band which is considered to be the finest in regards to data rate and bandwidth.

These concerns can possibly be addressed if the required budget gets approved for NASA, but in the past few years, it got reduced and affected the upgrade and implementation of DSN antennas.

5. Literature Review

Paper 1:

Clement, J, & Johnston, D, M. (2005). “The Deep Space Network Scheduling Problem”. The Jet Propulsion Laboratory: California Institute of Technology. 2005. American Association for Artificial Intelligence.

This research discusses the various activities, viewpoints, and tracks. The record from the perspective of network scheduling problems refers to the allocation of antennas over some time interval to a mission while the view period relates to the interval of time when the spacecraft becomes visible to the antenna. The activity, on the other hand, refers to the track wrapped with teardown and setup time. The authors go one in to define the essential characteristics of DSN network scheduling including the number of missions (56), the number of antennas (12) and the geometric, human operator constraints, shared equipment and different capabilities. According to these writers, some of the scheduling has an advanced time frame of ten years into the future and could consist of 1650 view periods per week against 370 tracks or 80000 annual observation periods against 2000 tracks. The account also talks about how JPL may require freezing the schedule for six months due to complex requirements.

However, the advantage is that there would be flexibility in gaps, the number of tracks, timing and antennas. For the scheduling to work, the system must centrally generate the schedule and make concessions to avoid the emergence of conflicts. The research paper does an excellent job of providing a breakdown of other problems associated with space scheduling. These include communication scheduling of AFSCN and TDRSS, Mars relay type of scheduling, generation of antenna command, measurement scheduling, science planning and the sequence of command generation, which occurs both onboard and on the ground. The research paper then proceeds to identify the constraints that would hobble network scheduling. These are the inability of two spacecraft to utilize one antenna at the same time; the space vehicle has given the antenna, Goldstone tracking conflicts, and timing conflicts.

In the ground complexes, the problem arises in that no two complexes can start operations within 5 minutes or so of each other. At the Goldstone facility, one cannot schedule an activity or tracking where two additional events or tracks start within a quarter of an hour of each other. The third problem is that the spacecraft must have an antenna. Finally, the last constraint of two spacecraft not using one antenna at the same time applies to all the cases, except MSPA, this is where the antenna points to two or more than two antennas but can only uplink with one. Scheduling requirements happen under some constraints, and there are relevant factors that those concerned must consider. These include the gap to track ratio, segmentation, continuous tracks, delta-DOR, arraying, locks on BOT duration ranges, BOT and the use of optional antennas.

These extra ones are the DSS24, DSS15, and the DSS14. The other major constraint is the implemented algorithm required for automated scheduling. This case study notes that there are specific requirements for network scheduling and it is best that those abstract the needs or utilize HTN planning. Also, there should be many resource usage, optional resource usage, fixed duration ranges and start times, evenly divisible track start times and locks on timing and resource. The last refers to the removal of resource choices, the shrinking if temporal constraints and scheduling permissions through ASPEN. In this case study, the authors focus extensively on how periodic tracks play a significant role in network scheduling and the key fundamentals to look at. These include time overlap or time gaps, individual track duration, total tracks duration, the overall period end and the initial commencement time.

All this is expressly about the ranges specified and the periodic tracks. ASPEN is an essential feature in the issue of network scheduling problems. According to the authors, there is a procedure or protocol one must follow to achieve success. This procedure includes taking care of the conflicts that occur by first selecting them, selecting a repair method for the conflict, choosing an activity, performing an action, collecting the new conflicts and then replicating the whole procedure all over again. The main thing in ASPEN scheduling is that one must not exceed the user time limit. The case study appears substantial regarding data and statistics, and one can see this in the breakdown in scheduling performance and search algorithms. The authors here state that regarding scheduling performance, the system must generate schedules with 1861 tracks via three weeks' worth of request and resolve 2305 antenna conflicts.

Reschedules must also accommodate emergency tracks of an individual nature and antenna emergency downtimes of 0.2 seconds. Finally, the scheduling performance must handle the doubling over a one week period of an individual mission track requests, which must occur within 2.7 seconds. The user design in problem resolution is also a major factor as far as the use of information technology. The paper outlines the importance of repeatedly meeting with different users such as DSN, RAPSO, Missions Operation Staff, and MDAPT, to obtain application design feedback and an understanding of the mission requirements. Based on collaboration and comments from the users, the author shows that a newly designed interface can help in resolving network scheduling problems. This interface refines user requirements and simplifies tasks through an automated scheduler, while another interface just edits requirements. Scheduling problems in the Deep Space Network can also get resolved using a modified version of the Gantt chart.

This advanced version can make simultaneous schedules, display metric visibility and demonstrate the specifiable gradient of the users. Additionally, visualization as a potent tool for network scheduling resolution can also portray the differences between two different schedule versions. To conclude, one can say that NASA may invest in future to build up to 3600 weather sensitive antennas with a 10-metre diameter with 1200 at each complex, divided into equal groups of 100 each. The system in future will operate at a higher automation with one operator exerting control over between 100 and 1200 antennas. Spacecraft will then have an ability to use any antenna depending on the Quality of Service Offered. However, only a few antenna signal subsets will have the ability to combine and local response time will get minimized.

Paper 2:

Abraham, D, Gao, J, SeguI, Clare, L, & Jenning, E. (2011). The Impact of Traffic Prioritization on Deep Space Network Mission Traffic. ResearchGate. Conference Paper in IEEE Aerospace Conference Proceedings.

In this paper, the authors start the analysis with a talk about the mode of operation of the Deep Space Network. They say that it provides downlink and uplink tracking and data communications. The authors then go on to say that the applications are in radar science and radio science. Additionally, the data transfer takes place from the Deep Space Communication Complexes (DSCC) to the operations center of the Deep Space Network and the MOC (Mission Operations Centre) through the NASA Integrated Services Network and the Wide Area Network. The authors suggest that the highly-diversified NASA missions will in future need higher data rates and this will, in turn, require Deep Space Network support. The other thing is that QOS or Mission Quality of Service requirements vary. For example, the data for bulk science has a much more relaxed requirement for latency and time critical information form only a small percentage of the total data that returns to the earth stations.

The time-critical information, in this case, can include status reports. In this research, the authors provide a clue as to what the SCMM or Space Communication Mission Model forecasts as missions in future that will need high data rates and hence enhanced Deep Space Network support. The two primary missions with above average data rate include the JDEM (Joint Dark Energy Mission) and the space telescope known as James Webb Telescope. The former is a wide field telescope with a 150 Mbps data rate while the latter is a Space telescope with a 28Mbps rate. The Ex Ep-M1 with a data rate of 7Mbps. Looking at this paper, one sees that the primary focus is on latency. Specifically, the research study seeks to ask or determine the main impact of the prioritization of traffic on the ground Wide Area Network bandwidth. The Deep Space Network requires this bandwidth to meet the different data type's latency requirements specified by the various user missions.

The case study examines the comparison of the bandwidth required when the return traffic gets treated the same with the bandwidth required when the system differentiates the traffic, separates it into different classes and handles it according to a prioritization arrangement. In this case study, the author uses a standard experiment method consisting of a premise and a method. The premise here is that the system handles all traffic identically, without Quality of Service imposing strict latency requirements on all the traffic moving through the network. The other two premises are that there is a reduction in available bandwidth when the service provider for the Deep Space Network applies QoS differentiation. The experiment method consists of two test sets, namely one applying QoS and another non-applying QoS. It also looks at optimization of iterative bandwidth with the iteration depending on data loss statistics and latency. The user also gets to specify the number of iterations run with the output forming the lowest bandwidth satisfying no data loss requirements and latency.

There are several assumptions made in this research paper. Primarily these are so-called trade study assumptions that look at monthly forecasts of mission traffic in later years (like 2018) and data flow latency estimates by the Deep Space Network which the paper then incorporates into a simulation model. Other assumptions occur in traffic streams containing several latency requirements and data types. These include critical engineering, bulk Science, and quick look science. The critical engineering data type has a latency of 10 seconds while the quick look Science and bulk science data type have a data latency of 30 minutes and 8 hours respectively. This research paper also looks at a simulation environment as part of a methodology to predict the problems that may occur in latency in the future and for the possible solutions as well. The simulation ranks as quite complicated and involves several tools including MSAT, OTIE, the DSN Simulator, and MACHETE.

MSAT refers to the Mission Set Analysis Tool and is a way to extract missions' sets from the SCMM tool operated by NASA. It plays a key role in analyzing the tracking requirements and characteristics of the space-ground link. The OTIE, on the other hand, refers to the Orbiting Trajectory Inference Engine and are the visibility files for missions. These missions occur in a relative manner to the ground tracking stations used by the Deep Space Network. The DSN simulator in a simulation environment plays a fundamental role in obtaining tracking

requirements and link budgets from the Mission Set Analysis Tool. The authors say that it also collects from the OTIE, visibility files. Finally, the Deep Space Network simulator carries out the generation of simulated schedules for the ground stations contacts of the mission, over the desired time frame. The MACHETE or the Multi-Mission Advanced Communications Hybrid for Test and Evaluation refers to a system where the return data transfers from every DSCC to the DSCOC. All above-discussed methods execute to size the given DSCC to DSCOC links. MACHETE also plays a role in the de-multiplexing of spacecraft data from individual missions.

The de-multiplexing is done at the DSOC to size the DSCOC to fit MOC links. To obtain the required information, this research paper also employs two key simulation models consisting of Data Traffic and Data Transfer models. The DTM or Data Transfer Model shows the link between DSCC, NISN, DSOC, NISN and six MOC's. In this model, pathways exist from DSCC to DSOC and DSOC to MOC. They provide modeling as abstract links to analyze the bandwidth requirements. The Data Traffic simulation model, however, includes all the SCMM mission data affiliated to a Deep Space Network Mission. This model also shows the JDEM representative data from a mission, which dominates all other mission traffic. This takes place through the measurement of sample mission traffic over the period of ten days, with an average peak of 150Mbps.

As mentioned earlier, the research paper seeks to determine how the critical data latency requirement affects the amount of bandwidth required. Based on this question, the authors observe that the bandwidth gain for QoS appears most prominent when a much smaller requirement for critical data latency occurs. That is a much more reduced one to other data types latency requirements. In this regard, an observed bandwidth reduction factor of 3 to 5 happens on the deployment of QoS (Abraham et al. 6). In conclusion, the study says that the DSN serves different missions with a high burst and data rate variation. MOC and DSN ground stations span the entire world and connect via WAN. The case research also analyzes the minimum amount of bandwidth required if the DSN uses a system of prioritization queuing or fails to use that system. Finally, the paper determines that bandwidth savings can occur if the data transfer service introduces basic mechanisms of prioritization.

6. Methodology

Figure 1. The Research Methodology Flow

a) Technology Case Study (TCS) on Deep Space Network (DSN)

As there are two different parts in this research study, the methodologies applied in each part are also different.

For the DSN case study, the primary resource is research papers, documentation provided by JPL NASA which is available for free on their website, video documentaries, the handbook on DSN and some reference books [1][4][5][6]. The service book presented by the NASA is very helpful to know the purpose and functionality of the DSN technology, and it is made available for all the personnel like government employees, researchers, students, enthusiasts and the citizens who want to get all the possible details [14]. In addition to this, a number of research papers (IEEE, ACM) will also be studied to gather the required information necessary for this research and will help to gain more knowledge to help others for their studies in the future. The JPL NASA website is the primary source to collect any information on the Deep Space Network, it has information of the DSN since its conception and for the future missions as well [1].

The DSN technology has been utilized for the past 50 years, and hence the study needed here is very accurate and valuable. Moreover, as there were many improvements in the technology from time to time, which made it available for use in a number of fields, a thorough study would help to cover the first part of the research. The research paper published by the number of researchers would help to get the details about some topic as it would be more concentrated on problems, a solution or improvement. With all the details gathered from different resources, it would give an excellent understanding to the researcher on how to enhance his/her knowledge and would also help to gather some points for the focused discussion which is the second part of this research project. Another way it will contribute to having an excellent conversation over the technology which is the prime purpose of the research paper.

Along with the above mentioned primary resources, for Internet links, the researcher will be looking for some domain extensions like organizational (.org), government (.gov), and educational (.edu), and some other commercial (.com) domains would also help to gather information. The reason for pointing out these domain extensions is because all these represent reliable information if it is not biased towards something.

As a member of the professional associations like IEEE, IETE, The Mars Society, ACM library (institutional access), the researcher might get a good hold of some important research papers, topics and access to the experts in these fields. Newspapers like The New York Times, USA Today, Los Angeles Times, Times of India, always publish trending topics and it could be beneficial for the researcher to find accurate news from the past or by following it daily (As these are not the primary resources, the researcher is not dependent on it for any purpose but the details can be missed out, and hence the newspapers are just to check for updated details). As there are many experts in the media, who dedicatedly work in the fields like space science, Mars mission, SpaceX, and NASA, the Internet forums like Quora, Facebook groups, Google group will provide useful information about what is going on [15].

For the TCS on DSN, the information is neither good nor bad, the main purpose of TCS is to have exposure to the vast DSN field. Moreover, as it provides the right background on the DSN, the knowledge can be used while asking questions on the Internet domains.

The TCS will cover the background and working of the DSN where the details will be shared since its conception back in 1958. The background will also cover the history of the DSN for the missions it helped from time to time. The technical details like the hardware, communication basics, the definition, and concepts will explain the current work. The space communication will also discuss its signal power requirement for the transmission and reception of the signal to/from the deep space. Applications of the DSN explains the command, telemetry, use in science and other technologies.

b) Focused Discussion

The second part of the research is based on the problems which are addressed in the paper and solutions/suggestions for them provided by the researcher. This may help to initiate the discussion for the possible agreed solution as the experts will have an excellent knowledge of the technology, its workings and limitations if there are any. For this research, the researcher will choose experts not only from space industry, but also students, university professors, and other enthusiasts who want to help the research.

The discussion could be conducted in different ways; using above-discussed online platforms or by having a direct discussion with the people who work directly on the technology. An unstructured discussion is nothing but a free flow discussion or a conversation where the researcher and the expert will start discussing on some topic and will conclude at the end. The semi-structured discussion will cover a list of specific questions where the expert can answer up to his/her knowledge and can also add additional details by discussing it. The structured discussion is also like asking a list of specific questions to the expert, and he/she will have to tick a box for the known answer up to his/her knowledge. At the same time, the researcher can also provision to add extra space for more details. As the research is very critical and based on the knowledge of the experts, the study required here must be qualitative. There should be specific questions which will cover more topics instead of having a random discussion which might lead off-topic, so an unstructured discussion fits perfectly for this research as the questions can be modified based on responses received.

While asking such questions, the researcher can explain the current progress and status of the technology which will help start discussion. Thus if the expert is aware he/she will speak freely but if they do not know about it then they might be uncomfortable, and at that time, the researcher can go with an alternate method.

In the end, the conversation between the researcher and the experts will be recorded and transcribed for verification for future use (in the case of one to one discussions) and responses can be identified by their names to give it credibility and will be published once approved by university officials.

The researcher is aware that, there must be many scientists working in this field to find a functioning solution for the problems which are addressed but all those should be gathered by somebody at one platform to have access to it for interested individuals to study. Using this research paper, the researcher can publish for all those people who are interested in communication technology like DSN and for those who want to know more about the feasibility of Mars missions in the future. There are excellent chances that it might help other researchers pick up any of the problems and/or solutions mentioned and work on them as a research topic for an advanced degree. This may probably contribute to finding a working solution.

The space agencies like NASA, SpaceX, ESA (European Space Agency), ISRO (Indian Space Research Organization), and China, have proposed their timeline to send humans to the planet Mars [15]. However, there are some technical issues which haven't been addressed yet, a few alternative approaches were put forth but did not mention present problems. As part of this research paper, the researcher is concentrating on end to end communication between Earth and planet Mars and the study of the DSN technology which has helped the scientists so far.
The technological case study and a focus group discussion with the experts would provide in-depth knowledge of this field which is the sole purpose of the research study and will also help the researcher fulfill his desire to pursue an advanced degree in this area.

The reason why the focus group discussion is the best method in this research is so that the information/knowledge the researcher is seeking should be qualitative and come directly from expert's views, observation, and feelings. As discussed above, depending on the topics concerning the issue, a series of questions will be asked about where the expert -who is ready to share their knowledge and opinion about the research topic- will present the thoughts.

