

# ROUTING IN LOW EARTH ORBIT (LEO) SATELLITE SYSTEMS BY USING THE GENETIC ALGORITHMS

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## ABSTRACT

*Today most of the satellite systems are designed in Low Earth Orbit (LEO) satellite systems. Because the satellites which are located in these orbits have small propagation delays than the satellites in other orbits. And also the closeness of LEOs to the earth gives them an advantage that there isn't any need to the more power for having a communication with earth stations. In this study, we consider a new routing algorithm. For the routing operation we use the Genetic Algorithms, which is the most known technics about the optimization problems. Hence we match each path in the satellite system with a structure in genetic algorithms. Lastly we obtain the most appropriate paths.*

**Keywords:** LEO, satellite, routing, genetic algorithms.

## 1. INTRODUCTION

### 1.1 General Information

Today satellites are especially used in broadcasting. In respect of the terrestrial wireless networks, the satellite constellations achieve the communication processes in a short time interval. Satellites can also supply geography and technology independent communications with less power consumption. This way, users located in far areas can easily communicate with each other. After the technological improvements, a satellite gives services to a wide area, which is projected as the footprint of this satellite. So the importance of the satellites increased proportionally with the technological requirements.

When the satellite orbits are divided into groups we encounter these two classes: Geostationary

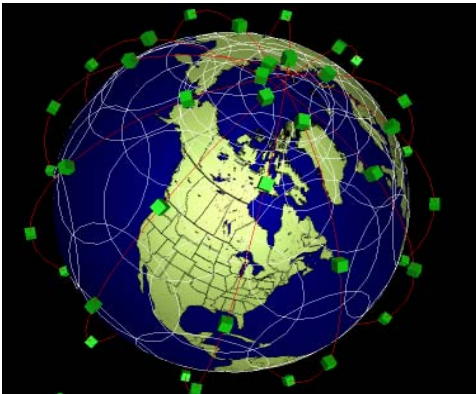
and Non-Geostationary Orbits. The differences between these classes are based on their positions in the sky. Therefore the required power and the delay have diversity. Most of the satellites are placed in geostationary orbits.

These orbits are launched about 36000 kilometers above the earth equator. A satellite located in these orbits looks stationary because of the synchronization between its revolution around the earth and the earth's rotation. Because of the high altitude of these orbits, satellites can cover 1/3 of the earth. Against these advantages, geostationary orbits have a challenge of power requirement because of the high position. The round trip propagation delay is approximately 250 milliseconds. This duration holds up the communication, therefore in real-time interactive applications it can cause some problems.

On the other hand, the Non-Geostationary orbits have a distance of about 700 km to 20000 km

from the earth's surface. These orbits have some sub categories. One of these categories is LEOs. They are located maximum 2000 kilometers above the earth. Because of this low distance the propagation delay is small and the power requirement is low. They also require small antennas. Therefore these orbits are useful for personal communications that include mobility. One disadvantage of them is that they don't have a large footprint as the geostationary orbits. So there has to be more satellites in Non-Geostationary orbits, especially in LEOs. After the supply of these conditions they have uninterrupted and global coverage. In LEO systems the size of the ground and satellite equipments is small. So the cost of such systems is less with respect to the other orbit systems.

An example LEO system can be seen in Figure 1.



**Fig. 1.** The Iridium system having 66 satellites [1].

## 1.2 Routing Process in Satellite Systems

During the development of the satellite technology, different concepts have been emerged and many studies have been made on this area. In the literature the studies about satellite communications include topology design, communication methods, routing techniques, etc. In this study we touch on the routing process in LEO satellite systems.

In the studies about the satellites it is assumed that there are some links, called as Intersatellite Links (ISL), between the satellites. During the propagation and communication operations, the signals are switched between satellite and a ground station or between two satellites. ISLs are used when the process is carried out between two satellites. Even though they aren't present in

concrete, they connect the neighbour satellites. ISLs work without the dependence of the terrestrial systems. We can divide the ISLs into two main groups [2]:

- 1) Intra-plane ISLs: They connect abreast satellites in the same plane. Because of the relative positions of these links are fixed, they are maintained permanently.
- 2) Inter-plane ISLs: They connect the satellites placed in neighboring planes except for the planes having locations across the seam which is the imaginary line that separates counter-rotating planes. They work in the polar regions. When the distance and viewing angle of the system change, they must be rearranged according to this modification.

