InterPlanet Computer Network: Modelling Delay-tolerant Networking to Get Information from Different Planetary Regions of The Solar System.

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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 design architecture to operate successfully and achieve good communication with other planets including the Earth. The architecture proposes network structure that addresses delays due to interplanet distances and proposes group of satellites orbiting a planet in a graph set-up to achieve delay tolerant network in a planetary system. In addition, the architecture proposes for tracking planetary resources with recurrent behavior, data replication with linkage analysis and use of Graph Algorithms to find connections/shortest path. As it is planetary based architecture outline, the test results show useful purpose of the design at a region level. However, we have not considered generalized suite of protocols to address variable delay and disconnected regions of the planetary system to achieve standard way of end-to-end communication through multiple regions.

INTRODUCTION

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.

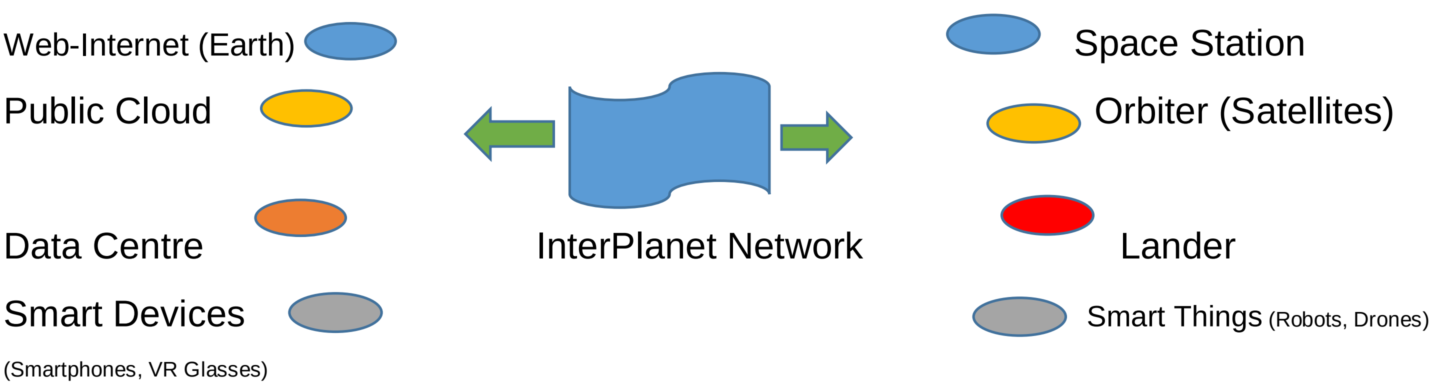
ARCHITECTURE and the METHODOLOGY

A **Computer Network Architecture** is a design in which all computers in a computer network are organized. An architecture defines how the computers should get connected to get the maximum advantages of a computer network such as better response time, security, scalability, etc.

Network architecture refers to the way network devices and services are structured to serve the connectivity needs of client devices.

- Network devices typically include switches and routers.
- Types of services include DHCP and DNS.
- Client devices comprise end-user devices, servers, and smart things.

