

# AN EFFECTIVE ROUTING ALGORITHM FOR LOW-EARTH ORBIT SATELLITE NETWORKS

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## **ABSTRACT**

*A new routing algorithm for Low-earth orbit (LEO) satellite networks is designed in this study. For this reason genetic algorithms are used. A new objective function is obtained to find the suitable path according to the criteria of the delay and an aging factor. Also Call Blocking Probabilities (CBPs) are considered due to the dynamic nature of the satellite systems. This dynamic routing type of new method is compared with the static routing which was introduced before. For practical application, several LEO systems having different numbers of satellites are discussed.*

**Keywords:** Genetic algorithms, satellite application, satellite communication, routing algorithm.

## **1 INTRODUCTION**

Satellite communication is a milestone for the wireless applications. Firstly it was used in the voice transmission. Then its usage areas have rapidly expanded proportional with the technological requirements of the people. The deployment of the mobile devices brings about the indispensable wireless communication. So the satellite communication continues its progress contrary to the terrestrial systems. Of course the improvements in satellite technology depend on its technical advantages according to the terrestrial systems. The architecture of satellite networks with some special notations were defined in [1].

Satellites are divided into two main groups according to their orbit types. These are Geostationary (GEOs) and Nongeostationary

Orbits (NGEOs). GEOs are located in the higher altitudes according to the NGEOS. For this reason they have large delays, such as 250 ms, during the connection with the earth stations. Because of the distance to the earth, they must have advanced equipment having large power for the quality of the communication. On the other hand, NGEOS have lower delays and do not need much power and complex structures for the connection with the terrestrial systems. They require small antennas. NGEOS are divided into some categories due to their positions. One of these categories is Low-Earth orbits (LEOs). LEOs are in the position of approximately 700-2000 km above the earth. They have very small delay values such as 20 ms. Because of the closeness to the earth, the satellites in LEOs rotate very fast around the earth. There are many satellites on a LEO system according to

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the other orbits. LEOs also have periodic and predictable structure. They repeat their orderings after a specific period of time called as system period. So the locations of the satellites can be predicted beforehand. Recent advances about N GEO satellite systems, especially some examples of LEO satellite constellations and their probabilities can be investigated from [2].

Satellites have particular connection structures. A satellite can communicate with its neighboring satellites by the help of the Intersatellite Links (ISLs). Besides, a satellite uses Up-and-Down Links (UDLs) for the connections with the terrestrial stations. In this study, it is assumed that the representative satellite systems were set up before the running of the application. We except the transmitting process between the terrestrial and the satellite systems. So it is accepted that the call packets formerly arrived to the related satellites. After these assumptions, routing the packets from a source satellite to a destination one is attended. So we do not need to use the UDLs. We only consider the ISLs in new algorithm.

In the routing operations, firstly source and destination satellites are selected. After that the packet transmission between these two satellites begins. When a satellite receives a packet, it can only send the packet to the neighboring satellites. It is assumed that each satellite has four neighboring satellites. So a satellite can route a packet to maximum four different directions. When a packet arrives at destination satellite, the algorithm ends. Thus the ending criterion is to reach the destination satellite. In this way, a path is defined as a route beginning from the source satellite, going over the intermediate satellites and ending at the destination satellite.

There are many routing algorithms in the literature. They use different objective functions and limitations. They consider generally the traffic distributions of the call packets over the links. For this reason the residual bandwidth of the links are computed frequently. A bound of bandwidth is used for the comparison operations. Besides, most of the routing algorithms use the delay as the computation criterion to elicit the suitability of the paths. Some routing algorithms using different methods can be searched from [3-7].

There are also some methods attending for the dynamic satellite systems. An example

study, which includes the dynamically changing topologies, computes the total delay of each node [8]. These delays are used to find the shortest path. In this algorithm, it is tried to minimize the total delays. All nodes must have an apriori about the network architecture. This consumes a lot of time. Because of the dynamical behaviour of the system, the network does not become stable. Thence the knowledge about the network changes continuously.