The packets must send from a source satellite for the accommodation of the packet propagation between the satellites. A packet travel through the satellite system and at the last of the process it arrives to the destination satellite. For the operations in these steps, satellites must select the next satellite during the routing. The most appropriate paths are tried to find for this selection process. In some algorithms, it is thought that the satellite topology is appeared again after a specified period of time. In this study, we consider that the topology of the satellite network is static, so it doesn't change by the time. The dynamic structure of the network can be obtained for another study.

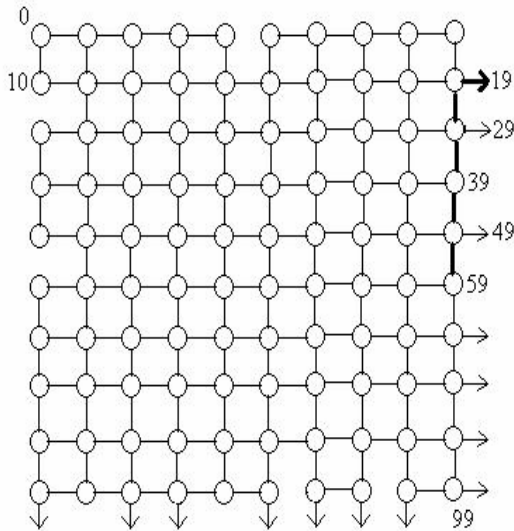
Many routing algorithms have been developed until now. These algorithms have different process steps. It is tried to minimize the propagation delay for the computation of fitness function in most of the studies. And also it is possible to minimize the handover number. After the determination of these criteria, the optimization is started to find the most effective path which has the minimum cost.

The detailed information about the special notations can be found in [3], and also some of the studies about the routing algorithms are in [4].

The rest of this study is designed as follows: In Section 2, the new algorithm is explained exhaustively. The paper is concluded in the Section 3.

## 2 THE NEW ROUTING ALGORITHM

In this study, the propagation delays of the paths are used as the fitness function. Then the handover numbers of different topologies can be found according to these values. These two concepts are very important for the computations in our algorithm. The paths, which is followed by the packet travelling in the satellite system, are represented as genetic constructions. Each path is a structure that takes the packet from the source node to the destination node.



**Fig. 2.** One of the topologies of an LEO satellite network built from 100 nodes.

An LEO satellite network, which is constructed from 100 nodes, is shown in Figure 2. This structure can be obtained by bringing up the orbital forms around the earth and rearranging of the satellites in these orbits. A satellite located in an LEO satellite system, is connected to the lower and upper satellites, and also to the right and left satellites via the links. As shown in Figure 2, each node has four neighbour satellites that can be connected with this satellite. The edge satellites have the links which is denoted as arrows in the figure. For example in this topology the satellite 10 has a connection with the satellite 19 via an arrow. It is definite that the satellites without any link between each other can't communicate. Now we suppose that a packet goes from the satellite 10 to the satellite 59. The path of 10-19-29-39-49-59 can be obtained as a suitable path. The cost computation

of each path is calculated through the sum of the cost values of the links, which are known before.

Each of the paths obtained from the genetic algorithms is denoted by a chromosome structure. The number of these chromosomes indicate the individual number of the population. This number is always hold as a constant. For example in our topology the paths in the form of  $u_1, u_2, u_3, u_4, u_5, u_6, u_7, u_8, u_9, u_{10}, u_{11}, u_{12}, u_{13}, u_{14}, u_{15}, u_{16}, u_{17}, u_{18}, u_{19}, u_{20}$  are found for a chromosome with a length of 20 units. In this representation the symbol of  $u_i$  shows the satellite in the path of the packet route. Each path is formed by the satellite numbers like this. For instance, the obtained path of a packet followed five satellites is defined as " $u_1, u_2, u_3, u_4, u_5$ " and the other variables in the form explained above is thought to be empty. In the other words, although the length of the chromosome is supposed to be 20 units, it isn't a requirement that all variables of these units must have values. It can be changed according to the path. At the end of the route selections, the number of the paths gives the individual number of the population. The steps followed in our algorithm can be summarized as follows:

- 1) The condition of the links in the real form is supposed and some of them are signed as active, and likewise some of them as passive. As in the real world most of the links are active.
- 2) A source and a destination nodes are selected.
- 3) Link costs are calculated.
- 4) After the departure from the source node, the paths going over the active links are found.
- 5) The fitness values of all paths are calculated.
- 6) The regeneration of the old population is made.
- 7) The crossover is made according to the genetic algorithms. New delays are obtained.
- 8) The handover numbers are calculated.
- 9) The most suitable, shortest path is selected.

