Various Routing Techniques for non-GEO Satellite Constellations

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ABSTRACT

Two different routing algorithm categories are studied in this paper for a typical LEO satellite constellation. Shortest path algorithms and optimal routing. Their performance is investigated through extended real time simulations.

In the context of satellite constellations the basic parameters for a typical network such as delay, throughput, link utilization must be supplemented by new factors imposed by the nature of satellite operation, like the handover procedures, the non-uniformity of load distribution in the space segment and the continuous topology variation. The pros and cons of the techniques are illustrated and helpful conclusions for the network design are provided.

I. INTRODUCTION

The main function of a routing algorithm is the selection of proper roots to achieve high performance measured usually in terms of delay, throughput, link utilization, e.t.c.

The nature of newly developed non-GEO satellite systems, which is characterized by the cost of resources [16], the geographic dependence of the service requests and the time-varying topology, commands the efficient utilization of the integrated (terrestrial and space) system.

Modern constellations [17] provide connections between their nodes (satellites) in the same or adjacent planes, called *Intra-plane* and *Inter-plane Inter Satellite Links (ISLs)*, respectively. Due to the satellite movement and pointing/acquisition problem of the antennas used, ISLs operation consists of active and idle periods, therefore the topology of a satellite system changes over time.

For these systems the *connection oriented* mode has been considered as the strongest candidate [1-4], while the utilization of *connectionless* mode is still under question. Thus in this work we implemented the *connection oriented* mode.

In terrestrial networks two routing approaches have been proposed and so far implemented, *shortest path* and *optimal routing*. The algorithms of the two categories defer in the way they operate. While the former uses decision variables that are "user" oriented aiming to the minimization of a source-destination path, the latter is "network" oriented aiming to the minimization of the mean network delay .

The rest of the paper is structured as follows: In Section II, the evaluation criteria that are important in satellite networks, such as propagation and queuing delay , network links utilization and topology variation, are identified, the two routing categories are examined and the implementation of two representative algorithms, the well-known Dijkstra and the Flow Deviation respectively, is described.

In Section III a detailed system description of the studied constellation is given. Finally in Section IV results obtained by simulation are reported and commented, leading in useful conclusions in Section V.

II. ROUTING TECHNIQUES AND CRITERIA

In general, routing algorithms can be divided into two categories, *shortest path* and *optimal routing*. All the known routing algorithms can be classified into subcategories of the aforementioned general categories.

One of the basic features of a routing algorithm is its adaptability to the changing conditions on a network. In satellite networks, sudden shifts of traffic [5]-[6] and the deterministic turn on/off of ISLs [6]-[8], shape a context in which the routing algorithm must adapt.

Furthermore, the highly non-uniform geographic distribution of the users requesting service from a satellite network, is depicted on the space segment, leading to highly unbalanced network loading.

In this work we applied for the routing algorithms a cost function that is able to adapt to traffic variations by a term expressing queuing delay in each link of the space

segment. The cost function also takes into account the propagation delay, which is not negligible in satellite networks and which is variable due to the relative movement of the network nodes.
The adaptability of the algorithm is accomplished using periodic and triggered activation. The periodic activation updates the cost function. The triggered activation is based on ISL on/off events and updates the algorithm about the network connectivity.
To accommodate the unbalanced loading of the network we implemented two different routing algorithms, an adaptive *Dijkstra* and the Flow Deviation.

1) Adaptive Dijkstra Algorithm

Dijkstra algorithm operates on precise knowledge of the network nodes connections. Its function is to find the optimal path between a given origin / destination pair, based on a link cost function.
This way of operation has been proved [2],[3] unsuitable for non-GEO satellite systems, because the intensive terrestrial traffic non-uniformity leads to a non-uniform load on the space segment, making impossible the better exploitation of the satellite resources.
The adaptive Dijkstra algorithm,[9],[6], uses a cost function that depends on the delay (propagation and queuing) on each link.
All the users requesting a connection between a pair of nodes within a specific time interval will be served by the same optimal path. In different time intervals, the best path may alter, leading to transfers of heavy load from one link to others.
The dominant role of the propagation delay forces the routing algorithm to load heavily only certain paths of the network and the possibility of local congestion becomes higher. Additionally the number of rerouting actions, due to link failures, can be high.

