Associate Prof. Dr. Tarun Varma, 2021, 9:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

Next Generation Satellite Design Challenges and Solutions

Associate Prof. Dr. Tarun Varma, Associate Prof. Dr. Laxminarayan Gahalod
Associate Prof. Dr. Shravan Kumar Sable
LNCT, Bhopal, MP, India
tarunv@lnct.ac.in, laxminarayang@lnct.ac.in, shravans@lnct.ac.in,

Abstract- Remote observations of Earth from space serve an extraordinarily broad range of purposes, resulting in extraordinary demands on those at the different space centers like National Aeronautics and Space Administration (NASA),Indian space research organization (ISRO) ,National Oceanic and Atmospheric Administration (NOAA).Earth observations promise large volumes of data to a variety of disciplines with differing needs for measurement type, simultaneity, continuity, and long-term instrument stability. Operational needs, such as weather forecasting, add a distinct set of requirements for continual and highly reliable monitoring of global conditions. The Role of Small Satellites in NASA and NOAA Earth Observation Programs confronts these diverse requirements and assesses how they might be met by small satellites. The preferred architecture for space missions was a single large spacecraft platform containing a sophisticated suite of instruments. But the recognition in other areas of space research that cost-effectiveness, flexibility,

Keywords- NASA, ISRO, NOAA, Small Satellites etc.

I. INTRODUCTION

In recent years space has experienced an exponential growth, at a global level, of new platforms and services, causing an inherent threat to frequency spectrum availability and security.Current surveys shows this trend is not slowing down.The rapid rise in non-geostationary (non-GSO) constellations and associated earth stations, both fixed and mobile, the hybridization of communication platforms, the ever-increasing complexity of very high throughput satellites (VHTS) and, last but not least, more nations having the capability to access space through cheaper technology and launchers, should be a concern to the regulatory authorities.

More generally, it should be a concern to the entire space industry. Communications satellites are usually categorized based on how high over the earth they orbit. Orbits very near the earth are called low-earth orbit (LEO), those a bit further out medium-earth orbit (MEO), and those quite a bit further out, so that their orbit matches the rotation of the earth are called geo-stationary orbits (GSO). The great thing about a GSO, is that it looks like the satellite stays still from the earth. This means you can point a dish at the satellite, and not have to keep moving it to track the satellite.The international space station is in an LEO, about 400 km above the earth; in part because the higher you want to go, the more energy it takes. But these cheaper, low orbits will decay more quickly, and thus need to carry more fuel to maintain orbit. In contrast, a GSO is a much, much higher orbit requiring much more energy to reach, and thus costs more to launch a satellite into. On the up-side, you don't need as much fuel to stop it from spiraling in towards the earth.

GSO communications satellites tend to be quite big, so that they can last a long time. Since they need to be big, and are expensive to launch, they tend to be decked out with as much communications capacity as possible.All this means that once you have launched your communications satellite, you need it to earn a lot of money. Satellite TV is good for this, because you can get regular income from lots of TV stations, often £500,000 per month or more. Satellite telephony is harder to do. This is because you either need LEO satellites, so that a small telephone can reach them (a story for another day), or you need to buy the exclusive rights to a particular frequency over a wide area, so that you can avoid interference from other satellites. Satellite TV does this using a receiver dish, but a phone with a dish wouldn't be that popular!

The other problem with satellite telephony, is that you need lots of subscribers, because each spends only a small amount. Prices are even higher if the service is special in some way, for example, if they have exclusive use of a frequency band over a large part of the earth, thus reducing interference, making a smaller dish or even a normal antenna possible. We only need to receive, not transmit, and our partners have created a new receiver using some innovative tricks. Basically, they can get the same benefit of being able to receive a signal from a satellite, without needing to use a dish but without having to use one of these premium exclusive-frequency services. The power of these monopoly services (and their value to customers who need it) is clearly demonstrated in the cost difference of the two alternatives being a factor of 10x or more.

However, while our partners had solved the technical problem, they were still not in a position to re-launch service over the Pacific for our development and testing. Issues such as frequency spectrum being more and more congested, leading to a potential increase in interferences and less-than-scrupulous firms accessing space without proper coordination, thus jeopardizing orbits with the risk of exponential debris creation, are two of the main concerns. Several leading developments in this field can be noted. New networks 5G and above are required to be very fast and have high capacity and minimum interference.

