1. Introduction

Satellite constellation of multi low Earth orbit (LEO) satellites for Earth coverage are needed to have a layout that supply quick revisit times and little reply times for big efficiency activities (Ashford, 2006). Earth coverage missions generally usage repeat this orbits ground footprint that let for special ground cover it is planned at specified intervals or with the same ground coverage conditions (Carlo et al., 2006). Hopkins tested the recovery location functions of the ascending and descending nodes and examines the effects of latitude (Christensen et al., 2001). Hanson et al. expanded a opinion about inter-plane and inter-orbit angular variations among orbital planes and satellites (Hopkins et al., 1988). Also, Circi et al. designed satellite
constellations of phase uniform satellites to gladden multi targets in the identical mission (Sturza, 1995).

Flower constellation theory (FC) is one of the most impressive methods for producing a ground cover footprint (Circi, 2014). FC usage in the Earth coverage in (Patterson, 1998), where four active satellites usage at an high of 740 km for did one revisit time in six days. However repeating ground track footprint covering a large number of satellites in the constellation, which is composed not needed. FC theory was newly porrect with the lattice flower constellations theory (LFCT), which include all feasible symmetrical solutions. So, The LFCT has the capability to split and separate form parameters and the compatibility conditions, it is beneficial to layout a big constellation of active satellites for the Earth coverage mission (Abdelkhalik, 2005).

All ground coverage systems have spatial and terrestrial segments that are interconnected by an advanced communications network to manage constellation operations and performance (Ashford, 2006). Many prevalent satellite constellations usage inter-satellite connections (ISCs) for communication of data between cross-satellites are available since ISC networks increase the self-rule of the satellite constellations without the cost of a universal earth-station network and decrease atmospheric communication damage. ISC are straight transmission routes along which one signal is transferred from one active satellite to other without earth-station connections (Leopold, 1992). The ISC can be ordered into the following two classes for satellite constellations in circular orbit:

1) ISCs inside orbit are links between active satellites in the identical plane of orbits. Any active satellite in the orbital plane links to a active satellite orbiting forward or back. Since of constant relative motion between the active satellites in the identical plane of orbits, the antenna center angles for all ISCs are fixed and guide of antenna is not needed (Middlestead, 1987).

2) ISCs inside orbit are links between active satellites in neighbor planes of orbit. Since the comparative situation of two active satellites in neighbor planes of orbit is variable with the passage of time, guide of antenna is needed (Wiedeman, 1992). Also, the intervals between active satellites in neighbor orbits change within a big span and the Earth maybe affect their line of sight. When the interval or observation angle between two active satellites are changes too quick for the guide of antennas to conform, ISLs can be provisionally switched off at specified distances (Keller, 1998).

Optical connections and radio frequency (RF) are the two kinds of connections which can be considered for ISCs. An optical connection is used at frequencies different instructions less than those of the RF connection (Leopold, 1991). So, it has benefits such as high information capacity, being slim beam, and antenna size small. The being slim beam is different instructions of importance lower than that of RF. It provides the extra benefit of removing capability to earth based or space based noises. So, it is a loss, since advanced pointer systems are essential due to the thin beamwidth (Lakshmi, 2008; Wertz, 1999).

The selection between optical connections and RF depending on the energy consumption, mass and capacity needed by the device. In this paper, the problem of designing accurate satellite constellations for full coverage of the earth with special emphasis on the communication between different orbital planes is discussed.

However optimal satellite constellation samples for continuous worldwide coverage presented in (Miriampally, 2013), it did not usage continuous ISCs. But this article focuses on continuous ISCs as well as satellite constellation design for continuous Earth coverage.

It also examines the type of vehicle that launches constellation satellites, and to optimize the launch, the design and launch parameters of the satellite are taken
into account. The data transmission between active satellites of the identical plane of orbit is supposed to be continuous. The two dimensional (2-D) LFCT is practical to layout a 44-satellite constellation applying circular orbits. With using genetic algorithms optimization done to assessment the constellation topic to inter-satellite connections connector for continuous worldwide transmissions. Provides analysis to evaluate the reliability performance of continuous data transmission between earth stations and each active satellite in the constellation. The diagram theory is used to evaluate communications between constellation satellites. We then bring up layout attentions and parameters for LFC and done optimization the design of the satellite constellation. And finally, the performance and results of the large satellite constellation designed to fully cover the Earth with ISLs are introduced.

2. System Architecture Review

This part evaluates OneWeb’s, Telesat’s and SpaceX’s systems.