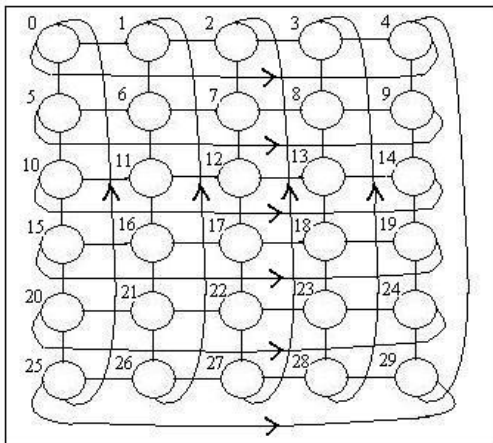
In new algorithm the delay and an aging factor measuring the permanence of each path are used. So the most appropriate path can be selected under these properties. The aging factor provides the selecting of the most repeated paths. This situation reduces the handover rate of the paths. The traffic characteristics derived from the footprints of the satellites are also computed. So new algorithm incorporates both the time and the location. At the end of the algorithm the path requiring the minimum handover number can be selected. A handover step is encountered when a satellite assigns its service area to another satellite because of the orbital movements. Some algorithms in literature have a re-routing operation when a handover operation occurs. This causes a waste of the process time. According to a different approach, a probability distribution function (pdf) is used to find the routes having no link handover with a certain probability during the active connection. This algorithm tries to reduce the number of re-routing operations caused from the handovers [9].

The rest of this paper is organized as follows: In Section 2, the selection of the paths by new algorithm is explained. The formation of dynamic topologies of LEO satellite networks and the genetic operations are explained in Section 3. The effect of aging factor to the calculations is in Section 4. CBP is detailed in Section 5. The static and dynamic versions of new algorithm is compared in Section 6. Lastly in Section 7, the conclusions are given.

## 2 PATH SELECTION IN THE NEW ROUTING ALGORITHM

### 2.1 Some Special Concepts

Different satellite topologies are used in new algorithm. The structures of these topologies are based on the number of satellites and the orbits. The setting of an initial topology is specified according to these numbers. LEOs have regular satellite orders. An example topology of the satellite networks having 30 satellites can be seen in Figure 1:

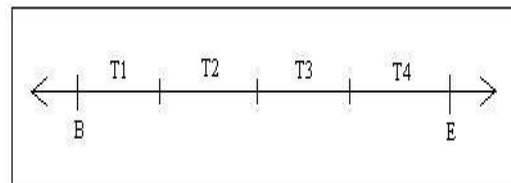


**Figure 1:** An example satellite topology which has all links active.

As seen in this figure, the satellites are distributed along five orbits. Each orbit has 6 satellites. A rightmost satellite has a link with the leftmost satellite in the same row. However an uppermost satellite has a link with the lowermost satellite in the same column. The links, which are physically present and seen in the topology, are active for the transmission operations. In new practical application the activity of the links are determined after the setting of the topology. Each satellite can have links among its all neighboring satellites. By the effect of the dynamically changing, some links become passive and lose the transmission ability. On the other hand, some passive links may become active in time. During the path determination, the passive links are not selected. Instead of these links the packet is routed through the active links by the current satellite.

New topologies appear by the activity changes of the links. In this way, different

topologies of the satellite systems are obtained between the beginning and the ending times of the call. New generations emerge via the path selections on these different topologies. Each generation can have desirable number of paths. So a path extracted from a topology is supposed as a chromosome of a generation in the genetic algorithm. The set of paths found during a topology time, shows one generation. After the initial generations, the operations related with the genetic algorithms have a role to get new generations and find the most suitable paths.



**Figure 2:** The intervals containing the topology changes during the call duration.

The intervals between the beginning and ending times of a call are reflected as a time schedule shown in Figure 2. In this figure,  $B$  shows the beginning time of the call, and  $E$  shows the ending time. The satellite network has some link changes in the specified time intervals. So different topologies of new system are obtained and called as  $T1$ ,  $T2$ ,  $T3$ , and  $T4$  in Figure 2. In a different study, the structure of the satellite network viewed in a discrete time is called "snapshot" [10]. In this algorithm satellites use the switching tables to route the packets through the suitable link. In new algorithm, the initial generations containing the paths are separately determined for each interval. After this stage the genetic algorithms are used independently for each generation in the intervals. The genetic operations like regeneration and crossover are applied over the paths to get the most appropriate one. Lastly final generations remain in each interval and they are compared with each other to have the common path requiring the least handover number.

Some criteria are required for the path selection in the topologies. With this aim it is projected that the links in the satellite network have a delay ( $d$ ) and a weight value ( $w$ ).  $d$  is an integer number. Besides,  $w$  takes the value of 0

if the link is passive, or 1 if it is active. Starting from the source satellite, the neighboring satellites, which have the weight value of 1, take part in the path. Thus the obtained paths along a time interval of a call duration form a generation. Each path determined in the satellite system shows the sequence of the satellites which the call goes over.

