Optimizing Satellite Handover Rate Using Particle Swarm Optimization (PSO) Algorithm

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Abstract

Low earth orbital satellites are able to provide access to worldwide wireless or regional mobile services. The Low Earth Orbit (LEO) satellite arrangement generally has a cellular type of contact, similar to the cellular telephone structure. Neighboring satellites are linked with each other through Inter Satellite Links (ISLs). The user device interconnects with the satellite through a user mobile link (UML) while Gateway Link (GWL) is used to link a satellite with an earth station. The consumer's call duration may exceed than the service duration of a satellite necessitating hand over of the call to another detectible satellite to avoid disruption of the call. At the time of handover a user may be covered by more than single satellite. Either the mobile stations at earth or the serving satellite must be intelligent enough to handover the call to a satellite having longest coverage time. In this paper, we suggest an algorithm which decreases the predictable hand over rate by selecting a satellite with the largest service time. Using the Particle Swarm Optimization (PSO) algorithm, the serving satellite itself calculates the service time of neighboring satellites and optimally handover the call to a satellite with a maximum coverage time. Simulations are performed using MATLAB and various results are obtained for two prominent LEO satellite constellations, IRIDIUM and GLOBALSTAR. The effects of the satellite parameters (elevation angle, height, angular velocity and trace angle) on service time are calculated mathematically by drawing different scenarios.

Key words*:* Satellite constellation; Satellite handover; Link layer handover; Particle swarm optimization

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INTRODUCTION

The first communications satellite was thrown in space in 1960s. Early satellites could only switch 240 voice circuits. These days, satellites transfer about one third of the voice traffic and all of the TV signals between countries. Recent satellites characteristically present a quarter-second broadcast delay to the signals they carry. Satellites in lower loops, with less characteristic signal delay, have been positioned to deliver data amenities such as Internet access (Stallings 2003; Theodore, 2001). The low earth orbits are lofted at the height in between 500km to 2000 km and their revolution period is about 90 to 120 minutes. The satellite takes a speed of 20,000 to 29,000 km/h or 8 km/sec. The propagation delay of one complete round trip is less than 20ms that is satisfactory for voice calls. Neighboring satellites are linked with each other through inter satellite links (ISLs). As the service time may be greater than the coverage time of the satellite, to avoid service break ongoing connection may be handed over to other visible satellite (linked layer handover). Contrary to this a mobile user may be served by more than a single satellite, at the time of handover. When the user is about to handover to the other satellite, the satellite minimizing the handover rate would be desirable. The well-known LEO satellite constellations Iridium and Globalstar are busy in their construction with high duties (Lin, 2010). There is need of satellite selection algorithm or criteria that can minimize the handover rate and call drop probability in LEO-MSS. This leads to a crucial investigation point that how to find a proper routing satellite or a proper handover satellite or algorithm that can reduce the handover rate and enhance Quality of Service (QoS). Research on handover process is rapidly increasing these days which leads to various handover techniques and principles. Series of techniques have been invented in order to reduce the handover rate.

Satellite Basics

Orbital Period

It is time required for a satellite to mark one complete trip around the globe in its orbit. It can be calculated through the Kepler's law. According to this law orbital period of a satellite is a function of distance of satellite from earth's center (Ding et al., 2008).

Satellite Footprint

The microwave signal from a satellite is typically expected at an exact range known as footprint of a satellite. The power of a signal is maximum at its middle. The signal strength drops as the traffic goes far from the middle of the footprint. At the edges of the footprint the power is at a predefined threshold (Ding et al., 2008).

Satellite Communication Frequency Bands

The rates set aside for microwave satellite communication comes in GHz series. Each satellite directs and accepts over two changed bands.

Table 1: Frequency Bands for Satellite Communication (Schiller, 2003)

Band	Frequency Range	Total Bandwidth	General Application
L*	1 to 2 GHz	1 GHz	Mobile satellite services (MSS)
S*	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS, Military, terrestrial earth exploration and meteorological satellities
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

Satellite Links

Broadcast from the ground to the satellite is termed as the uplink while Broadcast from the satellite to the ground is termed the downlink.