1) OneWeb

OneWeb satellite constellation with Ka + Ku-band includes 720 active satellites in 18 circular planes of orbit at an high of 1200 km, any plane have 87° inclination (WorldVu Satellites Limited, 2018). Fig. 1 illustrated the satellite constellation model of OneWeb’s constellation system. Any active satellite will have a bent-tube payload with 16 similar, unmanageable, very-elliptical beams of user. The ground tracker of these beams warranties when elevation angle more than 55°, that each user can be within the band of ground tracker and available at minimum one active satellite for user. Also plus, any active satellite will have two gimballed directional gate-line the antennas, one of them will be active, while the other will act as an antenna supporting and successor. Any user beam can be use a alone channel in Ku-band, Which is transmitted to a channel in the Ka-band. The channels on the back path have a bandwidth of 125 MHz, But those in the forward path have a bandwidth of 250 MHz.

OneWeb’s constellations system usage the Ku-band for the user data transmission, and usage Ka-band for gate-line data transmission. In specific, the 12.75-14.5 GHz and 10.7-12.7 GHz band can be applied respectively for uploading data (uplinks) user data transmission and the download data (downlinks), Also 27.5-30.0 GHz and the 17.8-20.2 GHz the bands can be applied respectively for the uploading data (uplinks) and download data (downlinks) data transmission gate-line. The earth parts is forecasted to form 50 or more gate-line ground centers, and each that have ten antennas with 2.4 m size for gate-line.

2) Telesat

Telesat’s satellite constellation with Ka-band includes at least 117 active satellites divided in two collections of orbits (Telesat, 2016): the prime collection (Polar Orbits) of 6 circular planes of orbit will be at 1000 km with inclined 99.5°, with at minimum 12
active satellites in each plane of orbit; Second collection (Inclined Orbits) with at minimum 5 circular planes of orbit, at 1200 km, with 37.4° inclination, with at least 10 active satellites in each plane of orbit. Due to Polar Orbits supplies universal worldwide observation, the secondary collection centralized on the areas of the worldwide where maximum of the population is centralized. Fig. 2 explains Telesat’s satellite constellation. The route of covered areas of the active satellites in the Inclined Orbits and Polar respectively are explained in red and blue. The least angle of elevation for the satellite to be available to the user is 20 degrees. Neighbor active satellites, whether in the identical plane, or in neighbor planes in the identical collection of orbits, and in the two orbital collections, They intercommunicate via optical satellite connects. Since the usage of cross connects, a user will be mighty to link to the system from each place in the earth, Even when a communication gate-line and a user are not simultaneously covered and accessed by a satellite.

Any active satellite is a knot of an IP network system and will transport on-board advanced digital data transmissions payload with a straight beam array (SBA). The payload will include an on-board demodulation and processing module, re-modulation abilities, and routing, so downlink and uplink, which expresses an significant novelty in the current design of bending tubes. Any active satellite is a knot of an IP network system and will transport on-board advanced digital data transmissions payload with a straight beam array. The payload will include an on-board demodulation and processing module, re-modulation abilities, and routing, so downlink and uplink, which expresses an significant novelty in the current design of bending tubes. The SBA can to organize at minimum 16 beams on the downlink path and at minimum other 16 beams in the uplink path, and have abilities beam-building and beam-tooling, with electricity power, bandwidth, measure, and alternate vision is dynamically specified for any beam to enlarge efficiency and least interposition to NGSO and GSO active satellites. Also, any active satellite have two guideable gate-line antennas, and a large field receptor beam to be applied for data transmission. This constellation system designed with multiple gate-lines distributed geographically worldwide, any hosting several antennas with 3.5 m size. Can be monitor it with the control center, control the resource allocation operations, and peculiarities, and also schematization, planning and repair of the channels of radio. Telesat’s satellite constellation can usage a 2.1 GHz bandwidth of in the superior (27.5-30.0 GHz) Ka-band for the uploading data (uplinks), and 1.8 GHz bandwidth in the less waves spectrum of the (17.8-20.2 GHz) Ka-band for the download data (downlinks).

