Darkening Low-Earth Orbit Satellite Constellations: A review

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ABSTRACT: The proliferation of low-earth orbit (LEO) satellites and the LEO satellite internet will be a game-changer for the low-latency high-speed global internet. While this new generation of the satellite internet in conjunction with fifth generation network (5G) and sixth generation network (6G) enabled emerging technologies, such as precision farming and smart cities, it will bring new challenges, such as satellite collision, limited satellite lifespan, security concerns, and satellite brightness. This article discusses the satellite brightness caused by LEO constellations that potentially affect the ongoing astronomical studies. It reviews the underlying contributors to the satellite brightness as well as the state-of-the-art technologies proposed to mitigate this emerging challenge.

INDEX TERMS Low earth orbit satellites, satellite brightness, satellite internet, phased array antenna, brightness magnitude, satellite communication, SATCOM

I. INTRODUCTION

In recent years, satellite internet has moved into the low earth orbit (LEO) arena, reducing latency, and increasing network speeds. Using several satellites in LEO, space players create constellations of internet satellites to cover the earth fully. SpaceX’s Starlink network is the most developed of these with 1497 active satellites, as of 19 January 2022. Others include Telesat LEO, Amazon’s Project Kuiper, IridiumNEXT, Globalstar and OrbComm [1].

A constellation of satellites in LEO comes with many benefits. Having a very high coverage percentage of the entire earth will help provide internet to remote areas to improve education and communication where traditional internet access is very limited and unreliable. Reduced latency will improve real-time communication speeds compared to traditional geosynchronous equatorial orbit (GEO) satellite internet. Running costs will be reduced due to the minimal ground-based infrastructure required as future satellites will be fitted with optical inter-satellite links for communication between the satellites without using ground stations, further increasing data transfer speed [2], [3]. Such constellations will play an essential role in emergency communications in regional areas and oceans where conventional satellite communications and other terrestrial technologies are minimal [4], [5]. LEO satellite constellations can provide low latency, high bandwidth internet from an orbital height of 550 kilometers (km), significantly better than GEO internet satellites which

| Abbreviation | Meaning         |
|--------------|-----------------|
| 5G           | 5th generation mobile network |
| 6G           | 6th generation mobile network |
| LEO          | Low Earth Orbit |
| MEO          | Medium Earth Orbit |
| GEO          | Geosynchronous equatorial orbit |
| GPS          | Global positioning satellite |
| O3b          | Other 3 Billion |
| SES          | Société Européenne des Satellites |
| NOJR Lab     | National Optical Infrared Astronomy Research Laboratory |
| m            | Meters |
| ms           | Millisecond |
| Mbps         | Megabits per second |
| Gbps         | Gigabits per second |
| PSO          | particle swarm optimisations |

Table 1: Speeds from different orbital heights
are stationed in a 35,786 km orbit [6] [7] to stay constantly aligned with specific areas of the earth and have a much higher latency as well as lower bandwidth [8]. Table 1 shows a comparison of coverage and distance of GEO, medium earth orbit (MEO) and LEO Satellites.

![Fig 1: Comparison of coverage and distance of GEO, MEO and LEO Satellites [6].](image1)

Additionally, the LEO satellites can be de-orbited after they reach the end of life, another advantage over GEO technology. This helps in reducing the amount of space junk in orbit earth. Traditional GEO satellites are positioned into a graveyard orbit when they retire, which is more efficient than trying to decoat or orbit it from its operating height [9]. Collision avoidance is an important aspect of LEO satellite constellations. The orbital space around earth is becoming increasingly busy with space junk, satellites, and other objects. Another major concern is that too many satellites may induce the Kessler effect, a cascading collision leading to a debris belt around the earth, limiting our capabilities to launch rockets into orbit and beyond [10] [11]. As stated in [12], there are over 120 conjunctions in a 30-day period that cross the threshold for the current collision avoidance regulations as well as 53 that cross the maneuver planning threshold that is used to control the current density of LEO space. For this reason, a collision-avoidance system has been implemented onto the satellites to maneuver the satellite. Another key feature is to make de-orbiting the satellites part of the satellite mission. When they reach their end of life, they complete a de-orbit burn, eventually burning up in the Earth’s atmosphere, further reducing the amount of space debris in orbit [13]-[15].

However, the LEO constellations require significantly more satellites to provide the same coverage amount compared to a GEO constellation [6], [16]. This increases the number of objects in the orbit, and with it brings new challenges, such as orbital collision, limited satellite lifespan, security concerns associated with tens of thousands of satellites, and satellite brightness. This review will systematically discuss the underlying factors of LEO satellite constellation brightness and the most recent technologies developed to mitigate this emerging challenge.

II. DEVELOPMENT OF LEO SATELLITES

Traditionally, internet satellites were in GEO, but in 2013 Société Européenne des Satellites (SES) launched four satellites, the start of its ‘Other 3 Billion’ (O3b) constellation into MEO to provide internet access to many countries around the world. The O3b constellation currently has 20 satellites in MEO, supporting many customers [17], [18]. In MEO, the satellites have a 100-120 millisecond (ms) latency, which is far better than GEO, but not as low as a LEO satellite constellation. Ob3 mPOWER is their newest satellite design, currently in production to increase bandwidth from 50 megabits per second (Mbps) to 1+ gigabits per second (Gbps) [19]. Since O3b’s success in providing MEO satellite internet, LEO satellite constellations have been developed to compete with broadband and fiber internet on the ground as well as provide internet to rural areas without compromise.