A generation having  $m$  number of paths is shown as follows:

$$Y_1 = \begin{bmatrix} u_{11} \\ u_{12} \\ \cdot \\ \cdot \\ u_{1k_1} \end{bmatrix} \quad Y_2 = \begin{bmatrix} u_{21} \\ u_{22} \\ \cdot \\ \cdot \\ u_{2k_2} \end{bmatrix} \quad \dots \quad Y_m = \begin{bmatrix} u_{m1} \\ u_{m2} \\ \cdot \\ \cdot \\ u_{mk_m} \end{bmatrix}$$

In this presentation  $Y_i$  shows the  $i$ th path,  $u_{ij}$  shows the number of the  $j$ th satellite of the  $i$ th path. The length of the path  $i$  is  $k_i$  and this value shows the number of satellites in the path.

Each path is conceived as a chromosome. The chromosome presentations of the paths for genetic algorithms are in the following:

$$Y_1 = u_{11}, u_{12}, \dots, u_{1k_1}$$

$$Y_2 = u_{21}, u_{22}, \dots, u_{2k_2}$$

$$\cdot$$

$$\cdot$$

$$\cdot$$

$$Y_m = u_{m1}, u_{m2}, \dots, u_{mk_m}$$

### 2.2 Computation of the Fitness Values

In genetic operations, the fitness value (FV) of each chromosome is calculated to find its availability according to the others' in the generation. There are 3 important steps in the computation term of this value. In the first step, the delay values of the paths (D) are computed. Second step contains the blocking probabilities of the calls arriving to the satellite network. In the last step the results are transformed to the FVs. These steps are summarized below:

Sum of the delay values of all links are found to calculate the delay value of  $D$  of path  $Y_i$ :

$$D_{Y_i}(t_r) = \sum_{j=1}^{k_i-1} d_{u_{ij}, u_{i(j+1)}} \quad (i=1,2,\dots,m)$$

$(r=1,2,\dots,n)$

The value of  $i$  indicates the index of the current path. Also  $d_{u_{ij}, u_{i(j+1)}}$  shows the delay value of the link between the satellites of  $u_{ij}$  and  $u_{i(j+1)}$ .

As explained before the call duration is divided into equal time intervals. The paths obtained in each interval compose a topology. The value of  $t_r$  in the formula  $D$  shows  $r$ th time interval in a system having  $n$  discrete topologies. The genetic operations are made independently in each time interval. The dynamic change of the system is obtained by the sequential flow of these time intervals as explained in Section 3.

The CBPs of all links in a path are calculated sequentially. Erlang-B formula is used for the probability evaluations. The important points about these operations are particularly explained in Section 5. The CBPs of five links, which form a path of the system presented in Figure 1, are shown in Figure 3. The transmission between 6 satellites is pointed in this figure. This transmission operation is made from satellite 10 towards the satellite 23.

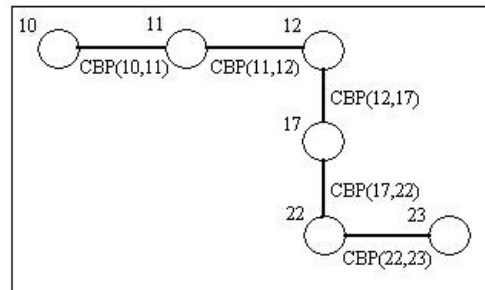


Figure 3: All CBPs of the links of a path.

The CBPs of the links is used to compute the availability of a path to transmit a call. The probability of  $P_{Y_i}$  indicates the availability of the  $i$ th path as follows:

$$P_{Y_i} = (1 - CBP_{u_j, u_{(j+1)}}) \cdot (1 - CBP_{u_{(j+1)}, u_{(j+2)}}) \dots (1 - CBP_{u_{(k-1)}, u_k})$$

$$F_{Y_i} = D_{Y_i} * P_{Y_i} \quad (i=1,2,\dots,m), (j=1,2,\dots,k-1)$$

In these presentations the value of  $F$  shows the fitness function of the path  $Y_i$ . So the availability of a path without blocking is obtained by these calculations.

In the previous step the delay value of a path during its availability is extracted. According to these evaluations, the path having large delay value also has big FV. This is an inverse situation. A new operation is required in this step. Because the path having large delay must have the small FV.

To solve this problem it is utilized from the number of all paths in the population. If there are  $m$  paths in the generation and it is started from the path having minimum delay value; the new fitness rates sequentially become as in the following formulas:

$$\frac{m}{(m * (m + 1)) / 2}, \frac{m - 1}{(m * (m + 1)) / 2}, \frac{m - 2}{(m * (m + 1)) / 2}, \dots, \frac{1}{(m * (m + 1)) / 2}$$

Thus in a population which has 20 paths, the path having minimum delay holds the new rate of 0,095238. Other rates are respectively 0,090476; 0,085714;.....; and 0,004762. For 20 paths, the  $F$  values and their reciprocal FVs obtained in practical application are shown in Table I.