3) SpaceX’s

SpaceX’s satellite constellation with Ku + Ka-band includes 4425 active satellites that be distributed in multiple collections of orbits (Space Exploration Holdings, 2016). The original constellation of the satellite that is initially deployed, is included of 1600 active satellites equally distributed in 32 planes of orbit at 1150 km, and inclined 53° (blue). The next
2825 active satellites will also be placed in secondary locations, and will be placed as follows: a collection of 32 orbital planes with 50 active satellites at 1110 km with inclined of 53.8° (orange), a collection of 8 planes of orbit with 50 active satellites any at 1130 km with inclined of 74° (magenta), a collection of 5 orbital planes with 75 active satellites any at 1275 km with inclined of 81° (black), and a collection of 6 planes of orbit with 75 active satellites any at 1325 km with inclined of 70° (yellow). Fig. 3 illustrates the satellite constellation model for SpaceX’s mega-satellite constellation. Any active satellite is carries an advanced digital load including a phase array, which can let any of the ray beams to be solely directed and formed. The least elevation of angle is 40° for users, While the total output power in the active satellite is forecasted to be 23-17GB/s, considering the features of the users. Besides, the active satellites also can usage optical interactive-satellite connects to greater reliability of data transmission continuously, performing communication services in sea, reducing interference and noise. The earth centers included of 3 several kinds of parts: telemetry and commands (TT&C) centers, gate-lines of antennas, tracking centers, and terminals of users. Also, the TT&C centers will be rare in quantity and distributed around the world, and their have antennas with 5 m size. Also, two gate-lines and terminals of users is supported on phase array system. SpaceX programs to have a many big quantity of gate-line of antennas, distributed around the world near to or co-placed with Internet peer and same spots. SpaceX’s satellite constellation system usage the Ku-band for the user data transmissions, and gate-line data transmissions will be performed on the Ka-band. In specific, the 14.0-14.5 GHz band and the 10.7-12.7 GHz band applied respectively for uploading data (uplinks) and download data (downlinks) users.

3. Usage ISC for Earth Coverage Mission

1) Modality and Quality of Coverage Mission

There are different methods to assessment the quality of observation to appraise the coverage efficiency as follows (Telesat, 2016):

1) The percentage observation for each area on the grid is easily the term of times that area was covered by one or more active satellites divided by the total term of simulation time stages.

2) The average observation gap is the average term of splits in observation for a certain area on the simulation grid space.

3) The average reply time (ART) is the average time from when we obtain a random demand to cover a area than we can cover it (Telesat, 2016).

In this paper, the ART is applied as a extent of the coverage efficiency.

2) The geometry required for the ISC

In this paper, the ART is applied as a extent of the coverage efficiency.

The creation of ISCs is usually a function of the azimuth angle, elevation angle, and transfer data
interval between active satellites. The less the domains of azimuth angle, elevation angle, and transfer data interval of the ISCs, the better the efficiency of the ISCs.

Specifically, the ISCs in the identical plane of orbit are more permanent than those between neighbor orbital planes. An instance of geometry for ISCs is shown in Fig. 4. Sat i and Sat j are specified as two satellites in orbit 1, and Sat k define the satellite in orbit 2. R define the orbit radius of satellites.

3) Inside orbit Angle of ISC

The geometry for inside orbit ISC is shown in Fig. 5(a). Given the equilateral triangle $O Si Sj$, the Inside orbit ISC angle $\alpha$ is depended to the angle between neighbor two active satellites, $Si$ and $Sj$, in orbit 1 as follows:

$$\beta + \beta' + 2\alpha = \pi$$  \hspace{1cm} (1)

Since the angle between the neighbor two active satellites, $\beta + \beta'$, is

$$\frac{2\pi}{N_{SO}} = \beta + \beta'$$  \hspace{1cm} (2)

So $\alpha$ is

$$\frac{\pi}{2} = \alpha + \frac{2\pi}{N_{SO}}$$  \hspace{1cm} (3)

Also, $N_{SO}$ is the number of satellites in each orbit. Fig. 6 displayed $\alpha$ and $\beta + \beta'$, as related functions of the number of orbits $N_{O}$. Then, the total satellites is presented by $N_{SO} \cdot N_{O} = N_{S}$. As $N_{O}$ increments, $\alpha$ reductions, where as $\beta + \beta'$ increments.
4) Inter-Orbital Angle of ISC

The Inter-Orbital Angle of ISC is \( \theta \) presented as the angle between two planes of orbit, as shown in Fig. 5(b).