The first iteration of the Starlink satellite started as a standard MicroSat. During development, the two test satellites were named Tintin A and Tintin B. They were a box design measuring 1.1 meters (m) x 0.7 m x 0.7 m. The MicroSat consisted of a flight computer, power system, a control system, broadband and ground positioning satellite (GPS) antennas, and two solar panels. The satellites have a total mass of 400 kilograms (kg) each [20]. Tintin A and Tintin B, shown in figure 2, successfully communicated with ground stations, leading to the development of Starlink version 0.9.

![Fig 2: Tintin A & B pre-launch [20].](image2)
This satellite was an all-new design that consisted of a new flat-panel layout, allowing the satellites to be stacked vertically when loaded onto the launch vehicle. It uses a single solar panel, a new propulsion system using Hall Effect thrusters with Krypton fuel and a new collision-avoidance system. This new package reduced the weight of the satellite down to approximately 227 kg. On 15 May 2019, 60 of the new version 0.9 satellites were launched on a Falcon 9 rocket and reached an altitude of 550 km [21][22]. The most current Starlink satellite in orbit as of this publishing date is v1.5. It uses two parabolic antennas and four phased array antennas in the Ku- and Ka-bands, as well as a star-tracker to help with attitude data and control while maintaining the single solar panel, Hall effect thrusters and the collision avoidance system from version 0.9. They weigh around 260 kg each [23][24]. OneWeb, another LEO constellation now operated by the British Government and Bharti Global, is working to extend its constellations with a plan to produce 648 satellites for its first-generation fleet for its initial constellation. Currently 394 satellites are successfully launched into LEO.

III. ONSET OF BRIGHTNESS

The presence of thousands of satellites orbiting the earth at a very low altitude causes the onset of streaks in the sky due to sun illumination known as satellite brightness. The brightness of satellites can affect astronomers observing the night sky by creating streaks in the images, which can cause blown highlights in the astronomical images, which causes fainter objects not to be visible. If the satellite remains on any pixel for any length of time as it can saturate the pixel, creating artifacts and reducing the data captured [26]. Observatories with a wider field of view will be greatly affected due to observing a larger area of the night sky. Observatories with a smaller field of view will be less affected, but the trails from LEO constellations can still affect their data. The reflections are at their worst during twilight hours when the satellites are in full view of the sun, yet the earth is still night. This is due to the height of the satellites in orbit. Most LEO satellites are around 550 km from the surface of the earth, resulting in a radial velocity of 7.6 km/s [26] which is slow enough to leave trails on the imaging sensors. The streaks of some LEO satellites, shown in figure 3 [27], are caused by the satellites being illuminated by the sun, and depending on the observational zenith angle, satellite altitude, and observing night, the brightness and number of streaks in the images can vary. Satellites are complex in design and shape, as there is no need for them to be aerodynamic. They consist of the body, which can vary in size and shape to house all the instruments in addition to a solar array or a singular solar panel. The solar panels and the antennas are known as two main reflection points on the LEO satellites, strongly contributing to satellites brightness. The solar array on most of LEO satellites is estimated size of 12 m x 3.2 m [28] that is large enough to reflect light.
The phased array antennas on most of LEO satellites are also a key point for reflections due to their reflective surface which helps reduce heat by reflecting the light away. These antennas are essential to LEO satellites as they are responsible for providing internet communications on the V and Ku-bands, as well as connecting to the ground stations for tracking and system monitoring on the V and Ka-bands [23]. Apart from phase array technology, a new beam steering mechanism has recently been proposed based on near-field transformation, contributing to low-cost manufacturing [29]-[36]. This technique does not require expensive active phase shifters and can be implemented by all-dielectric substances [29]-[31], all-metal structures [32]-[33], or hybrid materials [34]-[36]. Additionally, there are other antenna reconfiguring techniques that potentially can be adopted for such purposes [37]-[43].

Phased array antennas electronically steer the highly-directive beam of the antenna using several microwave phase shifters. The main beam can be oriented in any direction by fixing the arrangement of elements and changing the phase of each element accordingly. Despite their excellent performance, this class of antenna is susceptible to heat, where their radiation patterns, and particularly the antenna gain, are varied slightly as the heat increases. Because of this, reflective radiators are designed and placed on top of the antenna to minimize heat-driven variation in the antenna radiation patterns [44]. These radiators along with relatively large solar panels, reflect sunlight during sunrise and sunset as the satellites orbit the earth, producing both specular and diffused reflections [46].

Specular reflections occur when the incident rays are all aligned and reflect in the same direction as well as preserving the organization of the rays. This occurs on reflective and polished objects and means that the light is focused in one spot, rather than being scattered. Differently, diffused reflection occurs when the surface is uneven and the angle of the reflected rays are all different depending on what part of the surface is illuminated. If the surface has roughness, even at the molecular level, the light will be diffused due to the uneven surface [48]-[51]. Most LEO satellites have a square flat panel with flat radiators covering the phased array antennas. Both cause specular reflections back to the ground, making them appear as bright objects in the night sky as the sun reflects down to earth. This is because they are highly reflective to passively cool the satellite without the need for an additional cooling system [52]. Due to the orbital height of LEO constellations, the satellites are only visible around astronomical twilight and are not visible in the earth’s shadow for local solar midnight [53]. The sun reflects off the satellites and solar panels and phased array antennas during sunrise and sunset as they orbit the earth, and this produces both specular and diffused reflections [46]. Due to this reflectiveness, satellites reflect sunlight back down to earth creating a “string of pearls when they are maneuvering to their operational orbit as seen in figure 7. This undesired streak effect on images as well as being visible to the naked eye.
eye [49], [54]. This side-effect only occurs immediately after they have been released from the second stage of the rocket and while the solar panels are in a low drag mode to reduce the effect the atmosphere has on the satellite. Over the course of 3 to 4 weeks as the satellites separate from each other and rise to their operational orbit the string of pearls effect slowly disappears.

