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Multi-Criteria Space Based Internet Routing

Behnam Malakooti, Michael Griffith, Tom Linsky, Vincenzo Liberatore, Nima Malakooti
Electrical Engineering and Computer Science Department
Case Western Reserve University
Cleveland, Ohio 44106, U.S.A.

Dr. Kul Bhasin
Space Communications Department, Glenn Research Center
National Aeronautics and Space Administration
Cleveland, Ohio 44135, U.S.A.

Abstract

In this paper, we propose to develop a multi-criteria routing method which exploits the inherent deterministic qualities of satellite orbits to create an efficient routing mechanism for the next generation space Internet. Our approach will simultaneously optimize several criteria to generate an efficient solution to the Space Based Internet (SBI) routing problem. We define the objectives and use simulation and emulation for testing and validation.

Keywords: Multi-criteria decision making, space-based internet routing.

1. Introduction

Extending the terrestrial Internet to space is an active research topic. The network layer in the Open Systems Interconnect (OSI) model has gained much focus for implementing an IP-based network in space. Current satellites use a variety of different protocols, and recent research has focused on implementing a common protocol in space. IP is a good candidate because of its wide acceptance in terrestrial networks. In 1999, IP was successfully tested in space [5]. Also, several contributions to satellite network problems have been made at the transport level. Much effort has been placed into dealing with latency in an IP network that extends into deep space. In addition, the issues with placing sensitive hardware in the space environment are occupying attention.

Finding the most efficient and reliable route between LEO satellites, GEO satellites, and ground station gateways is a difficult but valuable problem. Potentially sensitive information could be transmitted, so security is an issue along with efficiency and reliability. We provide a solution which takes advantage of the predictability of the satellite orbits. Since we know the physical location of all nodes, we can find the shortest path between any two nodes at any given time using algorithms from graph theory. Our model extends the shortest path to include more than physical distances.

Handovers are unavoidable for any substantial satellite connection. We propose a method that reduces the signaling overhead associated with handovers in the network. One objective of our multiple criteria problem tries to ensure that the number of handovers is kept to a minimum.

1.1. Space-Based Internet Routing

The routing table at a given router shows the next hop (an adjacent router) for any given destination. Some routing suggestions have used the deterministic characteristic of the satellite orbits for creating routing tables; see [4, 9, and 10]. One common problem is that the network can quickly become congested because of the high frequency of routing table updates. Therefore, we will utilize quick reduction computational approaches to minimize the load on the space network.

The computing power of terrestrial nodes is substantially higher than space nodes and at a much lower cost. This asymmetry can be exploited by allowing the space routers to send the parameters of computationally intensive problems to Earth and then upload the results of the computation.

Communication links may be severed due to antenna pointing demands when the inter-satellite links (ISLs) occur between satellites in latitudes above 60° north or south [9]. Our method, discussed below, realizes this, and we avoid short lived communication links. This will also take care of the issue of satellites in different planes passing by each other too rapidly to establish good communication [7]. In addition, delay jitter is reduced by minimizing the number of routing changes.

1.2. Multi-Criteria Decision Making

A decision maker will often be confronted with several, usually conflicting, criteria for evaluating a group of alternatives. Multi-Criteria Decision Making (MCDM) methods can aid the decision maker in selecting the best alternative in the problem. The general steps for applying the MCDM methodology are:

1. Identify and assess criteria values for evaluating alternatives.
2. Identify the set of alternatives.
3. Identify efficient alternatives.
4. Choose a method for ranking or rating alternatives.
5. Rank or rate alternatives and identify the best alternative.

Many resources are available in the field of MCDM; see [1, 2, and 3]. MCDM methods have been applied to create many algorithms and heuristics for solving different problems. It has been suggested that using multiple criteria for space routing would be beneficial [9], but a formal definition of objectives and constraints has yet to be developed.

2. General Approach

We make several assumptions in our model that reflect a near-future state of NASA's satellite system. All satellites are considered to be capable of routing packets in an IP network. Any satellite which is not acting as a router in the network can still have access to the network if it sends a packet to any router in the network. We will assume all addresses are either gateway ground nodes or other satellites, since a single LEO satellite should not be expected to route packets destined for a terrestrial network [7]. If a terrestrial packet needs to be routed through space, it should be delivered inside a packet from one gateway destined to another, using Network Address Translation and/or tunneling.

Suppose there are n adjacent routers, $\{y_1, \ldots, y_n\}$. Based on a certain destination and the current network topology, we can find the best next-hop satellite within line-of-sight (LOS) to route a packet. We propose using a multiple objective approach which considers factors that can be calculated from data stored in a database on each satellite. Our objectives are to:

1. Minimize f_1 = the total latency from a given node, s, to destination, x
2. Minimize f_2 = the total processing time at a given node, s, to destination, x
3. Minimize f_3 = the average delay jitter from a given node, s, to destination, x
4. Minimize f_4 = the failure rate (percentage of packet drops) at a given node, s, to destination, x

The objectives are subject to a priority connectivity constraint, a bandwidth requirement constraint, and a security requirement constraint. We propose to minimize f_1, f_2, f_3, and f_4 in the creation of a routing table.