The discussion would either be a free flow conversation where both (researcher and expert) will be discussing the facts or possibilities about the research, or it could be a discussion on some specific topic. In the case of an interview, as an interviewer, the researcher will develop a set of issues approved by the advisor and University (IRB in this case) to cover the research area. With consent from the expert, the interviews will be recorded to be transcribed later to compile it in the research paper and be provided as a reference of proof to the advisors. This is so that, if the researcher is confused, the recorded version will help clarify the facts. It will also assist the advisor and the committee to verify the details included in the research paper and make sure that the researcher is not biased about any of his/her decisions.
(As the interview will not cover all the questions, the focus group discussion methodology will be used here to get the answers)

The questions asked will initiate the discussion, and the researcher may try to bring all the issues at once or just one depending on the response time of the expert and their expertise in the field. There will be a time when the expert might know about only one specific issue and may refer the other problems to someone else to answer. So, by following the flow of the discussion, the researcher will have an excellent opportunity to get as many details as possible. As the Internet is a public platform, anyone with expertise in this field can contribute to the research, so in this case, they could be contractors, government or private company employees, students, college professors or common people.

At some point, the researcher would also like to think about getting opinions from ordinary citizens about what they think about the Mars mission. However, this depends on time and other factors. It would be an optional task for him/her, so if the opportunity were given to interact with people whom he/she meets in regular life, he/she would try to discover and document if they do not mind. The sole purpose of considering all the possible issues altogether is to have a wholesome outlook on the mission for which people are so excited about and want to know more or share what they know.

If approved by the committee, the researcher also intends to have a group discussion with students who are from the same field to get an exact idea of their thoughts. With this approach, the latest information about the technology can be collected and will be helpful while working on the final draft of the research. This is again an additional task which will be done only when the research is complete and the researcher is willing to spend further time on it.

As the focus group discussion is part of this investigation, it is critical to know the sample size which helps determine the number of subjects that could be people or a non-living entity. The quality and quantity play a dynamic role in the research field and provide a firm ground to finish the critical task. It takes a considerable amount of time but is far more effective than depending on secondary resources.

The sample size is limited to the experts in this area which could be students, faculty or professionals. The researcher will try asking as many questions as possible in the given time frame to understand and document their opinion. While working on this part of the research, it is vital to identify the audience who are going to contribute their ideas or views and to what extent they are interested. As the questions asked on the Internet, the sample size cannot be defined here; there will be a number of responses. Any individual with knowledge in this field will provide their opinions, and hence they will be part of the research. Also, at the time of analysis, the researcher is going to use aliases for the experts to preserve anonymity. The anonymity of the experts is important here, the reason being, they will be sharing their thoughts/opinions which might or might not help the company they work for, and if they are not confident enough to use their names in any of the research paper, then it is not a good idea.

At the end of the paper, the researcher might want to add something from his mind or in other words his vision for the future which would be considered speculation if it is not currently in existence. As stated earlier, there were lots of things which were in previous movies (during the 1970s and 1980) about the laptop, tablet phone, or a wireless mobile (cellphone) which have recently become reality. So, movies (Star Trek, Star Wars, The Martian), TV series (Star Trek) might provide some useful ideas to add to a vision or speculations list.

c) How it was conducted

For the entire duration, more than 160 experts participated in the discussion and provided their valuable input on the topics the researcher was seeking an answer to. The experts were either common people with interests in DSN, working or retired from JPL NASA, universities, and from different organizations. More than 370 different responses were received and analyzed. They not only helped with the answers but provided good references as well.

The researcher posted one question at a time on platforms such as Quora, Reddit, Facebook groups, StackExchange, and Google groups and waited for the responses. Once it started coming in, he monitored it for some time so as to let other people take part in the conversation and asked for more details about what they shared.

From time to time he kept the discussion going on by asking follow-up questions, at the same time he did research on it for authentication purposes. The same question was posted on all the platforms mentioned above and analyzed for different opinions, which helped to understand what different types of people think of the topics and limitations of the DSN. Sometimes the responses were great and helped a lot, so much so that the researcher was overwhelmed and took days to respond.

Over the period of more than four months, one by one all the questions were posted on all the platforms. The platforms like Quora and Reddit were used purely for educational purposes; many people can ask any questions related to any technology, and has provisions there to ask the specific question to an expert who works for the company or in that technology. For instance, when the researcher posted one of the issues on Quora, he contacted experts from NASA JPL, and other space agencies to answer, not only them but he got to know more people who either worked in this field or indirectly helped it.

The same goes for other platforms like StackExchange, Google, and Facebook groups. The groups did not only help with the questions but also provided great assistance in connecting to the people who provided references to validate the worthiness.

The last part of this process was very critical. So, the researcher wrote down all the responses from all 160+ experts on paper, highlighted the key parts they mentioned, categorized them into the six categories he finalized and stated in the report. The content analysis was used to analyze all the responses by collecting and counting various aspects. As the replies were public, it was necessary to evaluate it and provide the exact count in the paper.

The researcher also contacted people working in this field using his contacts for clarifying questions and doubts to make sure what he is asking made sense and was not out of the scope. The groups like Maricopa County Emergency Communication Group (MCECG) in Phoenix helped him to understand the basics of RF communication and what are the major limitations. The MCECG also helped him to connect to Arizona Near Space Research (ANSR) group, a Non-profit organization sponsored by NASA to get in touch with technical people. The researcher closely observed how the communication takes place between Earth and in the Space, this was one of the big achievements for him which helped in this research.

The Canberra Deep Space Communication Complex (CDSCC), Australia also provided help with the questions to verify some details. The researcher got in touch with them through Twitter and then via official email. The social networking group provided all types of information for this research, and hence we can say, in this digital world today, the one who knows how to use the Internet applications can find any information.

7. Limitations and Delimitations

Limitations

As the research performed here is critical and vast, it needs to be done very carefully by studying ongoing activities, carried out in the past and which are scheduled for the future. Because of the awareness among the people for Mars missions and lots of activities happening in the space industry, everyone is curious and wants to know more about what's going on and what are the plans for the future. It is leading lots of people to contribute their opinions about what they think and which is resulting in having different views.

The main aim of the research will be to avoid biased perspectives of the expert and have a liberal discussion. Another important thing needs to consider is to stop experts getting lied about what they want to share, because if they lie about what they know, then that would cause important effects on the research. As we cannot prevent from this, we should be at least aware of what they are sharing and analyzed and verify it later.

Whole research is mainly dependent on some research papers, the solution provided by the different researchers, news published by the space agencies, and hence the careful is review is necessary. However, there are very slight chances of missing some important information because of the day to day progress of the technology and limitation to share the information about the current development of any DSN related mission because of the security concerns and other unknown reasons.

As the hardware and the technology are more than 50 years old, we cannot exactly tell what the space agencies are planning to do with it as it is already handling more than 200 missions, so no doubt the scientist will think about something different for the sake of inter-planet communication purpose. This research purely analyzes the existing issues with the technology and what can be done to resolve it. Also, replacing or upgrading it to a new set of devices is not easy so that only thing can be done to check whether we can do anything with the existing hardware to solve the communication issues.

The focused group discussion conducted in the second part of the research will be from experts in this field, so there is a possibility of no consensus of what we are expecting, and hence whatever they express will be shared in the research paper. Not all the problems will be addressed in the interview, and this is one of the main limitations of the study because of its dependency on the knowledge of the experts and also need to be more careful before sharing anything which they are not supposed discuss when they are working on the critical technology, and hence the focused group discussion is the best way to get the answers. This is one of the reasons the discussion should be open and not asking sensitive questions which the policy does not allow them to. In the debate, some issues asked can be followed by a discussion over it, which will lead to a good foundation to start the discussion on that topic. It will also give an opportunity to experts if they feel uncomfortable with some issues or don't know anything about it.

The best way of having this discussion is over the public platforms like Quora, Reddit, ResearchGate, etc. where people would love to contribute to several types of research going on in this field.

Delimitations

As discussed in the methodology and the introduction, the delimitation includes the activities performed by the researcher in this research paper.

The researcher will be working on the technology case study of the DSN technology by exploring several specific research papers published over the years by different researchers. He will also use official websites of NASA, SpaceX, ISRO, ESA, etc. as well as other articles which are posted by some enthusiasts in this field. The reason for using above Space Agency website is, all these companies use NASA's DSN network and they are the only ones who can provide the issues they are facing to the public.

The researcher will try his best to cover all the issues which are addresses in this paper. As discussed earlier, the conversations will be documented for analysis purpose, but if the expert is comfortable with it, then the researcher will only share the output of his response with others and will add it in the paper after getting approval from the expert. The reason behind this is, the researcher should not conclude what he wants from the discussion, but he should present what the experts have expressed (in other words, the researcher should not be biased towards conclusion). As the response recorded will be in the public domains like Google group, Facebook, Quora, the anonymity cannot be achieved completely. However, the researcher can use the alias for experts to reach the secrecy.

8. DSN Background

Space is indeed the last frontier. Its sheer vastness and remoteness offer multiple opportunities for science, communication, and research. From a telecommunication point of view, complexes such as the Deep Space Network provide a way to transmit radio signals and data to space probes and spacecraft. This uncovers information about celestial objects in space such as planets and galaxies [11]. The telecommunications method used is more complicated, but use the same fundamental principles of radio transmission and reception, narrow frequencies, data uplinks and downlinks and parabolic antennas.

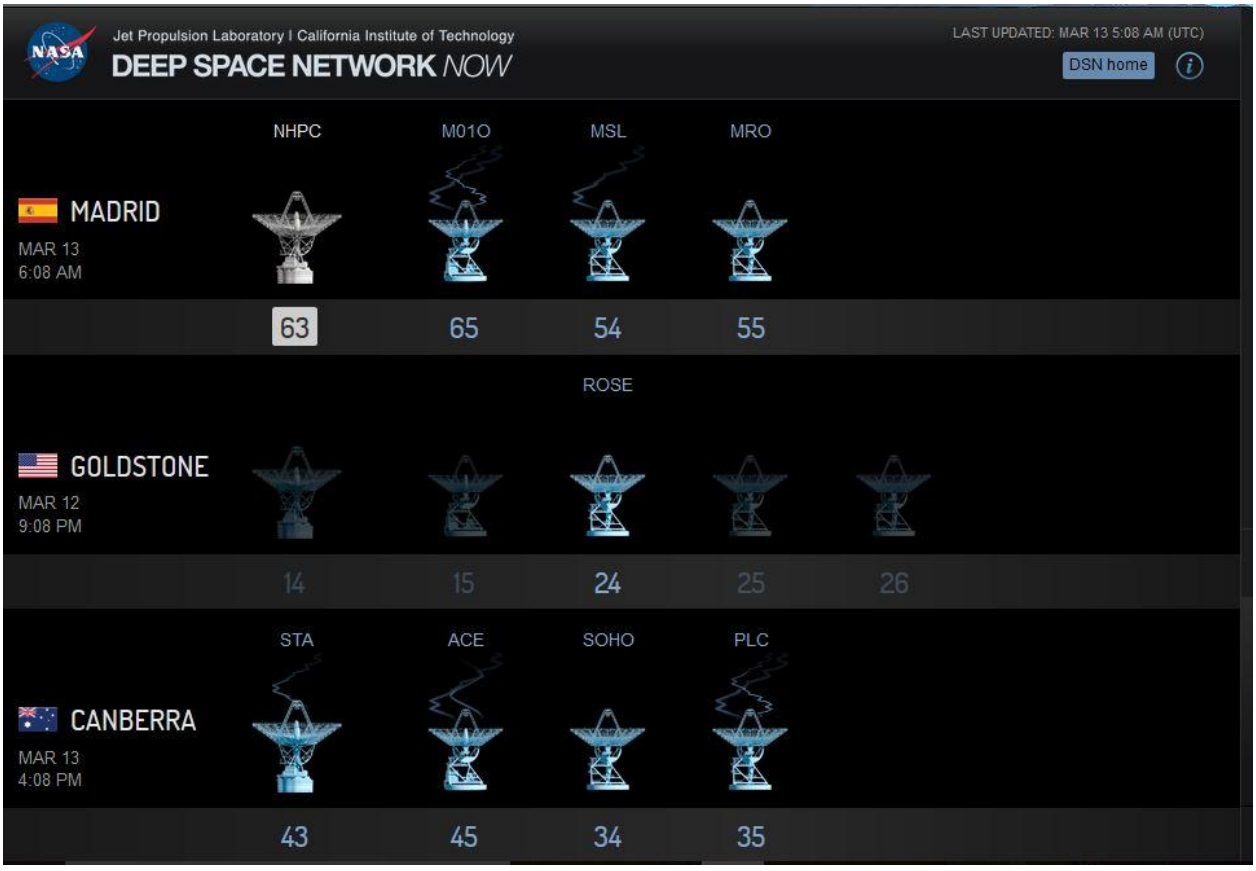


Figure 2: The DSN Complex Live View

http://eyes.nasa.gov/dsn/dsn.html

With regards to long-distance calls, those that traverse hundreds of millions of miles, the Deep Space Network operated by NASA remains unmatched. This network ranks as the most sensitive and largest scientific telecommunication network system on the planet [8]. Therefore, excluding potential alien intelligence, it qualifies as the most advanced in the universe. The DSN is an

international framework or array of massive radio antennae designed for the sole purpose of supporting interplanetary missions by spacecraft and Earth orbital missions [8]. The Deep Space Network also enables radio astronomy and radar observations which facilitate improved understanding of NASA's robotic space missions of an interplanetary nature. The current network consists of a total of three separate facilities.

These facilities are equidistant from one another (120-degree longitudinal spacing) on the earth's surface. The strategic placement helps maintain constant communication, despite the movement of spacecraft and the rotation of the planet. Therefore, if a spacecraft millions of miles away falls below the horizon in one of the sites in Canberra, Madrid or California, another one of the remaining two sites intercept the signal and maintain communication [5].

The diagram below shows how the communication takes places with the help of Earth based ground stations. Each station will cover 120 degrees of the Earth, so in total, the entire Earth can be covered. But, as seen in the diagram, the white portion between the ground stations can be missed and hence the schedule for the missions need to be planned very carefully to avoid any loss of information.

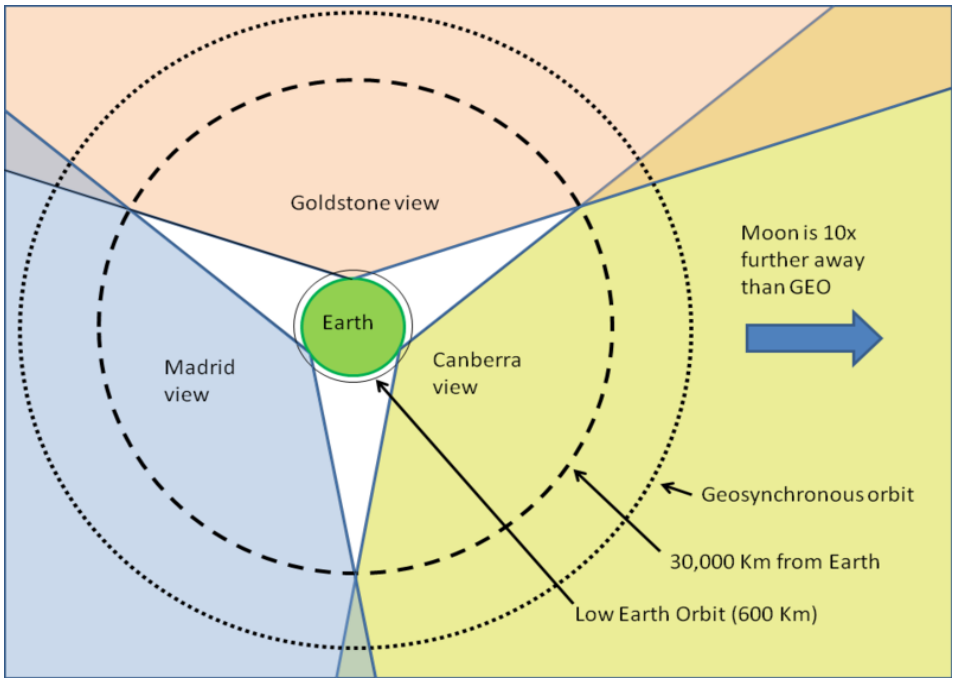


Figure 3: The DSN Coverage

http://www.nasa.gov/sites/default/files/thumbnails/image/deepspacenetwork2015.png

One can say that the Deep Space Antennas form the crucial link to spacecraft and by extension explorers traversing areas far beyond the earth's atmosphere. Without the Deep Space Network, scientists would not be able to make connections with the spacecraft, send navigational commands, obtain information about the earth or see images of objects beyond our solar system. In short, the Deep Space Network tracks and communicates with various American, European Union, Indian, Chinese, Russian and several other space agencies' spacecraft operations in our solar system round the clock [5]. The real-time datum undergoes critical information updates every few seconds and this, in addition to provide scientific information, allows the researchers to determine how long signals take to travel back and forth from the spacecraft and the rate at which data reception occurs.

a. DSN History

The origins of the Deep Space Network date back to the transfer of the Jet Propulsion Laboratory research center from the United States Army to the National Aeronautics and Space Agency (NASA). That transfer resulted the transfer of responsibility for the execution and design of the planetary and lunar exploration programs [10]. This was initially about remotely controlled spacecraft. Shortly after, NASA then went on to establish the DSIF or Deep Space Instrumentation Facility concept as a separately run, operated and managed communication system.

