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A Novel Protocol for Mobile Nodes Adjustable Dynamic Routing in Spacecraft Networks

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ABSTRACT : *Spacecraft's are being used increasingly for an emerging host of applications in almost all industries like weather prediction, geological conditions, river movements, mining etc. Most of the spacecraft nodes have predictable nodes with predictable routing topology. Spacecraft networks are mobile networks with independent, heterogeneous nodes but without spontaneous movement. In regular operation, each spacecraft flies along a predictable trajectory that can be computed well in advance. Hence, spacecraft networks constitute a subclass of mobile ad hoc networks that is characterized by its predictability. As in other networks, unpredictable changes may still occur and influence the evolution of the topology, in particular, when nodes or links fail. This study proposes a model mobile-routing protocol based on link-state routing, whose performance is superior to its static and ad hoc counterpart's dynamic topology. The proposed routing protocol for spacecraft routing accounts for occurrences of additional, unpredictable changes, as well as their interaction with predictable changes. The protocol outperforms traditional routing protocols and is well suited for routing in next-generation space networks. Thus a snapshot of the network topology helps to store the networks model in various timeframes and solve the problem in case of dynamic requirements either from the base station or due to some other obvious reasons requiring change of path. This is done without any loss to the data and also the security is not compromised in such conditions.*

KEYWORDS: *Spacecraft Network, Mobile Nodes.*

I. INTRODUCTION

Paragraph Spacecraft networks are mobile networks which have independent heterogeneous nodes and no spontaneous movement. They move along a predictable trajectory computed in advance. But these things are subjected to lots of assumptions.The Spacecraft Tracking and Data (Acquisition) Network (STADAN or STDN) was established by NASA to satisfy the requirement for long-duration, highly-available space-to-ground communications. Real-time operational control and scheduling of the network was provided by the Network Operations Control Center (NOCC) at the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland.Consisting of parabolic dish antennas and telephone switching equipment deployed around the world, the STADAN provided space-to-ground communications for approximately 15 minutes of a 90-minute orbit period. This limited contact period sufficed for unmanned spacecraft, but manned spacecraft require a much higher data collection time. In May 1971 STADAN was consolidated with the Manned Space Flight Network (MSFN) to form the Spaceflight Tracking and Data Network (STDN).

Space communications was developed to provide communication services that were specific and optimized to each mission. The nature, communication needs and inter-spacecraft networking requirements of such missions vary broadly, and although the interfaces and protocol used in different missions were standardized, the resulting "ensemble" of different communication systems is not integrated into an overall autonomous communication infrastructure, wherein the in-space nodes can communicate with each other as well as with users on Earth through the Internet. The need of a scalable integrated infrastructure is even more relevant today, and it is reorienting its focus to long-term missions oriented to human missions for exploration of the Moon, Mars and asteroids; human settlements in space; and large in-space observatories.The need of such an integrated space communications infrastructure, including requirements identification, concept-architecture and related technology developments, has been the object of investigations and workshops at the various centers. Very much like the terrestrial Internet, the architecture of the integrated space communications infrastructure is composed collection of networks deployed in the immediate vicinity of a celestial body being observed and/or explored called, generically, <plnet_name>-Vicinity Networks (e.g., Earth, Moon, Mars-Vicinity Networks) linked together through an inter-planetary backbone network that will likely include relay satellites placed in the Earth-Moon Lagrange orbit and in the Earth-Sun Lagrange pointsL1, L2, L4 and/or L5 to provide high data rate backbone capabilities to deep space observing and science missions.

