InterPlanet Computer Networking: Estimating Solar Disruptions with Deep Neural Networks and a.I. in an Autonomous Satellite

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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 autonomous relay satellites to the planet-to-planet direct communication with capacity to estimate delays and solar or planetary interference in a disconnected regions of the planetary system. We propose a constellation of autonomous relay satellites and Geosync satellites with intuition-enabled machine learning for routing information such that they always estimate beforehand and ensure they are 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 fuzzy logic based estimation of disruptions and positioning of autonomous relay satellites such they are out of conjunction band 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 with satellite setup over long distances however, the proposed approaches would be effective in addressing delays and disruptions in a 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. The Interplanetary Internet is a "network of regional internets". 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.

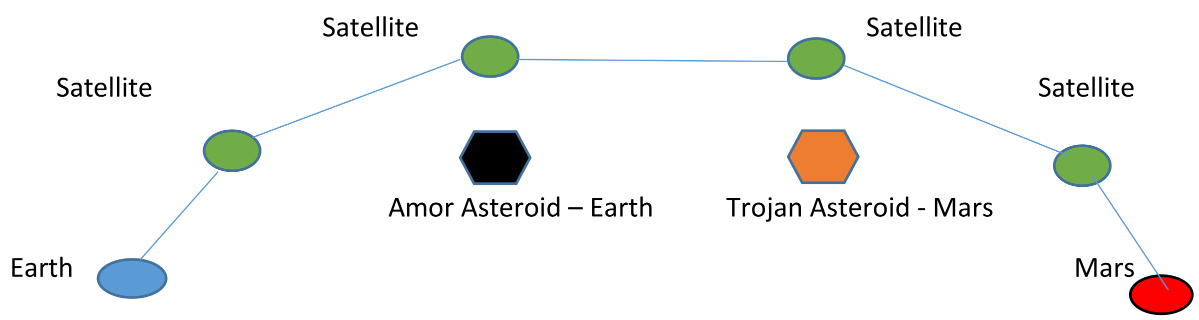

Fig. 1 Planetary Satellite Link

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.

AUTONOMOUS SATELLITES

Autonomous Goal for a spacecraft - is a software suite that ensures autonomous operations for space missions. It integrates state-of-the-art Artificial Intelligence algorithms and models. The most recent technologies in machine learning, expert systems and intelligent agents are used to process spacecraft data (telemetry and payload) to take decisions autonomously during the mission and this technology has wide applications in several domains, both for Earth-based applications and for deep space ones. The satellites become aware, understanding their surroundings, the internal health, and eventual response to commands provided by the mission control centre.

In being autonomous, they would be able to correct and maintain their trajectory, avoid collisions and supervise their on-board systems all on their own – all at a substantially lower operating cost. (While miniaturization is used to observe a planet from different perspectives simultaneously and sophisticated software can detect on board anomalies and correct these problems, and cooperation between small spacecrafts can also enhance their capabilities,)

Earth observation satellites generate tremendous amounts of data and high level data analytics is needed to make appropriate decisions. And true neural network-based on-board AI smarts, sensor driven intelligent agents would provide them with much more autonomy when it comes to performing tasks, like imaging a specific area or real-time analysis of clouds. Also AI has helped with solar radiation interference estimation using geostationary satellite data, among many other applications including conjunctions. AI for data processing can also be used for the satellites themselves.

We are currently witnessing Self-driving or Robotic cars operating on the roads and leveraging this autonomous driving technology is being applied to address a different industry and growing need such as autonomous satellite operation. Therefore, satellite and space-based technologies are required to be developed a hardware platform for performing AI operations onboard satellites and neural network accelerator is also to be applied for use on satellites, which will together have a set of operating conditions that in many ways resembles those onboard self-driving cars on the road — but with more stringent requirements in terms of operational management and environmental hazards.

The projected applications of onboard neural network acceleration extend to a number of different functions, including telecommunications, earth imaging and observation, autonomously docking satellites with other spacecraft, deep space mining, space exploration and more (true neural network-based onboard AI smarts would provide them with much more autonomy when it comes to performing tasks, like imaging a specific area or looking for specific space-based targets).

Technology firms and designers see scope for giving satellites more onboard control, to circumvent difficulties in communicating with Earth or Space station and reduce the need for continuous hands-on supervision and intervention from far away. That will reduce operating costs and potentially allow them to do more sophisticated tasks independently of their Earth or Space station bound supervisors. Further, by shifting the decision-making on-board the satellite, autonomous software eliminates the decision-making loop in the Mission Control Centre for all the events that were accounted for during spacecraft launch and operation including failures, and operators can focus on more critical decisions requiring intervention.