This communication system would handle all the Deep Space Missions and avoid the need for every single flight project to work or acquire personal space communication networks with specific purposes [2]. The CODORAC (Coded Doppler, Ranging, and Command) communication system developed by the team of Walt Victor, Richard Jaffe, and Eberhardt Rechtin formed the basis of the electronics system of the DSIF [2]. The team, like other earlier pioneers, discovered that they had to establish a new network of three stations situated such that at every 120-degree longitudinal position, a spacecraft would always be above a station's horizon due to the rotation of the earth. Thus, the first two stations with 26-meter antennas to serve as complements to the DSIF 12 and DSF 11 sites at California's Goldstone came into operation [7]. DSF 41 formed the first overseas site in Australia's Woomera Island Lagoon.

The site along with the Woomera rocket range operated under the authority of the Australian Department of Supply. The DSIF 51 site (at Hartebeesthoek in South Africa), on the other hand, performed under the auspices of the CSIR (The South African Council for Scientific and Industrial Research [7]. Both stations ended up being completed in 1961, and operated on the radio spectrum L-Band at a frequency of 960 Megahertz [16]. They could also send and receive telemetry data. The two stations had teletype and telephone circuits links to a mission operations room located at the Jet Propulsion Laboratory's facilities [10]. The increasingly high numbers of missions led to the operations room developing into the SFOF (Space Flight Operations Facility) and incorporation into DSIF. Eventually, all the common facilities became the Deep Space Network two years later.

Under these new patrons, the Deep Space Network received the responsibility of operating, developing and researching in various capacities [5] which led to the DSN becoming a global leader in the research and development of systems for Deep Space Navigation, Digital Signal Processing, Telemetry, Tracking and large parabolic type dish antennas as well as low noise receivers [5]. The golden age of the program came in 1961 to 1974, Mariner Era, where the agency designed telemetry and spacecraft systems that could handle the increased demands of the upcoming programs.

In 1963, for instance, new transmitters and amplifiers came into operation that operated at 2200 Megahertz. The new equipment could track at much higher frequency [18]. The 1974 to 1978 Viking Era introduced more changes to high power transmission, landing vehicle telemetry data relay and reception since the station had to communicate and exchange data with space probes heading to Mars. The 1986 to 1996 Galileo Era saw the high point of the Deep Space Network when it helped provide emergency services for the recovery of the European Space Agency SOHO-Solar and Heliospheric Observatory [12].

There has always been a need for the Deep Space Network due to NASA needing to communicate with later more capable satellites as they entered critical orbits. That is, as the satellites navigate their way through the solar system, they leave the prior (safe) low earth orbit that formed the main trajectory of early spacecraft like Sputnik [18]. Without DSN, the spacecraft going much farther than low Earth orbits (like onto the moon and far off planets, like Venus) would not be able to communicate with the Earth station or make corrective navigational changes. Furthermore, DSN helped in providing precise measurements in the field of plate tectonics.

For example, the sea floor spread and the mountain ranges uplifting were measured through the observation of radio sources via antenna pairs on the different tectonic plates that make up the earth's surface [18]. The Deep Space Network currently maintains contact with 14 NASA satellites and involved in several missions including the Mars Exploration Rovers (Opportunity, Curiosity, and Spirit), the Voyager program (Voyager 1 and 2), the Cassini-Huygens project, New Horizons (the Pluto mission) and the International Cometary Explorer. It has contacted at

one time over another 1100 private and public satellites since 1975 [11]. The present issues now include the age of the system, the increasing complexity of the system and the extension of wars into the frontier of space. The network must come up with higher level encryption because Russia and China continue to lay claim to their right to explore space and even position weapons and telecommunications systems to monitor rivals [11]. In addition, complex missions like the one designed to put men on Mars, also qualify as pertinent issues. The trip to Mars could take a full year, and a signal at light speed, from the planet would still reach Earth after a 20-minute delay.

The Figure below shows the Ultra Noise Amplifier needed for the conversion of the radio signal.

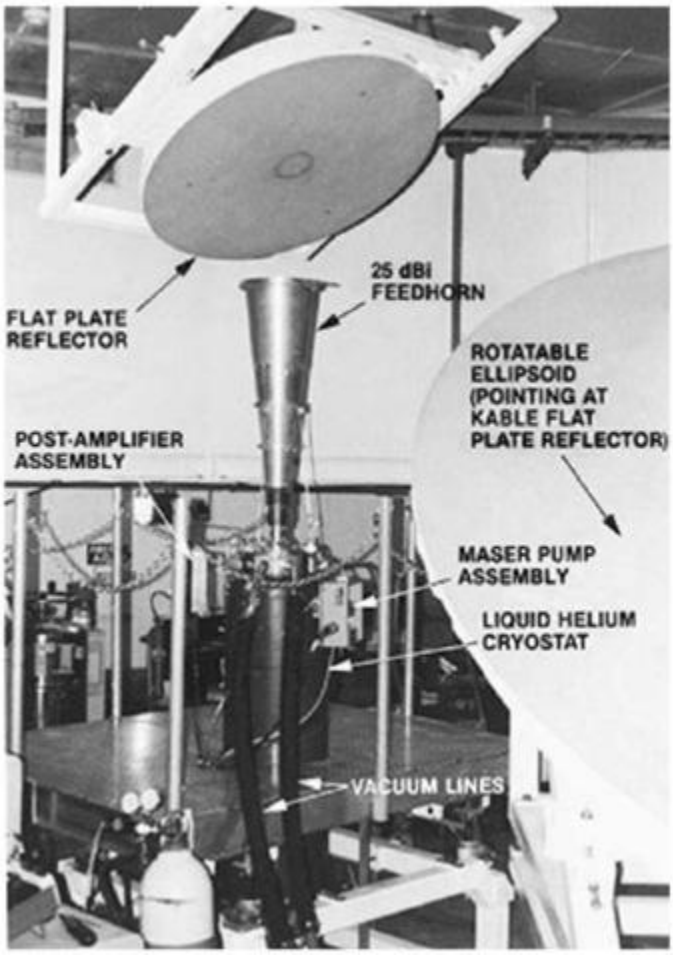


Figure 4: The Ultra Noise Amplifier to Detect Weak Signals
http://what-when-how.com/space-science-and-technology/deep-space-network-evolution-of-technology/

The figure above shows a very important piece in the recovery of the signal, an Ultra Noise Amplifier. This amplifier is one of the most sophisticated devices in the communication world as it recovers the signal which has traveled millions of miles and is full of noise. As per the direct information from the DSN Canberra site, “These are very narrow antenna beam widths, very cold(-4K) amplifiers to limit new noise & special telemetry coding to reduce effect of noise.”

9. Space Communication Basics

a. Signal power

In the Deep Space Network, signal power depends on of how much the transmitter can handle and the peak power available to the transmitter. Thus, communicating to the farthest probe possible in far space (the NHPC or New Horizons, the Voyager 1 – 11.3 Billion Miles as of September 2013) [24] at a mega distance of 31.86 million miles, the largest parabolic dish at the Madrid station transmits at a power of 20.63 Kilowatts [4]. For the Voyager 2, the power transmitted is 19.08 Kilowatts for the down signal and the power received is 8.88 X 10-23 [4]. The Friis equation can be used to calculate the received power with the help of transmitted power, same time, the link budget analysis can help to get the power loss in the space. Considering the data rate as an issue in the space, the Shannon limit helps to know the capacity of the transmitted signal in order to reach the destination. This is very important in the long distance noisy communication channel.

b. Uplink and Downlink

The Uplink refers to the feeder link portion in radio communication used for signal transmission from the earth station to the spacecraft and to the rovers. The Downlink is the feeder link portion used for transmitting signals from the spacecraft or rover directly to the Earth station at the Deep Space Network [5].

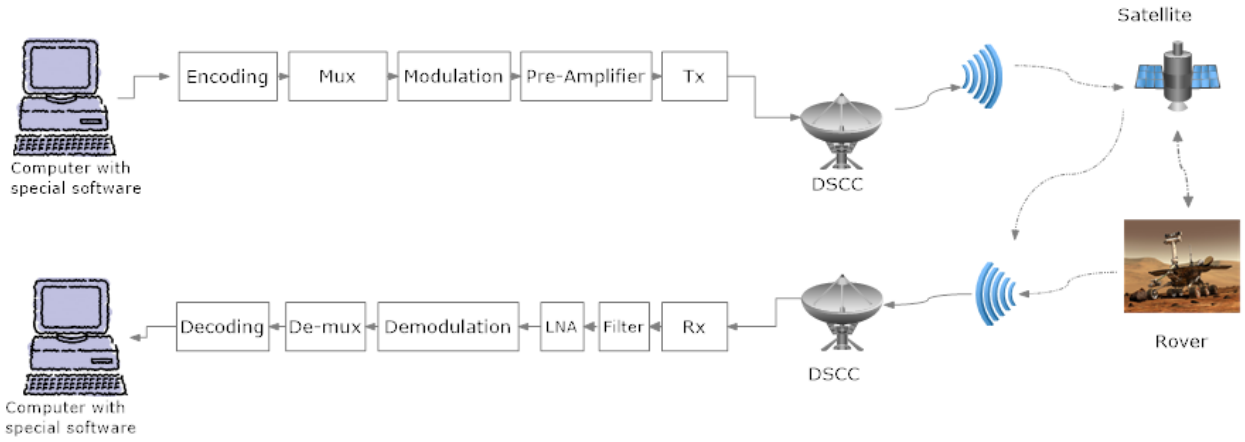


Figure 5: The functional block diagram of DSN communication system

Source – Prasad Falke

c. Modulation and Demodulation

The imposition of input signals to the carrier waves is a modulation. The modulation thus changes the carrier wave shape to encode the data communication required [5]. Modulation varies one or several carrier signal/waveform properties using a modulating signal containing the transmitted information. Demodulation, conversely, refers to the extraction of the original signal bearing the information from the carrier wave that underwent modulation [14]. In Deep Space Network Communication, the extracted signal consists of a digital data stream.

The modulation techniques like FM, QPSK, BPSK, and PCM can be used to modulate the signal, while arraying schemes like Full-Spectrum Combining (FSC), Complex-Symbol Combining (CSC), Symbol-Stream Combining (SSC), Baseband Combining (BC), and Carrier Arraying (CA) used while recovering the signal from the DSN antennas. The recovery (decoding + demodulation) takes place using a computer software by the DSN team (The name of the software is confidential) [25] [29].

d. Multiplexing/De-multiplexing

That multiplexing refers to the sending of numerous or multiple information streams or signals simultaneously over communication links [2]. The key here is that this must happen in the form of a complex single signal. The Receiver then recovers the separate information streams or signals through de-multiplexing. The Time Division Multiplexing (TDM) is used for multiplexing the signal at different time slots and then transmitted into the space. At the receiver station, the de-mux operation happens by matching the long binary digit using pseudo number generator [27].

e. Coherence

In two wave sources coherency occurs when they have the same frequency and a phase difference that is constant [1]. This enables stationary or spatially constant interference.

f. Half duplex vs. Full duplex

Since the distance covered in the case of DSN is in the millions, the half-duplex frequency is used for the communication, which means, either the signal can be transmitted or received at a same frequency. In full-duplex, the signal transmission and reception happens at the same time on the same channel but with different frequencies (TX - 435 MHz to 450 MHz, RX - 390 to 405 MHz) [26].

In the case of Mars Reconnaissance Orbiter (MRO), the transceiver output power is 5.0 W for full-duplex and 7.0 W for half-duplex. The half-duplex or full-duplex mode is selected based on the mission because of the multiple tasks handled by the DSN stations [26].

g. Error checking/Recovery

The DSN uses a number of techniques to improve the quality of the received signal such as the state of the art sensitivity of the system, telemetry coding schemes (FEC), higher microwave radio frequency, LNA, and receiver antenna placed at different location that the transmitter antenna. The turbo and convolutional code used as decoding techniques to recover the signal [28] [29].

h. Encoding/decoding

The differential encoding is used in the DSN to transmit the signal, which further divides into non-return to zero-space (NRZ-S) and non-return to zero-mark (NRZ-M). The first one changes the modulated signal when the zero occurs, and remains same when one occurs, whereas the opposite occurs for the second type of signal [29].

10.DSN Current State and Space Communications Basics

a. Current Work

The Deep Space Network consists of three communication facilities strategically located at positions 120 degrees apart on the surface of the earth [2]. The three facilities are the Goldstone Deep Space Communications Complex in California (Barstow), the Canberra Deep Space Communication Complex in Australia, and the Madrid Communication Complex in Spain. The geographical coordinates for the stations are 35°25′36″N 116°53′24″W), 40°25′53″N 4°14′53″W), and 35°24′05″S 148°58′54″E) respectively [2].

b. The Great Antennae of DSN

The diameters of DSN or Deep Space Networks range in size from 111 feet or 34 meters to 230 feet or 70 meters. That is roughly equivalent to the height of a building 22 stories high [3]. Looking at the network antennas, one sees they tend to consist of four terminals containing ultra-sensitive receiver devices and have large parabolic shapes. An example of a typical complex would host 112 feet or 34-meter diameter HEF (High-Efficiency Antenna). It would also host two or more 112 feet BWG (Beam Waveguide Antennas) such as those seen at the Goldstone Complex, the Canberra Complex and the Robledo de Chavela Complex [3]. In the case of the Goldstone ones, the beam wave guided type entered service towards the end of the 1990s.

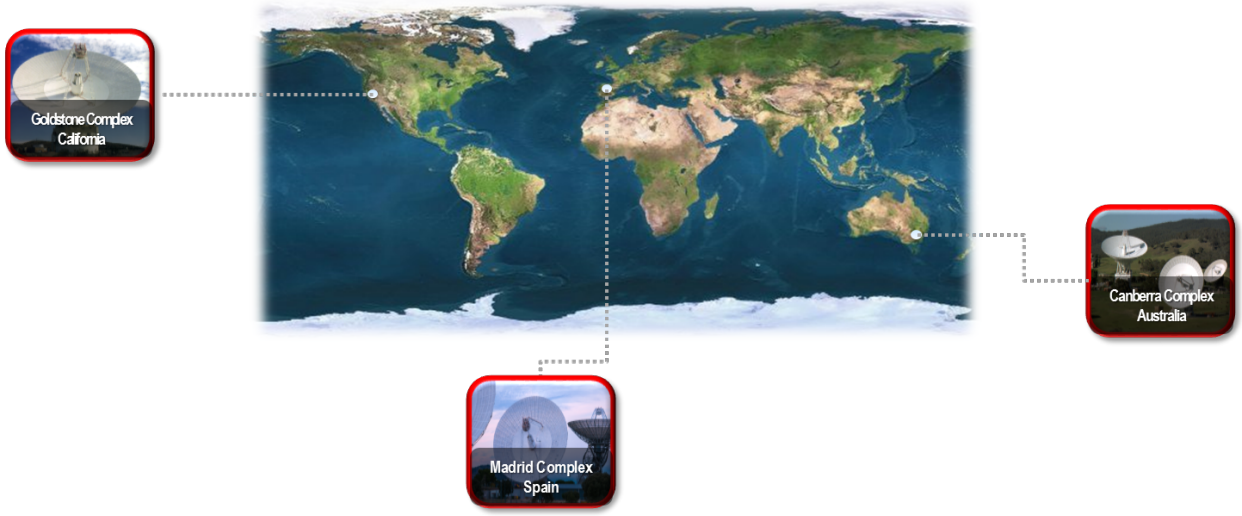


Figure 6: Three DSN Complexes Around the Globe

http://www.nasa.gov/sites/default/files/thumbnails/image/deepspacenetwork2015.png

The parabolic shapes show the best performance as they can collect a broad range of signals and transmit a greater range of signals with the least degradation of performance [9]. It is important to note that despite the sophistication of the Deep Space Networks antenna, there are many inherent limitations. These include the fact that there is a slight probability of reduced use in the future or for current plans for specific communication satellites to handle multi-mission and multiparty use. All the receiving and transmitting equipment are based here on earth.