The Mars-Vicinity Network in Figure 1, as an example of a planet-vicinity network, will likely evolve over time to include elements of the communications infrastructure deployed in and around the Earth.The architecture and key physical-layer and medium access control (MAC) layer technologies for a High-Throughput Distributed Spacecraft Network (or Hi-DSN) developed for NASA by BBN that could be used as the basis of future Internet-friendly planet-vicinity networks. The Hi-DSN provides a self-forming vertically integrated network infrastructure for establishing and maintaining high-throughput multi-hop communications among spacecraft operating in diverse orbits. It integrates the predictability of orbital movement to establish and maintain cross-links and multi-hop routes, ad hoc networking capabilities to autonomously discover “new” neighbors, spatial multiplexing to maximize re-use of the allocated spectrum, and variable-rate cross-links with multi-code spread spectrum to maximize network connectivity under large inter-spacecraft distances and distance differentials .Transmission is performed in bursts, with one packet per burst. The spectrum is fully re-usable in the cross-links that are spatially isolated. The spectrum is shared using time and/or time-code multiplexing during the times in which the spacecraft become “aligned.” Multi-code multiplexing is used, as described in this paper, to adjust each cross-link data rate to “close the link” between each source-destination spacecraft pair. The inter-spacecraft communication strategy is QoS-aware, and the number of shift-orthogonal codes used in the encoding of each packet burst is selected to meet bit error rate (BER) and delay/delay-jitter requirements of each flow that compose the aggregate packet traffic over each cross-link.

The number of in-range neighbors per each spacecraft, and the distances and link performance (e.g., signal to noise ratio or SNR) of each of the cross-links change over time with the constellation movement. Considering an example, snapshots (STK-tool animation of an OPNET simulation) of the geometry and the cross-link connectivity of a typical multi-orbit constellation with spacecraft in LEO, MEO and GEO orbits. In the Hi-DSN system, the transceiver in each spacecraft can establish, ideally, one cross-link per in-range neighbor spacecraft—at the data rate required to close the link—while using a single modem and a single array antenna. This capability is used to control the overall link-level connectivity properties of the network as a whole, including the formation of clusters.The Hi-DSN architecture is hierarchical and can be extended to both include ground-station gateways as integral part of the space-based network and provide dynamic “terminal affiliation and handoff” for transferring data from spacecraft to aircraft and spacecraft to ground terminals and sensors. STK-tool animation of an OPNET simulation illustrates the integration of ground-station gateways in the space-based constellation and the first-time establishment of cross-links (i.e., neighbor discovery) between the gateways and each spacecraft in their field of view.

Key aspects of the Hi-DSN architecture in action have been demonstrated using a laboratory prototype and OPNET simulation. The laboratory prototype enabled evaluating how the modulation, encoding, and multiplexing technologies perform under extreme differences of distance (attenuation) and synchronization (frequencies and delays) between space links. The OPNET simulation enabled evaluating how the higher-level protocols scale to large networks.The descriptions focus on the aspects of the architecture that are relevant for the planet vicinity network problem, and on the enabling physical-layer, medium access control (MAC) layer and sub-network level (i.e., below IP) technologies required to create a scalable communications infrastructure that can be used to extend the (terrestrial) Internet to space. In a follow-on development for NASA, BBN is designing the architectural extensions and developing the protocols to extend Internet VPNs to space, then known as Space VPNs.

As the spacecraft arrive at the destination, they will likely spread and self-arrange themselves into orbits around the planet, possibly at different altitudes. The resulting network, albeit fully deterministic, will exhibit aspects of an ad hoc network. This is true during its formation stage and when individual spacecraft do not have pre-stored (or access to) orbital information of ALL other spacecraft in the constellation. Naturally, with the appropriate communication mechanisms in place (as described in this paper), a spacecraft can learn about each other’s orbital parameters, measure relative distances and velocities and even, if needed, re-synchronize their internal clocks to a spacecraft dynamically-selected as reference. In the Hi-DSN the above initial information gathering and measurements, including the exchange of orbital parameters (when and if available), happen as part of a distributed protocol called Neighbor Discovery. A Distributed Network Synchronization protocol establishes, over time, of a common time and frequency among all nodes in the constellation. Over time, the initial deployed constellation around the planet will eventually be augmented by new spacecraft.Newcomer nodes may include spacecraft with specialized sensing capabilities and more powerful (i.e., next generation) communication capabilities and are required to fly at a different altitude orbit. In the Hi-DSN, newcomer nodes are able to integrate themselves into the network with minimal disturbance to the existing constellation, leveraging network adaptation techniques developed for terrestrial ad hoc wireless networks. These newly-arrived spacecraft, together with the already in- place spacecraft, creates a more complex communication environment, where link switchovers occurs very frequently and links with fast varying capacities are the rule, not the exception. The overall system, albeit fully “predictable” over time, becomes almost intractable when one considers the amount of information that needs to be “configured” in ALL spacecraft, and the additional synchronization requirements that would be needed if we were to continue using conventional, scheduled-link switchover technologies as a means to maintain continued connectivity. The Hi-DSN uses an ad hoc networking approach, where each spacecraft dynamically “discovers” in-range neighbor spacecraft, dynamically affiliates to neighbor router spacecraft, and dynamically form a three-level hierarchical network.