Latency is a measurement of time it takes a packet to travel between nodes and is based on the available bandwidth and the physical distance between two nodes. The delay jitter is the standard deviation of the latencies and is concerned with available bandwidth (to reduce congestion) and time remaining in LOS (to reduce rerouting). Minimizing the failure rate, thus maximizing reliability, is achieved by either maintaining statistics about each link, using physical factors such as elevation angles and distances between nodes, or a combination of the two.

The total end-to-end latency of a packet includes its transmission, propagation, processing, and queuing time on all hosts from source to destination. To minimize the end-to-end latency for the system, the latency associated with each of the routers should be minimized. It is also useful to measure the end-to-end latency and use quick and reliable sequencing methods for minimizing the latency of each packet.

Reliability should be considered and possibly guaranteed on various layers. It is important to measure reliability for space communications, where certain links tend to be less reliable.

When multiple connections are in contention for a link, issues such as priority and whether preemptions will be allowed, have an important effect on the efficiency of each individual connection. In developing a protocol, which uses different priorities for different connections, we must also consider the fairness of the system. For instance, it is desirable that the existence of high priority connections should not lead to the starvation of a lower priority connection.

3. MCDM Approach

3.1. Measurement of Objectives and Constraints

We propose the following measurements at a given node s, for the four objective functions with respect to each adjacent router.

$$f_1 = T_s(x) = \min\{ t_{sy} + T_y(x) \mid y \in N_s \} \quad (1)$$
$$f_2 = C_s(x) = \min\{ c_{sy} + C_y(x) \mid y \in N_s \} \quad (2)$$
$$f_3 = J_s(x) = \min\{ j_{sy} + J_y(x) \mid y \in N_s \} \quad (3)$$
$$f_4 = Q_s(x) = q_{sy} \cdot Q_y(x) \quad (4)$$

Equations 1, 2, 3, and 4 respectively represent the total latency, processing time, delay jitter, and failure rate for the system. The set of adjacent nodes is $N_s = \{y_1, \ldots, y_n\}$. Hence, for $y \in N_s$, $Q_y(x)$ is failure rate from the adjacent router y to x, and $q_{s,y}$ is the failure rate from current nodes to the adjacent router, y.

Constraints of the system at each adjacent router are presented by the following decision variables:

z_1 = Priority connectivity requirement (M)
z_2 = Bandwidth requirement (B)
z_3 = Security requirement (S)

The constraints are measured as follows:

$$M_s(x) = \max\{ \min\{ M_y(x), m_s, y\} \mid y \in N_s \} \in M_{min} \quad (5)$$
$$B_s(x) = \max\{ \min\{ B_y(x), b_s, y \} \mid y \in N_s \} \in B_{min} \quad (6)$$
$$S_s(x) = \max\{ \min\{ S_y(x), s_s, y \} \mid y \in N_s \} \in S_{min} \quad (7)$$

In Equations 5, 6, and 7; M_{min}, B_{min}, and S_{min} are minimum given requirements. The constraints are used when generating our alternatives.

3.2. Proposed Method for Ranking Alternatives

Since all of the aforementioned criteria can be quantized, we will develop a method of choosing between any efficient alternatives that we generate. The multi-objective optimization procedure can be used to identify efficient (non-dominated) alternatives (nodes), and hence, to screen out inefficient nodes [1, 2]. These efficient alternatives are all acceptable next-hop routers. Depending on the decision maker's priorities or weights on the objective functions (f_1, f_2, f_3, f_4), a different route will be selected.

Furthermore, a nonlinear (more complex) utility function can be applied [1, 2, and 3]. As a matter of illustration and simplicity; suppose that the utility function selected is a weighted additive function as follows: $U(f_1, f_2, f_3, f_4) = w_1 f_1$

$+ w_2f_2 + w_3f_3 + w_4f_4$ where w_1, w_2, w_3, and w_4 represent importance of weight for each objective and $w_1, w_2, w_3, w_4 \geq 0$.

4. Evaluation

4.1. Simulation

To test and validate our routing approach, we will perform various simulations ns, using custom modules. Currently, there is limited satellite support in ns, but we will expand this when creating our custom routing module. We will use Satellite Tool Kit (STK) to generate the data necessary to create a routing table for a given satellite.

An STK Access Report gives the start time and stop time of line-of-sight (LOS) access between two specified nodes. The setup of the STK scenario ensures that communication equipment is available. The node pair can be ISLs, ground-LEO connections, or ground-GEO connections. Thus, a router needs n(n-1)/2 access reports for n nodes, since the access time matrix is symmetric.

We then use LOS access reports along with our network statistics to create the routing tables. We propose to develop an algorithm based on our MCDM objectives and constraints to accomplish this. We will create an algorithm using this data whose output is a series of routing table update events, rather than the complete routing tables, which should conserve memory and possibly processing time.

4.2 Emulation

After our algorithms have been validated by various simulations, we will use a more realistic form of network performance emulation. Emulation offers additional accuracy that is required to make adjustments to our MCDM routing algorithm. We will modify the University of Kansas Space Based Internet emulation system [6] to include our new routing algorithm. We can then evaluate the algorithm's effectiveness.

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