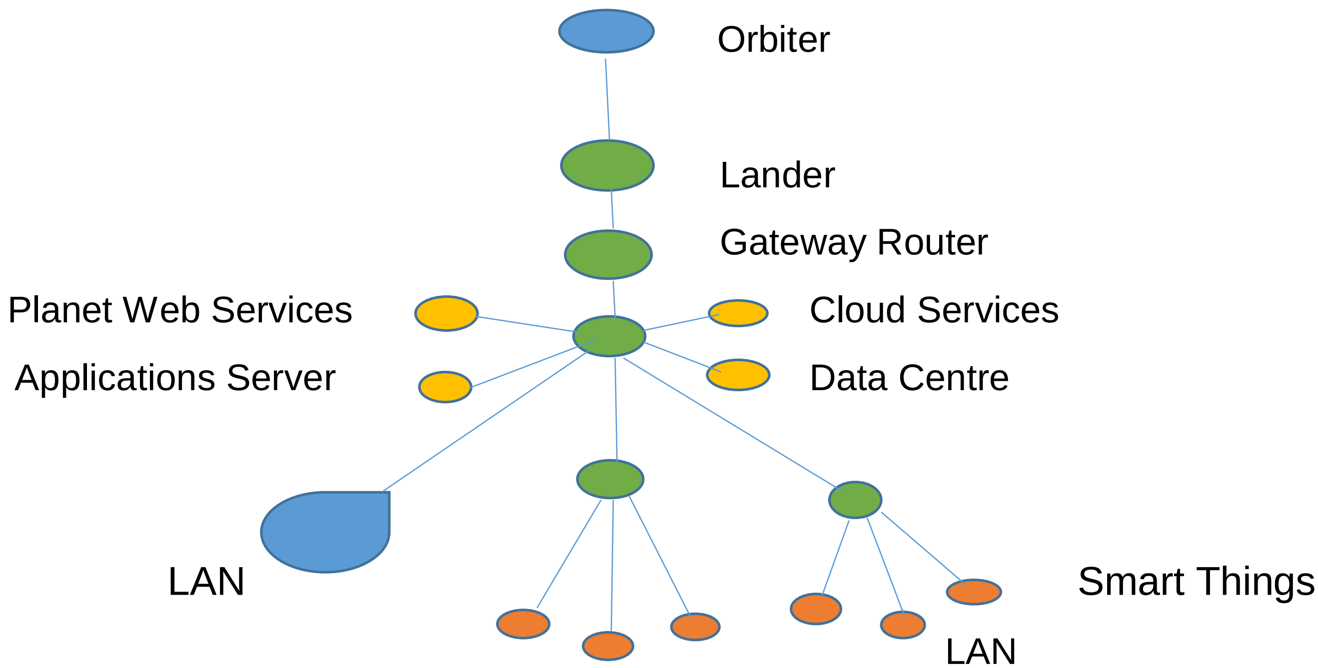
The network architecture for the planet Mars or the Moon is as shown in below figure:-



Computer networks are built to serve the needs of certain functionality and also their clients. Described below are three types of planetary networks:

- Access networks, for campuses and local areas, are built to bring machines and things onboard, such as connecting robots, drones, etc. within a location.
- Networks for data center connect servers that host data and applications and make them available to smart devices.
- Wide-area networks (WANs) connect robots and others to applications, sometimes over long distances, such as connecting robots to cloud applications related to space mining operations.

We give below the architecture of network on the planet Mars or the Earth's Moon is as shown in below figure:-



Local Area Network

The proposed network structure that addresses delays due to interplanet distances and its configurational attributes to serve the connectivity needs of planetary devices are as below:

Orbiting Section

The space section (SS) is composed of series of satellites, or Space-vehicles (SV), in medium planet orbit. The design proposes to include five or six orbital planes with four satellites each in approximately circular orbits. The orbital planes have approximately equal inclination to the planet's equator and are separated by equal angle along the equator from a reference point to the orbit's intersection. The orbital period is planned in such a way that the satellites pass over the same locations or almost the same locations every day. The orbits are arranged so that the satellites are always within line of sight from everywhere on the Planet's surface and the result of this objective is that the four satellites are either evenly spaced (90°) apart or unevenly spaced within each orbit. Orbiting at an appropriate altitude and orbital radius, each SV should make enough orbits each day, and repeating the same ground track each day. This is necessary because even with only four satellites, correct alignment means all four are visible from one spot for a few hours each day and the ground track repeat can be used to ensure good coverage of the region.

Tracking Planetary Resources

A planetary tracking system (PTS) can work in various ways. The PTS devices are generally used to record the position of smart things as they make their journeys on a planet. It is possible that some systems will store the data within the PTS tracking system itself (known as static tracking) and some send the information to a centralized database or system via a communicating device within the PTS system unit on a regular basis (known as dynamic tracking) or 2-Way PTS.

A static PTS tracking system will monitor location and will store its data on journeys based on certain types of events. So, for example, this kind of PTS system may log data such as where the smart device has moved in the past and what specific activity it has performed during the journey period. The data stored on this kind of PTS tracking system is usually stored in internal memory or on a memory card, which can then be downloaded to a computer at a later date for analysis.

A dynamic PTS tracking system is also a real-time system as this method automatically sends the information on the PTS system to a central tracking portal or system in real-time as it happens. This kind of system is usually a better option for space mining or space construction purposes such as fleet tracking or monitoring of drones, robots, such as autonomous or adaptive machines, as it allows a remote-controller to know exactly where the devices are, whether they are on time and whether they are where they are supposed to be during work execution. This is also a useful way of monitoring the quality of smart devices as they carry out their work and of streamlining processes and procedures for execution of assigned tasks.