2) Flow Deviation Algorithm

Flow Deviation algorithm operates in an entirely different way[10]. The network topology is identified in terms of all possible paths between all origin / destination pairs.
The algorithm routes traffic through all possible paths between a pair of source / destination, based on the path cost. Obviously the algorithm operates on a “network optimization” manner, allowing users to be served not by the best path in order to achieve uniform loading on the space segment.
An amendment of optimal routing algorithms that was presented in [11] , concerns the use of only k of all possible paths for the routing of traffic between two nodes. In this way we are able to limit the delay increase generated by the use of all possible paths, and still obtain an acceptable distribution of traffic on the space segment.
The Flow Deviation algorithm (FD), as proposed in [6], operates in two levels. First all the possible paths between two nodes are calculated. In our implementation of the FD, the calculation of the k shortest, based on propagation delay, paths is sufficient. The algorithm used for this purpose is presented in [12].
Path determination can be invoked in relatively large time intervals (because propagation delay is a slowly varying factor) as well as at every topology change, in order to erase the collapsed paths or utilize the newly established.
When the possible paths are determined, the algorithm using as inputs the loads of each link, determines the cost of each path. Then, based on the current situation of the network, the load carried by each path is decided in a way that a network cost function is minimized. On the determination of the routing plan, the new traffic coming into the network, is routed, through the k best paths, adapting the original state of the network to the new one.

III. SYSTEM DESCRIPTION

A) Space Component

For the performance evaluation of the two algorithms we used a real time simulation tool. The tool simulates the traffic end-to-end at a “connection” level, thus we work with the connection-oriented mode.
The algorithms were tested on a typical constellation, with varying topology, the Iridium [13]-[15]. In Table I the basic characteristics of the system can be found.

TABLE I
IRIDIUM SYSTEM PARAMETERS

Number of Satellites	66
Inclination	86.4^{o}
Orbit Altitude	780 Km
Interplane ISL’s	2
Intraplane ISL’s	2
ISL capacity	25 Mbps

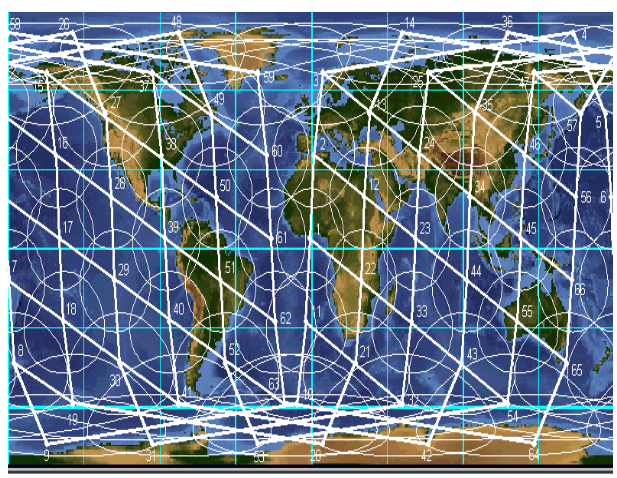

Figure 1. Snapshot of the system at t=0 sec

Each satellite employs four ISL’s, two *intra-plane* and two *inter-plane*. Because of technological limitations, Intra-plane ISL’s are permanent, while inter-plane are switched off in polar regions [2].

Werner et all, proposed a topology for the Iridium space segment, based on its specifications. This topology was adapted in this work and is depicted in figure 1.

B) Traffic Generation

In this study, the discernible case was used for the representation of the distribution of traffic on the earth surface. Thus the traffic emanates from discrete locations on the earth surface.

The spatial distribution used, typifies a highly non-uniform case of user requests, based on the mapping of the population distribution. In all cases the number of earth locations was one hundred, that can be considered sufficient to represent the surface distribution with the desirable resolution. In Table II the distribution of traffic sources in the continents of earth is presented. The distribution of sources within the continents is uniform.