These reflections can be mitigated by changing the orientation during the twilight hours where the satellite will be at its most reflective. During its orbital raising period, the satellite has the solar panel in a low drag mode, which increases the area that light can reflect from. The satellites are rotated so the solar panel is then in a “Knife edge” configuration, having the thin edge of the array facing the earth reducing the surface area that can reflect light during the orbital raising period, and thus reducing the diffused reflections back down to earth [46]. Once the LEO satellite is in its operational orbit, the satellite's orientation will be changed during sunset and sunrise to minimize the reflections by positioning the satellite into the “Shark fin” orientation which will not reflect any light from the solar array back down to earth. This reduces the operational reflections to just the phased array antennas as the satellites make their way into the night.

IV: Low-Albedo Coating

Low albedo coatings are used to absorb light on reflective surfaces and can be man-made or occur naturally in the world. While they greatly help reduce the solar reflectivity on objects, one downside is heat absorption. The surface reflects very little of the incoming light and heat, which in turn heats up the surface. Satellites are traditionally made to have a high albedo surface to reflect the heat away from them. This helps with cooling and keeps the weight of the satellite down as they do not need a cooling radiator to maintain a stable working temperature.

To mitigate the light reflectivity of LEO satellites, a low-albedo coating was proposed and applied to the satellite antenna system. This coating is compatible with both the parabolic and phased array antennas of a Starlink satellite, contributing to an overall satellite brightness reduction of 55% [46]. The satellites developed with the low-albedo coating were launched in March 2020 and placed in a LEO constellation orbit to investigate the satellite brightness of the antenna system.

According to the several observations carried out over a time frame of 1 year, the satellite brightness has decreased, resulting in an increased apparent magnitude by more than one magnitude compared to the standard satellites in the same constellation, as summarized in Table 2 [59]-[62]. This table compares the apparent magnitudes of satellites with and without coating over 10 observations carried out in different times and different terrestrial locations by three observatory sites. Apparent magnitude is a measure of brightness of different objects (stars, satellites, etc.) observed from Earth, where the brighter the object is, the apparent magnitude of it is lower [55], [56].

\[ M_x = -2.5 \log_{10} \left( \frac{F_x}{F_{x,0}} \right) \]

\[ M_1 - M_2 = -2.5 \log_{10} \left( \frac{L_1}{L_2} \right) \]
Each magnitude (M) increase implies a decrease in brightness by a factor of \( \sqrt[5]{100} \approx 2.512 \) also known as Pogson’s Ratio [55]-[58].

| Date          | Starlink Magnitude | +/- | DarkSat Magnitude | +/- | difference | Observer              |
|---------------|--------------------|-----|-------------------|-----|------------|-----------------------|
| 2020 Feb 26   | 4.5                | ±0.2| 5.7               | ±0.3| 1.2        | R. Cole               |
| 2020 Mar 01   | 4.7                | ±0.2| 5.9               | ±0.2| 1.2        | R. Cole               |
| 2020 Mar 06   | 6.59               | ±0.05| 7.46             | ±0.04| 0.87      | J. Tregloan-Reed      |
| 2020 Mar 06   | 5.15               | -   | 6.13              | -   | 0.98       | T. Boroson / J.A. Tyson |
| 2020 Mar 06   | 5.02               | -   | -                 | -   | -          | T. Boroson / J.A. Tyson |
| 2020 Mar 06   | 5.13               | -   | -                 | -   | -          | T. Boroson / J.A. Tyson |
| 2020 April 10 | -                  | -   | 5.87              | ±0.07| -          | T. Horiuchi           |
| 2020 May 18   | -                  | -   | 5.74              | ±0.1 | -          | T. Horiuchi           |
| 2020 June 11  | 4.25               | ±0.07| 5.33             | ±0.04| 1.08      | T. Horiuchi           |

Table 2: Data from observatories on the satellite brightness magnitude after the application of low-albedo coating [59]-[62]

Although observations show that the coating reduced the brightness albeit to varying degrees, the brightness of the satellite could interfere with astronomical observations. The images captured by Tregloan-Reed and Horiuchi in figure 10 show streaks from satellites with coating, although darker, are still persistent in astronomical imaging [59]-[62]. The results also show that the 55% reduction of reflectivity varies in different locations. This could be due to many factors such as the distance from the satellite, the angle of the satellite in relation to the sun and different altitudes of the satellites [61].

While there is some improvement in darkening LEO satellites through low-Albedo coating, the technology used in coating antenna systems increases the antenna’s heat absorption on the satellites, contributing to a short life span of the electronic components, such as phase shifters in the antennas system.

More importantly, the phased array technology, responsible for providing steerable, highly directive radiation patterns, is highly susceptible to heat and the antenna gain drops as temperature increases. This means that the satellite terminal antennas on the ground may not receive the signals transmitted by LEO satellites, posing a serious barrier to providing low latency, high bandwidth satellite internet promised by such new constellations. Additionally,
overheating the antenna system creates interference in infrared observations as the satellites will be visible due to their higher temperature. The heating problem associated with low-albedo coating makes this class of satellites less appealing.

VI. FUTURE IMPROVEMENTS

A new solution for darkening LEO constellations is being tested in which the sun is in-plane with the solar panel, reducing the area of reflection and flairs from the satellite body during the raising period. There are some challenges associated with this approach, including light reduction on the solar panels, which would reduce the operating power, reduction in antenna contact time, as the antenna facing earth for a shorter period of time, and satellite lifespan reduction due to higher fuel consumption [46], [68]. Along with the satellite orientation is to place the satellites closer to their final orbit on launch reducing the time spent in their raising period to reach the operational orbital height, reducing the amount of time in their most reflective position. The challenge with this is that it would be more expensive to raise the second stage of the rocket up higher by using the first stage for longer [69].