II. RELATED WORK

Satellite communication is traditionally one of two kinds: either 1) direct point-to-point links from control centers to spacecraft or 2) bent-pipe communication applications, where spacecraft relays a data stream. Neither approach uses network routing technologies. Earlier attempts to use more sophisticated spacecraft communication models in the form of Low Earth Orbit constellations with inter spacecraft links had limited commercial success due to their inability to integrate the spacecraft network with other terrestrial networks Direct Point to Point control links having direct control centers to the space craft. Does not use network routing technology. Multiple centers for different crafts use more resources. Bent Pipe Methods: Spacecraft streams data to the control center also does not use network routing technology. Does not integrate spacecraft with other ground networks, so to issue commands one has to first issue a request to the original station and then forward from there to the spacecraft. This is very time consuming and also obliterates the purpose of the command and makes the information thus retrieved very old.Requires manual commanding by operators, who will man the base station. To remember all the commands and routes and tasks assigned will be a very difficult proposition. Hence at one stage it becomes overloaded and efficiency is relinquished at some point of time.Provides a position-based routing architecture for space networks which is dynamic in nature. It also treats all nodes as equal in terms of routing protocol behavior and proactively propagates connection information on current and future links between nodes. All this involves lot of processing power and this in turn increases communication overheads.

III. PROPOSED MODEL

The proposed model is the Secured Link State Protocol. The proposed framework introduces a model to handle predictability without any manual intervention required for issuing commands or controls over routing. The proposed model is autonomous. It takes decisions dynamically in response to the topology snapshot. Also monitors topology continuously across domains. The model takes a snapshot of spacecraft topology at a particular time interval. Next it associates the topology of the snapshot with the time interval. There might be some changes in the sequences. Then observe the changes in the sequence of snapshots. This brings out any unpredictability and the system reacts. A sequence of snapshots describing predictable changes can be defined by an initial snapshot and a transition function that maps snapshots to snapshots. The transition function describes how the network connectivity is expected to change over time. Note that it may be different for each network topology and sequence of snapshots. Unpredictable changes are not covered by the transition function and must be discovered by the nodes using link sensing. This means that nodes must check their neighborhood for unpredictable changes either proactively, at regular time intervals, or reactively. These unpredictable changes at regular time intervals are captured and dissected by the snapshots.

The system responds reactively to both the states the initial and the present and it pre-computes these snapshots. Then all the nodes are realigned for all unpredictability. It also has security services against attacks and data thefts. This is the Secured Link State Protocol.The first problem related to the interaction of predictable and unpredictable changes at transition points. As the predictable snapshot sequence does not include unpredictable changes, such changes may be overwritten by the snapshot topology images. The second problem is the need for regular realignment of the original predicted snapshot incorporate modifications due to past unpredictable changes. This method provides solutions to both problems. Note that these problems (and opportunities) do not arise in mobile ad hoc settings without the a priori topology knowledge of node movement and communication opportunities since all changes are un-predictable. Both the problems are solved thus and the communication overheads are minimal when compared to the existing solutions. The efficiency is good with both processing and computing power utilization being minimal in terms of route computation at any point of time.All the spacecraft, together with the already in-place spacecraft, creates a more complex communication environment, where link switchovers occurs very frequently and links with fast varying capacities are the rule, not the exception.

The overall system, albeit fully "predictable" over time, becomes almost intractable when one considers the amount of information that needs to be "configured" in ALL spacecraft, and the additional synchronization requirements that would be needed if we were to continue using conventional, scheduled-link switchover technologies as a means to maintain continued connectivity. The space-craft network uses an ad hoc networking approach, where each spacecraft dynamically "discovers" in-range neighbor spacecraft, dynamically affiliates to neighbor router spacecraft, and dynamically form a three-level hierarchical network.

