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Original Article

Design of Mega LEO Constellations for Continuous Coverage over Pakistan

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Satellite communication was effectively done in Geostationary Earth Orbit (GEO) in the past years. Recently the trend has shifted from GEO to Low Earth Orbit (LEO). The objective of our study is to propose a satellite constellation for Pakistan in LEO that will provide continuous coverage over Pakistan. As LEO is much closer to the earth as compared to other orbits such as GEO and High Earth Orbit (HEO) etc. one can achieve benefits like low latency rate, less fuel consumption, and signal transmission loss. In ongoing research, an attempt has been made to design the satellite constellation in LEO using the software, System Tool Kit (STK) which has 2D and 3D environment modeling. In the designed constellation, the satellites pass over Pakistan and access the target area. To get uninterrupted continuous coverage, the number of satellites per plane and the number of orbits is increased. The orbital inclinations were also adjusted to achieve the objective. One of the important tasks for continuous coverage is the concept of satellite handshaking which means that soon a satellite gets away from the line of sight of the ground station antenna; another satellite comes within the line of sight of that antenna. LEO satellites are more favorable for communication purposes as they provide reliable communication as well as higher bandwidth.

Keywords: Satellite, Latency Rate, Constellation, Coverage, Inclination, Antenna.

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Author's Contribution
All authors have contributed equally.

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Introduction

The Constellations of small satellites are operated in LEO. These small satellite constellations are working together as a communication network, completing 5G New Radio (NR) and beyond 5G (B5G) communications [1], [2]. LEO has low manufacturing cost, less size, and less weight under 500 kg when it is compared with the Medium Earth Orbit (MEO) and GEO known as the traditional big satellites [3]. These qualities of LEO reduce the launching costs [4][5]. LEO is relatively closer to earth and is commonly used for satellite imaging as this capture high-resolution images. The satellite-based communication system is called Land Mobile Satellite System (LMS). It provides efficient benefits to remote lands, aerial services, sea, and global communications [6][7]. The applications of low earth orbit are Machine to Machine (M2M), Mobile broadband communications, Device to Device (D2D), broadcasting, and more [8].

Satellite Mega Constellations

In the future satellite system, Satellite mega constellation has a significant part that demands highly skilled and technical expertise. Hundreds to thousands of small satellites in LEO will serve different services in the future (Figure 1). A major purpose of these mega LEO constellations is to provide global internet coverage anytime and anywhere even in isolated and remote areas where internet service is not available through cables.

Earth Coverage

The satellites in LEO do not always follow a particular path around the earth, their planes can be tilted. The LEO provides faster communication and has a high bandwidth. For global coverage, many satellites will be needed in the mega LEO constellation. Individual LEO satellites are not so useful to serve the purpose because the satellite moves speedily over the sky, and this requires a lot of work to track such satellites from the ground station. The LEO satellites assist areas with terrestrial wireline and wireless networks [5]. The satellites in LEO act together as the communication network that presents the output to support the fifth generation (5G) of wireless technology and a faster network (Figure 2). These constellations deploy at the altitude in the range of 500 and 2000 km. and their combination with 5G New Radio (NR) provides near-global coverage and support.

i. It enhances mobile broadband service to increase user data transmission rates.
ii. Huge machine-type communication allows a range of Internet of things to work over large geographic areas.
iii. Ultra-Reliable Communications gives one-way latency guarantees in 30ms with a 2ms propagation delay between the ground and LEO [9].

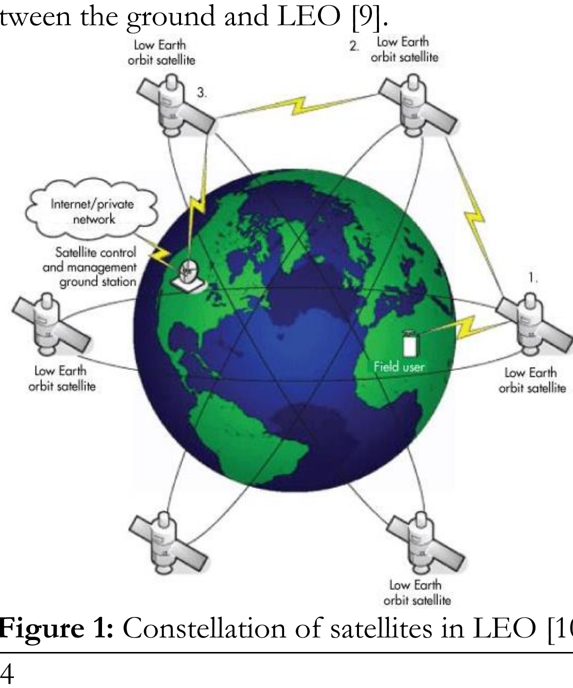

Figure 1: Constellation of satellites in LEO [10].