That means data transmission rates from any spacecraft or to any spacecraft and space probes faces severe constraints due to the distance between the objects in space and the surface of the planet. The other issue is that the failure of one component can put the entire DNS out of commission for several months [9]. This issue is compounded by the fact that many of the components have aged and might get older with the time, so there is need of an upgrade to newer technology or replacement it with the new ones. An example of this is the HEF and 70 Meter antennas which are in dire need of replacement. The replacement will require extensive funding which may not be easily available.

Finally, another thing worth noting is that the spacecraft exceeding geocentric orbits now use BMS or Beacon Mode Service [18]. The use of this beacon negates the need to communicate and exchange data with the Deep Space Network. The Beacon Monitor Experiment (BMOX) reduces time for DSN tracking and related cost of the mission by transmitting the spacecraft anomaly towards Earth based stations using four different states (Important, Urgent, Interesting, and Nominal). Each state represents the tone and measures how critical the message is. Therefore, the DSN does not need to be in constant communication with the spacecraft anymore.

c. Description of the Antennae array and its functionality

In space communication, the distance traveled by the signal may be in the order of several thousand or even millions of miles [14]. The signal would also travel in an environment hosting charged radioactive particles, other signals and massive bodies such as planets and asteroids. Thus inevitably, the signal must deal with a lot of interference and blockage that could degrade its quality. For that reason, there must be an antenna of such sophistication and power that the signal gets sent and received with absolute clarity [14]. Additionally, signals do not die off in

space as they do on this planet. A signal may travel for years throughout the galaxies and eventually reach its target long after the person or entity that sent it ceases to exist. For example, some crafts sent to explore the surface of distant planets like Pluto send signals that end up being received many years later. For the purpose of secrecy, the signals may need to be encoded [1]. The United States is not the only one pursuing activities in space for research and military purposes. Other countries such as Russia, India, EU, UAE and China also have space programs.

As discussed earlier, the signal travels thousands of miles before reaching the ground based antennas which results in very poor quality (attenuation) of the signal because of a number of noise sources in its path. To reduce the signal to noise ratio (SNR), the effective method is to combine the signal received by an array of antennas once it is available after going through low receiver noise temperature. This will not only help to get better coverage but will help enhance the feasibility of programming, operational robustness, save cost, and provide wide support for academics to explore [22].

In the Deep Space Network, many antenna arraying techniques exist. Each has its relative benefits and deficits, and so for any study, one must carry out a detailed analysis of the main types of arrays [1]. There are five primary or fundamental signal processing methods that the system employs. The methods used to serve the purpose of combining the output of the different antennas observing the signal from the spacecraft type. The schemes for signal processing are the Carrier Arraying Technique (CA), the CSC (Complex Symbol Combining), the FSC (Full Spectrum Combining), the SSC (Symbol Stream Combining) and the BC (Baseband Combining [15]. These different systems or schemes have undergone analysis and discussion by various scientists to determine the most suitable or complex scheme.

Of the five schemes, four of them, namely CA, BC, SSC, and CSC, can only function with a signal with excellently defined modulation characteristics [15]. These four utilize the fact that the signal source has spectral characteristics that are unique and which therefore process the given signal accordingly. Looking at the first scheme (FSC), it is observed that this scheme works well with signals with noise-like qualities or unknown signals. Unknown signals here are those whose

origin and purpose of transmission scientists cannot determine [16]. Examples in this respect include the so-called radio quasars of astronomical nature.

Looking at the techniques mentioned above, it is observed that they fall into the common signal processing category. The overall SNR tends to be determined by the thermal noise the first amplifier generates and the antennas capture area. Thus, in the typical diagram of the signal flow, one notices that the amplifier with low noise is followed by the two-stage open-loop type down converters [16]. These converters, convert the spectrum portion occupied by the spacecraft signal to an easily digitized signal. A digitized signal refers to one where the signal has the audio and the video element combined in both the transmission and the reception. The digital signal differs from the analog in that the signal gets sent in two different parts.

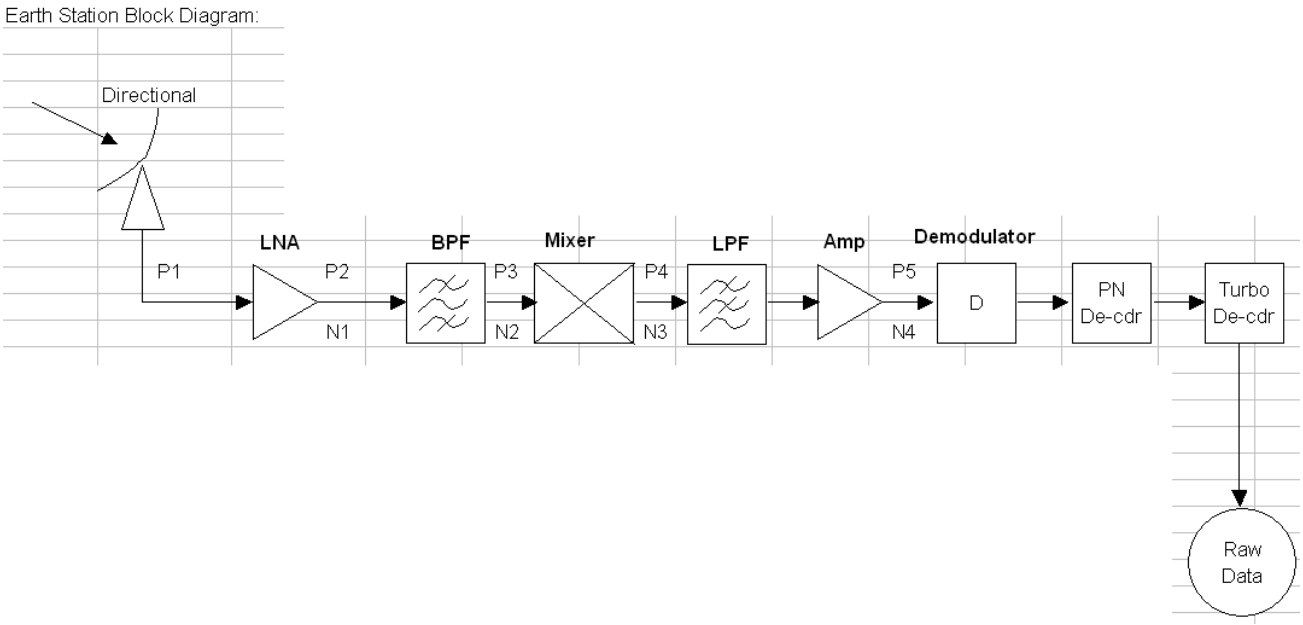


Figure 7: The Receiver Block Diagram

http://propagation.ece.gatech.edu/ECE6390/project/Fall2004/Joseph_Benin/Website/D_DSN.htm

The digital signal tends to have much more clarity, occupy a lower amount of bandwidth, and can hence travel much farther without degradation [19]. The conversion process uses techniques for digital signal processing and to do so; the system must carry out an estimate of the data bits impressed on the spacecraft carrier. The data then gets delivered to the specific project operating the spacecraft. While the signal flow diagram is like that of the arraying techniques, the ultimate goal of all the systems is the same, notwithstanding differing methods [19]. The result of this

difference, however, is that operational costs and capital investments in the project may vary. The differences also make consensus on the best antenna arraying techniques complicated since some parties may prefer a high capital inlay for a relatively minimal gain [13]. The Chinese space program shows such a characteristic with the benefit accrued not being proportional to the money spent on the equipment and the launch. On the other hand, the French Arianne project and to some extent the Russian counterpart rank as some of the most economical in the world, with the equipment put into space providing more value for money.

There could be a question about use of relay satellite networks in the DSN. Currently, networks such as the Tracking and Data Relay Satellite (TDRS) is being used for missions like the Hubble Space Telescope (HST), Space Shuttle, and the International Space Station (ISS). The TDRS is purposefully used for LEO and geosynchronous satellites as it is placed at a height of 22,300 miles from the Earth surface. Therefore, it performs signal communication exchange between satellites around the Earth without any interruption and 99.99% efficiency. Even if the space agencies start using it, the receivers on these TDRS satellites are not designed to receive very poor quality signals which are full of noise [23].

I. FSC (Full Spectrum Combining)

Full Spectrum Combining as an antenna type refers to a system or mode where the signals are at an instantaneous frequency from each antenna and get transmitted to a site where they then are combined [19]. The signals normally get phase adjusted and delayed the process of combination in order the coherence to occur. Signal stream correlation then helps in the accomplishment of the correct delay and phase. FSC has many primary advantages, but the most common one is that it can benefit from spectral signal source characteristics without depending on them [6]. An example of this would be the filtration of the spectrum received if prior knowledge of the spectral characteristic exists or if the spectrum has noise-like traits, FSC can also play a key role when the signal carrier cannot track using a single antenna, or the carrier itself is too weak.

In the case where tracking cannot occur using a single antenna, the gross relative phases and delays between the different antennas get determined through geometric calculations. Any residual relative phases and delays get determined through signal cross-correlation from each of the system's antennas [11]. The phases and delays can correct the IF signals of the antenna and then combine them. Costs in the FSC antennae type can arise when a noise like signal spectrum or an unknown comes into the picture. When this happens, the entire bandwidth of the signal must be transmitted onto the signal combining site [11]. For an analog transmission, the link should ideally have low dispersion and high phase characteristics. This is to maintain a coherence of phase at the radio frequency. On the other hand, for a digital link and multibit digitization, the system must use a much larger bandwidth. The figure below shows an example of FSC or Full Spectrum Combining. where is the figure below?

II. CSC (Complex Symbol Combining)

In the CSC type of array as shown in the diagram following this paragraph, the IF or Intermediate Frequency from single antennas get fed to the receiver [11]. After this feeding to the receiver, an open loop carrier tracks the IF via the BAC (Best Available Carrier) predicts. If the tracking remains within a certain frequency error (a value less than the symbol rate), it can be gainfully employed. The process of getting used simply means demodulation by the subcarrier [13]. In addition to demodulation, synchronization of the symbol can also occur. The complex symbols enabled through the open carrier then move on to the combining sites for the namesake

procedure. Coherence is a vital part of this process, and is ensured by the phase adjusting the signals before combination.

Correct phase estimation to prevent errors creeping into the process takes place through varying signal stream correlation. This technique has multiple advantages including the fact that the data gets transmitted to a central site for combination at a slightly higher rate than the symbol rate [13]. The symbol rate, in this case, is a multiple of the data rate and coding scheme dependent. Data communication rates to the central site rank as quite important factors concerning the cost. Most of the users require their data in real time and this in higher costs, especially when considering the additional element of instrumental phase stability [14].

The only disadvantage of the Complex Symbol combination is that like its SSC counterpart, each antenna must have the symbol tracking element or device and the subcarrier or carrier [14]. Additionally, open center tracking loops tend to lessen SNR demand.

III. SSC (Symbol Stream Combining)

In SSC, every signal from the antenna is employed by the receiver to track subcarriers and carriers and to synchronize the symbol. Once the system achieves symbol desynchronization, it becomes quite straightforward to delay data streams and align the symbols before it is too late [1]. The symbols get combined with the right weight to form raw data of telemetry. The raw data is by no means the end all be all as it can only accomplish a series of limited purposes. There are several advantages of the Symbol Stream combining including the fact that the data gets sent to a single combining location at the symbol rate [6]. The symbol rate here refers to some multiple of the data rate. It is highly dependent on the coding scheme and in most applications, has a modest rate.

It is worth mentioning that data communication rate to the central site has an impact on cost since users require their data in real time. In simple terms, users do not want their data delayed or passing through multiple applications and filters before reaching them [19]. A close analogy to this would be a user getting data from the cloud. The cloud can release data to users in real time as soon as it gets uploaded to the platform. However, if there are filters, firewalls or proxy

servers, the data must pass through them before reaching the user (for security reasons, this is necessary). In that case, the delay essentially means that the users do not enjoy data in real time [16]. Furthermore, the SSC does not impose stringent instrument phase stability requirements. Like its other counterparts, SSC does have disadvantages. The most notable is the fact that each antenna must have both a symbol tracking device and a carrier. From the perspective of system costs, this matters greatly because of modern technology; in theory, it allows the manufacture of cheap digital electronics [16]. On the other hand, to get high performance, both the carrier and the symbol tracking device must show a high degree of sophistication. That means that for these antennae systems, the concerned stakeholders must create high performance and personalized devices at significant cost. The system must also have a high loop SNR [15]. The reason for this is that the locking of the tracking loops must be effected through the minimum loop bandwidth and greater signal strength. For the small antennas with a weak signal strength, there are difficulties in obtaining narrow width bandwidth. The figure below shows SSC (Symbol Stream Combining).

Another thing about this system is that the loop bandwidth can determine the number of errors in a signal. For obvious reasons, the signal cannot have too many errors or an error that degrades it to the point that it cannot be recovered [11]. Narrow bandwidth loops do well in time integration and allowing the SNR to lock. They also help when the incoming signal varies considerably and shows inherent instability. If the signal has great instability and variation, then it must have a large bandwidth loop to accommodate the signal.

IV. BC (Baseband Combining)

In Baseband Combining, each antenna signal gets locked, and the carrier loop frequency operates at a baseband. It also consists of subcarrier harmonics. The signal with the baseband characteristics tends to be combined, weighed, delayed and digitized [1]. That delay often occurs through the cross correlating of different antennae's baseband signals. In BC, the combined signal serves the purpose of achieving a symbol demodulation and subcarrier lock. The harmonics and the bandwidth with the subcarrier tend to be narrow and heterodyned to the baseband. One should note that the baseband data should be transmitted to a single central combining location and must contain the crucial subcarrier harmonics [14]. The disadvantage of

BC is that a carrier lock must take place on every individual antenna. Additionally, a decrease in the antenna diameter results in a reduction in the carrier SNR.

V. CA (Carrier Arraying)

In this type of antenna arraying, the carrier tracking loops of individual nature on the array element get coupled to augment the SNR of the received carrier. This enhancement, in turn, decreases the loss of signal strength due to imperfect single antenna carrier lock [19]. Simply put, the tracking devices of the carrier arrive at one global carrier synchronization estimate. A single massive antenna can also provide the required carrier lock information and therefore act in the same manner as multiple small antennas. Combining can then occur at a baseband or an intermediate frequency, although the information of the carrier lock must get transmitted to a single central site [11]. Antennas which have a significant distance separation must, however, undergo carrier lock information correction using different geometries.

11.DSN Technology

a. Working of DSN

The DSN provides excellent two-way communication modes or links that control and guide multiple unmanned NASA probes and receives the scientific information and images the probes send. The three communication facilities consist of arrays of parabolic shaped antennas that send radio signals to the probes and receive feedback in the form of data [14]. The encrypted radio signals go to the probes via the uplink signal transmission and get received via the downlink signal reception. This helps in measuring radio wave variation, performing VLBI or Very Long Baseline Interferometry, tracking their velocity and position, transmitting commands to the crafts and acquiring telemetry data from them [14]. In a VLBI, the signal is collected from a number of radio telescope antennas, similarly, the array of DNS antennas collects the signal and recover it using its timestamp and quality.