In Fig. 7, angular momentum vectors \( \hat{h} \) and node \( \hat{h}_n \) are parameters of the orbit in the satellite constellation. Due to the satellite constellations with circular orbits and identical orbit inclination, we get angular momentum vectors of the \( k \) th orbit and \( i \) th orbit in the satellite constellation as follows:

\[
\hat{h}_k = \begin{cases} 
\sin \Omega_k \sin i \\
-\sin i \cos \Omega_k
\end{cases} \quad \text{and} \quad \hat{h}_i = \begin{cases} 
\sin \Omega_i \sin i \\
-\sin i \cos \Omega_i
\end{cases}
\]  

(4)

Where \( \Omega \) is the right ascension of the ascending node of the orbit and \( i \) is inclination of the orbit.

With usage scalar produce can obtain cosine of the angle \( \theta \) between two vectors. Since \( \cos \theta = \hat{h} \cdot \hat{h}_n \), so

\[
\cos \Delta \Omega \sin^2 i + \cos^2 i = \sin^2 i \sin \Omega_k \sin \Omega_i + \\
\cos \Omega_k \cos \Omega_i = \cos \theta
\]  

(5)

and according (WorldVu Satellites Limited, 2018) \( \theta \) is

\[
\cos \theta = \cos \frac{2\pi}{N_0} \sin^2 i + \cos^2 i
\]  

(6)

Fig. 8 displayed \( \theta \) obtained by Eq. (6) in conditions of \( i \) and \( N_0 \).

5) Data Transmission Time for Inter-Orbital ISC

Fig. 9 displays the geometry of data transmission time for Inter-Orbital ISCs. Sat \( k \) is at the decussating spot of the neighbor orbits when time is \( t \). The start time of Inter-Orbital ISC is \( t - \Delta t_1 \), whilst \( \Delta t_3 + t \) is the time to end Inter-Orbital ISCs between Sat \( k \) and Sat \( i \). \( \lambda_1, \lambda_2, \) and \( \lambda_3 \) are angular length of the sides of the triangle in radians, whilst \( \gamma \) is the angle of the triangle.

Use globular trigonometry for both globular triangles

\[
S_1(\Delta t_3 + t)S_k(\Delta t_1 + t)A_{Sk}(t) \quad \text{and} \quad S(t - \Delta t_1)S_i(t)A_{Sk}(t - \Delta t_1)
\]

give us

\[
\sin \lambda_1 \sin(\theta - \gamma) = \sin \gamma \sin \lambda_2
\]

And

\[
\sin \lambda_3 \sin(\pi - \theta - \gamma) = \sin \gamma \sin(\lambda_1 + \lambda_2 + \lambda_3)
\]  

(7)
Due to the $2\pi = N_S (\lambda_1 + \lambda_2 + \beta')$ and Eq. (7), $\lambda_3$ and $\lambda_1$ can be known as functions of $\theta$, $\gamma$, $N_S$, and $\beta'$. Data transmission time can be achieved by

$$\frac{\lambda}{n} = \Delta t$$ (8)

Where in $n = \sqrt{\frac{\mu}{\lambda}}$ is the average movement, and $\mu = 3.986 \cdot 105 \text{ km}^3/\text{S}^2$ is the gravitational constant parameter of Earth (Space Exploration Holdings, 2016).

Since $\theta$ related on $i$ and $N_O$, data transmission time $\Delta t$ can be obtained with a function of $i$, $\gamma$, $N_O$, and $\beta'$. Fig. 10 displays the data transmission time for Inter-Orbital ISCs. Fig. 10(b) shown that $\gamma \geq 9$ deg is needed to supply data transmission time for more than 1 min. About of a down RF connection, $\gamma$ bigger than 9 deg is obtained by beam width. A quick calculation is given to evaluation the beam-width in (Standish, 1995).

$$70(\frac{\lambda}{D})(\text{degrees}) = 3 \text{ dB beam – width}$$ (9)

That where the wavelength presented by $\lambda$, and antenna diameter presented by $D$. The beam-width is generally calculated between 3 dB spots since increase decline off quickly outside them (Deb, 2002). During the RF beam is a cone-type beam, the size and form of a cone-type beam is relevant on the altitude of the satellite and the efficiency of the antenna. So, the optical connection needs antenna guide since of the thin of the beam. In this paper, $\gamma = 10$ deg is applied for optimization as a least angle for fixed data transmission.