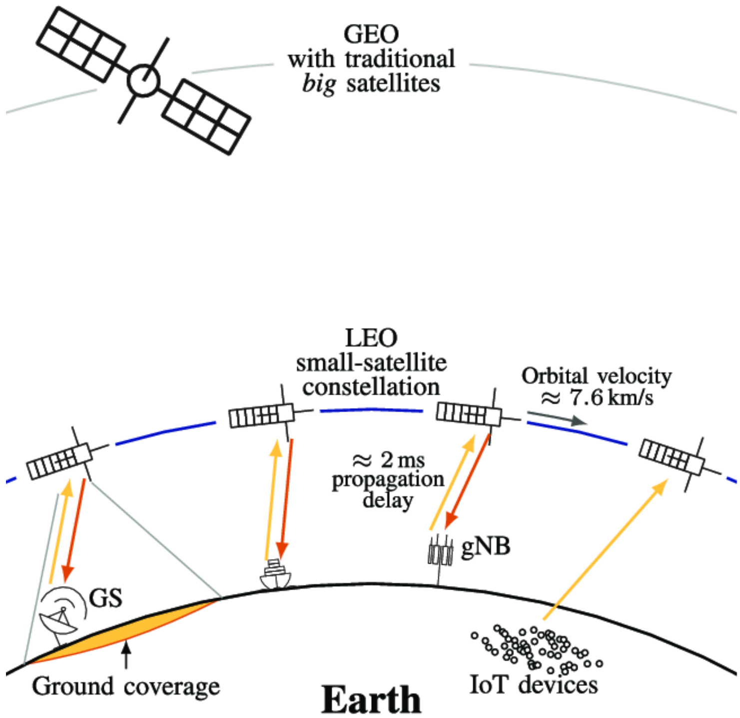

Figure 2: Overview of the unique characteristics of LEO small-satellite constellations with respect to traditional GEO satellites [9].

Doppler rates will be significantly larger due to the high angular velocity that the satellites have on LEO [10][11][12]. LEO satellites have very extensive scientific applications from earth's imagery with astronomical purposes or high resolution, detection of oceans, and the analyses of the climate of the earth changes. For investigations, these microsatellites provide us with opportunities for which different techniques are unfeasible to be used. In LEO the satellite has an orbital period of 90 to 110 minutes which indicates that the ground station antenna follows the satellite instantly and precisely. The proximity communication time between the ground station and the satellite takes 5 to 15 minutes, 6 to 8 times during the day [13][14]. The overlapping between the adjoining satellites is obligatory to maintain the continuity of real-time services and for complete coverage of the Earth's surface. For the overall system performance, the service interference and hand-over mechanism are important [15].

Constellations

The constellation of the satellite is the grouping of unnatural satellites that are operating together as a system that provides global coverage at any time and anywhere on the earth. For the ongoing study, we compared four major satellite constellations that are operational and active (Iridium, Global star, One web, Star Link) [16].

Iridium

This constellation has 66 active satellites at a height of 781 km having an orbital period of 100 minutes. It provides worldwide access for vocalizing, SMS, and detail as well as broadband services. Iridium gives true global (pole-to-pole) coverage and satellites communicate with each other over Ka-band ISLs operating at 10 Mbps [17][18].

Global Star

This is an (LEO) low earth orbit satellite communication that gives satellite-based voice services to its users worldwide. Its orbital height and inclination are 1414 km and 52° respectively. This constellation has 48 satellites in low earth orbit (LEO) with 4 more satellites in the orbit as spares [19].