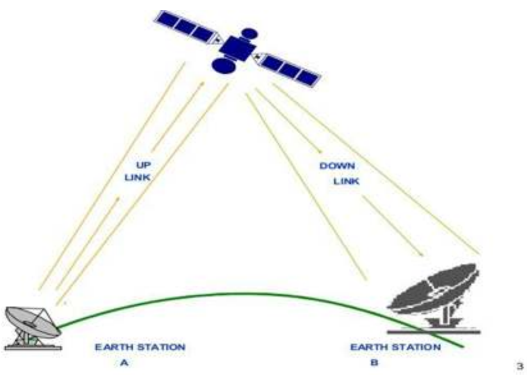

Figure 1: Satellite uplink and downlink

MATERIALS AND METHODS

The types of satellite handovers, spot beam hangovers and inter satellite links handovers are studied in detail in (Liu, 2015) where an improved least delay routing hand over strategy (ILDRHS) is presented to improve the time delay and link switching frequency ratio between satellites. But paper could not provide any simulations. (Feng et al., 2015) proposed a new satellite handover algorithm which uses GPS and satellite diversity, centered on the results derived in (Seyedi, 2012). Compared with Geostationary Earth Orbit Mobile Satellite Services (GEO-MSS), LEO Mobile Satellite Services (LEO-MSS) are intelligent in characteristics of broadcast suspension, broadcast influence, and bulk broadcast (Mirette, 2012; Chini, 2012).

Another technique in LEO- MSS is the first in first out queuing handover technique with Fix Channel Reservation (FCR).This analyses the supreme stream of traffic strength under predefined quality of service limitations. Later research presented a Guaranteed Handover (GH) system which counters this issue and gives zero handover failure likelihood. But the new call blocking chance gets high accordingly. Some other link-layer handover techniques such as Guaranteed Prioritized Handover schemes, Elastic Handover Scheme have been investigated in depth for resolving satellite handover issues (Liao et al., 2015). To improve guaranteed handover routine, another scheme namely threshold based handover scheme have been under consideration broadly in (Ding et al., 2008). Later on elastic channel locking scheme, a Dynamic Doppler Based Handover Prioritization (DDBHP) was offered in (Papapetrou, 2005). To improve guaranteed handover performance time based channel reservation algorithm is examined. It was continued to study in (Li et al., 2011).

Particle Swarm Optimization

Particles

The term particles mean population or entities that coordinate with other particles in order to give a better solution of certain problem. In this research work each particle is considered as a satellite.

Swarm

In PSO, Swarm refers to a family or a group of particles moving in group with certain velocities and accelerations in search of a better solution (Vijaalakshmi, 2014). A solution to an optimization numeric problem is represented by a position of a particle which has some magnitude and velocity.

Optimization

It is a process of finding a best solution out of all other available alternatives. It provides the best maximum or minimum value of some objective function consisting of some constraints in a defined domain (Lee and Park, 2007).

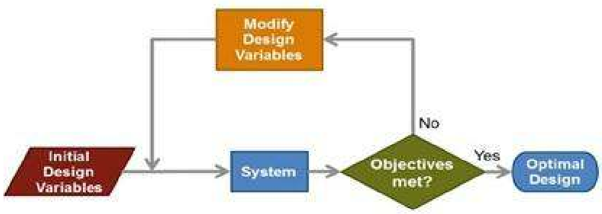

Figure 2: Optimization

PSO is a stochastic technique which is used for optimization problems. It is basically an artificial intelligence method to find the maximization and minimization of impossible numeric problems. It is being used in science and information technologies for complex optimization problems. It is also a heuristic technique (Bai, 2010).