6) Worldwide Communication Analysis

In the satellite constellation, the comparative status of two neighbor active satellites in the identical orbit is constant. So, the comparative status of two active satellites in neighbor orbits changes. If satellite constellation can linked by the ISC as a total, the satellite constellation supplied worldwide Communication. Han et al. presented the graph theory to the analysis of the worldwide communication of ISCs (Comparetto, 1994). The matrix graph theory of neighboring satellites is expressed by (Han, 2011)

$$A = \begin{bmatrix}
a_{11} & a_{12} & a_{13} & \cdots & a_{1N_S} \\
a_{21} & a_{22} & a_{23} & \cdots & a_{2N_S} \\
a_{31} & a_{32} & a_{33} & \cdots & a_{3N_S} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
a_{N_S1} & a_{N_S2} & a_{N_S3} & \cdots & a_{N_SN_S}
\end{bmatrix}$$ (10)

Number of satellites in the constellation presented by $N_S$, and $a_{ij}$ is the connection between the $j$th receiver satellite and the $i$th communicate satellite. All parts of the vicinity matrix are zero or one. On two-way data transmission, the vicinity matrix is symmetric. The vicinity matrix can be applied to specify the connection of ISCs as follows:

1) Appraise the matrix $A + A^2 + A^3 + \cdots + A^{N_S-1} = R$.

2) The required and enough situations for the connection (each active satellite is linked to other active satellite) is that all parts of matrix $R$ are not zero. In specific, the
valence of $R_{ij}$ tells you how many several methods the $i$ and $j$ active satellites can be connected. 

$$M = \begin{bmatrix} m_{11} & m_{12} & m_{13} & \cdots & m_{1N_0} \\ m_{21} & m_{22} & m_{23} & \cdots & m_{2N_0} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ m_{N_{0,1}} & m_{N_{0,2}} & m_{N_{0,3}} & \cdots & m_{N_{0,N_0}} \end{bmatrix}$$  \hspace{1cm} (11)

Number planes of orbit in the satellite constellation presented $N_{0}$, and $m_{ij}$ is the connection between transfer data satellites in the $i$ th plane of orbit and receiver satellites in the $j$ th plane of orbit. Applying the improved vicinity matrix in lieu of the main vicinity matrix decreases calculate load and increases optimization efficiency. Assessment of the matrix $M + M^2 + M^3 + \cdots + A^{N_{0}+1} = R$ can quickly specify the connection.

Checking the geometry of the satellite constellation, $T_p/N_{SO}$ represents the topological alternation of the satellite constellation. Finally, assessment for connection is needed during just $T_p/N_{SO}$.

### 4. Optimization

Optimal satellite constellation design is a hard subject since there are many degrees of freedom in the parameters for constellations, for example number of satellites in the plane of orbit, orbital inclination, number of planes of orbit, and height. So, an impressive method to layout a satellite constellation is to accept several orbital parts with joint valences and several others isolated by algorithms, and changes algorithms have been presented. The optimal plan of such satellite constellations can be accomplished applying available satellite constellation templates (e.g., Walker’s (Lüders, 1974; Evans, 1997) and streets of cover (Dumont, 1996), also the lately presented 2-D LFC (Walker, 1977). The target is to get a sensible decrease dimensions of the problem sans delete possible beneficial solutions. The LFCT is appropriate for optimization of satellite constellation design since it is a least parameterization theory and including maximum of the available methodologies as proper subsets (Evans, 1998).

#### 1) Two-Dimensional LFCs Design

Generally, 2-D LFCs are determined by four continuous parameters (semimajor axis, eccentricity, inclination, and argument of perigee) and three independent integer parameters establishing the constellation satellite reparation in the $(M, \Omega)$ space. Configuration number $N_C$ (phasing parameter), number of orbital planes of orbit $N_{0}$ and number of satellites per orbit $N_{SO}$ are integer parameters. Applying these integer parameters, the initial average anomaly $M_{ij}$ and satellites’ right ascension of the ascending node $\Omega_{ij}$ are solutions of the following equation:

$$2\pi \left\{ \frac{i-1}{j-1} \right\} = \left[ \begin{array}{cc} N_0 & 0 \\ N_C & N_{SO} \end{array} \right] \left( \begin{array}{c} \Omega_{ij} \\ N_{ij} \end{array} \right)$$  \hspace{1cm} (12)

And $N_C \in [1, N_{0}], J = 1, 2, \ldots, N_{SO}$ and $i = 1, 2, \ldots, N_0$ the “$i-j$” part is the $j$ th satellite on the $i$ th plane of orbit. If repeating the satellite footprint is needed, then the equation of adaptation

$$\frac{2\pi}{\omega_{SO} - \Omega} = N_{ij} T_p = N_j \frac{2\pi}{\omega + n} = N_{ij} T_d$$  \hspace{1cm} (13)