One Web

One Web is a low earth orbit constellation established by 648 satellites that orbit at 1200 km in 18 planes with an orbital inclination of 86.4°. The satellites communicate in the Ku band whereas the link to the gateway ground station will be in the Ka-band.

Star Link

This constellation is proposed by Space-X, and it holds 4,425 satellites that orbit at the height of 1,200 km in the 83 planes. Gigabit frequency speed has access to users with a latency of 25 milliseconds [20][21].

Research Objectives

The objective of our study is to propose a satellite constellation for Pakistan in LEO. In LEO the signal loss and time delay are less, while the signal strength is stronger. The onboard antenna size on the satellites while on the satellite ground station (SGS) is also smaller, which reduces the overall cost. The lower altitude of LEO leads to lower latency where the user can get better Quality of service (QoS) and network performance. The aim is to provide continuous coverage and information over our custom region Pakistan using LEO satellites.

Material and Methods.

A software System Tool Kit (STK) was used to examine and visualize complex systems in the context of our ongoing investigation. STK deals with the interaction and statistics from platforms across the aerospace, telecommunication, defense, and other industries. It generates a simulation model of our intended research and communicates the outcome with reports, charts, and 3D animations. STK was freely downloaded using https://downloadly.ir/. Pakistan was selected as the targeted area to define the coverage and satellite selection was made in STK (Figure 3 a,b). The assigned orbital inclination and altitude were 40° and 1000 km respectively as the satellite is in the Low Earth Orbit (LEO). The next step was to select the grid-based coverage area (Figure 4).

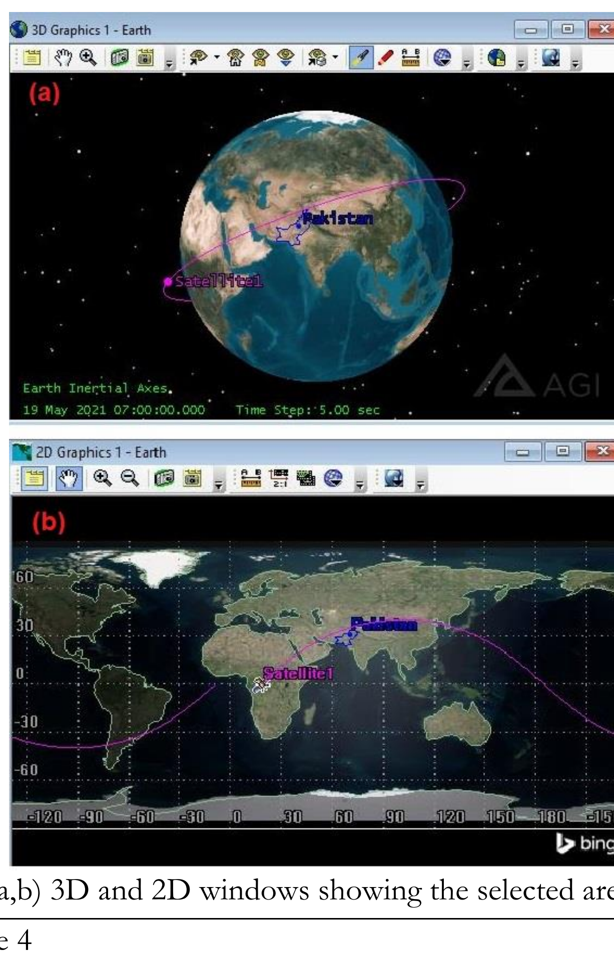

Figure 3: (a,b) 3D and 2D windows showing the selected area "Pakistan"