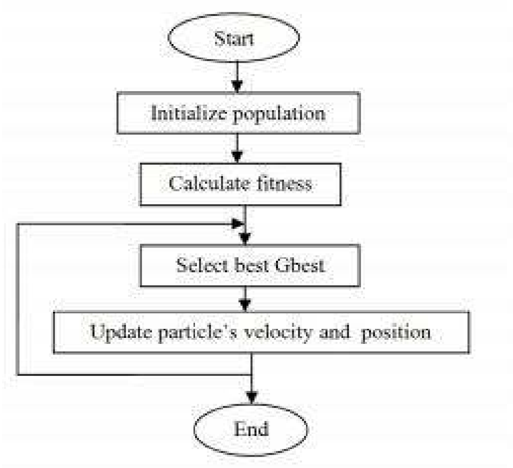

Figure 3: PSO Flow Chart

1. ***Initialization:***
    a. Generate First Swarm by random position $\forall X_i$
    b. Initialize the velocity V_i with smallest random number
2. ***Evaluate Function:*** Calculate the fitness Level of Particles
3. ***Loop Until*** (Termination Criteria)
4. ***For i range (1,PopulationSize)***
    a. $V_i^{k+1} \leftarrow \omega V_i^{k} + \alpha R_i (Pbest_i - X_i^{k}) + \beta R_i (Gbest_i - X_i^{k})$
    b. $X_i^{k+1} \leftarrow X_i^{k} + V_i^{k+1}$
5. ***Revaluate Function:***
    a. If $f(X_i^{k}) < f(Pbest_i)$ than $X_i^{k} \leftarrow Pbest_i$
    b. If $f(Pbest_i) < f(Gbest_i)$ than $Pbest_i \leftarrow Gbest_i$
6. ***End Loop***

Figure 4: PSO algorithm

Where
w= weight of inertia
V=velocity of satellite
C_1= is the constant used to expedite individual movement
C_2=constant that speeds up the swarm influence
Pbest=personal best position of satellite
Gbest=Global best position of satellite.

Implementation of PSO

First of all population of satellites i.e. the swarm size is taken. In Iridium and Globalstar constellation the numbers of satellites are 66 and 48 respectively. One foot print may be covered by number of satellite but it is not possible that all the satellites cover a single foot print at an instant of handover so we can take population size of 50 and 20. Each satellite is candidate in search space. For satellite i its position is x_i and it is a member of search space X i.e.

$$x_i \in X$$

To distinguish between time stamps we have a time index to this position denoted by t. It is the discrete time index which shows the iteration of this algorithm. Here i is the index of satellite and x is the vector of position.

i x_i ε X

i $x_i(t)$ ε X

We denote the position of satellite at time t with $x_i(t)$ to a position we have a velocity for every satellite. Let's denote satellite velocity with $v_i(t)$.

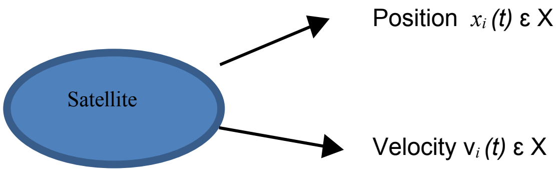

Figure 5: Velocity and position

The dimensions of v and x are same. The velocity describes the movement of satellite. So we have a satellite which is located at $x_i(t)$ and it moves towards the vector like $v_i(t)$. But this satellite is not alone but it is member of swarm. Satellites are interacting and learning from each other obeying some simple rules to find a best optimization solution.

In addition to position and velocity each satellite has memory of its own best position or the best experience called the personal best. In our case the personal best experience of satellite i is denoted by $P_{Best\ i}(t)$ or $P_i(t)$. In addition to the personal best satellite **i** has the global best experience or position among whole swarm Figure 6 denoted by $G_{Best\ i}(t)$ or $G_i(t)$.

Here G *(t)* does not have the index **i** because it belongs to a whole swarm of satellites. It is not a satellite's specific experience. It is a common swarm experience or a global experience of a satellite among the members of swarm.

By defining these concepts on iterations of PSO, position and velocity of every satellite is updated according to this simple mechanism described below.

Let's define a vector from satellite current position $x_i(t)$ to satellite P_{Best} and a vector from current position to satellite G_{Best}.

Satellite moves to a new position using all three vectors. Satellite moves somewhat parallel to the vector of velocity and somewhat parallel to the vector connecting its current position to the personal best and moves somewhat parallel to global best as described in Figure 8.

Here $x_i(t+1)$ is the new updated position of a satellite and addition of these vectors from the beginning of 1st vector to the end of 3rd vector is the new updated velocity of satellite. This is the simple PSO model behind this work. The new position of satellite is created according to the previous velocities of satellites to the personal best and to the global best. So $x_i(t+1)$ is the better position of a satellite because it uses the previous decision about the movement of satellite, previous best self-experience and uses the previous experience of whole swarm.

Based on this simple model and obeying these rules by every satellite in the swarm population, satellites will cooperate to find the best optimization solution.