We can also investigate the mathematical representations of these steps. Firstly we show the length of a chromosome as  $k$ , and the individual number of the population as  $m$ . A function named as  $connect(u_1, u_2)$  is used for the

activation of the links. This function connects the satellites equivalent to the values  $u_1$  and  $u_2$ . So it activates the link between these two satellites. After the request of the source and the destination nodes from the user, the paths routing over the active links are obtained. The representations of the paths are in the following:

$$\begin{aligned}
 Y_1 &= u_{11}, u_{12}, u_{13}, u_{14}, \dots, u_{1k} \\
 Y_2 &= u_{21}, u_{22}, u_{23}, u_{24}, \dots, u_{2k} \\
 &\vdots \\
 Y_m &= u_{m1}, u_{m2}, u_{m3}, u_{m4}, \dots, u_{mk}
 \end{aligned}$$

After this step, one of the selection methods named as Roulette Wheel is used to find the chromosomes which will be alive in the next generation. For this reason principally the total delay value of each path is calculated. The following fitness value is computed for each path:

Fitness value = The delay of the path / Sum of the delays of all paths.

By the help of this proportion, the efficiency of the path according to the other paths are found. If an optimization process is required for the proportions, these values are rearranged and new proportions are found. For instance we suppose that we have four paths for this operation and the sum of the delays is 1000 units. The fitness functions are  $f_1=300/1000=0.3$ ;  $f_2=200/1000=0.2$ ;  $f_3=100/1000=0.1$ ;  $f_4=400/1000=0.4$ . These values are shown as a roulette wheel in Figure 3. In this stage, a regeneration number is generated randomly from the interval of 0-1. The area containing this number in Figure 3 is specified. And this area's number shows the index of the path which must be alive in the next generation. For example if the random number is 0.35, the second path selected for the new generation.

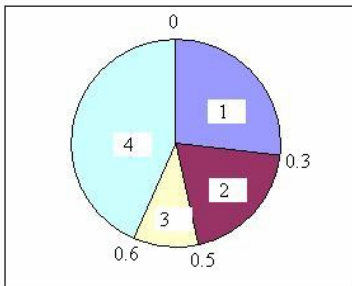


Fig. 3. The distribution of the chromosomes according to their fitness values.

The required crossover operations are made for new generation. Lastly the most suitable paths are selected due to their delay values. Then these values are thought for different topologies and handover numbers are calculated. The delay value of each path is calculated from the

equation of  $D_{Y_i} = \sum_{j=1}^k d_{u_{ij}}$  ( $i=1, \dots, m$ ). The

delay values of all links in the related path are added in the right side of this equation. All delay values of the paths are computed like this and then they compared with each other. The optimum path ( $Y_{optimal} = Y_i$ ), which has the minimum cost, is found by the help of this equality:

$$D_{Y_{optimal}} = \min\{D_{Y_i}\}_{i=1, \dots, m}$$

When it is considered that different topologies are equivalent to the situations in each time interval, new topologies are added to the application. Then the suitable paths are selected from each topology and lastly the most suitable paths are emerged by the comparing of different topologies due to the handovers. The detection of handover numbers can be seen in the following operation:

- 1.Topology: 10-19-29-39-49-59
- 2.Topology: 10-19-29-39-49-59
- 3.Topology: 10-19-29-28-38-48-58-59
- 4.Topology: 10-19-29-28-38-48-58-59
- 5.Topology: 10-19-29-28-38-39-49-59
- 6.Topology: 10-19-29-28-38-39-49-59
- 7.Topology: 10-19-29-28-38-39-49-59
- 8.Topology: 10-19-29-39-49-59
- 9.Topology: 10-19-29-39-49-59
- 10.Topology: 10-19-29-39-49-59

In this computation the satellite system in Figure 2 is used. The source satellite is 10 and the destination satellite is 59. It can be obtained that the route differences appear during the transition over the pair topologies of 2-3, 4-5 and lastly 7-8. So the handover number of this path selection operation is 3.

### 3 CONCLUSION

In this study we intensify on our routing method designing for LEO satellite systems. We

suppose that the satellite network doesn't change by the time, so the links can be protected against the flowing of the time. This method can be dilated by the conception of the dynamic structures of the satellite systems. In dynamic form, different topologies can be thought in each time interval. In this situation, our method can be applied to each time interval respectively.

#### 4 ACKNOWLEDGMENT

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