Graph Theory – Shortest Path and Time-dependent

In mathematics, **graph theory** is the study of graphs, which are mathematical structures used to model pairwise relations between objects. In computer science, graphs are used to represent networks of communication, data organization, computational devices, the flow of computation, etc. For instance, the link structure of a website can be represented by a directed graph, in which the vertices represent web pages and directed edges represent links from one page to another. Similarly, network theory is a part of graph theory: a network can be defined as a graph in which nodes and/or edges have attributes (e.g. names). Network theory has applications in many disciplines including the World Wide Web and Internet.

Network problems that involve finding an optimal way of doing something and the Examples include **network flow**, **shortest path problem** and **optimizing time**.

Graphs can be used to model many types of relations and processes in physical and information systems, and has a wide range of useful applications such as e.g.

1. Finding connections in networks and
2. Planetary Tracking System to find the shortest path to designated device/location from a source.

The challenge here is that given a “picking list of smart devices” as input, we should find the shortest route that passes all the points, but also complies to the restrictions with regard to where it is possible/allowed to access.

This problem can be formulated as an optimization problem in graph theory. All device points in the work-area/region form a “node” in the graph, where the edges represent permitted lanes and distances between the nodes.

Just having an abstracted representation of a planet region in the form of a graph, does of course not solve our actual problem. The idea is rather that through this graph representation, we can now use the mathematical framework and algorithms from graph theory to solve it.

Since graph optimization is a well-known field in mathematics, there are several methods and algorithms that can solve this type of problem. In this case, we have based the solution on the Dijkstra’s shortest path algorithm, which is a well-known algorithm for finding shortest paths in a graph.

Data Replication – Space Station

A **space station**, also known as an **orbital station**, is a spacecraft capable of supporting a human crew in orbit for an extended period of time, and is therefore a type of space habitat. It lacks major propulsion or landing systems. Stations must have docking ports to allow other spacecraft to dock to transfer crew and supplies.

The purpose of maintaining an orbital outpost varies depending on the program. Space stations have most often been launched for scientific purposes, but military launches have also been planned. As of 2021, one fully operational and permanently inhabited space station is in low Earth orbit: the **International Space Station** (ISS), which is used to study the effects of spaceflight on the human body as well as to provide a location to conduct a greater number and longer length of scientific studies than is possible on other space vehicles.

Data Replication is the process of storing data in more than one site or node and storing them at different locations to improve their overall accessibility across a network. The **data replicates** can be stored within the same system, on-site and offsite hosts, and cloud-based hosts. It is useful in improving the availability of data. It is simply copying data from a database from one server to another server so that all the users can share the same data without any inconsistency.

Replication in computing involves sharing information so as to ensure consistency between redundant and to improve reliability, fault-tolerance, or accessibility. We have considered Replication in computing and mainly refer to: *Data replication*, where the same data is stored on multiple storage devices.

There are different models exist for data replication, each having its own properties and performance and we have considered **Transactional replication**: used for replicating transactional data, such as a database. **Transactional replication** only sends modifications to the data.

Database replication can be used on many distributed management systems (DMS), usually with a master-slave relationship between the original and the copies. The master logs the updates, which then ripple through to the slaves. Each slave outputs a message stating that it has received the update successfully, thus allowing the sending of subsequent updates. The planetary network consisting of Networks of hosts of data center, web services, cloud connect servers that host data and transactions and It is simply copying data from a database from one planetary server to another server on the space station through group of space-vehicles/satellites so that all the users including from other planets can share the same data without any inconsistency and latency.

Database replication becomes more complex when it scales up horizontally and vertically. Horizontal scale-up has more data replicas, while vertical scale-up has data replicas located at greater physical distances. Problems raised by horizontal scale-up can be alleviated by a multi-layer, multi-view access. The early problems of vertical scale-up have largely been addressed by improving Internet/network reliability and performance.

