InterPlanet Computer Networking: Practical Approaches to the Planet-to-Planet Direct Communication Without Intermittent Link Connectivity

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ABSTRACT

The interplanet internet is a conceived computer network in space, consisting of a set of network nodes that can communicate with each other. These nodes are the planet's orbiters (satellites) and landers (e.g. robots, autonomous machines, etc.) and the earth ground stations, and the data can be routed through Earth's internal internet. In this paper, we propose an interplanetary internet system architecture to operate successfully and achieve good communication with other planets including the Earth. The architecture proposes a suite of practical approaches to the planet-to-planet direct communication without lossy links by addressing delays and solar or planetary interference in a disconnected regions of the planetary system. We propose a constellation of Polar relay satellites and Geosync satellites for routing information such that there is always one satellite above the conjunction band that do not come under the influence of sun's radiation interference because that hinders the direct communication between the planets. Also propose a location set-up for planet Mars – Earth direct communication network for transmitting through other planetary spacecrafts and positioning of relay satellites such that at least one relay satellite is not in a conjunction that addresses delays during the periods of solar conjunctions thereby providing continuous communications access. As it is planetary based architecture outline, the results could not be tested due to unavailability of large scale wireless networks over long distances however, the proposed approaches would be effective in addressing delays and disruptions in achieving direct planetary communication.

INTRODUCTION

Inter-planetary exploration, be it Lunar habitation, asteroid mining, Mars colonization or planetary science/mapping missions of the solar system, will increase demands for inter-planetary communications. The movement of people and material throughout the solar system will create the economic necessity for an information highway to move data throughout the solar system in support of inter-planetary exploration and exploitation. The communication capabilities of this interplanet information highway need to be designed to offer; 1) continuous data, 2) reliable communications, 3) high bandwidth and 4) accommodate data, voice and video.

The **interplanetary Internet** is a conceived computer network in space, consisting of a set of network nodes that can communicate with each other. These nodes are the planet's orbiters (satellites) and landers (e.g., robots), and the earth ground stations. For example, the orbiters collect the scientific data from the Landers on Mars through near-Mars communication links, transmit the data to Earth through direct links from the Mars orbiters to the Earth ground stations, and finally the data can be routed through Earth's internal internet.

Interplanetary communication is greatly delayed by interplanetary distances, so a new set of protocols and technology that are tolerant to large delays and errors are required. The interplanetary Internet is a store and forward *network of internets* that is often disconnected, has a wireless backbone fraught with error-prone links and delays ranging from tens of minutes to even hours, even when there is a connection.

In the core implementation of Interplanetary Internet, satellites orbiting a planet communicate to other planet's satellites. Simultaneously, these planets revolve around the Sun with long distances, and thus many challenges face the communications. The reasons and the resultant challenges are**:**

The interplanetary communication is greatly delayed due to the interplanet distances and the motion of the planets.

The interplanetary communication also suspends due to the solar conjunction, when the sun's radiation hinders the direct communication between the planets. As such, the communication characterizes lossy links and intermittent link connectivity.

The graph of participating nodes in a specific planet to a specific planet communication, keeps changing over time, due to the constant motion. The routes of the planet-to-planet communication are planned and scheduled rather than being fluctuating.

The Interplanetary Internet design must address these challenges to operate successfully and achieve good communication with other planets. It also must use the few available resources efficiently in the system.

While IP-like SCPS protocols are feasible for short hops, such as ground station to orbiter, robots to lander, lander to orbiter, probe to flyby, and so on, delay-tolerant networking is needed to get information from one region of the Solar System to another. It becomes apparent that the concept of a *region* is a natural architectural factoring of the Interplanetary Internet.

A *region* is an area where the characteristics of communication are the same. Region characteristics include communications, security, and the maintenance of resources, perhaps ownership, and other factors. The Interplanetary Internet is a "network of regional internets".

What is needed then, is a standard way to achieve end-to-end communication through multiple regions in a disconnected, variable-delay environment using a generalized suite of protocols. Examples of regions might include the terrestrial Internet as a region, a region on the surface of the Moon or Mars, or a ground-to-orbit region.

SYSTEM ARCHITECTURE

The overall communication system architecture for the planetary information highway between earth and mars and also between earth and moon is given below in Figure 1 however, for all practical purposes we will consider network between earth and mars as communication delays between earth and our moon are minimal because of shorter distance compared to the planet mars.