TABLE II. Partition of traffic sources on earth surface

Continent	Number of sources
Africa	20
Asia	29
Europe	23
North America	12
Oceania	4
South America	12

All the volumes of traffic originating from each location were considered equal. The destination of the generated calls from a specific location is determined proportionally to the fraction of the volume originating from one location and the total traffic volume fed into the network.

The generation of user requests is Poisson distributed, the mean value of which was calculated so that the load of the most loaded UDL (Up-Down Link) equals to 50% and 100% of its capacity.

The duration of the generated calls is exponentially distributed with a mean value of 180 seconds.

IV. SIMULATION RESULTS

The efficient utilization of the system resources commands the uniform loading of ISLs. The immanent ability of the FD algorithm to route traffic, in more than one path, supports effectively this objective. In figures 2 and 3 the distribution of ISLs load, for the two algorithms in a specific *time moment*, is depicted. As can been seen, the FD algorithm manages to smooth the load peaks, while utilizes more efficiently ISLs that are under-utilized in the Dijkstra case. The effectiveness of the FD algorithm is based on two reasons. First, on its ability to route traffic, through six paths simultaneously [3]. Dijkstra algorithm, routes traffic only over one path and will switch this path only when the queuing delay will be of the same magnitude with the propagation delay. This is hardly the case in future satellite systems, because technological advances can achieve queuing delays less than 10 msecs, whilst propagation delay will always be of a size of tens of milliseconds.

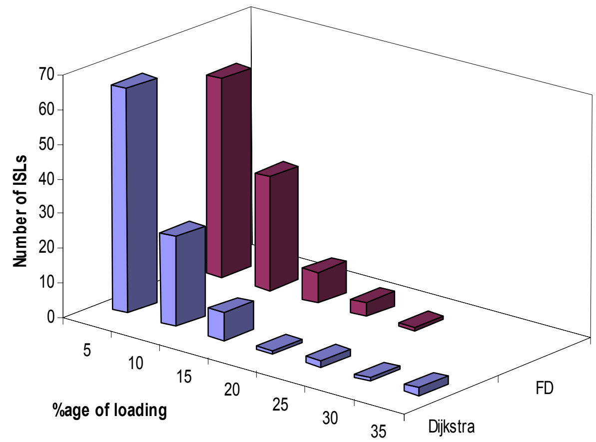

Figure 2. Distribution of ISLs loading at t=2500 sec, for low system utilization

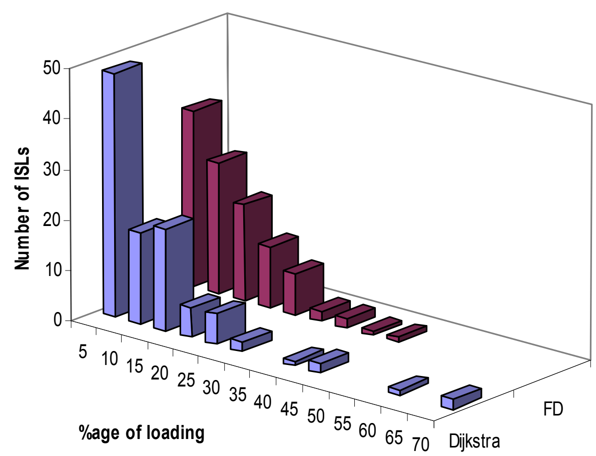

Figure 3. Distribution of ISLs loading at t=2500 sec, for high system utilization

Second, on its adaptability on sudden and massive shifts of traffic, situations frequently occurring in satellite networks, due to the changing topology context. In such a situation, FD manages the shifts of traffic, because it uses six alternatives.

In figures 2 and 3 we can see the described situation for low and high utilization of the system. The differences between Dijkstra and FD are intensified as the utilization of the system rises. This is well understood, if we keep in mind that any increase in the incoming for an origin destination pair traffic, affects in a degraded manner the ISL load, because it is highly unlikely for this ISL to be included in all of the six paths used for the origin/destination pair. On the Dijkstra case this traffic change affects directly the ISL load.