Linkage Analysis

Linkage analysis is a subset of network analysis, exploring associations between objects/nodes. An example may be examining the addresses of smart things like robots, drones, autonomous machines, etc., for performance measurement, the activities they have performed and the quality of transactions that they have partaken in during a given timeframe, and the familial relationships between these subjects as a part of successful work execution. Linkage analysis here provides the crucial relationships and associations between very many objects of different types that are not apparent from isolated pieces of information. Computer-assisted or fully automatic computer-based linkage analysis is increasingly employed by commercial agencies in fraud detection, by telecommunication operators in telecommunication network analysis,

We used graph theory algorithms to carry linkage analysis for data center servers for data updation and can also be applied for respective cluster of satellites covering the planet area of data center on time series analysis for data updation regarding the work executed by smart things and replication of transactions to Space Station servers.

Recurrence Networks

We present an approach for analyzing the properties of time series from complex dynamic systems. Starting from the concept of recurrences in phase space, the recurrence matrix of a time series is interpreted as the adjacency matrix of an associated complex network, which links different points in time if the considered states are closely neighbored in phase space.

Natural processes can have a distinct recurrent behaviour, e.g. periodicities (as seasonal or Milankovich cycles), but also irregular cyclicities (as El Niño Southern Oscillation). Moreover, the recurrence of states, in the meaning that states are again arbitrarily close after some time of divergence, is a fundamental property of deterministic dynamical systems and is typical for nonlinear or chaotic systems.

Eckmann et al. (1987) introduced recurrence plots, which provide a way to visualize the periodic nature of a trajectory through a phase space. Often, the phase space does not have a low enough dimension (two or three) to be pictured, since higher-dimensional phase spaces can only be visualized by projection into the two or three-dimensional sub-spaces. However, making a recurrence plot enables us to investigate certain aspects of the *m*-dimensional phase space trajectory through a two-dimensional representation.

A **recurrence** is a time the trajectory returns to a location it has visited before. The recurrence plot depicts the collection of pairs of times at which the trajectory is at the same place, i.e. the set of (i, j) with $\vec{x}(i) = \vec{x}(j)$

. To make the plot, continuous time and continuous phase space are discretized, taking e.g. $\vec{x}(i)$

as the location of the trajectory at time i and counting as a recurrence any time the trajectory gets sufficiently close (say, within ϵ) to a point it has been previously.

Operationally the plot is drawn as follows:

(a) A certain time window $\vec{w} = < t_1, t_2, \ldots, t_T >$

is chosen where any two successive time steps are separated by the time interval δ, and where the state $\vec{x}(t)$ of the system is recorded for each time step, thus collecting the trajectory $X =< \vec{x}(t1),\ \vec{x}(t2), \ldots\ldots, \vec{x}(tT) >$

(b) A 2D plot is created where the x-axis and y-axis both report $\vec{w}$, forming a *T* x *T* lattice of little squares each with side measuring δ

(c) The data X are used to compute a matrix R formed by binary elements recording the recurrence/non-recurrence of values $\vec{x}$ through the binary function:

$$R(i, j) = \begin{cases} 1, & if\ \ \|\vec{x}(i) - \vec{x}(j)\| \leq \epsilon \\ & 0,\ otherwise \end{cases}$$

where . $i, j \in \{ t_1, t_2, \ldots\ldots, t_T \}$

(d) The recurrence plot then visualises *R* with a black little square of the lattice at coordinates *(i, j)* if *R(i, j)* = 1, and a white little square if *R*(i, j) = 0..

A **recurrence** is a time the trajectory returns to a location it has visited before and the location of the trajectory at time *i* and counting as a recurrence any time the trajectory gets sufficiently close (say, within ϵ) to a point it has been previously. Therefore recurrence networks which provide a way to visualize the periodic nature of a trajectory through a phase space and links different points in time if the considered states are close in a complex system such as orbiting group of satellites for real-time tracking of objects on a planetary region.

TEST RESULTS

Since, the communication on a planet is in a wireless mode, the connections are made using antenna as a medium to transfer data and no wired NIC using cables and connectors are made to transfer data. In obscene of full blown large-scale wireless network, the network architecture is tested for some of its features in wired mode with cables and connectors on existing internal internet and the results are not comparable to actual wireless type of network.

CONCLUSION AND FUTURE WORKS

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 graph design with a group of satellites orbiting a planet with data replication and real-time tracking to achieve delay tolerant network communication in a planetary system. At a region level the architectural design shows useful purpose. However, we have not factored-in generalized suite of protocols to address variable delay and disconnected regions of the planetary system to achieve standard way of end-to-end communication through multiple regions.

For future works one may expand the network architecture as 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.

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