The DSN ground stations directly communicate with either the orbiters around the planet or with the rovers on the surface. Once the signal is received by the rover from earth based ground stations or from the orbiter, the rover performs the functions as per the instructions and responds back with the telemetry. The instructions sent are coded computer files which gets executed as a series of actions. The telemetry is then received by the big 70m parabolic reflector antennas on the earth. The reason for using the big parabolic antenna is because of its strength to receive the very weak signal coming from deep space in the presence of different types noise. Once the signal is recovered and processed, it is then analyzed by the team at the respective ground stations and sent to the JPL team in California for final review. The JPL Operations and control team is responsible for all the tasks and provides the data to the teams which need it.

b. Communication Facilities

The Communication facilities consist of BWG (Beam Waveguide Antennas and High-Efficiency Antennas. The BWG ones have several distinct features namely Geometric Foci, Microwave packages, Azimuth tracks, pedestal room, Beam Waveguide, 34-meter diameter shaped surface reflectors and shaped surface sub-reflector [6]. The BWG functions by the radio waves getting

transported between the stationary receiver or transmitter and the movable dish. High-efficiency antennas radiate away most of the power at the antenna's input.

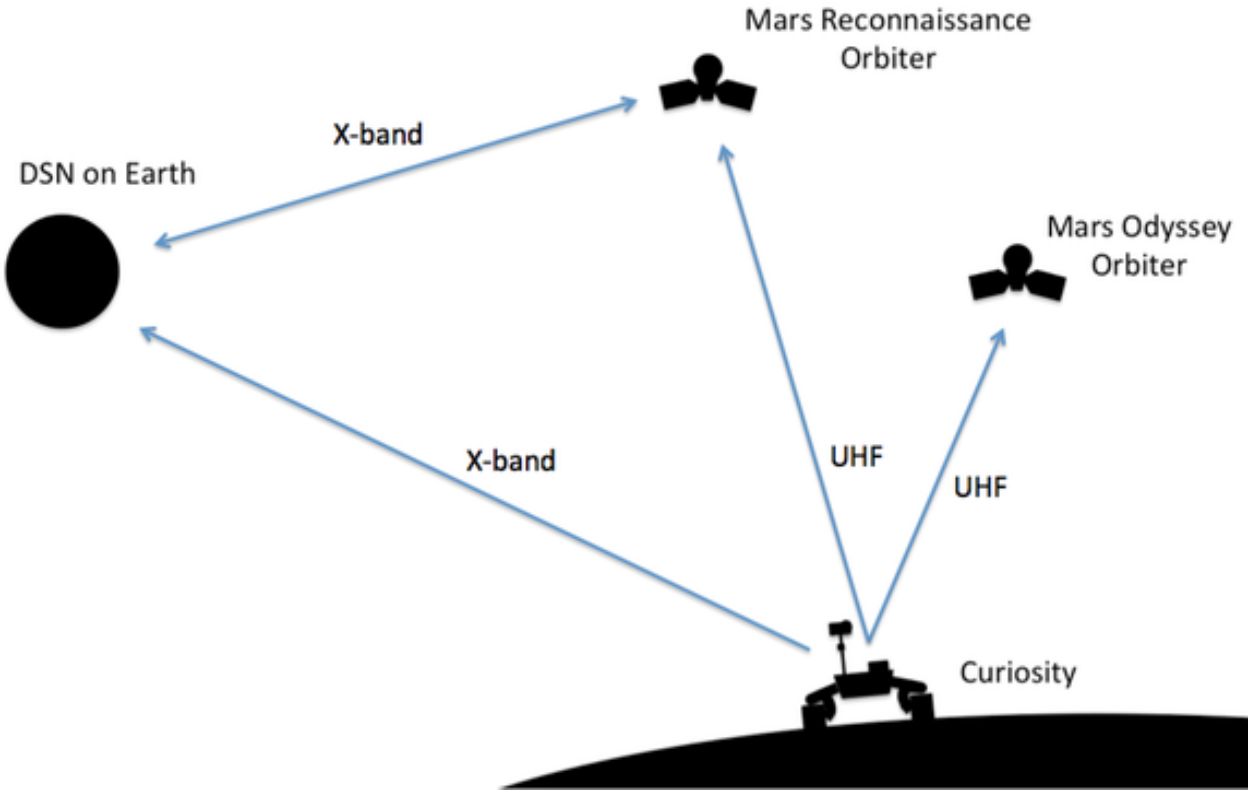


Figure 8: The DSN, Satellite and Rover Communication

https://www.quora.com/Robert-Frost-How-does-the-Mars-Rover-communicate-with-Earth-despite-being-so-far-away

c. Spacecraft Communication

The spacecraft have receivers and transmitters for radio waves and systems for decoding the information received. However, the radio waves that the craft receives from the Deep Space Network tend to be weak, and thus the parabolic dishes amplify as well as decode and encrypt them [6]. The radio signals get exchanged in the form of data bits sent up by the uplink and received by the downlink. The output can be digital images, telemetry data or word based teletype information.

12. Applications of DSN

a. Telemetry

In the Deep Space Network or DSN, telemetry refers to data that shows the health and status of the spacecraft along with other key information such as speed, trajectory, and orbit [21]. The importance of this is that the spacecraft cannot orient itself in the proper position without the use of the parabolic dishes of the DSN which calculate the position by getting fixes on the spacecraft and specific stars. This is because naturally, space has neither frontiers nor fixed static features. Thus, an ordinary gyro compass would not suffice. The telemetry, therefore, is the data sent from the space probe or spacecraft to the networks of ground stations.

From a telemetry point of view, it is important that the ground station (DSN) always must know the specific parameters of the spacecraft [17]. This is because spacecraft usually travel through space at speeds more than Mach 7 or seven times the speed of sound [17]. Some even travel at even higher speeds to avoid the gravitational pull of planets which could cause them to be forcefully pulled into orbit.

From a general standpoint, the telemetry data received by the Ground Stations includes battery voltage levels, operating temperatures of the outside surface and cabin interior temperatures, critical details of the surrounding, health of the solar panels, the distance covered by the spacecraft/rover, any failure in the system, trajectory, pictures, scientific discoveries and oxygen levels, if the spacecraft has a crew [17]. In simple terms, the parameters hold information about the spacecraft's health and resources and the acquired data gets mapped to form the telemetry frame format. The parabolic dish plays the most important part because it has something called the Focal Point. In the central point, sits the Low Noise Down Block Converter device or the LNB which converts the electromagnetic and radio signals received as telemetry data to electrical signals. It also shifts the signals from C and KU band in the downlink to L-Band.

The telemetry function in Deep Space acts through specific software systems that are designed to capture and analyze the raw data [9]. The Software based system has many components that enable it to carry out its mandate, namely, the Payload, the Power Subsystem, the ADCS, the

Transmitter, the Log and the Receiver. In other words, onboard the spacecraft, these elements function to send and receive various packets of data to the Deep Space Network to carry out a multitude of tasks [18]. In the case of the Payload aboard the spacecraft or probe, this payload will capture images such as photos of distant stars and transform them into bits of data, compress the data and then transmit it.

For the actual telemetry that determines the health of the spacecraft, the power system on the spacecraft will use the status handler to send data to the Deep Space Network receiving ground stations showing the current situation of the craft. The duration of travel to the specific destination, the power consumption, the solar cells battery levels, trajectory and other pertinent factors [11]. In turn, the Deep Space Network will send signals that reconfigure or reset the trajectory of the spacecraft or command it to hibernate to save energy or reorient the solar panels to capture more energy [11]. The other telemetry data that can flow to the ground stations includes altitude and orbit related information. For example, the spacecraft may transmit a series of data pieces to the Deep Space Station Ground Network to show that it has reached a certain orbit about a given star.

The Deep Space Network ground stations will take fixes on this star and others and pinpoint if the spacecraft is exactly on track [18]. One should note that the data does not just flow in the same manner as say, the Internet on Earth. If the Spacecraft sends data to the Deep Space Network ground station, that data passes through the Data Acquisition Buffer, the 1st Telemetry Buffer, the 2nd Telemetry Buffer, the Telemetry port, the demodulation system to decode the signal and then to the memory [18]. The same occurs if the ground station sends a signal to the spacecraft. The data signal must pass through the data acquisition buffer, the first and second telemetry buffer, the demodulation system and then the memory [12]. In this case, the demodulator acts in a similar manner to the Modem for Internet access. Modulating Demodulator receives a radio signal and then converts from a series of zeros and ones & data bits to something comprehensible such as a velocity reading. In summary, the telemetry data is as follows:
Status Data is a type of data that is concerned with the spacecraft mode of operation, altitude, health, and resources. The scientific evidence collected by different onboard sensors such as thermometers, electrometers, accelerometers, magnetometers, spectrometers and infrared

telescopes [12]. Critical data such as timing data and spacecraft required for navigation and guidance, locations of objects in space relative to the spacecraft and telemetry data to other spacecraft in the vicinity.

b. Spacecraft Command

The command system has the responsibility of communicating required changes from the ground to the spacecraft such as corrective actions. The telemetry system, on the other hand, handles all the data communication from the space probe or craft to the ground station [5]. Thus, the data and radio signals sent from the Deep Space Network to the spacecraft telling it what to do command while the telemetry gives feedback on the command status, the mission specific data and the spacecraft vitals. The commands purpose is to provide the space vehicle with instruction sets that it must perform to ensure mission success [5]. The commands normally happen on a priority basis, and some must therefore immediately get executed while others may occur after some delay.

That is, a time frame must elapse before the command comes into play. Also, a combination of events could be the trigger. The space vehicles tend to carry out the function ranges based on the unique coded commands they receive [10]. As mentioned before, power based commands can form some of the most important ones. One command can result in power application or removal from a single subsystem of the spacecraft. Another command could focus on the navigation element or the antennas movement, the control boom movements, the drawing back of protective covers and the extension of solar arrays [10]. One should note that command systems can take the form of entire programs contained and executed in conjunction with microprocessor based systems.

In the Deep Space Network, the radio frequency type signal arrives after transmission at the command receiver for amplification and demodulation. The command needs amplification because the signal becomes weak after traveling a long distance from the earth. Next in line to the amplification and the demodulation is the command decoder which examines the so-called subcarrier signal [7]. It then detects the specific command message carried by this carrier signal.

Additionally, it provides the command logic with clock information and tells it when a valid data bit occurs on the data line. The bit stream command sent to the command processor is unique in that the bits go out in different forms.

For example, the first thing that could go out is the address bits. The address bits functions like a license plate or IP address, in that it is the only property of a specific spaceship [7]. It, therefore, has coding and encryption such that no other spacecraft can receive the signal and execute an unintended act (to avoid cross-functioning). The specific identification code becomes a necessity when one considers that there may be hundreds of space vehicles in space, including Voyager type crafts and satellites using an identical modulation and frequency type.

The command decoder in this function sends output to the microprocessor, and the operation or action happens based on this input [4]. ROM or RAM memory modules ensure the correct deciphering of the input which creates an output headed for the interface circuitry. Modern day command systems tend to use pre-programmed microprocessors (specially designed for space related activities) due to the wide range of message and command types [21]. Commands can also come in the form of data, level, pulse and relay types, with the relay ones activating the Central Power switching electromagnetic relays. The pulse types are short current ones aimed at the designated subsystems command logic. The commands to the spacecraft tend to format according to the information in the spacecraft database. They also must first undergo validation before transmission [21].

Commands may go out in the real time, manually or through semi-automated and automated procedures. In special cases, closed loop types of controls may occur as part of housekeeping requirements aboard the aircraft. Either way, the telemetry, and commands must pass through encryption mechanisms to prevent unauthorized people from breaking into the communication cycle [2]. In the early days of the Deep Space Network, the procedures the spacecraft would execute would be tested first in a simulator to see if the ground stations could command the spacecraft and the effectiveness of the executed procedures. The key thing to note in command of spacecraft as a function of the Deep Space Network is that up-linking of the Baseband signals must get extracted from the data packets of the ground network [2].

Subsequently, the packets will undergo encoding and modulate onto an IF (Intermediate Frequency) carrier. After this, the signals got up-converted and assigned to the RF (Radio Frequency Band). The system amplifies the RF signal to high power and carries through the waveguide to the parabolic dish antennae for transmission. Downlinked or received signals, on the other hand, pass through LNA or Low Noise Amplifiers [11]. These have their location in the hub of the antenna to minimize signal distance travel before down conversion to Intermediate Frequency. The previously mentioned LNB combines the two functions of downlinking and down converting. For the data stream to provide the key information required for action (bit and frame wise) the IF signal must get demodulated [4]. Data errors can happen during the command data communication and exchange process.

For this reason, many systems have large storage modules where the engineer can save the packetized data stream containing vital information. Just one spacecraft can use multiple Radio Frequency bands for the command prompts and telemetry based on the available bandwidth.

c. Tracking

Tracking refers to the monitoring of the spacecraft or space probe by the Deep Space Network from the moment it leaves the earth and enters the outer edges of the atmosphere (150,000 feet) to when it enters a certain orbit [3]. In general terms, there are four different ways of tracking spacecraft namely, one-way, two-way, three way and coherent three-way. In the one-way method, the space probe generates the given downlink using an oscillator onboard. The Deep Space Network then carries out a comparison of the received frequency against a frequency locally generated. In the two-way method, the DSN performs transmission of a signal, and the spacecraft then tracks the uplink signal phase [4].

The process leads to the generation of a downlink signal that is phase coherent. The Deep Space Network compares and analyzes the frequency it receives with the identical reference frequency of the generated uplink. The spacecraft gets tracked by two different stations. The first has a two-way method of operation and carries out signal comparison against the locally created frequency [4]. This is particularly the case when handing over communication between Deep Space Communication stations. Coherent Three Way tracking refers to the actions whereby the stations that transmit and receive a standard reference frequency. At the three facilities that form the Deep Space Network, this can occur because the antennas used share the same frequency reference.

A prime event where high-level tracking occurred can be seen in the sophisticated monitoring of the 1981 Voyager mission. In this mission where the Voyager space probe had an encounter with the planet Saturn, the Deep Space Network used a kind of tracking called differential tracking to guarantee that the probe did not enter the wrong orbit nor suddenly get drawn into the planet's gravitational pull and crash at high speed into its surface [7]. Such a crash would have naturally resulted in the destruction of the space probe.

In the interferometry method, two large DSN stations situated at a considerable distance apart (on two different continents) received on a simultaneous basis the signals transmitted from the space probe as it went about its trajectory. This may happen because one of the station is getting

away from the signal (because of the rotation of the Earth) and the other one is coming into the coverage, so the data received at both the station will play a critical role. The stations also at the same time received radio signals from a quasar or natural radio source in the vicinity [10]. The radio source, in this case, had celestial coordinates already known to the Deep Space Network. The tracking used the procedure of taking the data from the two different stations and then correlating this data to provide exact angular separation measurements between the natural radio source and the space probe data.

The natural radio source can come in the form of a star in the process of disintegration or even any of the heavenly bodies such as meteors, and hence it is very necessary to differentiate the data between this natural radio source (noise) and the telemetry. The measurements that the Deep Space Network revealed had an extremely high accuracy of 50 to 55 Nano-radians [10]. To put it in another way, the accuracy was ten times that of the best radar tracking array in existence. At that point, the phased array system had just started coming into service, but only in the US Navy to see skimming anti-ship missiles. The tracking enabled the space probe to carry out the closest flyby possible of the planet without getting to a point where Jupiter's gravitational pull could deform the space probe's travel and reduce its time in space.

The other tracking used (but much later) is the phased array type of tracking [17]. The phased array type just refers to modified radar with the ability to track even the smallest objects moving at a low altitude or extreme altitude, hundreds of miles away. The phased array used for spaceship tracking currently operates at the Deep Space Network complex in America in a standby mode [12]. The radar tracker itself has a flat shape with a slab-like an appearance hosting, in effect, thousands of tiny transmitters and receivers. The tile form replaces the parabolic aerial but performs almost the same function. It can receive telemetry data, but the slab shape does not focus the received signal (downlink) to the focal point as there is none. Instead, as mentioned before, the slab has hundreds or thousands of the receiver and transmitting diode type apparatus that one cannot see with the naked eye [12].

