InterPlanet Computer Networking: an Application of Stigmergic Intelligence for Enhancing Spacecrafts Capabilities in Information Networks

Poondru Prithvinath Reddy

November 14, 2021

InterPlanet Computer Networking: An Application of Stigmergic Intelligence for Enhancing Spacecrafts Capabilities in Information Networks.

Poondru Prithvinath Reddy

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. Spacecrafts are key resource for most planetary resources, both for the planetary exploration and for the variety of application areas including communications. We present Stigmergic distributed Intelligence implementation to solve complex routing problems in planetary information networks by exploiting the possibilities offered by stigmergic procedure. Stigmergic intelligence is considered as a disruptive force to improve the spacecraft resource efficiency through sensing and interacting with the environment. This article presents an information network based on the decision-making processes of ant colonies looking for food. When ants search for food, they modify their surroundings by leaving traces of pheromone, which may be reinforced and function as a type of path marker for when food has been found. This process is based on stigmergy, or the modification of the environment to implement distributed decision-making processes. The paper demonstrates a network that can be wholly operated by reproducing the stigmergic distributed intelligence both at the spacecraft level as well as at the router stage. This is highly significant in the field of interplanetary technologies, within which decision processes are implemented into a networking routeways with a software code. 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 implementation was tested with

small number of nodes and the results are effective in addressing efficiency of resources 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.

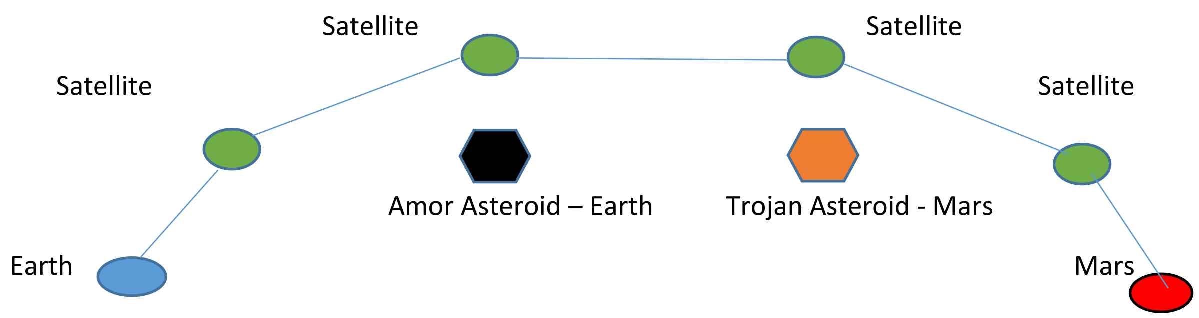

Fig. 1 Planetary Satellite Link

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.

Stigmergic Intelligence

An implementation to solve complex routing problems in modern information networks by exploiting the immense possibilities offered by stigmergic procedure and this article presents an addressable network of relay satellites and ground based planetary resources(robots, drones, autonomous machines, etc.) based on the decision-making processes of ant colonies looking for food. When ants search for food, they modify their surroundings by leaving traces of pheromone, which may be reinforced and function as a type of path marker for when food has been found. This process is based on stigmergy, or the modification of the environment to implement distributed decision-making processes. The implementation that this work proposes is a collection of Geosync satellites, Realy satillites and ground based planetary resources that simulates this stigmergic procedure. The experimental implementation is based on the use of dynamic underneath elements, i.e. network nodes that can be modified dynamically with a rapid changing topology, simulating the modification induced by the ants on the surrounding environment when they leave the pheromone traces. The paper demonstrates a network structure that can be wholly operated with a changing topology and that can be the basis of complex hardware configurations that might reproduce the stigmergic distributed intelligence. This is a highly significant in the field of highly distributed network technologies, within which decision processes are implemented into a network routeways and with a software code.

Network Structure & Classification

In communication networks, establishing the routes that data packets must follow to reach the destination is an important process. In this process, a routing table is created which contains information regarding routes which data packets follow. Various routing algorithm are used for the purpose of deciding which route an incoming data packet needs to be transmitted on to reach destination efficiently.

We look at the adaptive algorithms which change their routing decisions whenever network topology or traffic load changes. The changes in routing decisions are reflected in the topology as well as traffic of the network. Also known as dynamic routing which is more relevant to InterPlanetary Internet where network resources keep changing dynamically, these make use of dynamic information such as current topology, load, delay, etc. to select routes. Optimization parameters are distance, number of hops and estimated transit time.