In figure 4 the percentage of loading of the most loaded ISL is depicted with respect to time. The use of FD in high system utilization results approximately in the same situation with the Dijkstra algorithm when it is used in low system utilization. This is another proof of the FD performance.

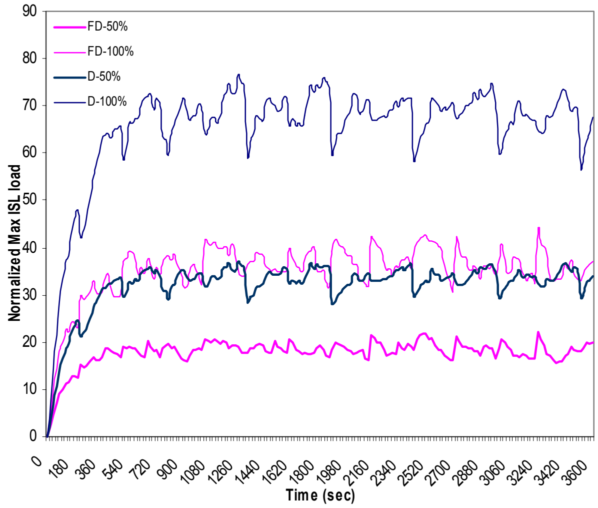

Figure 4. Maximum ISL load.

The drawback of the FD algorithm is that uses paths for the routing of traffic that are not always the optimal ones. In any case the overhead in the delay of some paths can be considered acceptable and in a sense limited. This is because the use of only six paths in a high connectivity topology results in a limited increasing of hops for the worst case paths [3].

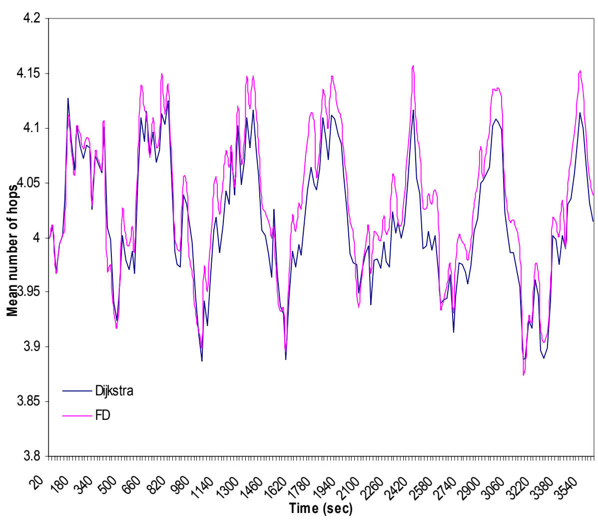

Figure 5. Mean number of hops for Dijkstra and FD

All the conclusions stated about the performance of FD and Dijkstra in terms of propagation and queuing delay, are consolidated by figure 5, where the mean number of hops per serviced call are presented over time for both FD and Dijkstra cases.

Considering only propagation delay, figure 5 indicates that FD results in an overhead of about 1.5 msec (increase of 0.07 in mean hops) in the delay of the serviced calls. This is because FD uses some paths that may consist of more hops.

Because FD results in lower loading of ISLs the queuing delay will be lower than the Dijkstra case and can diminish the overhead of 1.5 msecs. In fact, if a smaller number of paths is used in FD, a further improvement of its performance is guaranteed.