A report by C Walker at National Optical-Infrared Astronomy Research Laboratory (NOIR Lab) in 2020 suggests developing a software application to identify, model and mask the satellite trails to predict the satellite interference in astronomy imaging [53].

For example, an artifact detection and masking algorithm was proposed in [70] which relies on 1- a dataset containing several visits to the same part of the sky, 2- detailed modeling of the position variable point spread function (PSF) on single epoch images, 3- the production of PSF homogenized artifact-less images, 4- the image’s model fitting catalogs, 5- the construction of position variable PSF convolved simulated images utilizing PSF models and the model fitting catalogs. Such methods can be adapted to detect objects that leave streaks using an algorithm to remove these streaks and artifacts. Using multiple images and interpolation to create an image that has no artifacts, this method can be applied to any survey that images the same section of the sky multiple times. This could be implemented and developed further to work with specific observatories to reduce the impact of brightness as more satellites enter orbit [71]. There are other algorithms that can be used alongside this method to improve the tracking and detection rate covering more potential

V: Specialized Foam Visor

Foam visors have been used in many applications all over the world to block light and reduce surface reflections. They can be made from many different materials but when they are used with satellites, they need to be designed to allow radio waves to pass through without degrading the signal or blocking it all together as well as being light weight, as every gram counts when launching a group of satellites into LEO. Being radio transparent is one of the biggest challenges as the design of current and future constellations require high speed connections with minimal data loss and interruptions, as they are intended to be a consumer-based internet connection, so the foam visor has to be transparent to radio waves over a vast frequency range.

There are many companies producing polyurethane foams that are transparent to radio frequencies that would be ideal for keeping a satellites reflective components shaded without compromising the antennas on the satellite.

In order to block the sun hitting the phased array antenna systems, that are widely used in the LEO satellites, a special foam visor was recently proposed to cover the antennas [46]. It has been designed to maximise the shade on the antennas while keeping weight down, which is why they are the shapes as seen in Figure 12, the white outline. At the time of publishing, no detailed information has been released on what type of foam was used to form this visor used in the trial.

Such specialized visor foam allows radio frequencies to pass through while reducing the heat absorbed by the LEO satellites equipped with this technology. Starlink satellites were launched in June 2020, resulting in 1.29 magnitudes darker than other LEO satellites in the same constellation with a mean magnitude of 5.92, 5.8, 5.9 and 6.0 [59]-[61]. It was observed that while the visor foam blocked most of the light, there were still some minor bright spots due to potential gaps in the panel sections, which allow sunlight to reach the rear side and the edges of the satellite still being illuminated by the sun [67].

Unlike low-albedo coating technology, the visors will also stop the antennas from heating up and provide more protection to the antenna system. Based on the limited information released, visors are slightly darker than LEO satellites with the low-albedo coating, while there is more room for improvements in the design and implementation of the visor such as removing all gaps in the panel as well as expanding it past the edges to fully cover the underside of the satellite reducing all possible chances of sunlight hitting the reflective surfaces. The only downside to increasing the surface area of the foam visor is the added weight, which in terms of satellites and rocket launches, every gram needs to be accounted for, that is why the visors has a particular shape to block the most reflective components.

...
objects that could leave streaks and artifacts in the imaging [62], [72]-[73].

Another method for brightness mitigation is to develop software that plans and predicts the time and projection of the satellites’ transit over the observatory so they can take images of the night sky when there are no satellites in transit in their desired area of the night sky for the duration of the exposure [53] [74]. This seems more promising as observatories can then see when they will have clear skies overhead to image the night sky. In addition to knowing when they have clear skies, it also depends on what type of imaging the observatory is performing and the required time to take the image. If a minimum timeframe for the exposure can be identified, the orbital spacing can be defined to ensure that there is a minimum window of time between each satellite passing through these selected orbital zones. However, having a minimum operating window would prevent longer exposures occurring without interference from these constellations.

 Interruption of the observations can be another approach to brightness mitigation. If observations are required in the same region of the sky where the satellites are illuminated the exact time they cross the field of view, this can be computed, and the shutter can be closed during that time while the satellite passes over and then reopened to continue capturing data and won’t appear in the final image. However, this approach is not practical for all observatories. For example, there would be too many interruptions for a large field of view telescope, due to the large area of the night sky it is imaging, more satellites would cross this zone, causing it to close its shutter more frequently, which in turn reduces its exposure time, reducing the amount of data collected in each image, making this approach less effective [47]. There are other measures such as satellite number minimization based on particle swarm optimizations (PSO) as reported in [16]. More information on the implementation of a PSO algorithm can be found in [75]-[76]. Apart from PSO, other nature-based algorithms such as grey wolf optimization [77]-[79], ant colony optimization [74]-[75], artificial neural networks [75]-[89], and genetic algorithms [90] can be adopted for the same purpose.

In summary, operators need to do their best to avoid specular reflections in the direction of observatories [48]. This is critical particularly for the observatories with larger field of view and can be implemented by adjusting the satellites to reduce specular reflections while transiting over observational areas. However, it will cost the satellite fuel every time it passes over to rotate the satellite to an angle to reduce the reflections and then return to its normal position, further reducing the satellite’s lifespan.

Every day, more and more satellites are being put into LEO, as such, observation times will slowly decrease as the sky fills up with bright satellites. At this current time, there is little to no information on the reduction of observable time due to these satellites and it being a new emerging technology.

VII. CONCLUSION

One of the critical emerging challenges associated with the LEO satellite constellations is the unwanted brightness of these constellations visible from earth in the night sky. Such brightness interferes with astronomical viewing in many ways, potentially disrupting the observatories’ function. The urgency for the LEO constellations brightness rectification was understood recently, and several technologies have been proposed and tested to mitigate this issue.