PSO Mathematical Model

The mathematical model for moving satellite in PSO can be described as follow

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (1)$$

$$v_i(t+1) = \omega\, v_i(t) + c_1[P_i(t) - x_i(t)] + c_2[G(t) - x_i(t)] \quad (2)$$

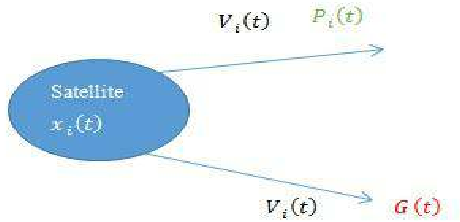

Figure 6: Personal and Global best

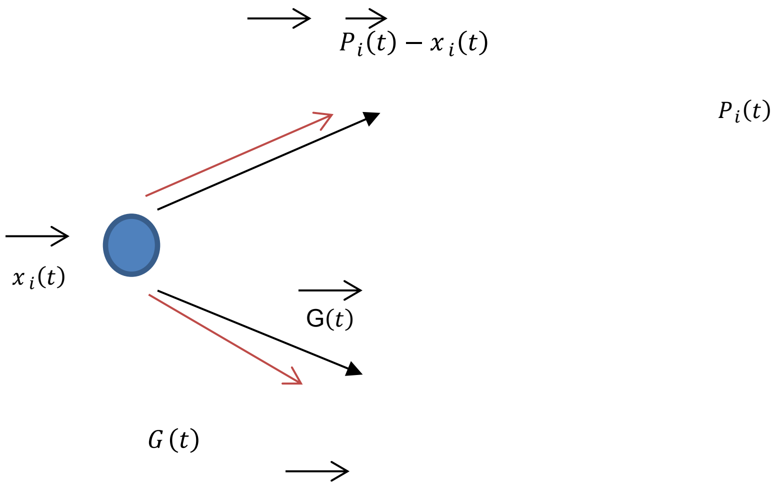

Figure 7: Personal and Global best Vectors

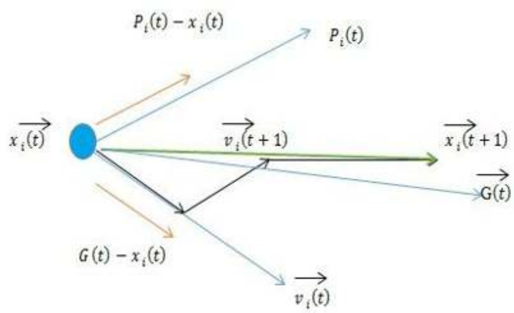

Figure 8: Satellite moving to a new position

Equation (1) is for updating the position of satellite however v_i (t+1) its own updated equation. It is the sum of three components parallel to previous velocity and vectors connecting current position to the P_b and G_b expressed in (2). These two equations completely describe the mathematical model of PSO. However, these two equations are the simplified version of mathematical model behind standard PSO.
The equation for updating the velocity of satellite is as follows

$$v_{ij}(t+1) = \omega\, v_{ij}(t) + r_1 c_1 [P_{ij}(t) - x_{ij}(t)] + r_2 c_2 [G_{ij}(t) - x_{ij}(t)] \qquad (3)$$

In equation (3) v_{if} (t+1) denotes the j^{th} component velocity of i^{th} satellite at time stamp t+1 and is a scalar quantity, r is a random number uniformly distributed in the range of 0 to 1, and c_1 c_2 are the acceleration coefficients.
The updated equation of position can be stated component wise as follows.

$$x_{ij}(t+1) = x_{ij}(t) + v_{ij}(t+1) \quad (4)$$

Equations 3 & 4 are the two simple rules which are obligated to obey by each satellite in the swarm intelligence behind PSO. The components of these equations are:

$\omega\, v_{ij}(t)$	=	inertia component.
$r_1 c_1[P_{ij}(t) - x_{ij}(t)]$	=	cognitive component.
$r_2 c_2[G_{ij}(t) - x_{ij}(t)]$	=	social component.

Whereas are acceleration coefficients.

We combine these three components to create new velocity component. This translates the position of a satellite to a new position in search space. According to this geometrical model new location is the better location of satellite i.