SOLAR RADIATION MEASUREMENTS

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.

The measurement of solar energy is all about how much energy reaches certain locations? There are numerous variables involved. In order to effectively use of solar radiation data , we need on-board instruments(Pyrheliometer, Photoelectric recorder) to measure such data . This may also include additional information such as likelihood of radiation interference to assist in the estimation of the solar radiation data.

The intensity of the solar radiation just outside the planet ' s atmosphere (extra-terrestrial radiation) varies because of the varying distance of the planet (earth/mars) from the sun as the planet moves along its almost circular but slightly elliptical orbit. The angle at which direct solar radiation is read on a surface affects the solar radiation measurement. The angle of incidence of direct (beam) radiation is the angle measured between the beam and the normal to the plane. The solar intensity on a surface is greatest when the beam radiation is normal to the surface (the incidence angle is 0) .

The rotation of the planet also determines the zenith or elevation angle of the sun and affects the amount of atmosphere through which the sun’s rays travel . The increased atmospheric absorption and scattering (called attenuation) thus produces a decrease in solar intensity at the surface of the satellite when the sun is near the horizon as compared to solar noon when the minimum attenuation occurs .

Because of the various effects , intensity of solar radiation is continually varying in space and time thus, complicate its measurement and measuring solar radiation is of most significance in the design of satellites especially in practice of hourly and daily measurements of solar radiation.

NEURAL NETWORKS IN SOLAR RADIATION ESTIMATION

We give below different methods for solar radiation estimation approaches after gathering solar impact data dedicated to the management of Geosync satellites.

1. Statistical models based on online radiation measurements are applied for estimation and examples of direct time series models are autoregressive (AR) and autoregressive moving average (ARMA) models. Furthermore, artificial neural networks (ANN) may be applied to derive radiation forecasts which largely determine surface solar radiation, may also be used as a basis.

2. Artificial neural networks (ANN) may be applied to derive radiation forecasts which largely determine surface solar radiation, may be used as a basis not only for forecasting but also for a broad range of applications, including control, data compression, optimization, pattern recognition, and classification. There are different applications of AI techniques for modelling and forecasting of the solar radiation and we particularly look at TDNN and MLP which is analysed in detailed with representative dataset in absence of real solar radiation data on time scale which is presented below. A time delay neural network (TDNN) model is a general feed forward neural network to obtain the relationship between the input and output position in time series. Conventional ANN provides their response to the weighted sum of the current inputs. For TDNN, it extends the sum to a finite number of past inputs. In this way, the output provided by a given layer depends on the output of the previous layer’s computed values based on the temporal domain of input values. Because of the very similar structure of the TDNN and the general MLP (Multilayer Perceptron model), back-propagation with some modifications can be applied to train the TDNN. The MLP-model is to forecast the solar radiation and the strength of this algorithm is its ability to model nonlinear series. With TDNN, there is no need to specify a particular model form, since the model is adaptively formed based on the features presented by the data. This data driven algorithm is suitable for many time series models.

Multilayer Perceptron Model with Time Series

A **multilayer perceptron** (**MLP**) is a class of artificial neural network (Feedforward ANN) and composed of multiple layers of perceptrons (with threshold activation). An MLP consists of layers with a hidden layer and except for the input nodes, each node is a neuron that uses a nonlinear activation function. MLP utilizes a supervised learning technique called back-propagation for training.

Multilayer Perceptrons, or MLPs for short, can be applied to time series per forecasting. Multivariate time series data means data where there is more than one observation for each time step and a problem may have two or more parallel input time series and an output time series that is dependent on the input time series. The input time series are parallel because each series has an observation at the same time step. The dataset essentially consist of one row per time step and one column for each of the input and one output parallel time series. The different time steps of each parallel series are provided as input to the model and the model associates this with the value in the output series.

The above problem of multivariate solar radiation is modelled where each input series is handled by a separate MLP and the output of each of these submodels is combined before a prediction is made for the output sequence. In obscence of any real data, we tested the model with small dataset using the Keras functional API, Dense layers with Relu activation function, Adam optimizer with Mean Square Error Loss function and the model is able to concatenate the output from each separate model into one vector, which the model is interpreted for making a prediction for the output sequence.

SOLAR CONJUNCTIONS ESTIMATION

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.