Where the Greenwich nodal term is $T_d$ and the orbit nodal term is $T_p$, which for any coprime integer $N_d$ and $N_p$ supply the valence of the orbit radius. For LEO, the oblateness and drag of atmospheric of the Earth supply it plays an important role in the intruder forces (Mortari, 2011). The gravitational disorder because of the Earth’s oblateness, this is known as $J_2$, the second is the region harmonic coefficient of the series expansion of the Earth’s gravitational field (Evans, 2000; Brouwer, 1959). It is enough to Include the $J_2$ efficacy for LEO since the $J_2$ is 1000 times larger than periods contributed by superior-order zonal, tesseral harmonics and partial (Shaw, 1999; Abramson, 2001). So, Eq. (13) obtains into calculate the $J_2$ efficacy. The secular and continuous $J_2$ efficacy improves the average movement matching to
\[ n_0 \left[ 1 + (2 - 3 \sin^2 i) \left( \frac{R_0}{p} \right)^2 \frac{3}{4} J_2 \sqrt{1 - e^2} \right] = n \]  
(14)

Where \( n_0 = \sqrt{\mu/a^3} \) is the average of motionless movement, linearly variable the right ascension of the ascending node,

\[-\cos i \cdot \left( \frac{R_0}{p} \right)^2 \frac{3}{2} nJ_2 = \Omega \]  
(15)

Also the argument of perigee,

\[(5 \cos^2 i - 1) \left( \frac{R_0}{p} \right)^2 \frac{3}{4} J_2 = \omega \]  
(16)

All satellites have the identical eccentricity, inclination, semimajor axis.

### 2) Least Spacing Limitation for Crash Avoidance

To beware the design of satellite constellations with satellites crashing, the outcomes presented by (Le May, 2018) are accepted. In that analytical research, the nearest happening is between the two active satellites \( \rho_{\text{min}} \) in two circular orbits with the identical inclination and radius using the following equation analytically stated:

\[ 2 \left| \sin \left( \frac{\Delta \phi}{2} \right) \right| \sqrt{\cos \Delta \Omega \sin^2 i + \cos^2 i + 1} = \rho_{\text{min}} \]  
(17)

And

\[ \Delta M - \Delta F = 2 \tan \left[ -\tan \left( \frac{\Delta \Omega}{2} \right) \cos i \right] \]

Also \( \Delta \Omega \) and \( \Delta M \) respectively indicates the discords in the right ascension of the ascending node and average anomaly. Notice that \( \rho_{\text{min}} \) should be measured by the orbit radius to discover the real valence of the least interval of happening. According to the orderly template (lattice) of the LFC, it is not required to appraise the least interval applying all couples of active satellites. It is enough to appraise the least interval between the first active satellite \([M_{11}, \Omega_{11}]\), with all another active satellites staying on several planes of orbit. This very abbreviate to endeavor in the optimization to beware satellite constellations affected by satellite connections (This is normal for symmetric distribution).

### 3) Genetic Algorithms (GA)

GAs invented by John Holland, his students, and colleagues at the University of Michigan in the mid-1970s, are adaptive exploratory search algorithms that imitate the normal election/jump garlic (Speckman, 1990). These are really search operations and supply a beneficial way for detection optimized solutions (Foreman, 2017). However, there is no warranty that GAs will supply optimized solutions (and this is correct for all optimization ways), GAs are most assigned in very nonlinear several-parameter problems (McLain, 2017).

The GA outline is as follows:

1) Beginning: Random produce population of \( N \) chromosomes.
2) Suitability: appraise the suitability function for any chromosome \( x \) in the population.
3) Choice: elect the parents matching to their suitability to produce the novel population.
4) Intersecting: mix genes of parents to form the child. If no intersection was do, child is an precise copy of parents.
5) Jump: With a jump possibility, change new child at any place.
6) Acceptation: location novel child in the novel population.
7) Repeat loop: Go to stage 3 and repetition up to the most repeat or least fault criteria are not achieved.

A population of 200 is selected to perform the simulation and the maximum number descendant is 150. The intersecting amount and jump amount respectively are chosen to be 0.7 and 0.3.