They simultaneously transmit and receive such that collectively, they act as one giant transmitter and receiver. The advantage of the phased array system is that it can detect even the slightest changes to trajectory and even a small object striking the space probe [5]. An object the size of a golf ball that comes off an asteroid and hits the spacecraft will register regarding speed and trajectory. The disadvantage lies in the much too sensitive nature of the detector and range limitations.

Arraying has an advantage over the phased array method in that it shows greater data returns and tracks over much larger distances. In the arraying method used in the Deep Space Network, the apparatus uses two different and separate antennas for the tracking process. The antennas collect telemetry data from the space probe, and then through electronic means, enhancing the effect of the collected signals to produce the same effect as antennae with much larger diameters [12]. The Pioneer 2 spacecraft sent to study Saturn and the Voyager spacecraft sent to explore Jupiter used this technique. Maser type antennas operating on the low noise X-band worked with existing antennas of 64-meter size through a combined assembly operating in real time [12]. The spacecraft signals received from the two new antennas electronically combined to provide a result at least 35 to 38% better than that from the 64-meter antenna.

In the 1986 mission, the Deep Space Network combined antennas at the Australian Canberra complex and the Parkes based radio telescope to produce high-efficiency antennas with greater data clarity. The largest ever array used came in 1989 with the Neptune project when the arrays had the equivalent diameter of 151 meters and a 19,300-kilometer range [18]. This array was so powerful that it could track both the spacecraft and a supernova called Supernova 1987A this should be cited like your other references. The last tracking method for spacecraft used is the tried and tested Doppler method. In the simplest terms possible, "The Doppler Effect is a change, decrease or increase in the frequency of sound or light waves that occur as the observer and source move away from each other or moves towards each other."

One can see an example of this effect in the sudden pitch change noticeable as an ambulance with a screeching siren passes by. In the space tracking mode, a radar sends a radar signal to the spacecraft and then calculates the apparent change in frequency of the return signal based on a signal sent to another artificial body such as a satellite passing in the opposite direction [18].

d. Radio Science

Radio Science refers to a technique used to find out a planet or moon's gravitational field by observing the shift in Doppler. The requirement for radio science interventions is a very stable oscillator placed aboard the space probe. The technique can also employ a two-way transponder with a high coherency that locks the frequency of the transmitted signal in phase [11]. This locking occurs due to the received uplink's rational multiple that also hosts the spacecraft commands. Another technique for deployment involves using the movement of the spacecraft as it transitions behind a specific planet [11]. As the ship passes behind the planet, the radio signals it sends also pass through multiple planetary atmospheric layers. Researchers can look at the signal polarization and strength to determine the temperature of the planet and its physical composition.

The Deep Space Network plays the role here of sending a telemetry signal to the spacecraft to realign itself behind the planet and hence be in a position to send messages to the planet for analysis purposes. The received telemetry data from the planet then returns to the spacecraft which forwards them via downlink to the Deep Space Network receivers [9]. For this technique to be useful, the system must use multiple radio frequencies from one source. That will ensure the best propagation medium dispersion. A technique such as this can detect a planetary ionosphere free electrons [9]. It can work best especially if the spacecraft uses a stable signal in both the transmission and reception. Finally, since the signal parameters in transmission tend to be stable, the parameters realized about the spacecraft's motion, also tend to be stable.

e. Science

According to Sagan, for scientific purposes, the Deep Space Network performs multiple functions [17]. These include

- Keeping in contact with all the different spacecraft in the deep space
- Transferring information and data collected from the various spacecraft to labs around the world.
- Exploring energy sources that cannot be detected by visible light or the naked eye from earth
- Exploring objects in space to determine if they pose a danger to planet Earth.
- Communicating with stricken spacecraft to see how to troubleshoot malfunctioning systems through the exchange of telemetry.
- Capturing signals from low gain antennas.
- Determining the gravitational influence of the sun and other celestial objects to choose the best possible launch direction for a spacecraft from literally 10,000 possible connections.
- Sending messages to the spacecraft that typically take 18 hours to go and come back in the form of feedback. Without DSN, scientists would wait several days to receive sent messages.

Even though it was said long time ago, the suggestions still suit for the existing technologies.

13. Analysis of the Focused Discussion Reponses

The DSN limitations are divided into six categories for this research:

1) Data Rate/Channel Capacity
2) Secure Communication requirement
3) Propagation Delay
4) Priority Communication Traffic
5) Alternate Technology
6) Hardware Upgradation and New Install

The questions were asked on the above six topics and the responses were as follows:

a. Data Rate

The below question was asked on all the different platforms.

Question: How can the data rate be increased in the space which is full of noise?

As per the JPL NASA, the data rate is from 500 bits to 32,000 bits per second and which will not be enough to transmit/receive great information in the future. The crewed missions planned by NASA, SpaceX, India, ESA, China would require good bandwidth for the communication purpose and hence it needs to take care from now only.

From the responses received, 78.94% experts agreed about the data rate issues and provided some fixes for it. Remaining 21.05%, experts think we do not need additional bandwidth to increase the data rate or channel capacity as we should stick with the existing technology. As per them, we have survived the last 50 years or more than that, so there is no need for additional improvement.

The Expert 1 says that we are suitable for the present missions as the only thing we receive is a picture message and other study data, but for the future missions, we need advanced hardware. The Expert 2 says, to increase the bandwidth, move the DSN is to Ka band (27-40GHz) for the downlink from Mars to Earth and also start using Deep Space Optical Communication device (Laser technology which is being tested now) to get the speed of 50 Mbps. As per expert 3, the chain of repeaters should suffice, but it will need more power from the sun and physics is hard to handle in the space. The expert 4 suggest encouraging the Satellite development for such a bandwidth limitations and link all the satellites to DSN and talk. Expert 5 suggest building the infrastructure around Earth first, do the exact on Mars and communicate, this way it will increase the channel capacity and other issues.

Expert 6 states that the bandwidth for this channel capacity can be increased using data bursting technique, but there are communication jammers (E.g.- Sun) in the space which would eventually not letting us work. Satellite repeater will help here but need a huge budget.

The countries can help each other as they do now, using the communication network for maintaining the connection 24/7 (E.g.- The NASA DSN is helping India for its Mars Orbiter Mission). Not only governments but commercial stations can also provide their assistance in return for some money.

As per the paper "Mars Network: An Orbital Relay Infrastructure for Mars Exploration," the DSN communication can be improved by evolving the relay network like science orbiter and dedicated telesats (telecommunication satellites) around Earth and Mars. The proximity payload for Electra can be increased which is the prime component in the orbiter like Mars Reconnaissance Orbiter (MRO). This will cover the entire planet but not at once.

As per one of the expert, the data rate should be as it is and there is no need to improve it. To support his claim, he said 300 baud is enough to communicate which helped all the missions for last 50 years, and he is fine with existing data rate. However, few other experts denied his claim by mentioning the need for good data rate for science-related missions. By 2012, MRO returned 174 TB of data to Earth; the curiosity transmits up to 250 MB per sol day. The mission crew will be updating lots of details from Mars, so the space agencies cannot cut off the communication simply because the bandwidth cannot be increased. It is an essential part and needs to be fixed.

People would expect data like images, the description in words, audio/video recordings, scientific evidence, medical data of space travelers, geological data of planet, chemical analysis of atmosphere, engineering data of how machines are performing, biological data of how plants are working in a greenhouse, etc. Moreover, hence the communication is must get all the above details.

If nothing is changed and we still send our scientists to Mars, the channel capacity used by them will be huge, and if they share it on the red planet, then it will be very slow. Few suggest building the communication infrastructure on the Mars so as to have real-time communication between the colonies there and then have a direct link between Earth and Mars. Even though it will not solve the latency issue, with the good bandwidth, we can exchange large data, only requirement here is good hardware and lots of money.

As NASA is planning to deploy the Laser technology on the new rover by December 2017, the bandwidth will eventually be increased by some proportion [30]. This limitation can also be reduced by using a planetary model on Earth which will rotate as per the requirement. The existing 70-m diameter antenna is not easy to operate, and hence something alternative to it would help to receive the signals with more efficiency.

Use of powerful transmitter and the larger dish can help the signal to reach the destination, but the receiving is the problem, because of the limited power on the spacecraft to transmit the signal, it gets attenuated by the noise in the space. The power can be doubled, and 2-meter can replace the 10-meter transmitter antenna, but the issue is same, the spacecraft design becomes very complex. The link budget analysis would answer more details, by increasing transmitter power, using a directional antenna, larger receiver, and efficient modulation technique.

The advanced signal processing and transmission protocols will help with better error correction, and hence the reconstruction is required for this purpose. The big antenna means great hardware and extra money for that, so budget needs to be increased. There is one more concern regarding future missions; the space agencies start working on the set up 3-4 years in advance, by the time they send the spacecraft into space, the hardware is already considerably old.

Most of the people agreed that the maximum data rate could be obtained by reaching the Shannon limit but also said that it is difficult and impractical to say so. According to them, it is highly unlikely to fix or reduce the noise level in the communication channel in the deep space. It is possible till some extent to reduce the error rate to achieve the maximum exchange of information but impractical to get it. The noise sources and the great distance plays a vital role in affecting the communication.

The experts also expressed that the combined detailed study of the Friss equation for power transmission and link budget analysis for signal rate would be a help but cannot promise the higher efficiency.

b. Secure Communication Requirement

Question: How important is secure communication in the space?
Question: How important will be the secure communication between Mars and Earth?

When asked "How important is secure communication in space?", mixed responses were received. According to some people, it should be available to the public because it is science related research and nobody would create any harm to it, but some people say it is required to have secure communication for a number of purposes.

The expert who says the scientific research should be available to the public is partially true; it can be agreed to some extent but not completely. As per NASA, there are more chances to steal the technology or new ideas by making malicious attacks for the terrorism purpose, not only this, but it can be done for potential commercial advantage as well [31]. The scientists and the government spend years to achieve something, and if it is made public to all, not everyone is going to use it for the good purpose. The time, money and efforts are invested in such research, so it is not possible to publish everything to the public. Information like weather, atmospheric changes, astronaut health, food supply, and other research can be made available but not the technologies we use for communication, hardware for rockets and spacecraft, and fuel (nuclear energy) details.

On the other hand, if somehow terrorist gets in between the communication, then that can jeopardize the life of astronauts and the mission. Recent spacecraft works on nuclear-powered energy, and hence anybody can understand how dangerous this will be if a hacker or terrorist breaks the communication.

As per one of the expert, the communication must be secure as it involves not only the government/private space agencies but corporate money, intellectual property and lots of efforts. Once the colonies form on the Mars, there will be a political discussion on many things, so that should not be made public as people might misinterpret it and will cause chaos.

Besides, everyone has their right to privacy, if the space travelers want to talk to the family and friends on Earth, making all the research public would make it hard for them to have a conversation.

We are already facing the breach in the information; nobody is secure today, if that is the case here, then the hackers or terrorist can do anything to the communication channel and might put the mission in danger. Bad people might intercept the information for the potential commercial advantage which should not happen when it comes to the space travel.

As the signal travels very long distance and reach to one of the DSN antennae, we can say that the signal reception can be picked up anywhere in the world, so nobody can deny the possibility of trying to decrypt the traffic and steal the valuable information. If somehow it is not possible to secure all the traffic because of the hardware limitation and decoding techniques, the space agencies should at least decide what type of information should be secure and send it to the Earth. This way, the receivers will not spend much time in processing the signal which already travels vast distance and gets attenuated.

As per European Union Space Association, the system and assets involving space communication are very critical which guarantee safety on Earth. Sometimes it serves the military as well as civilian objectives, in that case, it is necessary to safeguard it [32]. There are some cases in which, the technology used in defense was then handed over to space communication use, so any breach of this information would risk the safety of the whole world.

c. Propagation Delay

Question: How can we reduce the propagation delay in the space while exchanging (transmission/reception) the information (signal)?
Question: Skype, Google Hangout from the planet Mars?

The propagation delay is an unsolvable issue in the space and 98% people agreed that we would not be able to talk about how we do on Earth. The main purpose behind asking this question was to see if we will ever be able to solve the latency issue in the space or not and it looks like, it is impossible to fix it at this moment. As the RF or Optical signal travels at the speed of light, the technology which travels faster than light needs to be invented. From all the responses received, only two to three people said we would be able to interact in the future because nothing is impossible in science, but many other people strongly denied this claim.

Now when it comes to the long-distance communication, everyone needs to be in touch with someone just in case of an emergency or something else, that time if we do not have any support then our life would be a danger before receiving any help. Likewise, we are talking about sending our people to Mars millions of miles away from home, if in case something like this happens, then there should be something we need to do from our end. Even if the propagation delay cannot get fixed at this time, we are risking our people, and hence everyone would want to know what can we at least do to improve it if it cannot be fixed.

The closest average distance between Earth and Mars is 55 million miles, and the average farthest distance is 225 million miles. So, it takes minimum 3 minutes to reach the signal when they are close, and 21 minutes when they are far (One way, the round trip time is double). One thing to note here is, the time duration mentioned is from Earth to Mars and not the reverse way. The reason it matters is that the hardware used on the rovers, satellites on the Mars have limited power and are completely dependent on solar polar, so the X-band transmitter antenna can only transmit at 100 watts, and the solar panels provide 580 Wh each day. The new rovers are using the nuclear energy for the functioning of the system, so both combines a good amount of energy.

The rover either communicate with orbiter around Mars or with the Earth directly, while transmitting to the Earth, it needs much more energy compared to the orbiter, and hence not all the energy can be used in the transmission and reception, it has other tasks to do as well.

When asked the question to Dr. Zubrin, he also agreed that we would not be able to communicate instantly, but if the scientists try working on called Tachyon Particles, then we can say there are some hopes. Back in the 1960s when the scientists were trying to see if there is anything that could travel faster than light and proposed Tachyons which are considered to be hypothetical particles. It involved a study of the theory of relativity [34].

Even though we do not have any solution for these issues, it was worth to noting down the opinions from the experts. In the end, we can say that the propagation delay cannot be fixed completely, but it can be reduced to some extent.

d. Priority Communication Traffic

Question: If we have crew on Mars, what things we need to prioritize?
Question: What type of communication traffic for deep-space missions needs to be prioritized?

When it comes to the exchange of the information, the traffic divides into important and non-important groups. There are thousands of things going on in the channel the communication is happening, and to differentiate it, the prioritizing must occur.
At the moment, all the traffic is communicating on a same channel irrespective of the mission it is supporting i.e. it is transmitting and receiving on the same channel but at a different time. This is a bad practice to work on the future missions and has also lead to a scheduling problem.

It is not an easy job to be in touch with the spacecraft, rover, or satellite; the reason is money and other limitations like power, delay, bandwidth, etc. As the other limitations are already discussed, the money is the biggest problem in any technology, without money, nothing can happen. For instance, the 70-meter diameter DSN antenna cost $4770 per hour, and 34-meter antenna costs $954 per hour, so not all the space agencies afford such a significant amount [37]. In the case of the red planet, even though the minimum round trip time is 45 minutes, transmitting the message does not guarantee its delivery, the space vehicle which is accepting this message as a command takes some time to process it and then sends the output back to the Earth. The wait time is not fixed, it keeps changing depending on the distance, blockades, power requirement, etc. which clearly explains the importance of prioritizing the communication traffic.

On top of that, almost all the space communication systems (NEN, DSN, SN) use Ka and X-band frequencies for the communication purpose to exchange the information, so it is far difficult to make way for the important message sent from a different planet [37]. The increase congestion has become a headache for all the scientists and is looking for new ideas to implement.

The missions are always planned two to three years before the launch and involve extraordinary efforts. If the schedules are not planned properly, it might result in a big failure and can cause the project shutdown [36].

Once the problem is solved for the present missions, the crewed mission in the future will not be an issue anymore but need more dedication and willingness to do it. Furthermore, the traffic can be divided and prioritized into many ways. A number of things can be asked to get an exact answer; whether the connectivity should be maintained all the time or not or should be open for some time, at what point the travelers should report to Earth-based stations, what to do in emergency situation, how to acknowledge the delivery of the message to a team.