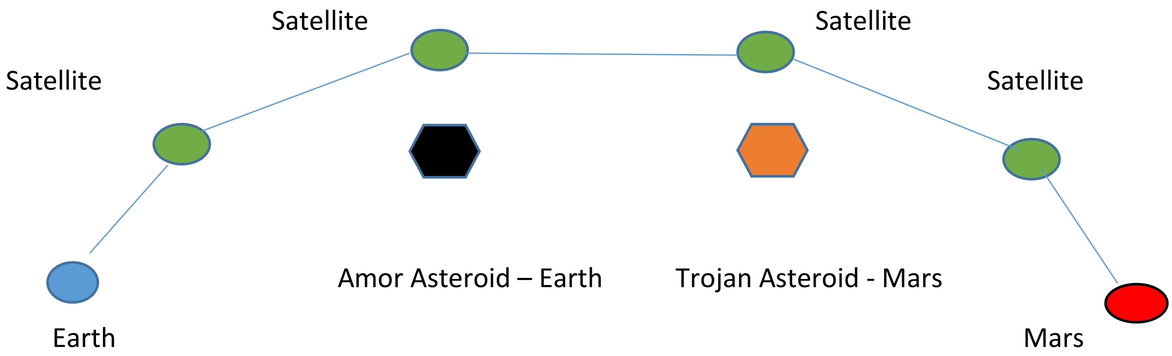

Fig. 1 Planetary Satellite Link

Since the earth already has a substantiate internet infrastructure suitable to transfer video, voice and data, we tum our attention to the communications subsystem of the proposed satellites that would orbit the mars. These satellites could communicate with the existing earth infrastructure and would act as satellite-to-satellite relays, also known as satellite cross-links, to relay signals to their intended receiver located in space. The destination could be personnel transports in route to Mars, for example, or a satellite cross-link in orbit around Mars. This is depicted in Figure 1. For the purpose of analysis, the satellite cross-links are assumed to have the same characteristics in both directions.

Currently, satellite communications are based on the electromagnetic radiation of signals in the RF region and also laser beams to transfer information nearly error-free in the gigabit per second range. The advantage of laser cross-links is its resistance to interference in the microwave region. The current explosion in network technology offers additional areas of interest. ATM switching and routing features is very much applicable to a satellite based relay system. The methods used in the wireless communication industry to transfer calls between cells are also applicable to the proposed satellite relay concept.

DESIGN CRITERIA

Orbital Positioning

The Space Network that helps provide transmission of data between Earth and the various satellite centres and the space vehicles deployed to transmit to Earth have always encounters outages caused by solar or planetary obstructions that has greatly limited the amount of data that will be available to Earth based receivers. Large propagation delays due to the size of the planetary system and service interruptions caused by planetary and solar interference need to be minimized to the extent possible.

Newton's laws of motion ensures to accurately assert the orbital motions around planets and different parameters are needed to completely describe the size, shape, orientation of an orbit and the location of an object along its orbital path at a specified time. The first orbit of interest is a geosynchronous orbit, is a planet-centered orbit at a distance with an orbital period that matches planet's rotation on its axis, and is defined as an orbit plane that is along the equator of a planet.

The second type of orbit of significance is circular orbit that is the Polar orbit. A polar orbit is one in which a satellite passes above or nearly above both poles of the planet body being orbited on each revolution. It has an inclination of (or very close to) about 90 degrees to the body's equator. It is defined as an orbit plan perpendicular to a planet's equator and it occurs when the orbital eccentricity is very close to zero . A special use of polar orbits around the Earth is used by the weather forecasting satellites and are placed in a polar orbit with an inclination just about 90 degrees such that its orbit plane would move around the earth. In our case, we use three or four polar orbits around the Mars as in Earth. The three or four Martian polar planes are required to be evenly separated by 120 degrees or by 90 degrees and with an eccentricity such that they could maintain a constant distance from the Mars.

An approach for inter-planetary communications is proposed and the approach employs three or four polar orbiting satellites around the Earth and Mars, and a combination of geosynchronous and polar orbiting satellites around planets of interest such as Mars. The key aspect of this approach is that it ensures a continuous communication connection between two objects within the planetary system of interest, be it a spacecraft or a robot or a drone on a planet. The approach proposes the use of geosynchronous satellites in planetary orbits to form planetary communication networks to support planetary operations as we have good experience in the design, launch and operation of geosynchronous communication satellites around Earth. This experience can be utilized in setting up similar geosynchronous communication constellations around other planetary bodies such as Mars or our Moon to provide planetary communications. These planetary constellations would be interconnected to a network of three or four polar orbiting satellites operating in the planetary plane around a planet. These polar orbiting satellites would form the hub of an interplanetary communication network and various types of polar orbiting satellites including advanced robotic (autonomous) space vehicles could be introduced around a planet to provide complete coverage.

Solar Conjunctions

Since the Sun is a strong source of electromagnetic energy, it causes significant interference to communications. Solar conjunction occurs when a planet or other solar system object is on the opposite side of the Sun from the Earth. From an Earth reference, the Sun will pass between the Earth and the object. **Mars** Solar **conjunction** is a period that occurs when the Mars and Earth in their eternal march around the Sun, are opposite from each other. As the Sun moves between two inter-planetary objects (planets or spacecraft) the ability to maintain communication degrades until it is no longer possible to operate. These periods of interference are called conjunctions.