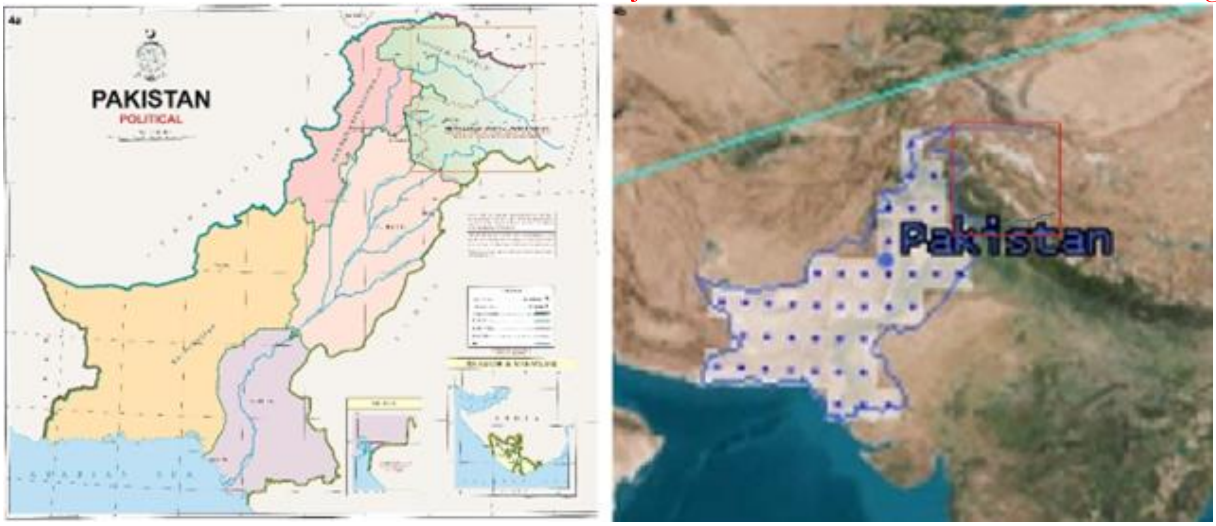

Figure 4: Grid-based boundary of Pakistan selected in STK

In ongoing research, we created a constellation of twenty satellites for continuous coverage. There are five orbital planes and four satellites in each plane (Figure 5). The minimum and maximum number of satellite access are 147 and 160 respectively while the average number of accesses is 153.047619 with five orbital planes and four satellites in each plane i.e. constellation of twenty satellites (Figure 6).