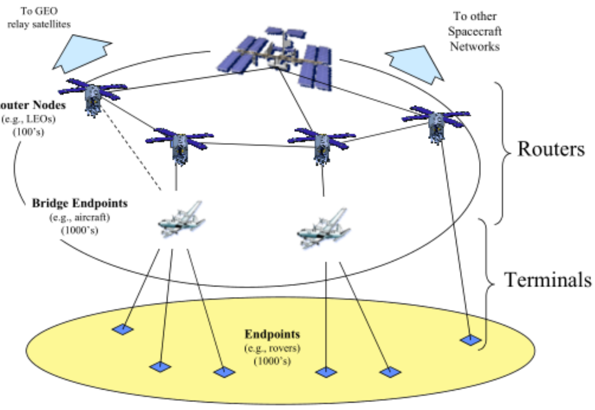

Fig 3.1 spacecraft network

Each spacecraft is equipped with a single router, a single transceiver and a single pair of transmit-receive array antennas to achieve low cost. All router nodes have identical Physical-Layer level characteristics (e.g., modulation, FEC, multiplexing, etc.) but can have different RF front-end capabilities (e.g., RF power, and beam gain and agility). Inter-spacecraft cross- links use RF array antenna technology to achieve the required beam agility and Ka-band frequencies to achieve high-directivity with a relatively small profile antenna. They also assume the use of spatially isolated transmit-and - receive array antennas to achieve full re-use of the allocated spectrum in each cross-link. Because of the nearly arbitrary albeit predictable topology, digital beam forming is used to establish a varying number of cross-links per spacecraft. Because of the nearly arbitrary, albeit predictable geometry, antenna null steering is used to minimize interference between cross-links. In addition, because of the large inter-spacecraft distances and, more importantly, because of the typical multiple order of magnitude difference between such distances, a novel multi-code multi-bit modulation-and-encoding is used on each cross-link to achieve bit rates varying over a four-order-of-magnitude range (e.g., from 100 Kbit/s to approximately 1 Gbit/s) to "close the link" to neighbor spacecraft.

In order to optimize the use of on-board power, a BBN-developed patent-pending Split-Phase Shift Keying (or SPSK) modulation is used to enable signals transmission at a constant power with the SSPA of each array antenna element operating at or close to saturation. Finally, because of the typical large delays of the inter-spacecraft links, a multiple access strategy that does not require "burst transmission coordination" among neighbor spacecraft was developed.Each node in the network does the routing as described below. It looks at the tag of the incoming data packet. It then does a table look-up with the help of its ingress label which indicates its QoS parameter. If the transition to the next snapshot is nearing or a transition has just occurred, then the shortest path is chosen as stated previously. If the ISL along which it is going to send the data is congested or the node at the other end has failed, then the next suitable shortest path is chosen. It then stamps the data packet with the egress label obtained from the table entry in place of its old ingress label. It then sends out the packet along the egress link obtained from the table entry. A space-time routing framework for instances of these networks that have predictable motion, either over finite time horizons or infinite time horizons due to periodicity. Specifically, we solve this routing problem: Given a set of nodes and how they move up to a certain time in the future, our goal is to construct space-time routing tables that specify when and to whom a node must forward a message in order to meet some routing objective. The proposed solution is based on a space-time graph model of the network derived from the mobility of nodes. The space-time graph model captures the dynamic evolution and connectivity over time of the network topology. They devise a routing algorithm using this space-time graph model to select a suitable next hop node from the current as well as the future neighbors. Consequently, the next hop for forwarding a message from a node is a function of both the destination and time, unlike traditional forwarding approaches based only on the destination of a message.

IV. CONCLUSION

Thus the model for predictable mobile topologies and used it to design the PLSR routing protocol. The proposed protocol is correct and performs well compared to other routing protocols in a topology that has been generated using a random-waypoint model. They have carried out the first detailed study of predictable routing for space networks. Using realistic simulations based on two application scenarios, we showed that PLSR is efficient and offers advantages over competing protocols. The simulations are based on actual flight-dynamics data and show the superiority of PLSR over LSR. Together with the generic simulations, our results provide strong evidence of PLSR's general usability. Also adequate security has been developed for data theft possibilities and optimized in such a manner that provides dynamic routing coupled with data security.

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