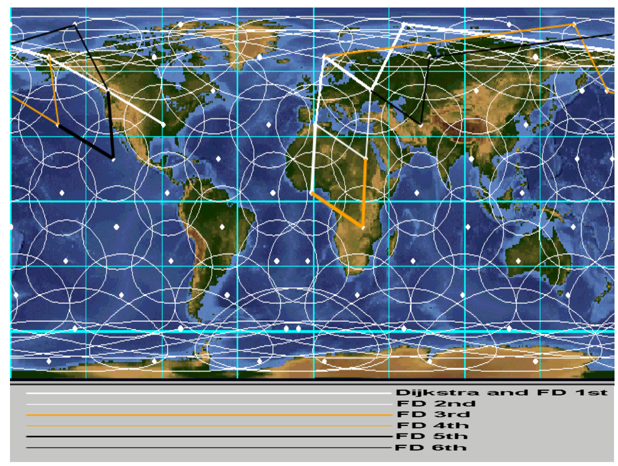

Figure 6. The paths connecting satellites 1 and 38 at t=0 sec.

Another interesting aspect of the operation of FD algorithm is its good performance in terms of rerouting actions in the network. This performance depends highly on the distribution of traffic sources and on the type of the constellation. In the distribution we used in our simulation, major amounts of traffic are located in latitudes above 30^{o} north (for example North America, Europe, Asia). The Dijkstra Algorithm in the implemented topology, derives a shortest path for the satellites covering these North areas, which is comprised of ISLs that are located near the area of 60^{o} latitude (figure 6).

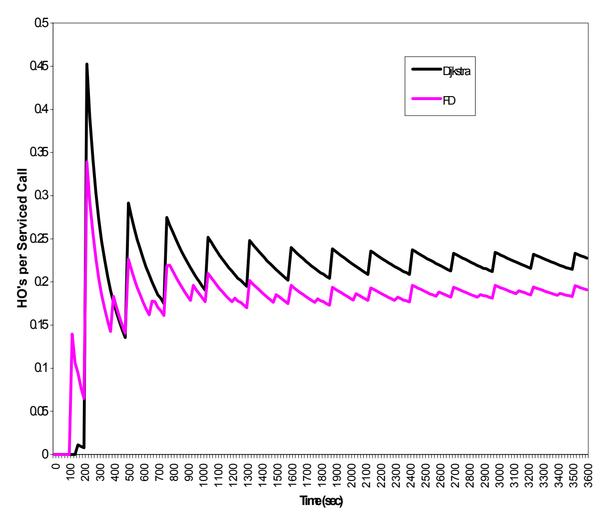

Figure 7. Mean number of HO's per serviced call

In this area the ISLs are entering an idle period, thus the traffic must be rerouted. In the case of FD, the paths in question are used, but in combination with other paths. In this way smaller amount of traffic must be rerouted.
In figure 7 the number of reroutings encountered by a call, namely the handovers (HO's) per serviced call in the network are presented. The peaks in this diagram correspond to the entering of highly loaded ISLs into idle periods, as described earlier. In the case of FD the peaks are smoothened, because the load of these links is restrained due to the utilization of a set of paths.
However the utilization of a set of paths generates a second set of rerouting actions, that can be detected in the diagram. The difference is that these rerouting actions emanate from ISLs that were able to serve more traffic, before entering the idle periods, thus the overall result is to contribute less in the increment of HO's per serviced call. The smoothing of the two curves as the time elapses, is caused by the fact that the system reaches its equilibrium state, as the monitoring time becomes sufficient.

V. CONCLUSIONS

The implementation and the performance evaluation of shortest path and optimal routing algorithms for non-GEO satellite systems have been presented in this work. A real-time simulation tool was developed and extended simulation tests provided solid results.
Special characteristics of satellite networks, like manufacturing cost, technological limitations and the prominent role of propagation delay, support the use of optimal routing algorithms. A modification of the FD algorithm has been applied with a minimum degradation of user's quality of service.
The FD proved to perform better in terms of space segment loading, queuing delay and necessary rerouting events. However its performance in terms of rerouting actions, depends strongly on the distribution of traffic sources and on the specific constellation structure. The main result is that by using FD we come to a very homogenous distribution of traffic and we need lower capacity links for the same performance results.
The design of new constellations can become more cost effective, taking into account the characteristics of FD. Furthermore a combination of Dijkstra and FD algorithms may be used for routing two or more different traffic classes with different QoS requirements.

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