Even though the apparent diameter of the sun from the Earth is 0.48 degrees, the diameter of solar radiation interference ranges from roughly 6 degrees (+ 3 degrees from center) for a quiet sun and as high as 14 degrees (+ 7 degrees from center) for an active sun. Using this, one can construct a sphere, centered in the middle of the solar system that is used to estimate periods of conjunctions and the worst case estimates for the sphere of influence in terms of surface length for a quiet sun (+3 degrees from center) as well as for an active sun (+7 degrees from center).

Since planetary orbits are not perfectly circular, the worst case range of angular magnitude of interference by planet varies. It is, therefore, important to estimate the difference between the maximum and minimum angular range of interference for both the Earth and Mars to ensure continuous interplanet communication. Hence, it is essential to use accurate method to estimate the availability of communication between two planets based upon solar conjunctions.

We propose a combination of Geosync and polar satellites for each of the planet Earth and Mars to assure uninterrupted internetworked communication.

While the presence of one polar orbiting relay satellite around a planet significantly improves visibility but its availability's is still not 1oo percent. Since most of the conjunctions occur within a 20-degree band along the planet systems' orbital plane, the question exists on how to position a constellation of relay satellites such that there is always one satellite above the conjunction band. We propose four satellites, separated by about 90 degrees and this configuration will always assure that at .least one relay satellite is not in a conjunction -thereby providing continuous communications access.

Further, we look at option of transmitting signals through existing nearby other planet spacecrafts or satellites orbiting in planetary space which do not come under the influence of solar interference as we can accurately estimate the periods and extent of solar conjunctions before the event accurance. However, there could be propagation delays in communication due to diversion of signals to other planetary bodies in comparison to direct link through relay satellites.

Solar Radiation Interference

In addition to conjunction, the sun acts as a jammer of ground surface terminals when the Sun is aligned with the downlink terminal. A sun transit is an interruption or distortion of geostationary satellite signals caused by interference from solar radiation. At these times, the apparent path of the sun across the sky takes it directly behind the line of sight between an earth station and a satellite. This alignment happens twice a year around the equinoxes (the center of the visible Sun is directly above the equator) for geosync satellites thus jamming the Geosync activity. During this period, around the equinox, the ground terminal's receiving system is saturated with the sun's radio signal for short periods each day and the period of disruption is also based upon solar activity. Worst case outages for a quiet sun can be as long as 23 minutes and for an active sun it can be as high as 55 minutes. Assuming about 8 hours a year of outages due to this type of conjunction yields a communication availability contribution of 0.9988. An overall availability can be derived using the model of availability and we can estimate the availability ranges due to solar radiation interference and conjunctions.

From Mars to Earth, the availability is reduced when the planet’s polar orbiting satellite is in the planet's line of sight with the sun. This is the same type of interference effect as with geosync orbiting satellites during periods of equinox. In order to address such an interference, we propose to position a constellation of relay satellites and Geosync satellites such that there is always one satellite above the conjunction band. We propose four polar relay satellites, separated by about 90 degrees and two Geosync satellites orbiting around planet’s surface and this configuration will always assure that at .least one relay satellite and one Geosync satellite is not in a conjunction -thereby providing continuous communications access.

Planetary Interference

Planetary Interference (Conjunctions); Planetary interference is based on planets that travel through the communication path. While this effect is small, it is relevant since our objective is to achieve continuous connections. These planetary conjunctions can be grouped into two sets: l) conjunctions caused by a planet's moons that orbits around larger bodies and 2) conjunctions caused by other planets. However, for all practical purposes this type of interference is small and can very well be addressed with the proposed infrastructure of combined polar and Geosync satellites.

CONCLUSION

The interplanetary computer network in space is a set of computer nodes that can communicate with each other. We proposed a network architecture with planet’s orbiters, landers (robots, etc.), and the earth ground stations and linked through Earth’s internal internet, and consisted of practical approaches to address direct planet-to-planet communication without lossy links. We propose a constellation of Polar relay satellites and Geosync satellites such that there is always one satellite above the conjunction band that do not come under the influence of sun's radiation interference. Also proposed alternative set-up for Planet Mars-Earth network of positioning of relay satellites such that at .least one relay satellite is not in a conjunction and transmitting through other planetary spacecrafts that addresses delays during the periods of solar conjunctions. As it is planetary based architecture outline, the proposed approaches would be effective in addressing disruptions in a planetary communication among disconnected regions of the planetary system to achieve end-to-end communication.

REFERENCE

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