The Scenario Setting
On ground station take user T that initiates a call at t=0 to connect with a second party through a LEO satellite as shown in Fig 9. This user is presently attended by a satellite S_1 and its service time is T_s. Service time is time taken by a satellite to serve a certain user as the user initiates a call until the satellite cover the user under minimum elevation angle with respect to the user. When the call duration of user goes on increasing from the service time of a satellite then the call should be handed over to the satellite S_2 or S_3 in order to avoid the interruption in on going connection. This would happen at t_h (the hand over) instant. The presently serving satellite should have the knowledge of nearby satellites and have to take handover decision to select the satellite that have the maximum service time. In this research work there are P (P>1) satellites chasing the user at t_h instant and the serving satellite has to pick a satellite with maximum service time from all satellites. As the satellite movement is very fast compare to user on earth so we neglect the movement of user. The sub satellite points (SSP) of satellite S1 are represented by the (λS) and the user location represented by (λT). The satellite could get the SSP in the form of latitude and longitude as shown in Fig 9.

RESULTS

Parameter Settings A
Population size or swarm size = 50
No of iterations =100
No of decision variables = 4
Lower bound and upper bound of decision variable is -10 to + 10
Acceleration coefficient c_1 and c_2 = 2
In Figure 10, y-axis shows the best cost i.e the maximum service time of satellite while x- axis shows the number of iterations. There are 100 iterations and a black pointer shows that on 23rd iteration the satellite which is selected for handover has the service time of 0.05 milli seconds.
Fig 11 shows the total 100 iterations. On each iteration the service time of satellite is mentioned as a function of best cost. The population size is 50. Here cost function is the maximum service time.
Parameter Settings B
Population size or swarm size = 20
No of iterations =150
No of decision variables = 4
w= 0.72
wdamp =1
Other parameter remains the same.

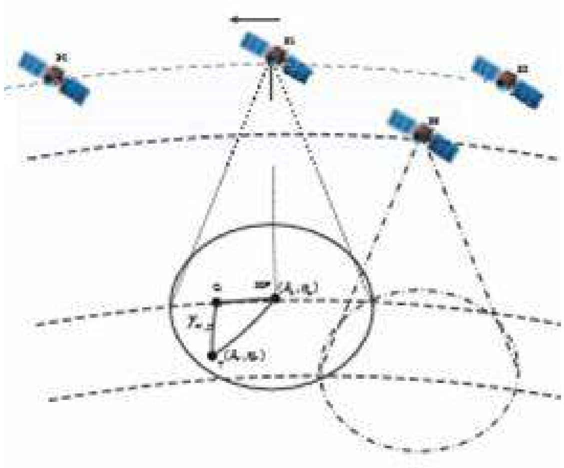

Figure 9: Scenario setting

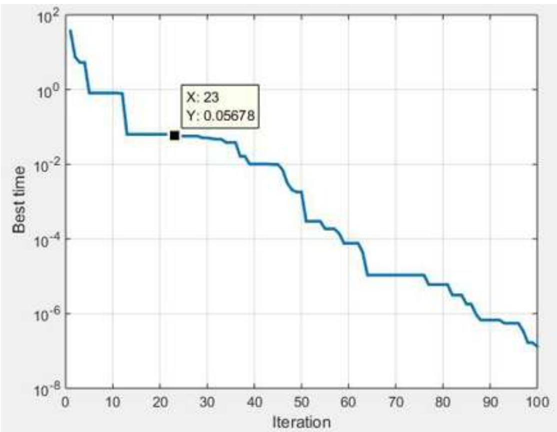

Figure 10: Maximum time vs no of iteration

In Figure 12, there are 150 iterations and a black pointer shows that on 39th iteration the satellite which is selected for handover has the service time of 2.55 milli seconds.