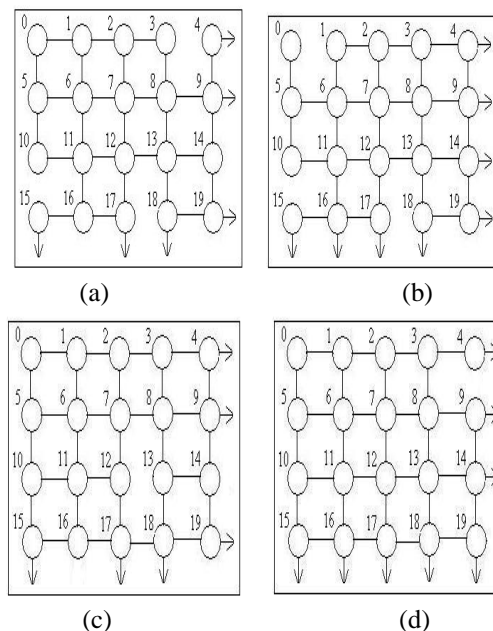
**Table I:** Fitness Function Values and Their Reciprocal Fitness Values.

Fitness Function Values (F)	Fitness Values
2.960048	0.023810
1.814296	0.052381
2.630889	0.033333
0.329138	0.080952
0.189007	0.095238
0.189007	0.090476
0.495586	0.071429
1.814296	0.047619
0.265001	0.085714
2.630889	0.028571
1.702172	0.066667
11.558361	0.004762
1.702172	0.061905

0.329138	0.076190
4.985862	0.009524
1.702172	0.057143
1.957111	0.042857
2.960048	0.019048
3.348441	0.014286
2.464910	0.038095

### 3 HAVING THE DYNAMIC TOPOLOGIES

Several LEO satellite systems having different numbers of satellites are used. Because the satellites move in orbits, a LEO satellite system has different structures in different time intervals. This means that the links between the neighboring satellites change by the time. So it is treated that a new system appears after the link changes. Thus different paths are obtained in each time interval. As mentioned before, the complexity of the dynamic changes can be achieved by selecting the most permanent path in new algorithm. For this reason it is intended to find the permanent path having a small delay value.



**Figure 4:** Different topologies obtained by the time in a satellite system.

In Figure 4, four different topologies of a system is illustrated. These topologies are

formed by the link changes occurring at different time intervals. A link which is active in a topology can be passive in the other topology.

In Figure 4(a), it can be seen that the link between the satellites 0 and 1 becomes passive after a period of time like in Figure 4(b). In common, the link between the satellites 12 and 13 is passive in Figure 4(c). But in Figure 4(d), this link becomes active. These link changes continue during the call duration time. In this way, the dynamic nature of the system is analyzed.

It can be obtained different paths by considering the dynamical structure of the system. In each topology several paths are independent from the paths in other topologies.

Once the path selections or in other words initial topologies are completed, the regeneration and the crossover operations are made in each interval. The detailed information about the genetic operations or genetic algorithms can be found in [11,12].

When we assign satellite 3 as source, and satellite 5 as destination from Figure 4, we determine the paths in Table II.

**Table II:** *The Paths Obtained from Different Four Topologies.*

Topology 1	Topology 2	Topology 3	Topology 4
3,2,7,12,11,16,15,0,5	3,2,1,6,5	3,4,0,5	3,4,0,5
3,18,13,12,11,10,11,6,5	3,2,7,6,5	3,2,1,0,5	3,4,0,5
3,2,7,6,5	3,8,7,6,5	3,8,7,6,5	3,2,1,6,5
3,2,7,6,5	3,4,0,5	3,4,0,5	3,2,1,0,5
3,18,13,12,7,6,5	3,2,7,6,5	3,2,1,0,5	3,4,0,5

The genetic operations are applied to the paths in each topology to have the new generations. It must be known that the FV of each path for the genetic operations. The computation of this value is explained exhaustively in Section 2.2. The FVs of the first topology in Table II can be seen in the following:

**Table III:** *The Paths and Fitness Values of the First Topology.*

Paths	Fitness Values
3,2,7,12,11,16,15,0,5	0,13
3,18,13,12,11,10,11,6,5	0,07
3,2,7,6,5	0,33
3,2,7,6,5	0,27
3,18,13,12,7,6,5	0,20

After this observation, regeneration and crossover operations are made in order as in Section 3.1 and Section 3.2:

### 3.1 Using the Roulette Wheel in Path Selection

In genetic algorithms, the regeneration is applied to the starting generation before the crossover and mutation operations. There are some selection rules in the application step of this operation. One of these rules is Roulette Wheel. The probability of being chosen for a chromosome is calculated by the formula of

$$\frac{f(i)}{\sum_i f(i)}$$

The values of the roulette wheel

are composed from the proportions, so they are between the bound of [0,1]. It is started from 0 and added the proportion of each chromosome one by one. Each intermediate sum determines a bound of the wheel. The last bound is 1.