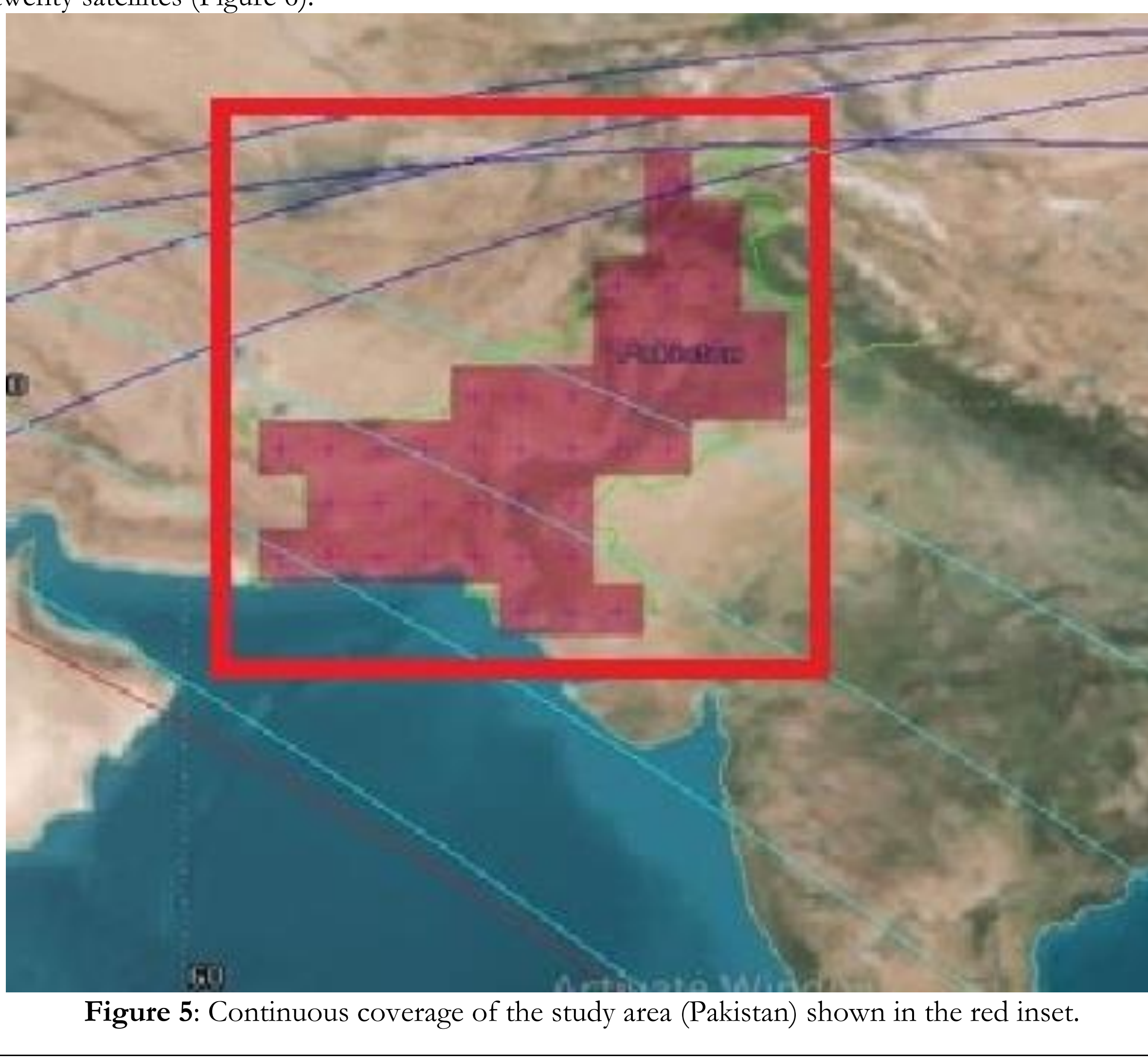

Figure 5: Continuous coverage of the study area (Pakistan) shown in the red inset.

Figure 6: STK window showing the figure of merit for satellite accesses over Pakistan with twenty satellites constellation

The adopted methodology for the current research is shown in the flow chart (Figure 7).

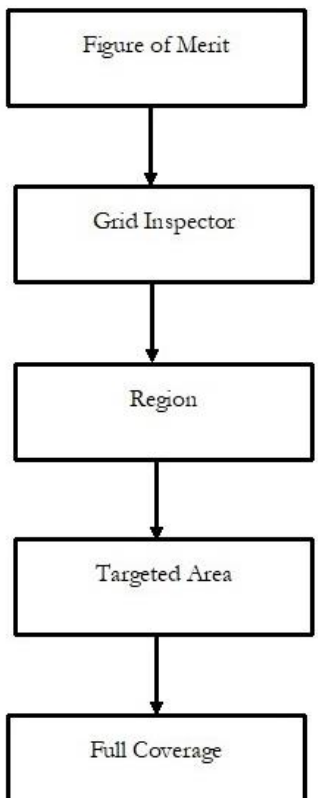

Figure 7: Flowchart sequence in STK to achieve continuous coverage

Result and Discussion.

STK was used to check the number of satellite access per day of the satellites for the proposed satellite constellation. The minimum and maximum values of the total number of accesses are 43 and 48 respectively whereas the average value of accesses is 45.97619 with three orbital planes and two satellites in each plane i.e., the constellation of six satellites (Figure 8).

Figure 8: STK window showing the figure of merit for satellite accesses over Pakistan with six satellite constellations.

The next objective was to design a satellite constellation using STK. Walker tool was selected to create a constellation and three orbital planes with two satellites per plane were proposed which means a total of six satellites. The orbital planes and satellites appear in the STK viewer. The circle in the globe represents orbit planes with three satellites orbiting in these planes. The satellite names are also mentioned in these planes. (Figure 9). The green color in the inset shows that the satellites are passing over our area targeted and will disappear when it will move away from the target area i.e. Pakistan (Figure 10).