SUN TRACKING WITH FUZZY LOGIC

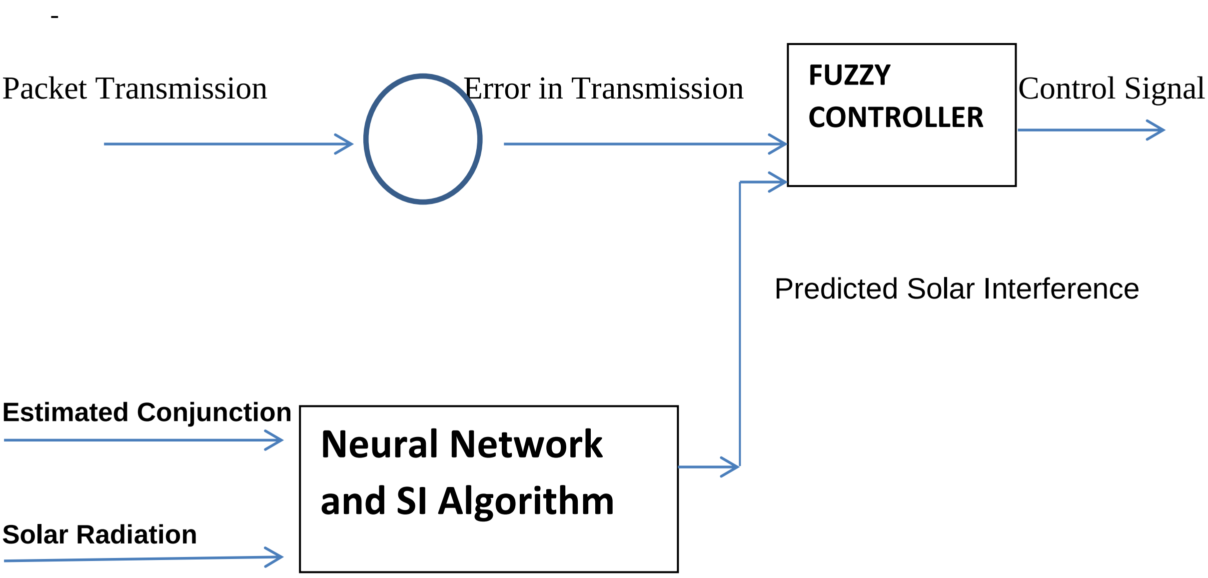

Fig. 2 Adaptive Fuzzy Logic Controller for Solar Interference

The AFSI model is a framework that is obtained by combining the concepts of fuzzy logic and neural networking into a unified platform. The model has a fuzzy inference system in the form of an adaptive network for system identification and a predictive tool that maps a given input space to its corresponding output space based on a representative data set. The AFSI inference system relies on both human knowledge (human knowledge modelled in the form of fuzzy ‘‘if-then’’ rules), machine intelligence and a set of input–output data pairs (patterns) to accomplish the process of input–output mapping. The AFSI modelling strategy is widely used in applications addressing uncertainty or imprecision in the definitions of the variables constituting the system's behaviour. In other words, it has the ability to qualitatively model machine intelligence and represent human knowledge without the need for precise or quantitative definitions. Moreover, it is capable of modelling and identifying nonlinear systems as well as predicting time-dependant behaviour.

The main aim of the AFSI model is to reduce the lossy links in interplanet communication due to solar interference(Conjunctions and Radiation). The fuzzy controller is designed to have two inputs; the first is the error between the sending packets and the undelivered packets and the second is the predicted future solar interference. The controller can be implemented in real-time using a test conditions with controlled interference and a modulating error rate in transmission.

The lossy links in communication can be reduced or eliminated when AFSI controller determines that the relay satellite is likely to be in conjunction then the autonomous satellite could divert the communication to nearby satellites which are not affected by conjunction or tilted itself out of conjunction band/ change trajectory in different path position as proposed in Gangale Orbit(Thomas Gangale) design to provide more communication opportunities for the satellite.

We propose using a MATLAB script/algorithms that begins by setting up the locations, movements of all the bodies and model-based design for systems like communications, etc.

The results of solar tracking with AFSI model when compared with validated simulations of conventional satellites, could confirm that the proposed interference controller achieves superior tracking and reduced lossy links in transmission when compared with the conventional satellites without any tracking..

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 autonomous relay satellites to address direct planet-to-planet communication without lossy links. We propose a constellation of self-driven relay satellites and Geosync sattelites such that they estimate using machine learning/ AI and ensure that they are always above the conjunction band that do not come under the influence of sun's radiation interference. Also proposed fuzzy logic estimation set-up for autonomous relay satellites such that they are not in a conjunction 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.

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