In new satellite network each path has a fitness value. The roulette wheel is built from these values. Then several random numbers are determined. The chromosomes having the regions which include these numbers are selected, so the chromosomes of the new generation are specified.

The roulette wheel for the starting generation in Table III is shown in Figure 5:

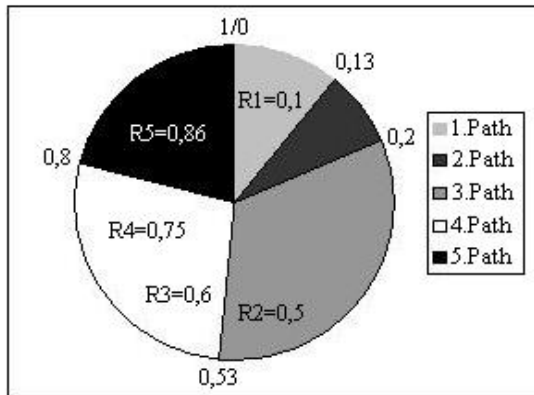


Figure 5: The roulette wheel for five paths and the determined random numbers.

The random numbers shown in Figure 5 are included in the regions of the paths 1, 3, 4, 4, and 5 respectively. So these paths are selected and the new generation is obtained as below:

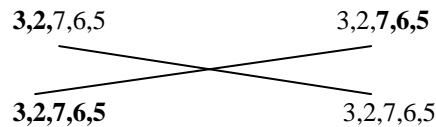
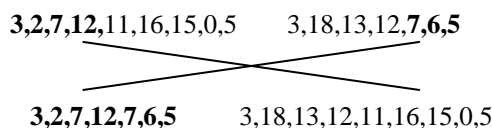
Table IV: Regeneration Stage.

The starting generation	New generation	New fitness values
3,2,7,12,11,16,15,0,5	3,2,7,12,11,16,15,0,5	0,07
3,18,13,12,11,10,11,6,5	3,2,7,6,5	0,33
3,2,7,6,5	3,2,7,6,5	0,27
3,2,7,6,5	3,2,7,6,5	0,20
3,18,13,12,7,6,5	3,18,13,12,7,6,5	0,13
	5	

### 3.2 Crossover Operations

Once the regeneration is obtained after the starting generation, the crossover operations are applied to the new generation.

By the help of the FVs the suitable path pairs is found for the crossover operations. The path pairs of 1-5 and 2-3 are derived from the new generation in Table IV. Crossover operations of these pairs are made as in the below:



The new four paths are the elements of the new generation. In these operations the path “3,2,7,6,5” repeats again in the new generation. This is not a disadvantage. Because the crossover operation is made between the paths with the best and suitable FVs. So the protection of the paths having good FVs is useful for the generations.

## 4 THE EFFECT OF AGING FACTOR TO THE FITNESS VALUES

After the path specifications new generations are derived in each topology. The paths of each generation are compared with the previous one in the same topology to find the aging factor (AF). The repetition number of a path by a counter is calculated. As seen in Table V, if a path in the new generation is present in the previous generation, AF increases by one. Otherwise AF is 1 like its default value. By this factor, the selection probability of the repeated paths increases. So that, the handover rate is reduced by selecting these paths. The calculation of the AFs can be seen in Table V.

Table V: The Calculation of The Aging Factors.