Both approaches of low albedo coating and foam visor have been seen to have similar results in reducing the satellite brightness [59]-[62]. The former has advantage of little to no additional weight being applied with the coating, whereas the latter has the additional visor system that adds weight and takes up more space which will affect the launch process [46]. The former has more disadvantages than the latter, mainly due to the additional heat absorbed. The visor can also be expanded to cover a larger area of the satellite and block more potential reflections in future iterations. Despite these changes to the original satellite, they are not enough to darken the satellites for astronomical explorations worldwide [59]-[61], [67].

The future improvements have some promising methods that will also need improvement over time as new methods and technology are created to help with this new problem. Adjusting the satellite to have the satellite in-plane with the sun would be the easiest method to help reduce the reflectivity of the solar panel. The downside to this is that this uses up more fuel than normal [46], reducing the satellite lifespan and reducing the time the solar panel will be in direct sunlight and will change the orientation of the antenna, reducing the contact area with the ground stations.
Masking the trails, satellite planning, and imaging interruption will make moving the satellites to be in-plane with the sun unnecessary. These two methods will help imaging directly, reducing the streaks and artifacts in both scenarios. The downside to masking the trails, is there will be more images required to cover the viewing area, making sure the combined images have no overlap of streaks that can be removed [53]. As well as this, these methods could lose valuable scientific data from losing data due to streak removal, or not being able to operate at specific times due to satellites flying overhead [74]. Satellite planning will dictate when the observatories can view the night sky and they might miss key events due to the satellites blocking the view. A way to mitigate this is to plan and work with the constellation companies to create a gap in the constellation for these events [74].

Interuption of the imaging process will be more viable for small field of view observatories as there will be less satellites crossing its viewing area compared to wide field of view observatories. As with the other two methods, there is a potential to lose data when interrupting the imaging and would lose more data compared to the other methods above as well as taking longer from all these interruptions and additional processing.

Apart from all modifications proposed or implemented on the satellite’s configuration, mathematical modeling highly tailored for each major observatory to predict the brightness caused by each LEO constellation is another promising avenue to rectify this existing challenge [75]-[83]. As this is an emerging technology, this is an area or study and will take years to refine to find the perfect balance of global connectivity while still maintaining a dark sky for astronomers around the world.

References:

[1] Del Portillo I, Cameron BG, Crawley EF. A technical comparison of three low earth orbit satellite constellation systems to provide global broadband. Acta Astronautica. 2019;159:123–35.
[2] Space Exploration Holdings LLC, “Application for approval for orbital deployment and operating authority for the SpaceX Gen2 NGSO satellite system,” Federal Communications Commission, Washington DC. 20554, 2020.
[3] Lee Y, Choi JP. Connectivity Analysis of Mega Constellation Satellite Networks with Optical Inter-Satellite Links. IEEE transactions on aerospace and electronic systems. 2021;1–1.
[4] Pierdicca N, Pulvirenti L, Chini M, Guerrero L, Candela L. Observing floods from space: Experience gained from COSMO-SkyMed observations. Acta Astronautica. 2013;84:122–33.
[5] Razoumny YN. Fundamentals of the route theory for satellite constellation design for Earth discontinuous coverage. Part I: Analytic emulation of the Earth coverage. Acta Astronautica. 2016;128:722–40
[6] https://www.satellitetoday.com/content-collection/ses-hub-geo-meo-and-leo, Artist, Schematic of orbital altitudes and coverage areas. [Art]. Satellite Today, 2020.
[7] European Space Agency, “ESA.int,” 30 March 2020. [Online]. Available: https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits#GEO. [Accessed 18 March 2021].
[8] Dgtl Infra, “Elon Musk’s Starlink and Satellite Broadband,” 2 December 2020. [Online]. Available: https://dgtilinfra.com/elon-musk-starlink-and-satellite-broadband/. [Accessed 19 March 2021].
[9] U.S Government, “Orbital Debris Mitigation Standard Practices,” 2019.
[10] Drmola, J., & Hubik, T. (2018). Kessler Syndrome: System Dynamics Model. Space Policy, 44-45, 29–39. https://doi.org/10.1016/j.spacepol.2018.03.003
[11] D.J. Kessler, B.G. Cour-Palais, Collision frequency of artificial satellites: the creation of a debris belt J. Geophys. Res., 83 (1978), pp. 2637-2646
[12] Muelhaupt, T. J., Sorge, M. E., Morin, J., & Wilson, R. S. (2019). Space traffic management in the new space era. Journal of Space Safety Engineering, 6(2), 80–87. https://doi.org/10.1016/j.jsse.2019.05.007
[13] Jonas Radtke, Christopher Kebschull, Enrico Stoll, Interactions of the space debris environment with mega constellations—Using the example of the OneWeb constellation, Acta Astronautica, Volume 131, 2017, Pages 55-68, ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2016.11.021.
[14] Lucken, R., & Giolito, D. (2019). Collision risk prediction for constellation design. Acta Astronautica, 161, 492–501. https://doi.org/10.1016/j.actaastro.2019.04.003
[15] Le May S, Gehly S, Carter B., Flegel S. Space debris collision probability analysis for proposed global broadband constellations. Acta Astronautica. 2018;151:445–55.
[16] Deng R, Di B, Zhang H, Kuang L, Song L. Ultra-Dense LEO Satellite Constellations: How Many LEO Satellites Do We Need? IEEE transactions on wireless communications. 2021;1–1.
[17] SSA S.A. “03b MEO – Our Coverage” 2020. [Online]. Available https://www.ses.com/our-coverage/03b-meo [Accessed 9 June 2021]
[18] N2YO.com “Satellite tracking” 2021 [Online]. Available https://www.n2yo.com/satellites/?c=43 [Accessed 9 June 2021]
[19] Boeing. “Boeing to build four additional 702X Satellites for SES’s O3b mPOWER fleet” [Online] Available https://boeing.mediaroom.com/2020-08-07-Boeing-to-Build-Four-Additional-702X-Satellites-for-SES [Accessed June 9 2021].
[20] G. Krebs, “MicroSat 2A, 2b (Tintin A, B),” June 2018. [Online]. Available: https://space.skyrocket.de/doc_sdat/microsat-2.htm. [Accessed 18 March 2021].
[21] SpaceX, “Starlink Mission Press Kit,” 15 May 2019. [Online]. Available: https://web.archive.org/web/20190515091900/https://www.spacex.com/sites/spacex/files/starlink_press_kit.pdf. [Accessed 18 March 2021].
[22] G. Krebs, “Starlink Block v0.9,” 2019. [Online]. Available: https://space.skyrocket.de/doc_sdat/starlink-v0-9.htm. [Accessed 18 March 2021].