In addition, we have chosen a method, where a centralized node has entire information about the network and makes all the routing decisions. And it is distributed as the node receives information from its neighbors and then takes the decision about routing the packets. Advantage of this is only one node is required to keep the information of entire network. Link state in this method is aware of the distance in the network as the data packets move between source and destination.

•

METHODOLOGY

We consider the method of routing packets in a mobile wireless network as the InterPlanet Internet is a large scale wireless network very similar in structure to mobile networks. Such a network can be envisioned as a collection of routers (equipped with wireless receiver/transmitters) which are free to move about arbitrarily. The status of the communication links between the routers, at any given time, is a function of their positions, transmission power levels, etc. The mobility of the routers and the variability of other connectivity factors result in a network with a potentially rapid and unpredictably changing topology. Congested links are also an expected characteristic of such a network as wireless links inherently have significantly lower capacity than hardwired links and are therefore more prone to congestion.

A routing method, in general, well-suited for operation in this environment should possess the following properties:

• Executes distributedly

• Provides loop-free routes

• Provides multiple routes (to alleviate congestion)

• Establishes routes quickly (adopting to the topology changes with stigmergic intelligence)

• Minimizes communication overhead by localizing algorithmic reaction to topological changes when possible (to conserve available bandwidth and increase scalability)

ROUTING ALGORITHM

Existing shortest-path algorithms and adaptive shortest-path algorithms are not particularly well suited for operation in such a large wireless network. These algorithms are designed for operation in static or quasi-static networks with hardwired links. If the rate of topological change in the network is sufficiently high, these algorithms may not be able to react fast enough (i.e. to maintain routing) and flooding will be the only recourse. Furthermore, most of these algorithms provide only one path for routing between each given source/destination pair which exacerbates the link congestion problem. While link-state algorithms provide the capability for multipath routing, the time and communication overhead associated with maintaining full topological knowledge at each router makes them impractical for this environment as well.

Routing optimality (i.e. determination of the shortestpath) is of less importance. It is also not necessary (nor desirable) to maintain routes between every source/destination pair at all times. The overhead expended to establish a route between a given source/destination pair will be wasted if the source does not require the route prior to its invalidation due to topological changes.

We have considered a routing algorithm which is tailored for operation in this highly dynamic network environment with a high rate of topological change. The algorithm is based, in part, on the adaptive and distributed characteristics and also on the path of spanning tree reported by each neighbor ; however, it does not share their undesirable characteristics associated with network.

The process of network communication essentially involves:

- A centralized node makes all routing decisions(perform multipath routing)
- Centralized node contains information about Distance, Routing data, Link cost, and update message list(Nodes inform each other of link changes using update messages)
- Nodes send update messages after processing updates from their neighbhours or after detecting change in the link. Also each node maintains a stigmergic mark. If the node has stigmergic trace and does not update message, that node is not required to be reached
- If the node receives a message from a new node, that node added to the link. Similarly, if a node is not sending messages, it must send a message within specified time to ensure connectivity

The method of routing information packets for achieving efficiency in communication based on stigmergic intelligence applies for both planetary ground resources like robots, drones, autonomous machines, etc. as well as for orbiting relay spacecrafts (circular orbit based satellites).

IMPLEMENTATION

We tested the method in static network with hardwired links with small number of nodes simulated dynamically by changing topology and found to be effective in addressing efficiency in communication among connected nodes.

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 complex information routing through relay satellites to address direct planet-to-planet communication. This paper presents an addressable information network based on the decision-making processes based on stigmergy, or the modification of the environment to implement distributed decision-making processes. The experimental implementation is based on the modification induced by the agents on the surrounding environment when they leave the pheromone traces. The paper demonstrates a network that can be wholly operated by reproducing the stigmergic distributed intelligence in both spacecrafts as well as at router level. This is a highly significant in the field of interplanetary technologies, within which decision processes are implemented into a networking routeways with a software code. As it is planetary based architecture outline, the proposed approach would be effective in addressing efficiency in a planetary communication among disconnected regions of the planetary system to achieve end-to-end communication..

REFERENCE

1. Poondru Prithvinath Reddy: “InterPlanet Computer Networking: Estimating Solar Disruptions with Deep Neural Networks and A.I. in an Autonomous Satellite”, Google Scholar
2. I. Kassabalidis , M.A. El-Sharkawi , R.J.Marks II , P. Arabshahi , A.A. Gray:” Swarm Intelligence for Routing in Communication Networks”,
   http://faculty.washington.edu › globecom01_2