Gen.1	AF1	Gen.2	AF2	Gen.3	AF3
A	1	A	2	A	3
B	1	B	2	H	1
C	1	E	2	E	3
D	1	F	1	F	2
E	1	G	1	I	1

New generations are obtained from the paths in Table III by the genetic operations. The AF calculation of the paths in these generations and the effect of AFs to the FVs are summarized in Table VI:

**Table VI:** *New Fitness Values Calculated By The Aging Factors.*

Paths in the starting generation	Paths obtained after the genetic operations	FVs after the genetic operations	A F	New FVs (FV* AF)	FVs after normalization
3,2,7,1 2,11,16 ,15,0,5	3,2,7,12 ,7,6,5	0,13	1	0,13	0,07
3,18,13 ,12,11, 10,11,6 ,5	3,2,7,6, 5	0,33	2	0,66	0,37
3,2,7,6, 5	3,2,7,6, 5	0,27	2	0,54	0,30
3,2,7,6, 5	3,2,7,6, 5	0,20	2	0,40	0,22
3,18,13 ,12,7,6, 5	3,18,13, 12,11,1 6,15,0,5	0,07	1	0,07	0,04

The sum of the FVs in a generation must be 1. By the help of these values the effect of a path in its generation arises. The aim of the normalization operation in Table VI is to convert the FVs so that their sum becomes 1 after the effects of the AFs.

## 5 CALL BLOCKING PROBABILITIES

In LEO satellite topologies the call packets come to the satellites according to some traffic values. CBPs which are dependent on the traffic and location properties are used for calculation. A CBP determines the blocking of a packet caused from the fullness of the current link. In the other words, a link can not carry the calls over a constant limit. When the call numbers passes this limit, incoming calls are blocked.

For CBP calculation, the arriving and the departing call packets are considered. The queueing models are used for these computations. These models are useful for some flow operations in dynamical systems. There are many examples for queueing models between the daily activities. Generally they are consisted of a network and the packets coming to this network according to some traffic proportions.

It is benefited from the Markov models for the satellite networks. The selection of the new link of a path is dependent on the previous link by the effect of the memoryless property in Markov models. The following formula called as Erlang-B in the literature is used:

$$P_m = \frac{(\lambda / \mu)^m / m!}{\sum_{k=0}^m (\lambda / \mu)^k / k!}$$

This formula gives the probability that all of the  $m$  servers are busy in a network.  $\lambda$  shows the arrival rate and similarly  $\mu$  shows the departure rate of the packets to the network. In practical application it is assumed that each link of a path has different number of channel. Each channel indicates a server. CBP is calculated for each link. The probability of the activity state of a link is computed by the value of (1-CBP). Consecutive links in a path are independent from each other. So the result values of all links are multiplied to find the selection probability of the path. For a path having  $n$  links, the computations are given below:

$$P = (1 - CBP_{m_1}) \cdot (1 - CBP_{m_2}) \cdot \dots \cdot (1 - CBP_{m_n})$$

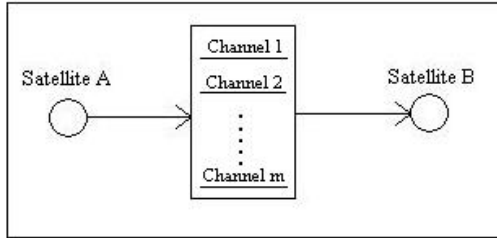
$$P = \prod_{i=1}^n (1 - CBP_{m_i})$$

This probability shows the transmission probability, in the other words the activity/usability probability of each path. In each path each link has different  $m$  numbers of servers (in other words channels) and also different  $\lambda$  values. These values also change according to the location of the caller. Despite some regions like cities have dense callings, the others like oceans have rare callings. For this reason the value of  $\lambda$  can change based on the location properties in new algorithm. They become large in cities and crowded areas, oppositely they are small in the regions having rare population.

Firstly  $m$  value of each link is defined in practical application. This value can be shown by a diagram as in Figure 6. In this figure it can be seen that the link between any two satellites includes  $m$  channels. The packet transmission



is made over the link by these channels. Each channel is called “server” in the following expressions.



**Figure 6:** The channels between two satellittes.

After the specifying of the value of  $m$ , the paths starting from a source satellite and ending in a destination satellite are found. The server numbers of the links for each path are appointed to an array. Then this array is sent as a parameter to the sub function for CBP calculation of the current path. For a LEO satellite system having 20 satellites as in Figure 4, the satellite 7 is defined as source and the satellite 19 as destination satellites. Server numbers of each link and each path are found as in Figure 7:

```

1.Path: 7,2,3,8,3,8,3,4,19.
2.Path: 7,2,3,8,3,4,19.
3.Path: 7,6,7,6,11,10,15,19.
4.Path: 7,2,1,16,15,19.
5.Path: 7,12,17,18,13,14,9,14,19.

Server numbers of the links in 1.Path:
Server_num[7][2]=3
Server_num[2][3]=5
Server_num[3][8]=4
Server_num[8][3]=4
Server_num[3][8]=4
Server_num[8][3]=4
Server_num[3][4]=1
Server_num[4][19]=5

The new array consisted of the server numbers of 1.Path:
new_server_num[1][10]={3,5,4,4,4,4,1,5,-1,-1}