When population size is 20 and w is increased to 3 the service time appears to be more complex. It remains same for a long period of iterations. The service time is same for long interval till 150th iteration (Fig 14). Blocks of same ranges are appeared. It is concluded that graph will more accurate when the values of w are placed between 0 and 1

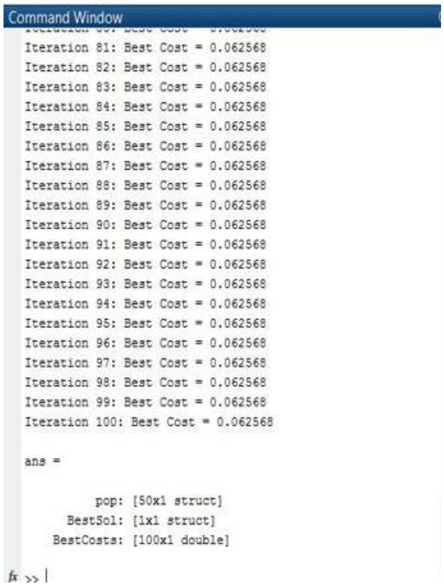

Figure 11: Total iteration with its service time

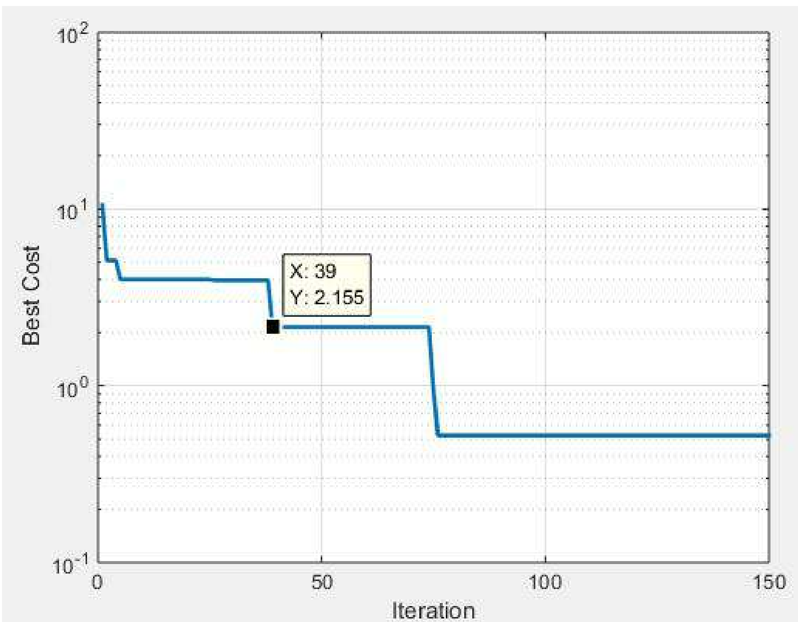

Figure 12: Total iteration with its service time

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Iteration 125: Best Cost = 0.13241
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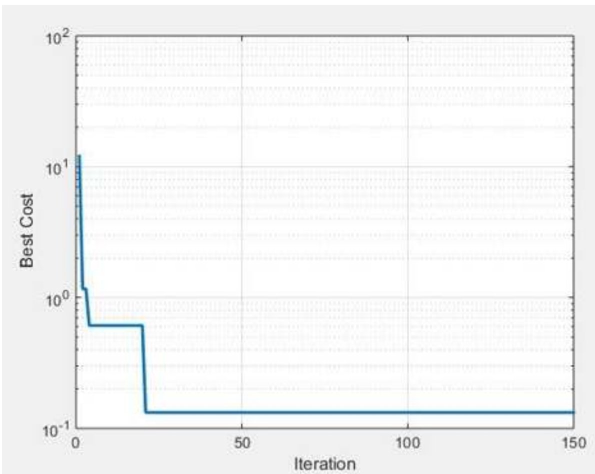

CONCLUSION

This research work provides a simple and better way to reduce handover rate by calculating the service time of nearby satellites and make handover to a satellite which has the maximum service time. In this research work the handover decision is shifted from mobile station at earth to serving satellite. The coordination between the satellites is achieved using Particle Swarm Optimization algorithm where each satellite is taken as a particle and number of satellites in the constellation form a swarm of satellites. Using the Particle Swarm Optimization (PSO) algorithm, the serving satellite itself calculates the service time of neighboring satellites and optimally handover the call to a satellite with a maximum coverage time. Simulations are performed using MATLAB and various results are obtained for two prominent LEO satellite constellations, IRIDIUM and

GLOBALSTAR. The proposed algorithm decreases the predictable hand over rate by selecting a satellite with the largest service time. Using the same frequencies in neighboring satellite beams enables frequency reuse a good research field for future research. There is a need to work in reducing the transmission delay between satellites. Other future applications may include the laser beam based satellite communication systems and military applications etc.

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