[23] S. (., Persona), “Starlink Compendium,” 22 May 2019. [Online]. Available: https://www.elonx.net/starlink-compendium/. [Accessed 18 March 2021].

[24] T. Sesnic, “Starlink 22,” 14 March 2021. [Online]. Available: https://everydayastronomer.com/starlink-22/. [Accessed 18 March 2021].

[25] G. Krebs, “Starlink Block v1.0,” 2019. [Online]. Available: https://space.skyrocket.de/doc_sdat/starlink-v1-0.htm. [Accessed 18 March 2021].

[26] S. Gallozzi, D. Paris, M. Maris, M. Scardia and D. Roma, “Concerns about ground based astronomical observations; quantifying satellites’ constellations damages,” Instrumentation and Methods for Astrophysics, 2020.

[27] C. J. Clara Martínez-Vázquez, Artist, A wide-field image (2.2 degrees across) from the Dark Energy Camera on the Víctor M. Blanco 4-m telescope. [Art]. Cerro Tololo InterAmerican Observatory / NOIRLab/NSF/AURA/DECam DELVE Survey, 2019.

[28] Damir, “Space Related Ideas,” Space Related Ideas, 27 April 2020. [Online]. Available: https://libibots.blogspot.com/2020/04/starlink-satellite-dimension-estimates.html. [Accessed 25 March 2021].

[29] M. Afzal, et al, “Beam-Scanning Antenna Based on Near-Electric Field Phase Transformation and Refraction of Electromagnetic Wave Through Dielectric structures,” IEEE Access, no. 8, pp. 199242 - 199253, 2020.

[30] A. Lalbakhsh, Muhammad U. Afzal, Faruq U. Esselle, Stepanie L. Smith, “Wideband Near-Field Correction of a Fabry-Perot Resonator Antenna,” IEEE Trans. Antennas Propag., vol. 67, no. 3, pp.1975–1980, 2019. DOI: 10.1109/TAP.2019.2891230.

[31] T Hayat, et al, “Additively manufactured perforated superstrate to improve directive radiation characteristics of electromagnetic source”, IEEE Access 7, 153445-153452, 2020.

[32] A.Lalbakhsh, M. Afzal, T. Hayat, K. Esselle and K. Mandal, “All-metal wideband metasurface for near-field transformation of medium-to-high gain electromagnetic sources,” Scientific Reports, vol. 1, no. 11, pp. 1-9, 2021.

[33] A. Lalbakhsh, M. Afzal, K. Esselle, S. Smith, “All-Metal Wideband Frequency-SelectiveSurface Bandpass Filter for TE and TM polarizations” IEEE Trans. Antennas Propag. Accepted, 2021.

[34] M. Afzal, et al, “Method to Enhance Directional Propagation of Circularly Polarized Antennas by Making Near-Electric Field Phase More Uniform,” IEEE Transactions on Antennas and Propagation, 2021.

[35] A. Lalbakhsh, M. U. Afzal, K. P. Esselle and S. L. Smith, “A high-gain wideband EBG resonator antenna for 60 GHz unlicensed frequency band,” 12th European Conference on Antennas and Propagation (EuCAP 2018), London, 2018, pp. 1-3.

[36] M. Afzal, et al, “A metasurface to focus antenna beam at offset angle,” URSI Atlantic Radio Science Meeting, vol. 2, pp. 1-4, 2018.

[37] Iqbal, A., Waly, M.I., Smida, A. and Mallat, N.K., 2021. Dielectric resonator antenna with reconfigurable polarization states. IET Microwaves, Antennas & Propagation, 15(7), pp.683-690.

[38] Awan, W.A., et alie., 2021. Design and Realization of a Frequency Reconfigurable Antenna with Wide, Dual, and Single-Band Operations for Compact Sized Wireless Applications. Electronics, 10(11), p.1321.

[39] A. Lalbakhsh, M. U. Afzal, K.P. Esselle, S. L. Smith, “Low-Cost Non-Uniform Metallic Lattice for Rectifying Aperture Near-Field of Electromagnetic Bandgap Resonator Antennas,” IEEE Trans. Antennas Propog., vol. 68, no. 15, pp. 3328 -3335 May, 2020. DOI: 10.1109/TAP.2020.2969888

[40] Yalda Torabi, Gholamrezad Dadashzadeh, Ali Lalbakhsh, Homayou Oraizi, “High-Gain and Low-Profile Dielectric-Image-Line Leaky-Wave-Antenna for Wide-Angle Beam Scanning at THz Frequencies”, Optics and Laser Technology, 2022.