### 4) Identical diffusion of spots on a circle

In the instance of a universal mission, the suitability function for a satellite constellation design is calculated in universally distributed spots (Gallagher, 1994; WorldVu Satellites Limited, 2018). Maximum of the
grid data collection are supplied with a constant stage in longitude and latitude. So, standard calculated spots are distributed with a constant stage in longitude and latitude (Davis, 2013). Since this is assuredly not an identical distribution of spots on the Earth, usually due to the impact of increasing dot compression in high latitude areas (as shown in Fig. 11(a)), the identical distribution of spots on a circle is needed. Different algorithms for an identical grid on a circle have been expanded (Davis, 2013; Hanson, 2016; Teanby, 2006). This significantly reduced the quantitative data collection, and it decreases the amount of computing and computing time. The development of an identical distribution of spots is begotten by correction of the way introduced in (Teanby, 2006). The algorithm to beginning by usage incisions with an Twenty-sided (40 same equilateral triangular forms) and done one divided into three parts and then five consecutive splits in same globular triangles: \(40 \cdot 8 \cdot 2^4 = 1920\) triangles with similar-same globular regions are achieved, for which the vertices about 960 seamlessly distributed spots on a globe. Before done divide into three parts, the primary Twenty-sided is trolled about a special axis of \([1, 1, 0]^T\) by 40 deg in order to beware last distributed spots having longitudinal and latitudinal symmetries.

5) Suitability Function

As a satellite constellation layout for the Earth coverage applying GAs, describing a suitability function to guide the optimization garlic is the main subject. The suitability function is designed to least the ART. It has been performed to the origin average square of the ART of seamlessly distributed spots on the Earth. Therefore, the optimality is specified by minimizing the use of the following function:

\[
L = \sqrt[\text{1}}]{N} \sum_{i=1}^{N} x_i^2
\]

(18)

Where \(x\) represents the ART for any spot on the Earth. In the mathematical phrase of the suitability function, the parameters to be optimum are computed in a collection of \(N\) grid spots distributed on the surface of Earth. Since a less elevation angle reduces the modality of the signal, the least grazing angle for coverage is collection to 9.1 deg. This least grazing angle is generic for this kind of mission (Pratt, 1999). So, 99.59% connection is applied as a limitation to warranty consecutive worldwide communication.
6) Necessary parameters for design

To drive the optimization procedure, the layout parameters space must initial be specified. An admissible orbit radius for LEO must be limited by the most atmosphere elevation and the internal van Allen ray girdle. Due to the less border of the internal van Allen ray girdle, the most elevation is collection to $h_{\text{max}} = 1610$ km (del Portillo, 2018). The least elevation is collection to $h_{\text{min}} = 250$ km since that would be impossible due to the great drag of atmospheric (Jamalipour, 1998). Applying these two elevation limitations, the max and min terms are

$$2\pi \sqrt{\frac{(R_\oplus + h_{\text{min}})^3}{\mu}} = T_{\text{max}}$$

And

$$2\pi \sqrt{\frac{(R_\oplus + h_{\text{min}})^3}{\mu}} = T_{\text{min}}$$

Radius of Earth is $R_\oplus$. The domains of these parameters are shown in Table 1.

<table>
<thead>
<tr>
<th>Domain</th>
<th>Parameter</th>
<th>$N_g, N_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1, $N_o$], integer</td>
<td>$N_C$</td>
<td>[2, 66]</td>
</tr>
<tr>
<td>[1.43, 1.92]</td>
<td>$N_p, h$</td>
<td>[4, 55]</td>
</tr>
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<td>$i, \text{deg}$</td>
<td>[11, 33]</td>
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<td>250.161</td>
<td>$h, \text{km}$</td>
<td>[22, 11]</td>
</tr>
<tr>
<td>[1, 99] [2, 66] [4, 55]</td>
<td>$N_C, N_o$</td>
<td>[44, 88]</td>
</tr>
</tbody>
</table>

5. Results

In this part a discussion using the 2-D LFCT was accomplished. This simulation, the satellite constellation was distributed with 5 deg stages in average anomaly. The simulation consequences illustrated that topological frequency and the dynamics of ISC are accessible and possible.

1) Designed LFCT

At an height of 1451.11 km above ground surface, 44 active satellites are ordered in four planes of orbit that with orbital inclination 59.01 deg with recourse to the plane of equatorial. Eleven usable active satellites are in the same number distributed by 33.24 deg in any plane of orbit, as shown in Fig. 12. A designed satellite constellation can be quite defined with optimal parameters of LFCT, shown in Table 2. The least interval of a designed satellite constellation is 701.02 km. Fig. 13 shown the ISC topology of the designed satellite constellation.
designed LFCTs at a primary time. Solid streaks define the internal orbit ISCs, and dashed streaks define the inter-orbit ISCs. Due to the coverage, the ground tracker of all active satellites are imagined. It should be noted that the high latitude and part of equatorial tropics are not covered.