As per experts, there are some ways to solve the problem. 61% Experts say the mission handling capability should increase to help and ease the congestion, and to that, the number of antennas compatible with the latest technology should be added to all the stations on the Earth. In addition to that, there is a need for two more DSN stations to handle the 400 number by the year 2020. If this is done, it can be a significant milestone for the future.

Few of the experts suggested using something like Transit Signal Priority (TSP) which we use in the major cities like Los Angeles. As per them, there are hundreds of ways to fix the problem with the daily life solutions. The TSP helps to manage the traffic by using its algorithm on time and day; it switches between different algorithms to reduce the traffic jams. A similar model with more study can be utilized to the issue; the countries will keep increasing their crewed missions and to solve it, the better solution needs to be in place.

More than 13% expert say the missions will handle the additional traffic in the future and should use the present system more efficiently. The main reason they stated this statement is because they are not sure about the funding and doubtful about any crewed missions. As per them, there are more chances to get the rejection for this type of mission because of risks involved in it like human life, vulnerable unknown species and diseases, and wars.

Rest of the 26% experts stayed moderate on this question. They think the mission should be flexible as per the time, and should not involve additional hardware. If one specific mission needs extra efforts, then only building the setup should start.

e. Alternate Technology

Question: The Deep Space Network is already being used by several deep space missions, do you think it will be able to handle man-on-Mars missions?

When it comes to the communication, in this digital world, everyone wants to have fast and reliable Internet, but in the space, it is an entirely different thing. The DSN works on the RF-X, K, and Ka band frequencies to talk with the satellites, spacecraft, and rovers in the deep space. For that purpose, there are three ground-based stations on Earth located at 120 degrees to each other (120x3=360), to maintain the contact with outside world all the time.

The main question arises if the DSN is required or not? No doubt it has played a crucial role since 1963, and has helped us to see the pictures of Moon, Mars, Jupiter, Saturn, but is it necessary to rely on it all the time completely? The same question was asked and received amazing answers within some hours.

As per most of the experts, the use of alternate technologies should be in place. For example, the Lasercomm, Array of Satellites, Spacewire, and use of Nanocube Satellites in the space. The Laser technology, i.e. Laser Communications Relay Demonstration (LCRD), was favorite amongst the majority of the population.

The DSN has been in use from past 54 years, even though it is working fine, the scientists should not depend on it completely for the future use. The race to Mars and to explore the deep space has just started, it is going to grow, and for challenging missions like Crewed Mars mission, the use of latest technologies should be tested out. The other techniques are in testing phase and need to implement faster. The Laser Communication (Lasercomm) has several advantages over all other techniques and has proved its worthiness in the Low Earth Orbit (LEO) and in the recent Lunar mission (August 2013). Even if the line of sight (LoS) still an issue, it can be taken care in the future, some other things worked perfectly well.

The use of optical technology over the RF is much beneficent when it comes to comparison of size, power requirement, and weight. The data rate achieved during the Lunar mission by Laser Communication Relay Demonstration (LCRD) was 622 Mbps while it was 100Mbps for the same experiment. Not only the data rate but it helped to reduce the Mass and power requirement by half and 25% respectively [38]. Even though it was tested for the Lunar mission, it can still be tested on Mars for the next launch in 2020.

Few of the experts recommended opting for Relay satellite network and Nanocube Sats. The Relay satellite can maintain the connectivity in the space and will act as a repeater; few others contradicted the statement by saying it is too difficult to operate the satellites in the space and would need lots of research on the astrophysics. Building few satellites and sending them to space is a little bit easy but maintaining them in the space is way too difficult. Both the planets orbit around Sun all the time, where exactly the satellites should be deployed. Nobody could answer above questions and the idea to use the relay satellite got away.

The use of Nanocube satellite was also discussed by dropping a number of cube satellites on the way to Mars and using it as linked repeaters. The idea was good and got the appreciation as the expert also provided the benefits of using these Nanosatellites. Because of the compact size, light weight, and less power requirement, the expert succeeded to let others think about his ideas. However, again it was just an idea and need to test out first, so it can be used in the recommendation.

f. Hardware Upgrade and New Install

Question: Is Deep Space Network (DSN) technology sufficient for a crewed Mars mission?

Off all the responses, 99% experts agreed to work on the hardware upgradation and install. It is not like it is not helping at all but the hardware is 54 years old, and the NASA cannot just rely on it completely. There were some recent updates on how to get it upgraded, but so far NASA is running out of luck and needs to rethink the whole plan.

Half of the experts said, the DSN by JPL NASA used by almost all the leading agencies, so NASA should look out for the funding from those respective countries, US government is not bound to take the huge burden. When cross-verified, the sites in Spain and Australia are being funded by NASA only, and it charges some fees to the agencies who use the services for some period.

One of the other suggestion was to replace the 70-meter diameter antenna but 34-meter high gain beam width antenna, and use it for the current missions. There are pros and cons of doing this so, the replacement would help a lot as 34-meter antennas are easy to operate and fix. Additionally, they can support four spacecrafts at a time and can collect more data when they spread (Arraying). The disadvantage is, with the help of 70-meter parabolic dish, maximum signal reception can happen, and at the same time, a signal can also travel a long distance. If the NASA is okay to perform the changes, then the efficiency can be improved to a real extent.

One of the expert more issues regarding the existing 70-meter antenna, as per him, the hardware on Earth as well as on the rovers sent to Mars are way too old and needs to replace with a new one. Once done, advanced signal processing capability and transmission, as well as reception, would increase drastically, it will also help to do better error correction once the attenuated signal is received. Big antenna means, great hardware, maintenance is difficult and involve lots of money to do all the stuff; instead, they should use a small array of antennas. The satellite and rover build up process start way early before launch and by that time the hardware gets considerably old.

Few experts opposed the idea of upgradation and new install because it is currently helping the missions and nothing needs to be changed. If required, it can be done over the period of new few years, in the meantime, the scientists should work on the new solution and how the Laser technology can be adopted into of our services. At last, he concluded that there is need of willingness to work on these technologies and all the countries should invest not much but a little bit to make it work.

Surprisingly one of the retired JPL engineer who worked on the JPL telemetry mentioned in his comments that "get away from the voice communication, and use texting model. The lot of NASA still stuck in the 1960s". From his statement, it is clear that the DSN at least need some modifications, not everyone will be able to speak on the social platform if they are already working as an employee or contractor.

As per the book "NASA's Management of The Deep Space Network" published by NASA Office of Inspector General in November 2016 written with the permission of NASA, "Budget Reductions and Uncertainty of Projected Future Savings Increased Risk to NASA's plan to Build New Antennas and Transmitters." The book was presented to the government officials for the purpose not to reduce the budget which will affect the future missions, at the same time, all the existing work postponed for some time. This has put a significant risk to what NASA has planned and announced in the past.

In another book, "NASA's Deep Space Network: Current Management Structure Is Not Conductive to Effectively Matching Resources with Future Requirements" presented to United States Government Accountability Office, it was clearly mentioned about the DSN is facing and what could happen if the necessary budget is not provided.

14. Future Scope

a. DSN frequencies

Currently, the Deep Space Network uses different frequencies based on the target chosen and the ultimate aim of the mission. Thus, looking at the various missions, space probes and spacecraft selected by the network, one sees the following. The New Horizon target has a power transmission or 20.63 kilowatts a frequency of 7.18 Gigahertz. For Voyager 2, the power transmitted is 19.08 Kilowatts; the down signal source is the Voyager 2, the type of service is Data, the data rate stands at 160.000 bits per second, and the Frequency operates at 8.42 Gigahertz. Finally, the power received is 8.58 X 10 23. In the case of the Voyager 2, the station transmits at a peak power of 19.08 kilowatts and communicates with the ground station from a distance of 1.5 million kilometers from the surface of the earth [20].

One should note that the power transmitted varies and depends on multiple parameters including the distance to the target, the angle of the horizon and the frequency. It also depends on the thickness of the atmospheric layers the transmitted signal must go through, the humidity, temperature, and wind in the lower atmosphere.

Additionally, the lower the given angle between the probe and the earth, the greater the atmospheric effects of the Earth including attenuation, refraction, and diffraction. Looking at the Voyager one probe, one sees the following figures: The range of the probe is 19.64 billion kilometers and takes 1.52 days to complete a round trip. The antennae on the Deep Space Network operates on an azimuth of 169.83 degrees and an elevation of 61.66 degrees to provide data at a bitrate of 16 bits a second. The power transmitted is 19.08 kilowatts at a frequency of 2.11 gigahertz for the up signal. For the down signal, the data rate stood at 159.00 bits per second, a frequency of 8.42 Gigahertz and a power of 9.45 X 1023.

The New Horizons 2 space probe operates at a range of 4.77 billion kilometers and takes 8.85 hours for the round trip. The antennae on the Deep Space Network ground station operates at an azimuth of 185.44 degrees, against an elevation of 33.70 degrees. For the up signal, the power transmitted stands at 21.44 kilowatts, and an operating frequency of 7.18 Gigahertz.

The Frequencies of the future depend on negotiations with the IND (Interplanetary Network Directorate) and the CPO (Commitments Program Office). Based on this, the following could possibly occur. Deep Space Research could see the use of Ka or X-band Phase calibration generators for the frequencies, which work with BWG antennas. At DSS 25, work continues and the new design will have frequencies operating at 3 to 40 Gigahertz (an enormous amount of power). The table below shows the proposed capability and the operating parameters.
Another proposed development uses S-PFD) or Stabilized Photonic Frequency Distribution [17]. This replaces the open loop frequency distribution with a closed loop one that can work independently of thermal variations. The distribution link goes up to 30 kilometers and compensates for induced phase variations. The result is a 50-100-time enhancement in the performance.
(Refer to the appendix for frequency details)

b. DSN Antenna

Tyson [21] says that the future of the DSN antenna will show the following: The antennas will support a downlink performance 1000 times that of the current antennas. The antennas will consist of multiple small ones to big arrays (fields or banks of antennas), scalable architecture, high-tech signal combining algorithms, 6 to 13-meter small diameter dishes, and advanced compression and coding. Other possible developments include Ku-Band performance increase of 400%, 200 Watt K-Band Transmission power and optical communication between the network antennas and the spacecraft [21].

c. Research

The research thesis provides all the details related to Deep Space Network in one document, and hence, it will be very convenient for any student, faculty, researcher or Mars mission enthusiast to find all the details at one place with reference. The documentation provided by JPL NASA is easily available but provided in too much detailed, and as it contains information from 1963, it is hard to read each and every research paper.

The research will also help the students to pick a topic for their project, thesis or postgraduate research to work on it. As the obsession for Mars Mission is growing day by day, no doubt some individuals would jump into it.

15.Conclusion

The Deep Space Network performs a useful function by monitoring the health of onboard systems aboard spacecraft and space probes as well as external functions such as trajectories and velocities [11]. It enables the space vehicles to explore the fringes of space much farther and with more accuracy. The exchange of data communication to and from the spacecraft through telemetry therefore provides information on the spacecraft and the destinations the spacecraft and probes ultimately explore. However, the issue of signal accuracy remains a troublesome one. In future, the Deep Space Network will have to employ more numerous arrays of smaller antennas and advanced optical communication technologies such as Blue-Green Laser [21].

After studying all the responses carefully, the experts suggested getting more funding for the DSN complexes around the globe from different countries as it is helping them as well for the deep space research. Either add the additional 70-meter high gain antenna or replace the existing one with multiple 34-meter antennas; this will help to collect the signal at different places and will be easy to maintain. The array of antennas has always proved its worthiness in the past, and for sure it will make a difference once it is adapted. The future mission should be optical technology compatible so as to use it as a backup when the RF antenna is not helping.

The new technology like Laser Communication, NanoCube Satellites, Space wire should be tested at the earliest which has several advantages over all; it is a low cost, full-duplex, low latency, point to point serial link packet routing method with low error rate (L1 and L2).
Even though the propagation delay cannot be reduced (fixed) because of the great distance, some experts think nothing is impossible in science, and they are hopeful for mankind to communicate faster than the speed of light in the future. The instant messaging or live streaming is impossible now, and hence the scientists need to adapt receive-read-reply-wait technique.

In the end, almost all the experts raised the concerns about a budget issue which affects the progress of the missions. It is also important to not to rely on US government completely because the DSN is used by some other countries as well and all should help the NASA to keep the DSN complexes active all the time.

References

[1]. Boccia, K, Gao, S & Imbriale, W., 2011. Space Antenna Handbook. New York: SUNY Press.

[2]. Corliss, R, W., 2013. A History of the Deep Space Network (5th Edition). New York: National Aeronautics and Space Administration.

[3]. Corliss, R, W., 2012.The Interplanetary Pioneers. (4th Edition.) New York: National Aeronautics and Space Administration.

[4]. Corliss, R, W., 2006. Earth Orbital Science. (3rd Edition). New York: Springer Academic Press.

[5]. Groupe, L., 2011. Jet Propulsion Laboratory: Deep Space Network, Mars Pathfinder, Theodore Von Kármán, Frank Malina, Spice. New York: General Books LLC.

[6]. Hansen, R, C., 2011. Apertures. London: OUP Press.

[7]. Imbriale, W, A., 2011. Large Antennas of the Deep Space Network. New York: John Wiley & Sons.

[8]. Imbriale, W, A., 2012. Space Borne Antennas for Planetary Exploration. New York: Springer

[9]. Impey, C., 2015. Beyond: our Future in Space. Los Angeles: UCLA Press.

[10]. Jet Propulsion Laboratory., 2011.The Deep Space Network: An Instrument for Radio Science Research (3rd Edition). New York: JPL.

[11]. Michener, J, A., 2012. Space. New York: McGraw & Hill.

[12]. Murray, B., 2012. Journey into Space: The First Three Decades of Space Exploration. New York: Routlege.

[13]. Mudgway, D, J., 2011. Uplink- Downlink: A History of the Deep Space Network. New York: McGraw & Hill.

[14]. Reid, S, M., 2014. Low Noise Systems for Deep Space Network. New York: SUNY Press.

[15]. Rusch, W, V., 2011. Analysis of Reflector Antennas. Los Angeles: UCLA Press.

[16]. Rudge, A, W., 2012. The Handbook of Antenna Design. New York: Springer Academic Press.

[17]. Sagan, C., 2015. Pale Blue Dot: A Vision of the Human Future in Space. Los Angeles: Caltech University Press.

[18]. Schilling, G., 2012. Deep Space: Beyond the Solar System to the End of the Universe and the Beginning of Time. New York: Routlege.

[19]. Sharma, S & Rao, S., 2011. Handbook of Reflector Antennas and Feed Systems Volume III: Applications of Reflectors. New York: McGraw & Hill.

[20]. Steinhoff, J., 2016.Space Stack Exchange. [Online]: Available at: http://space.stackexchange.com/questions/9824/how-much-rf-transmit-power-does-dsn-need-to-send-commands-to-voyager/18737#18737). [Accessed 23rd October 2016].

[21]. Tyson, N, D., 2015. Space Chronicles: Facing the Ultimate Frontier. New York: John Wiley & Sons.

[22]. Rogstad, D. H., Mileant, A., & Pham, T. T. (2003). Antenna Arraying Techniques in the Deep Space Network. Antenna Arraying Techniques in the Deep Space Network.

[23]. Dunbar, B. (2015, April 28). Tracking and Data Relay Satellite (TDRS). Retrieved April 22, 2017, from https://www.nasa.gov/directorates/heo/scan/services/networks/txt_tdrs.html

[24]. Contributor, E. H. (2013, September 12). Voyager 1: Earth's Farthest Spacecraft. Retrieved April 22, 2017, from http://www.space.com/17688-voyager-1.html

[25]. Sadr, R., & Hurd, W. J. (jan-mar 1988). Digital Carrier Demodulation for the DSN Advanced Receiver. Digital Carrier Demodulation for the DSN Advanced Receiver. Retrieved from https://ipnpr.jpl.nasa.gov/progress_report/42-93/93E.PDF.

[26]. Taylor, J., Lee, D. K., & Shambayati, S. (2016). Mars Reconnaissance Orbiter. Deep Space Communications, 193-250. doi: 10.1002/9781119169079.ch6

[27]. S, W., G, S., M, W., & N, R. (1999, November 11). Deep Space Network. Retrieved April 23, 2017, from https://www.netlab.tkk.fi/opetus/s38118/s99/htyo/3/2.shtml

[28]. NASA, J. (2005, December 05). Deep Space Network FAQs. Retrieved April 23, 2017, from https://deepspace.jpl.nasa.gov/faq-data.html

[29]. JPL, N. (2013). Telemetry Data Decoding. Telemetry Data Decoding, B, 1-38.