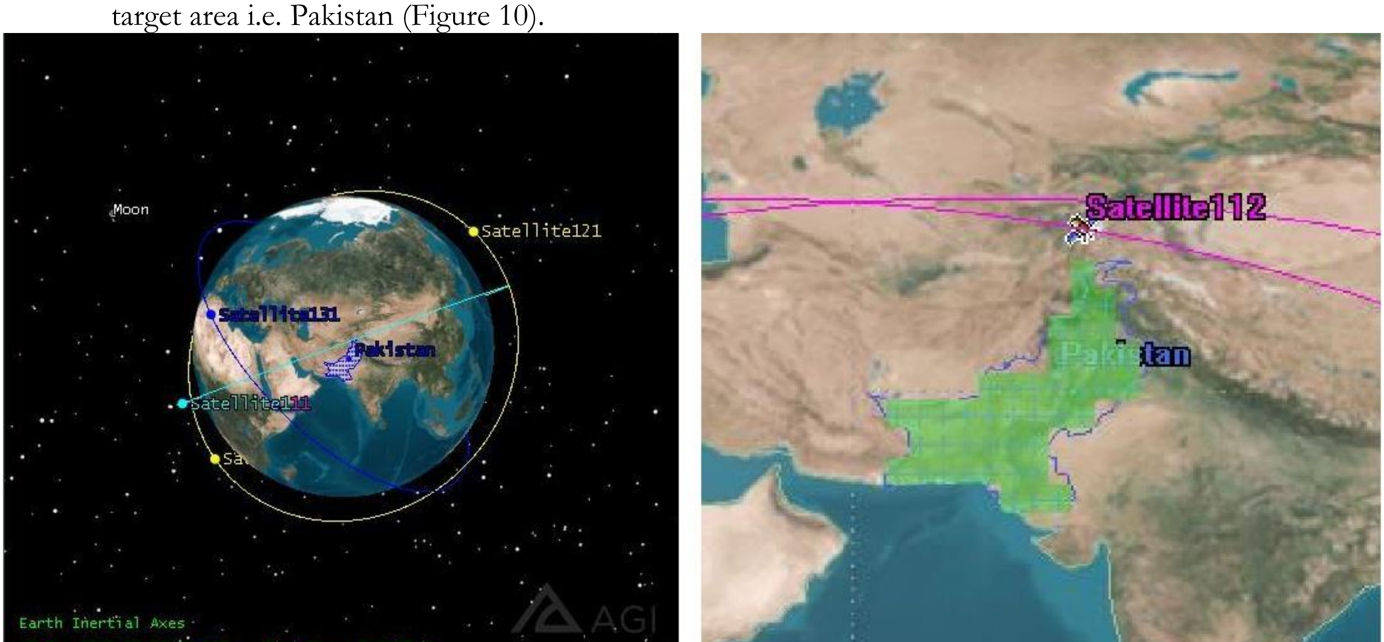

Figure 9: STK viewer showing orbital planes and satellites

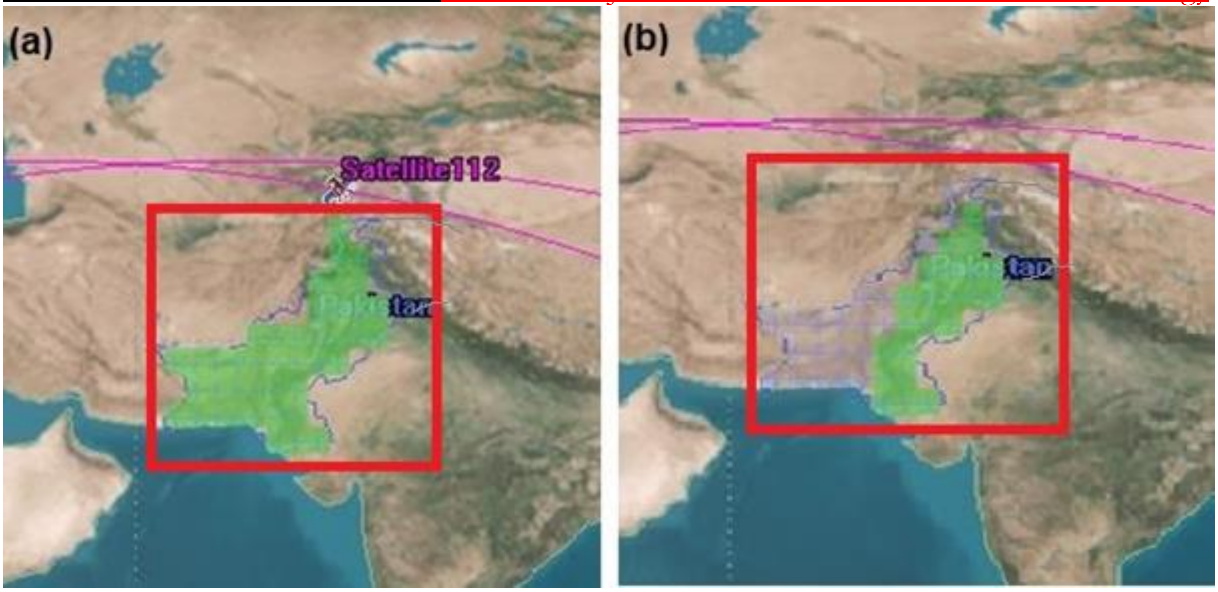

Figure 10: (a) The green highlighted area in the red inset showing coverage over Pakistan (b) Green highlighted area disappears soon after the satellite gets out of the line of sight.

This creates a problem when continuous coverage is not available, and our objective is to get continuous coverage of the targeted area. The region gets green only when the satellite passes over that area otherwise it's not highlighted. It is quite evident that satellite coverage is more at higher altitudes which means more information. To accomplish the task, we set the orbital inclination and altitude