2) Coverage Efficiency

Fig. 14 shown simulation consequences of the designed satellite constellation in one day. The histogram illustrates the distribution of the ART in Fig. 14(a). As illustrates in Fig. 14(b), the designed satellite constellation to least the ART with worldwide consecutive connection supplies best coverage efficiency in maximum of the areas, but without tropical and polar regions. The ARTs in the poles and equator are superior than those of another regions since of ground trackers of the equator, and the poles are lesser overlap, as shown in Fig. 13. Fig. 15 illustrates the distribution of the ART applying 7943 spots. Also, there are several without coverage spots has been shown by not filled rings in the polar areas.

3) Connection Analysis

This satellite constellation warranty consecutive worldwide connection. The period records of link between orbits are frequented each $\frac{T_p}{N_{SO}}$, as illustrated in Fig. 16. The peculiarities of the earth centers were (62.17°N, 151.32°W) and (50.02°N, 105.11°W). The simulation illustrated that, during orbital motion, the satellite is in sight and accessible to at minimum one of the Earth’s centers.

Fig. 16. Time records of connection.

Fig. 17 supplies the circulation of data at the special period. Active satellites in the prime plane of orbit send data to active satellites in the fourth plane of orbit at the period time as illustrated in Fig. 17(a). Since the
The subsystems of network 4-3, 3-2, and 2-1 are as well as linked, the all system of network is linked; and entire active satellites share all data. Since the subsystems of network 1-2, 2-3, 3-4, and 4-1 are linked, the all system of network for period time $B$ is as well as linked. Also, subsystems of network 1-3 and 2-4 supply two way links. So, the all system of network is linked with increasingly at period time $B$.

Fig. 18 shows the optimization results of the satellite availability optimization using the new constellation design model with the proposed genetic algorithm. In the new constellation simulation, the percentage of users accessing satellites is a function of the number of satellites launched.

For achieve consistent and high quality coverage by the newly designed constellation, we can design and use 3 or 4 satellites and ... neighbor to one orbit. But the optimal design is when the satellites neighbor to the orbit do not overlap in the observation of the region. Then, we can achieve the optimal observation with the minimum number of satellites, given the $\alpha_{\text{satellite}}$ and $\Omega_{\text{satellite}}$ characteristics for any satellite. The optimized method has least overlap and least interval between two satellites. Fig. 19 and Fig. 20 shows functional comparison of coverage and overlay error for the newly designed constellation with existing constellations. Also shows the variation in the error rate of the overlap of neighbor satellites, the curves show that the efficiency of neighbor satellites provides the most observation for the newly constellation designed, any of the neighbor satellites in the orbital $\alpha_{\text{satellite}}$ and $\Omega_{\text{satellite}}$ are various.
It is also shown in Fig. 21 that the regional coverage of the horizons range dependent and function of satellite elevation, It means that as the satellite’s elevation increases, the regional coverage of the horizon rises. Table 3 show the results of the simulation parameters for optimal design of the LEO triplet constellation with different RAAN and arguments. In this research, satellite constellations have been designed and studied for regional and global coverage, which can be considered as a subset of CMEMS, because the satellites used in these constellations are equipped with the most advanced telemetry equipment. 

Table 4 shows the results amount of coverage circle \( (\theta) \) is shown on the Y-axis required for the earth in one

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Table 4. \( \theta \) requirement for constellation

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revisit and X-axis is the number of satellites. Important results can be seen in the inclination of orbit, but not in the vibrational altitude. It is because altitude is not considered as a parameter. The conclusion is that the volume of coverage circle ($\theta$) is reduced by increasing the number of satellites.

6. Conclusions

In this research, LEO satellite constellations were designed and analyzed for the global coverage mission with inter-satellite connections. Before the starting of optimization method, the geometric specifications of inter-satellite connections (ISCs) were studied to assessment the possibility of the global system and find appropriate valences for $\gamma$. The GAs method with the 2-D LFCT was applied to discover the privileged LEO satellite constellation for the coverage mission. An optimal LEO satellite constellation was obtained by least the average reply time with worldwide continuous connection and least interval limitation. The algorithm was presented applying an improved vicinity matrix according to theory of graphic, which could streamline the assessment of connection by checking just inter-orbital ISCs. To obtain the optimization garlic with the best performance, the average reply time according to quasi-identical distribution spots was assessment. It was obtained that the presented design of function law explained best coverage efficiency with worldwide continuous connection from two earth centers.

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