```

**Figure 7:** Presentation of the server numbers of the links and the paths.

As it is mentioned before the paths are consisted of the satellite indices.  $Server\_num[7][2]=3$  means that the server number of the link between the satellite 7 and the satellite 2 is 3. Finally the server numbers of all paths are obtained in the following equations:

```

new_server_num[1][10]={3,5,4,4,4,4,1,5}
new_server_num[2][10]={3,5,4,4,1,5}
new_server_num[3][10]={5,5,5,5,5,4,4}
new_server_num[4][10]={3,3,1,5,4}
new_server_num[5][10]={2,5,5,4,1,2,2,3}

```

At the next step, these arrays are alternately sent to the sub function to find the CBPs of each path. Each element of an array is used to find the CBP of a link, then all  $(1-CBP)$  values in an array are multiplied to find the usability of the current path. For first path these results are found:

$$(\lambda=3, \mu=2)$$

$$CBP_3 = \frac{(\lambda/\mu)^3/3!}{\sum_{k=0}^3 (\lambda/\mu)^k/k!} = \frac{(3/2)^3/3!}{\sum_{k=0}^3 (3/2)^k/k!} = 0,134328$$

Similarly  $CBP_1=0,6$ ;  $CBP_4=0,047957$ ;  $CBP_5=0,014183$  are computed. The usability of the first path is found as in this probability:

$$P_1 = \prod_{i=1}^8 (1-CBP_{m_i})$$

$$P_1 = (1-CBP_3) \cdot (1-CBP_5)^2 \cdot (1-CBP_4)^4 \cdot (1-CBP_1)$$

$$P_1 = (0,865672) \cdot (1-0,014183)^2 \cdot (1-0,047957)^4 \cdot (0,4)$$

Lastly  $P_1 = 0,691149$  is computed. This probability value is multiplied by the total delay value of the path. Thus the delay of the path along its usage duration is found.

## 6 RESULTS

### 6.1 The Performance Comparison of The Static and Dynamic Routing Algorithms

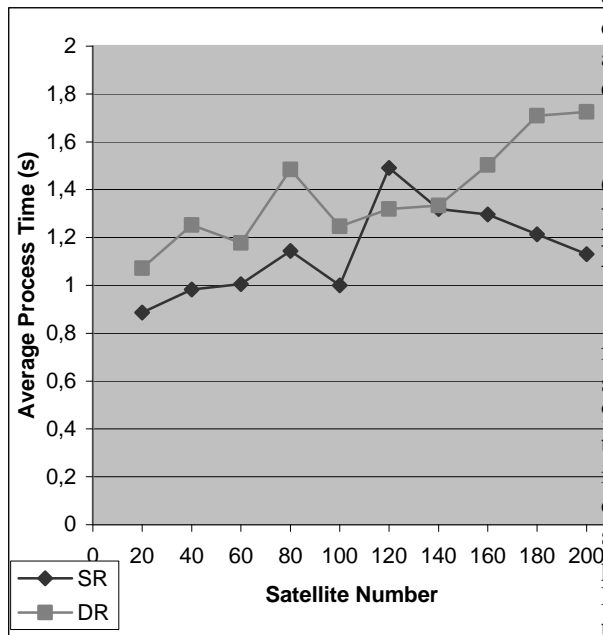
Different satellite topologies which have various satellite numbers between the interval of 20-200 are composed. First of all, same hardware conditions for both of the static and dynamic routing algorithms are supplied. Then the process time for each routing method are calculated and the results are shown on Table VII. In this table first column indicates the satellite numbers of topologies. The process time of Static Routing (SR) algorithms is in the second column. The last column shows the process time of Dynamic Routing (DR) algorithm. When the process times were calculated, the application was run several

times. The average values of each method's results were computed. The numbers shown in Table VII are derived from average values. And also the source and the destination satellites were treated the same in both of these routing algorithms.

**Table VII:** Average Process Times of Static and Dynamic Routings.

Number of Satellites	SR(s)	DR(s)
20	0,887	1,072
40	0,982	1,253
60	1,006	1,178
80	1,144	1,484
100	1,000	1,247
120	1,491	1,319
140	1,319	1,334
160	1,297	1,503
180	1,213	1,709
200	1,131	1,725

The results in Table VII can be examined in Figure 8. As seen in this figure, SR is more efficient than DR.