[41] Priyanka et al, “Single Layer Polarization Insensitive Frequency Selective Surface for Beam Reconfigurability of Monopole Antennas,” Journal of Electromagnetic Waves and Applications, vol.34, no. 1, pp. 86-102, 2020.

[42] Iqbal, A. et al. Design, fabrication and measurement of a compact, frequency reconfigurable, modified T-shape planar antenna for portable applications. Journal of Electrical Engineering and Technology, 12(4), pp.1611-1618.

[43] M Hadej, G Dadashzadeh, Y Torabi, A Lalbakhsh, Terahertz Beamforming Network with Non-Uniform Contour, applied optics, Vol. 61, No. 4, pp. 1087-1097, 2022

[44] Y. Wang, C. Wang, P. Lian and S. Xue, “Effect of Temperature on Electromagnetic Performance of Active Phased Array Antenna,” MDPI, p. 6, 2020.

[45] Jeffrey T. Phased-array radar design application of radar fundamentals. Raleigh, NC: SciTech Pub.; 2009.

[46] SpaceX, “Starlink update - April 28, 2020.”, SpaceX, 28 April 2020. [Online]. Available: https://www.spacex.com/updates/starlink-update-04-28-2020/. [Accessed 19 March 2021].

[47] Hainaut OR, Williams AP. Impact of satellite constellations on astronomical observations with ESO telescopes in the visible and infrared domains. Astronomy and astrophysics (Berlin). 2020;636: A121.

[48] R. T. Tan, “Specularity, specular reflectance,” 5 February 2016. [Online]. Available: https://link.springer.com/referenceworkentry/10.1007/978-0-387-31439-6_538. [Accessed 19 March 2021].

[49] P. J. Marlow, J. Kim and B. L. Anderson, “The Perception and Misperception of Specular Surface Reflectance,” Current Biology, vol. 22, no. 20, pp. 1909-1913, 2012.

[50] H. Partanen, N. Sharmin, J. Tervo and J. Turunen, "Specular and anti-specular light beams," Optics Express, vol. 23, no. 22, pp. 28718-28727, 2015.

[51] GianniG46, “Diffuse reflection,” 27 October 2010. [Online]. Available: https://en.wikipedia.org/wiki/File:Lambert2.gif. [Accessed 19 March 2021].

[52] A. Mallama, “A Flat-Panel Brightness Model for the Starlink Satellites and Measurement of their Absolute Visual Magnitude,” Instrumentation and Methods for Astrophysics, 2020.

[53] C. Walker, J. Hall and Et-al, “Impact of Satellite Constellations on Optical Astronomy and Recommendations Toward Mitigations,” Bulletin of the American Astronomical Society, vol. 52, no. 2, 2020.

[54] M. Langbroek, Artist, Starlink Satellite train. [Art]. SatTrackCam, 2019.

[55] A. Mallama and J. Hilton, “Computing apparent planetary magnitudes for The Astronomical Almanac,” Astronomy and Computing, vol. 25, pp. 10-24, 2018.

[56] Y. Wang, X. Du, J. Zhao and R. Gou, “Apparent magnitude calculation method for complex shaped space objects,” Advances in Space Research, vol. 62, no. 11, pp. 2988-2997, 2018.

[57] E. Schulman and C. V. Cox, “Misconceptions about astronomical magnitudes,” American Journal of Physics, pp. 1003-1007, 1997.

[58] J. Heamshaw, “ An analysis of Almagest magnitudes for the study of stellar evolution,” New Astronomy Reviews, vol. 42, no. 1, pp. 403-410, 1999.
wolf optimization algorithm. Flow Meas. Inst.um. 2018, 64, 164–172

[78] Roshani, G. et al, Usage of two transmitted detectors with optimized orientation in order to three phase flow metering. Measurement 2017, 100, 122–130, doi: 10.1016/j.measurement.2016.12.055

[79] E. Nazemi, et al, Optimization of a method for identifying the flow regime and measuring void fraction in a broad beam gamma-ray attenuation technique, international journal of hydrogen energy, 41, (2016) 7438-7444

[80] P. Lalbakhsh, B. Zaeri, A. Lalbakhsh, and M. N. Fesharaki. "AntNet with reward-penalty reinforcement learning." In 2010 2nd International Conference on Computational Intelligence, Communication Systems and Networks, pp. 17-21. IEEE, 2010.

[81] Bahram Zaeri and A. Lalbakhsh, "An Improved Model of Ant Colony Optimization using a Novel Pheromone Update Strategy," IEICE Trans. Inf. & Syst. Vol. E96-D, No.11, pp. 2309-2318, Nov. 2013. DOI: 10.1587/transinf.E96.D.23

[82] Roshani, M.; Phan, G.; Roshani, G.H.; Hanus, R.; Nazemi, B.; Corniani, E.; Nazemi, E. Combination of X-ray tube and GMDH neural network as a nondestructive and potential technique for measuring characteristics of gas-oil–water three phase flows. Measurement 2021, 168, 108427, doi: 10.1016/j.measurement.2020.108427

[83] Sattari, et al Applicability of time-domain feature extraction methods and artificial intelligence in two-phase flow meters based on gamma-ray absorption technique. Measurement 2021, 168, 108474, doi:10.1016/j.measurement.2020.108474

[84] Feghhi, S.A.H., Mahmoudi-Aznaveh, A., Nazemi, E. and Adineh-Vand, A., 2014. Precise volume fraction prediction in oil–water–gas multiphase flows by means of gamma-ray attenuation and artificial neural networks using one detector. Measurement, 51, pp.34-41

[85] Nazemi, E. Intelligent densitometry of petroleum products in stratified regime of two phase flows using gamma ray and neural network. Flow Meas. Instum. 2017, 58, 6–11, doi:10.1016/j.flowmeasinst.2017.09.007

[86] G.H. Roshani, E. Nazemi, S.A.H. Feghhi, Investigation of using 60Co source and one detector for determining the flow regime and void fraction in gas-liquid two-phase flows, Flow Measurement and Instrumentation, 50 (2016) 73–79.