The Internet of Things (IoT) promotes the connection of trillions of IoT devices to the Internet. Cloud Computing and XAAS move from computing ownership to computing services over communication networks. The phenomenal growth of social networks, e-commerce, and e-delivery are attracting numerous people around the world. Most of the countries and people in the world still have little exposure to advanced communication networks. These examples demonstrate the huge demand for immediate expansion of the global communication medium and design infrastructure.

Current Scenario

Satellite communications seem to be the most appropriate and promising approach to cope with the huge demand for a comprehensive, high-capacity, stable, fast, and safe global data transmission system. However, satellite communications are undergoing several challenges such as satellite deployment coverage and optimization, signal attenuation due to climate, the impact of global warming, high-frequency channels, inter-satellite communication optimization, management of a network of satellites, satellite–earth interfacing, extended cyber security risks, interfaces, standards, and protocols in all layers and more.

There are already several developments in this field such as the initiative to deploy about 42K satellites in the sky or the recent initiative to deploy communication balloons using very high frequencies and millimeter waves, advancements in free-space lasers, and optical communication. The objective of this Special Issue is to present studies in the field of satellite communications. The issue will address the obstacles that lay ahead, original studies of models, and methods that can overcome thephysical and technical boundary conditions, considering technical, economic, and environmental aspects.

II.CURRENT CHALLENGES & ISSUES

Although the spectacular progress in Space Technologies slowed down toward the end of the past century, together with that of the whole Aerospace sector, very important achievements continued to be made. These include the development of the International Space Station and the robotic exploration of other planets and celestial bodies, including landing on a comet. Through the years, space has often been identified as the new frontier, fueling the imagination of writers and film directors, who created visions (more or less plausible) of a future enabled by fantastic developments in Space Technologies.

However, consistent with what history has shown us, is the fact that, after an initial phase of exploration of a new environment and consolidation of the relevant technologies, what follows is an explosion of businesses to exploit the new opportunities offered by the new environment. The need for new solutions National administrations should strive to provide radio space monitoring capabilities to guarantee reliable licensing and orbital usage, as well as interference-free operation for all the different services.Basic fixed radio-frequency measurement sites are no longer enough to ensure the thorough test and verification of non-GSO and VHTS space stations.New solutions, sensors and measurement techniques need to be introduced. Mobile and airborne sensors will be the tools of the future allowing for distributed measurements over vast or hardly accessible territories.

As an example, the measurement of emissions from GSO and non-GSO space stations to verify compliance with the ITU equivalent power flux density (EPFD) recommendation is causing a lot of head scratching. Future space constellations will add another aspect to the monitoring mission that have so far been consigned to a handful of space stations. This includes a dynamic and complex structure with transient conditions that could be detected only by deploying a much higher number of sensors.

As this is evidently not economically viable, more ingenious ways need to be used. The ability to collect and correlate data not only limited to the radio frequency (RF) elements, scalable and transportable sensors that could be dynamically reconfigured, and on-board signal processing capabilities are among the most promising developments to mitigate this.
New Space and the Need for Appropriate Regulatory Framework Entering a domain traditionally occupied by institutional players ("Old Space" e.g., space agencies working with large companies) to exploit the new opportunities opening in front of them. These could include new services, offered through applications of space data (from precision navigation/agriculture, surveillance, to Earth environment monitoring, etc.), to more futuristic opportunities, such as space tourism or asteroid mining.

Successful entrepreneurs from other sectors, from Richard Branson in the UK to Elon Musk in the US, have entered the "space" arena, taking risks and challenging the conservatives of the established "Old Space" business model. Here is where we can identify a first challenge and learn a lesson from history, preventing space from becoming a lawless "wild west" where the strongest can take an unfair advantage. This should apply to Low Earth Orbit (LEO), where the current regulatory framework should be further developed and enforced to manage the increasing space traffic as well as to Medium (MEO) or Geosynchronous Earth Orbit (GEO) and interplanetary exploration and exploitation. Indeed, new regulations should be implemented respecting established treaties and principles In areas where an appropriate regulatory framework is already in operation and largely followed by all the stakeholders, like the satellite telecommunication sector, the challenge becomes to stay abreast with technology progress and market evolution. Together with the challenge, there is an opportunity to develop new regulations that spur further technological progress.

The issue of the overcrowded radio-frequency spectrum, as well as the sustainability of the space environment which is threatened by the growing amount of space debris, have to be tackled. Solutions that are acceptable to the various stakeholders (from commercial organization to political entities) have to be found and, most importantly, implemented.