**Figure 8:** The comparison of average process times.

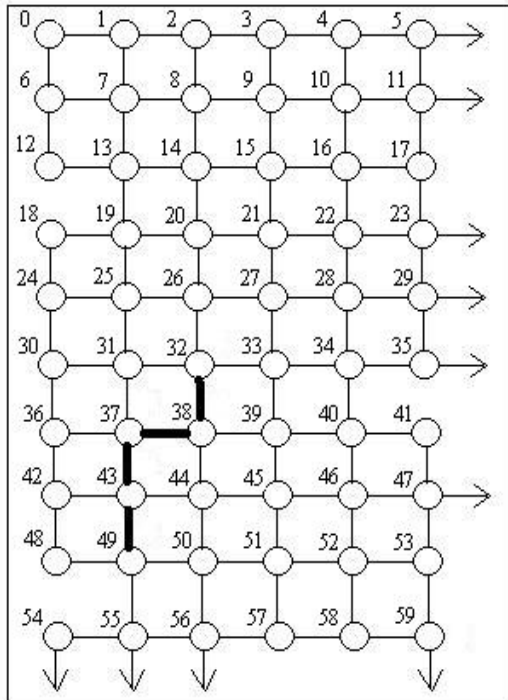
Overall, the process time of SR method is smaller; e.g. when the satellite topology

consisting of 80 satellites is used, the process time of SR algorithm is 1,144 seconds. On the other hand the DR algorithm runs in a time interval of 1,484 seconds. These process times can be different when the hardware capacity of the computer changes. But the effectiveness of the routing methods according to each other doesn't change because this property is based on the process steps. Therefore the environmental features don't have vital importance on the performance comparison. Additional simulation results about the routing process in SR algorithm can be searched in [13] to test this situation exhaustively.

The difference between the process times is caused from the complex operations of dynamic routing algorithms. Links changes also cause the time delay during the selection of a new link instead of the broken link. The activity of the next links is always controlled. Another reason for the extent of process times in DR is that the time elapsed during the topology changes is also included in the process time. After the topology changes some links become active, so the values of  $d$  and  $w$  of these links are considered in the new calculations. But in SR, because of the consistency of the satellite system, these values are fixed. So the time is not spent for these extra evaluations.

## 6.2 The Comparison of The Handover Rate of the Two Routing Methods

New practical application is run again to find the handover rates. In this step the satellite system having 60 satellites as shown in Figure 9 is used. In SR algorithm 5 different topologies are obtained. These topologies are independent from each other for the next calculations. 32th satellite is assumed as source, and 49th satellite as destination. The paths obtained from SR can be surveyed on Figure 10. The paths chosen from five different topologies were ordered in this figure. And it can be extracted that there is only 1 handover in this selection. This handover is between the third and the fourth paths.



**Figure 9:** An example satellite topology having 60 satellites and showing the path ordering as 32,38,37,43,49.

```

=32,38,37,43,49,
=32,38,37,43,49,
=32,38,37,43,49,
1=32,31,37,43,49
1=32,31,37,43,49

```

**Figure 10:** Chosen paths from five different topologies in SR Algorithm.

The system built from 60 satellites is applied to DR Algorithm. This algorithm gives the solution by running only once. This is because it already consists of unstable topologies. As seen in Figure 11, the DR algorithm has 2 handovers. One of them occurs when the system passes from topology 2 to topology 3; and the other occurs between topologies 4 and 5.

```

The path chosen from 1.topology=32,31,37,43,49
The path chosen from 2.topology=32,31,37,43,49
The path chosen from 3.topology=32,38,44,50,49
The path chosen from 4.topology=32,38,44,50,49
The path chosen from 5.topology=32,38,37,43,49
HANDOVER NUMBER=2

```

**Figure 11:** Chosen paths in DR Algorithm.

At the end of this comparison it can be said that SR algorithm is more stable than DR algorithm. The results show that the movement of the satellites causes the DR to spend more time for routing a packet from the source to the destination. In DR algorithm the topology always changes, so the information about the previous links doesn't help to find the next routes. All operations are made due to the current state of the satellite system. On the other hand all states of the system are dependent on each other due to the continuity of the time. For this reason DR algorithm has more complex and time required operations according to the SR algorithm.

## 7 CONCLUSION

A new routing algorithm is recommended in this study. This routing algorithm was designed for LEO satellite systems and it is divided into two categories: Static and Dynamic Routing algorithms. Process times and handover rates of these two categories are compared under various topologies having satellite numbers between 20 and 200. Also a new fitness function, which included both the delay and the traffic probability, is used for new dynamic satellite networks. In this method the location of the caller was important too. Eventually the complex dynamic structures are conveyed by these criteria.

## 8 ACKNOWLEDGMENT

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