at 37° and 1800 km respectively. Making certain settings in STK the lines show that satellites pass on the targeted area. When the satellite moves away from the Field of View (FOV) of the antenna the second satellite comes into its FOV which is the concept of satellite handshake (Figure 11 a, b).

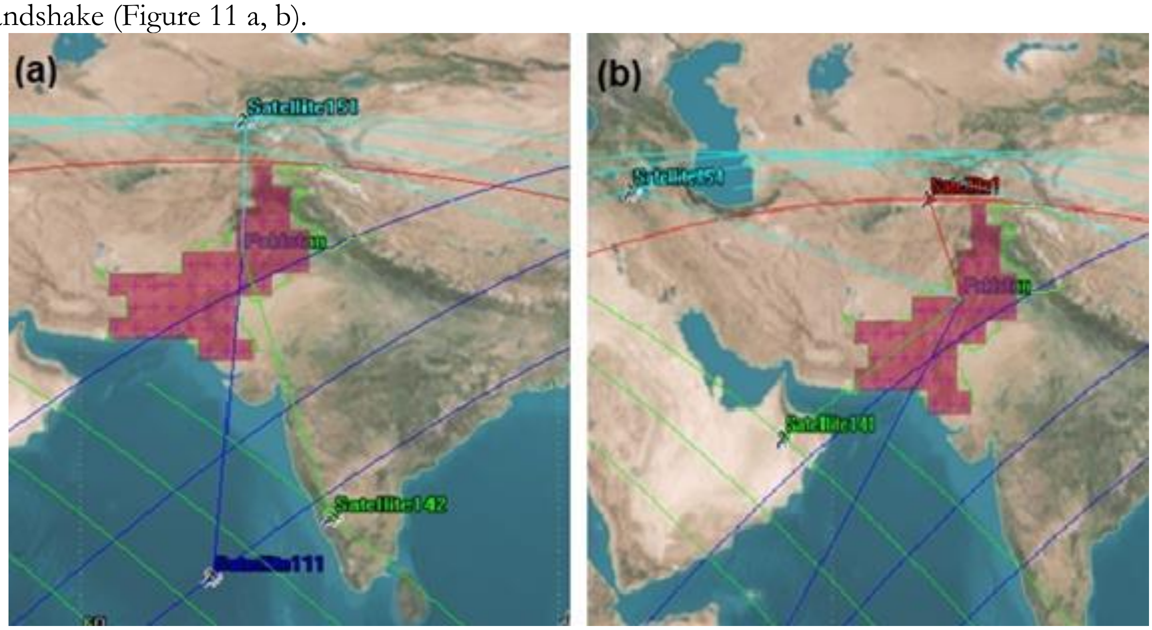

Figure 11: (a) The lines showing the satellites in the targeted area (b) Another satellite comes into FOV soon after the first satellite moves away.

Finally, to check the results we used the following options in STK (figure of merit, grid inspector, region selection, and targeted area as shown in the flowchart (Figure 7). The results show 100% coverage is done Per day (Figure 12).