[30]. Boen, B. (2013, October 26). Technology Demonstration Missions: Laser Communications Relay Demonstration (LCRD). Retrieved April 30, 2017, from https://www.nasa.gov/mission_pages/tdm/lcrd/lcrd_overview.html#.WQVrCFKZP-Y

[31]. Dunbar, B. (n.d.). Reliable and Secure Space Communication Protocols. Retrieved April 30, 2017, from https://www.nasa.gov/centers/ames/research/technology-onepagers/secure_space_communication.html

[32]. Union, E. (2017, January 05). Space and security - Growth - European Commission. Retrieved April 30, 2017, from https://ec.europa.eu/growth/sectors/space/security_en

[33]. Advanced Communications Technology. (n.d.). Retrieved April 30, 2017, from https://www.spacefoundation.org/programs/space-technology-hall-fame/inducted-technologies/advanced-communications-technology

[34]. What exactly are tachyons? (n.d.). Retrieved April 30, 2017, from http://scienceline.ucsb.edu/getkey.php?key=292

[35]. Williams, M. (2015, December 03). Mars Compared to Earth. Retrieved April 30, 2017, from https://www.universetoday.com/22603/mars-compared-to-earth/

[36]. Taylor, J., Lee, D., & Shambayati, S. (2006). DESCANSO Design and Performance Summary Series. DESCANSO Design and Performance Summary Series. Retrieved from https://descanso.jpl.nasa.gov/DPSummary/MRO_092106.pdf.

[37]. Thompson, R. S. (2013). CCSDS Mission Operations Services for Mission Planning. Space Operations: Experience, Mission Systems, and Advanced Concepts, 387-400. doi:10.2514/5.9781624102080.0387.0400

[38]. Cornwell, D. (n.d.). Space-Based Laser Communications Break Threshold. Retrieved May 01, 2016, from http://www.osa-opn.org/home/articles/volume_27/may_2016/features/space-based_laser_communications_break_threshold/

[39]. Yuen, J., Deutsch, L., & Townes, S. (n.d.). Deep Space Communications. Retrieved May 11, 2017, from https://scienceandtechnology.jpl.nasa.gov/research/research-topics-list/communications-computing-software/deep-space-communications

[40]. N. (n.d.). Data Rates/Returns - Mars Science Laboratory. Retrieved May 11, 2017, from https://mars.nasa.gov/msl/mission/communicationwithearth/data/

[41]. N. (n.d.). Mars Reconnaissance Orbiter. Retrieved May 13, 2017, from https://mars.nasa.gov/mro/

Appendix A

Frequencies used for the DSN communication

Uplink	Downlink	Ratio (downlink/uplink)
S	S	240/221
S	X	880/221
S	K_a	15.071/15.235*
X	S	240/749
X	X	880/749
X	K_a	4.4506/4.4923*
K_a	S	0.066959/0.066282*
K_a	X	0.24561/0.24352*
K_a	K_a	0.92982/0.93084*

Table 1: Spacecraft Transponder Turnaround Ratios
http://deepspace.jpl.nasa.gov/dsndocs/810-005/201/201B.pdf

Band Designation	Deep Space Bands (for spacecraft, greater than 2 million km from Earth)		Near Earth Bands (for spacecraft, less than 2 million km from Earth)	
	Uplink (Earth to space)	Downlink (space to Earth)	Uplink (Earth to space)	Downlink (space to Earth)
S-band	2110–2120	2290–2300	2025–2110	2200–2290
X-band	7145–7190	8400–8450	7190–7235	8450–8500
K-band	*	*	*	25500–27000
Ka-band	34200–34700	31800–32300	*	*

Table 2: Allocated Frequency Bands
http://deepspace.jpl.nasa.gov/dsndocs/810-005/201/201B.pdf

Channel	S-band U/L (MHz)	S-band D/L (MHz)	X-band D/L (MHz)
5	2110.243056	2291.666667	8402.777780
6	2110.584105	2292.037037	8404.135803
7	2110.925154	2292.407407	8405.493826
8	2111.266204	2292.777778	8406.851853
9	2111.607253	2293.148148	8408.209876
10	2111.948303	2293.518519	8409.567903
11	2112.289352	2293.888889	8410.925927
12	2112.630401	2294.259259	8412.283950
13	2112.971451	2294.629630	8413.641977
14	2113.312500	2295.000000	8415.000000
15	2113.653549	2295.370370	8416.358023
16	2113.994599	2295.740741	8417.716050
17	2114.335648	2296.111111	8419.074073
18	2114.676697	2296.481481	8420.432097
19	2115.017747	2296.851852	8421.790124
20	2115.358796	2297.222222	8423.148147
21	2115.699846	2297.592593	8424.506174
22	2116.040895	2297.962963	8425.864197
23	2116.381944	2298.333333	8427.222220
24	2116.722994	2298.703704	8428.580248
25	2117.064043	2299.074074	8429.938271
26	2117.405092	2299.444444	8431.296294
27	2117.746142	2299.814815	8432.654321
28	2118.087191		8434.012344
29	2118.428241		8435.370371
30	2118.769290		8436.728395
31	2119.110339		8438.086418
32	2119.451389		8439.444445
33	2119.792438		8440.802468

Table 3: Frequency and Channel Assignments for S-band Uplink
http://deepspace.jpl.nasa.gov/dsndocs/810-005/201/201B.pdf

Channel	X-band U/L (MHz)	S-band D/L (MHz)	X-band D/L (MHz)
1	7147.286265	2290.185185	
2	7148.442131	2290.555556	
3	7149.597994	2290.925926	8400.061729
4	7150.753857	2291.296296	8401.419752
5	7151.909723	2291.666667	8402.777779
6	7153.065586	2292.037037	8404.135802
7	7154.221449	2292.407407	8405.493825
8	7155.377316	2292.777778	8406.851853
9	7156.533179	2293.148148	8408.209877
10	7157.689045	2293.518519	8409.567903
11	7158.844908	2293.888889	8410.925927
12	7160.000771	2294.259259	8412.283950
13	7161.156637	2294.629630	8413.641977
14	7162.312500	2295.000000	8415.000000
15	7163.468363	2295.370370	8416.358023
16	7164.624229	2295.740741	8417.716050
17	7165.780092	2296.111111	8419.074073
18	7166.935955	2296.481481	8420.432097
19	7168.091821	2296.851852	8421.790123
20	7169.247684	2297.222222	8423.148147
21	7170.403551	2297.592593	8424.506175
22	7171.559414	2297.962963	8425.864198
23	7172.715277	2298.333333	8427.222221
24	7173.871143	2298.703704	8428.580248
25	7175.027006	2299.074074	8429.938271
26	7176.182869	2299.444444	8431.296295
27	7177.338735	2299.814815	8432.654321
28	7178.494598		8434.012345
29	7179.650464		8435.370372
30	7180.806327		8436.728395
31	7181.962190		8438.086418
32	7183.118057		8439.444446
33	7184.273920		8440.802469
34	7185.429783		8442.160493
35	7186.585649		8443.518520
36	7187.741512		8444.876543
37	7188.897378		8446.234570

Table 4. Frequency and Channel Assignments for X-band Uplink
http://deepspace.jpl.nasa.gov/dsndocs/810-005/201/201B.pdf

Parameter	Proposed Capability
Stability (Allan Deviation) 1 s 10 s 100 s 1000 s 10,000 s < < 100,000 s	 5×10^{-14} 8×10^{-15} 1.0×10^{-15} 1.2×10^{-16} $<5 \times 10^{-17}$
Amplitude Flatness	±1.7 dB, 32 — 33 GHz
Comb Spacing	1 MHz, 2 MHz, or 4 MHz selectable

Table 5. X/Ka-band Phase Calibration Generator
http://deepspace.jpl.nasa.gov/dsndocs/810-005/201/201B.pdf

Appendix B

Internet Questions Links

- https://www.facebook.com/groups/TheMarsSocietyUS/permalink/10154269858427151/?comment_id=10154271438517151
- https://www.facebook.com/groups/TheMarsSocietyUS/permalink/10154454040047151/?comment_id=10154455092372151&notif_t=group_comment&notif_id=1489687484841271
- https://www.reddit.com/r/space/comments/5zw4s6/skype_google_hangout_from_the_planet_mars/
- https://www.reddit.com/r/space/comments/63rjyu/if_we_have_men_on_mars_what_things_we_need_to/
- https://www.reddit.com/r/space/comments/64g8xd/how_important_will_be_the_secure_communication/
- https://space.stackexchange.com/questions/21085/is-deep-space-network-dsn-technology-sufficient-for-a-crewed-mars-mission
- https://space.stackexchange.com/questions/21256/how-do-we-track-the-exact-location-of-the-spacecraft-which-is-millions-or-billio
- https://www.quora.com/The-Deep-Space-Network-is-already-being-used-by-a-number-of-deep-space-missions-Do-you-think-it-will-be-able-to-handle-man-on-Mars-missions-because-of-limited-channel-capacity
- https://www.quora.com/How-can-I-reduce-latency-or-propagation-delay-in-satellite-transmission
- https://www.facebook.com/groups/TheMarsSocietyUS/permalink/10154417019827151/?comment_id=10154418650317151&notif_t=group_comment&notif_id=1488664980746176
- https://www.reddit.com/r/space/comments/65q4oh/week_of_april_16_2017_all_space_questions_thread/
- https://www.reddit.com/r/space/comments/673bjj/week_of_april_23_2017_all_space_questions_thread/
- https://www.reddit.com/r/space/comments/68gi65/week_of_april_30_2017_all_space_questions_thread/
- https://www.reddit.com/r/space/comments/608748/how_can_data_rate_be_increased_in_the_space_which/
- https://space.stackexchange.com/questions/21253/how-can-the-data-rate-be-increased-in-the-space-which-is-full-of-noise

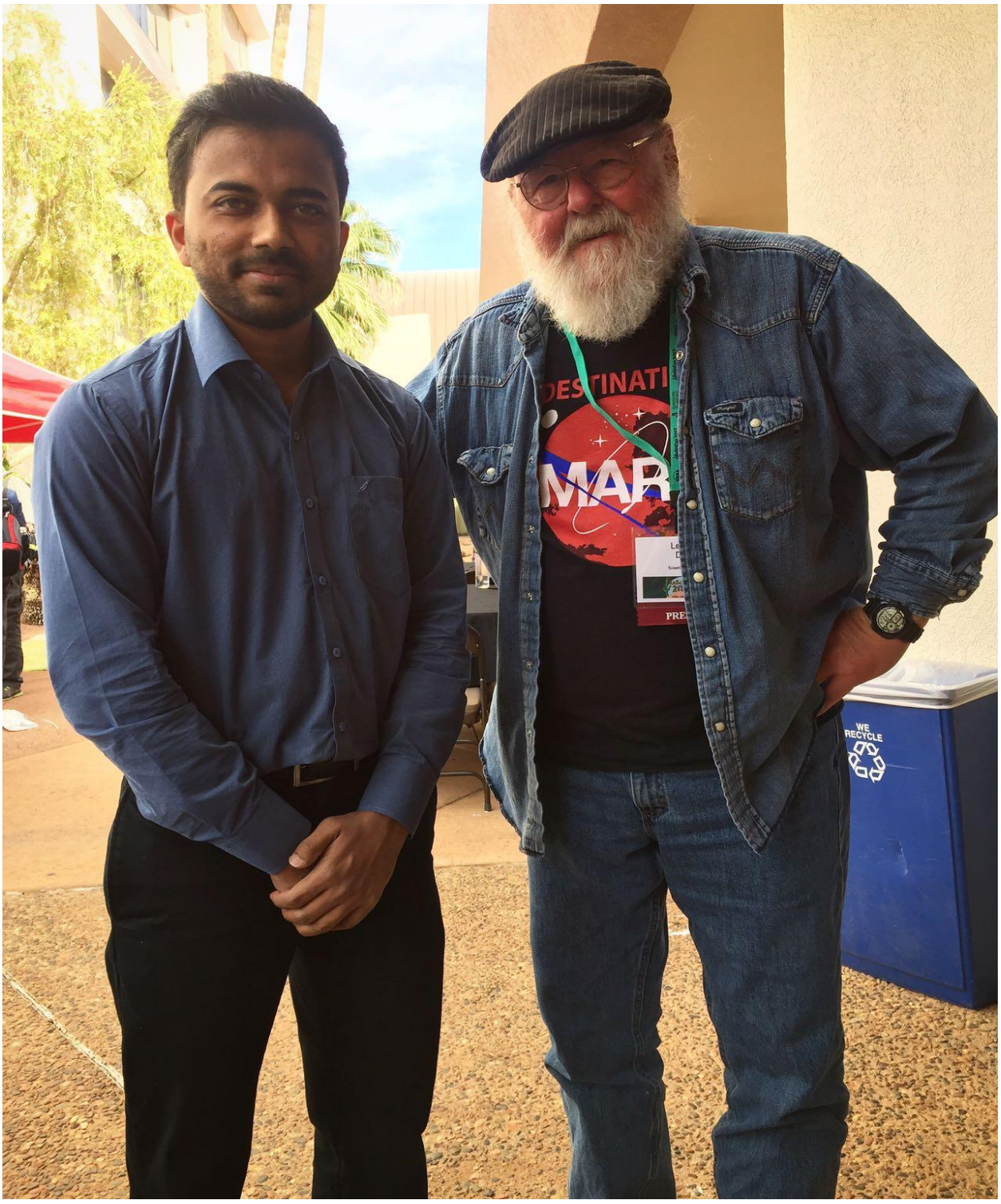
- https://space.stackexchange.com/questions/21306/how-important-is-secure-communication-in-the-space
- https://space.stackexchange.com/questions/21339/what-type-of-traffic-in-the-space-needs-to-be-prioritized

Appendix C

Discussion with Experts

Dr. Robert Zubrin - President of The Mars Society, author of many books on Mars mission, and inventor of several space exploration concepts.

More info. - https://www.nasa.gov/ames/ocs/2014-summer-series/robert-zubrin



Mr. Leonard David - a space journalist, author to many Mars related books, and several space award winners

Discussion with Dr. Zubrin (Transcribed version):

Prasad: Will be able to fix the propagation delay?

Dr. Zubrin: No, the delays cannot be fixed, you need to record the message and send it to the Earth. It will take 17 to 40 minutes to reach the other side, so it is like email messages, the reader will respond to you when they are available. Earlier it used to take months or years, but now it is very quick.

The speed of light cannot be defeated, and it is not important at this time.

Prasad: Will there be any difference between the communication with Laser vs. RF?

Dr. Zubrin: The direct communication is far more efficient; the amount of data is higher for given power. However, we still need RF because when you are somewhere out and don't know the direction, the RF is going to help you out using UHF communication and not the Laser technology. The RF wave goes in all direction, and that can save us if we know the exact location, the Laser waves are way superior.

Prasad: When will be going to Mars and who will be the first one?

Dr. Zubrin: We are going to Mars in 2020, and Elon Musk will take us to the red planet for sure.

Discussion with Mr. Leonard David:

Prasad: How soon we will be visiting Mars?

Mr. Leonard: Between 2020 to 2025

Prasad: Who will take us there?

Mr. Leonard: Most likely NASA or SpaceX

Prasad: Will be technologically sufficient by that time? (Regarding fuel, communication, and other technologies)

Mr. Leonard: The way we are working on the Mars-related missions now, we will be reaching soon and achieve what we have dreamed of.

Appendix D

Vita

Name - Prasad Falke

Email - falkep@sunyit.edu

prasad.f4@gmail.com

Website- www.prasadfalke.com

Interests/hobbies - RF technology related discussions and news, Space (NASA, SpaceX, ISRO, ESA), Deep Space Network, Volunteering, Soccer, exploring new places (especially historical places to understand the history behind it).

Memberships -

1) MCECG
2) ARA
3) ARRL
4) Thunderbird Amateur Radio Club
5) ANSR
6) IEEE Student
7) IETE
8) NSPE
9) Amateur Radio – Technician License