[87] S. A. H. Feghhi and S. Setayeshi, Flow regime identification and void fraction prediction in two-phase flows based on gamma ray attenuation, Measurement 62 (2015) pp. 25–32

[88] Phan, G.T, et al, Evaluation of flow pattern recognition and void fraction measurement in two phase flow independent of oil pipeline’s scale layer thickness. Alex. Eng. J. 2021, 60, 1955–1966, doi:10.1016/j.aej.2020.11.043

[89] Roshani, M.; Phan, G.; Faraj, R.H.; Phan, N.-H.; Roshani, G.H.; Nazemi, B.; Corniani, E.; Nazemi, E. Proposing a gamma radiation based intelligent system for simultaneous analyzing and detecting type and amount of petroleum by-products. Nucl. Eng. Technol. 2020, doi:10.1016/j.net.2020.09.015

[90] BM Karambasti et al., Design methodology and multi-objective optimization of small-scale power-water production based on integration of Stirling engine and multi-effect evaporation desalination system, Desalination 526, 115542, 2022.

[91] Karami, A. et al, Enhancing the performance of a dual-energy gamma ray based three-phase flow meter with the help of grey illumination.

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From 2018 to 2020, Karu chaired the prestigious Distinguished Lecturer Program Committee of the IEEE Antennas and Propagation (AP) Society – the premier global learned society dedicated for antennas and propagation - which has close to 10,000 members worldwide. After two stages in the selection process, Karu was also selected by this Society as one of two candidates in the ballot for 2019 President of the Society. Only three people from Asia or Pacific apparently have received this honour in the 68-year history of this Society. Karu is also one of the three Distinguished Lecturers (DL) selected by the Society in 2016. He is the only Australian to chair the AP DL Program ever, the only Australian AP DL in almost two decades, and second Australian AP DL ever (after UTS Distinguished Visiting Professor Trevor Bird). He has served the IEEE AP Society Administrative Committee in several elected or ex-officio positions 2015-20. Karu is also the Chair of the Board of management of Australian Antenna Measurement Facility and was the elected Chair of both IEEE New South Wales (NSW), and IEEE NSW AP/MTT Chapter, in 2016 and 2017.

Karu has authored over 600 research publications and his papers have been cited over 11,000 times. In 2020 his publications received over 1,200 citations. His h-index is 52 and i-10 is 191. He is in world’s top 100,000 most-cited scientists list by Mendeley Data. Since 2002, his research team has been involved with research grants, contracts and PhD scholarships worth about 20 million dollars, including 15 Australian Research Council grants, without counting the 245 million-dollar SmartSat Corporative Research Centre, which started in 2019. His research has been supported by many national and international organisations including Australian Research Council, Intel, US Air Force, Cisco Systems, Hewlett-Packard, Australian Department of Defence, Australian Department of industry, and German and Indian governments.

Karu’s awards include Runner-up to 2020 Australian national Eureka Prize for Outstanding Mentor of Young Researchers, 2019 Motohisa Kanda Award (from IEEE USA) for the most cited paper in IEEE Transactions on EMC in the past five years, 2019 Macquarie University Research Excellence Award for Innovative Technologies, 2019 ARC Discovery International Award, 2017 Excellence in Research Award from the Faculty of Science and Engineering, 2017 Engineering Excellence Award for Best Innovation, 2017 Highly Commended Research Excellence Award from Macquarie University, 2017 Certificate of Recognition from IEEE Region 10, 2016 and 2012 Engineering Excellence Awards for Best Published Paper from IESL NSW Chapter, 2011 Outstanding Branch Counsellor Award from IEEE headquarters (USA), 2009 Vice Chancellor’s Award for Excellence in Higher Degree Research Supervision and 2004 Innovation Award for best invention disclosure. His mentees have been awarded many fellowships, awards and prizes for their research achievements. Fifty-five international experts who examined the theses of his PhD graduates ranked them in the top 5% or 10%. Two of his recent students were awarded PhD with the highest honour at Macquarie University – the Vice Chancellor’s Commendation.

Karu has provided expert assistance to more than a dozen companies including Intel, Hewlett Packard Laboratory (USA), Cisco Systems (USA), Audacy (USA), Cochlear, Optus, ResMed and Katherine-Werke (Germany). His team designed the high-gain antenna system for the world’s first entirely Ka-band CubeSat made by Audacy, USA and launched to space by SpaceX in December 2018. This is believed to be the first Australian-designed high-gain antenna system launched to space, since CSIRO-designed antennas in Australia’s own FedSat launched in 2002.

Karu is in the College of Expert Reviewers of the European Science Foundation (2019-22), and he has been invited to serve as an international expert/research grant assessor by several other research funding bodies as well, including the European Research Council and funding agencies in Norway, Belgium, the Netherlands, Canada, Finland, Hong-Kong, Georgia, South Africa, and Chile. He has been invited by Vice-Chancellors of Australian and overseas universities to assess applications for promotion to professorial levels. He has also been invited to assess grant applications submitted to Australia’s most prestigious schemes such as Australian Federation Fellowships and Australian Laureate Fellowships. In addition to the large number of invited conference speeches he has given, he has been an invited plenary/extended/keynote speaker of several IEEE and other conferences and workshops including EuCAP 2020 Copenhagen, Denmark, URSI’19 Seville, Spain; and 23rd ICECOM 2019, Dubrovnik, Croatia.

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