Figure 12: STK window showing the targeted area and 100% coverage

Proposed Constellation for Pakistan

The proposed constellation specifications are:

Orbital type = circular
Orbital altitude = 1000 km
Orbital inclination = 40 °
Latitude = 30.91°
Longitude = 70.15°
For 24 Hours continuous coverage
Orbital altitude = 1800 km
Orbital inclination = 37°

The above-mentioned specification of the proposed constellation is based on the concept of "satellite handshaking" which means soon the first satellite gets out of sight from the visibility circle of the ground station antenna, and another satellite comes in the Field of View (FOV) of the antenna. Pakistan will be benefited from the following services from the proposed LEO constellation:

i. Voice
ii. SMS
iii. Broad band

The constellation will not only provide continuous and timely coverage without any gap but will also provide instant information for the coverage area. The satellite onboard antenna will cover broad ground coverage that will provide more continuous information with a small time delay. Being closer to earth, i.e. in LEO, it has access to data services, voice, and a low communication latency rate. Being at LEO also means being cost-effective and less fuel consumption. The constellation design will provide satellite-based voice services to a broad range of users and subscribers.

Discussion:

LEO Satellites have a lifetime of around 5-8 years [22] [23]. To keep the constellation operational, replacement satellites are launched based on either of these strategies:

- Launch on-demand.

- In-orbit spare satellites.

Compared to GEO, the complexity and cost per satellite in a LEO constellation system is lower. LEO broadband constellations can present a viable cost-effective solution for developing countries that are yet to enjoy decent cellular and fiber infrastructure availability [24]. Also, as I mentioned in my manuscript "It also has short signal transmission loss, as the signal travel distance is lesser compared to the Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO). As LEO is much closer to the earth as compared to other orbits such as GEO and High Earth Orbit (HEO) etc. one can achieve benefits like low latency rate, less fuel consumption, and signal transmission loss" which makes it cost-effective.

There are no restrictive rules preventing both States and private entities from deploying very numerous spacecraft into LEO constellations [25]. Every space object is registered. The ITU recently adopted a tiered management approach, whereby listing a mega-constellation in its 'Master Register'[26].

The concept of slots/orbital slots is only in GEO. However, according to the literature, there shouldn't be any problem in launching the constellation as far as it is complying with International Telecommunication Union (ITU's) recently adopted tiered management approach [26].

Examples of existing small constellations of satellites in low-Earth orbit are:

i. Telecommunications systems Iridium (USA, 75 satellites (66 primary and 9 reserve ones) at an altitude of about 780 km
ii. Globalstar (USA, 48 satellites at an altitude of 1414 km, and 4 reserve satellites)

Future projects include the deployment of mega-constellations carried out by private companies such as:

i. The American SpaceX 7 (12,000 satellites in LEO, altitude of 550 km by 2027) and the British OneWeb 9 (600–700 small satellites, altitude of about 1200 km).
ii. Another project of the Russian satellite system of global communication for the deployment of 640 satellites by 2030, located at an altitude of 870 km [27].
iii. The Chinese project of the Guowang mega-constellation of satellites in low Earth orbit. It is assumed that the constellation will include up to 13,000 satellites at an altitude ranging from 500 to 1145 km.

Conclusions

In the ongoing research, the LEO constellations of the small satellites are discussed. The prime research of these mega constellations was to give global coverage at any time and everywhere in particular to the areas where the internet is not available. Modern satellite communication is switching more and more towards LEO. Satellite communication is gradually shifting from the traditional L-band to greater Ku and Ka bands being cost-effective. It also has short signal transmission loss, as the signal travel distance is lesser compared to the Medium Earth Orbit (MEO) and Geostationary Earth Orbit (GEO). It also plays an important role in the field of remote sensing. The satellites are working together as a communication network to support 5G i.e., the fifth generation of wireless technology. Satellite orbital elements are also considered to determine the size, shape, position, direction, and location of the satellite in the orbital plane. A satellite constellation has been designed and proposed to provide continuous coverage of Pakistan and some of the surrounding areas.

It is recommended to reduce the number of satellites and orbits for practical design consideration, keeping in view the satellite's swath width. It can be done by installing more sensors per satellite which can make the program cost-effective.

Novelty Statement.

The novelty of our work entitled "Design of Mega LEO Constellations for Continuous Coverage over Pakistan" states that the Author (Co-authors) guarantees that the Materials are original work, submitted only to this Journal, and have not been published previously.

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