Activities in space cannot be contained within the boundary of a country's border and have the potential to affect assets or areas of the planet well-beyond the jurisdiction of a launching country or the nation where a satellite operator is registered. Therefore, the international regulatory framework should clearly prevail on national regulations and limit the capability of countries to use less stringent regulations as a means to attract foreign business. At the same time, some consideration also has to be given to how to enforce at an international level the agreed rules and regulations.

Indeed, the development of rules and regulations must be mitigated to avoid unnecessary red tape stifling new enterprises, and space law should preserve the freedom to generate new ideas and implement new applications. Hence the challenge lies in balancing these competing requirements: a regulatory framework which protects stakeholders, countries' interests, and current and future human rights on one side, with the freedom to develop and exploit new technologies on the other.

II.TECHNICAL CHALLENGES

1.Propulsion Systems

Coming now to the more technical challenges, propulsion systems performance is a significant hurdle to overcome in the space sector.Starting with the launch vehicles, their capabilities (broadly speaking, payload size and thrust) have essentially platitude, as only relatively minor incremental progress has been made in the last decades. Indeed, materials have improved with the introduction of composites with mechanical properties far superior to the typical alloys that were used at the beginning of the space age. Design and manufacturing techniques have also improved, with progress in software simulation enabled by the extraordinary growth of computer power, or new manufacturing methods such as additive manufacturing.

Guidance and control systems have also improved thanks to advances in electronics and software. However, besides the push toward green propellants, nothing substantial has changed with the solid or liquid propellants performance and related technologies, which are key to overall launcher capability. Reusable launchers are being used by a few companies in order to reduce costs or increase launch frequencies, and it is undeniable that costs have slowly come down, although this is largely due to combinations of countries' policies and market forces, but truly economic access to space is yet to be achieved.

On a longer timescale, the challenge is to develop and implement technologies, such as hypersonic air breathing rocket engines2, to be used in hybrid launchers to cut the need for large amounts of oxygen that have to be carried by current vehicles. Launch vehicles that could take off and land as aircraft, without the need for extensive and expensive service between missions, should also be developed. Similarly, in-space propulsion offers opportunities for improvement, in particular on Electric propulsion systems, which are also hybrid systems that would utilize different modes of operation.

Propulsion systems performances are also fundamental to interplanetary missions in terms of enabling faster travel and larger payloads to be delivered where required. Our current limitations in the manned exploration of the solar system are mainly due to the length of travel, which is directly related to the level of performance that is available from existing propulsion systems. Similarly, propulsion systems performance limits our exploration and exploitation capabilities (also for robotic activities) as it is a significant limitation to the mass of payload that can be safely transported to/from other celestial bodies.

2.Protection of Humans

Strictly related to human exploration are space health and medicine, to enable humans to withstand the space environment for long periods, and the creation of artificial habitats in space and on other planets to support a reasonable quality of human life. The challenge here consists in the creation of a whole artificial environment to support people's well-being and physical and mental health, with means protecting against the negative effects of the space environment. Whether we are considering a man-made vessel for long distance space travel or a space platform for large-scale human inhabitation or a planetary colony, some challenges overlap.

These overlapping challenges include the need to create efficient closed loop systems to replenish resources and minimize waste, with the common goal to generate an artificial ecosystem for the long-term support of human life Another aspect of our need to protect and preserve human life is the issue of planetary defense. Near Earth Objects like asteroids or comets can pose a significant threat. Although smaller objects (such as meteors) hit our planet daily and mostly burn up whilst traveling though the atmosphere, some larger objects can survive and hit the Earth's surface with significant energy.

Most of the craters produced by the larger objects that have hit Earth since its formation have been erased by the planets geological processes, but there are dozens of large craters still visible (a great example is the 1 kilometer wide Barringer Meteor Crater in Arizona, which was formed ~50,000 years ago by the impact of a metallic object ~50 m in diameter) that serve as reminders that these impacts can occur. Depending on the size of the object, which could be 100's of meters or kilometers in diameter, and the location of the impact, consequences could range from relatively minor damage, to a major catastrophe that could destroy life on vast regions of the planet, if not all life entirely.

Fortunately, the probability of these events is very low, but their consequences are dramatic, hence appropriate mitigation strategies must be developed. All major space organizations have given some attention to this issue,the United Nations have taken good steps to improve coordination, establishing the International Asteroid Warning Network and the Space Mission Planning Advisory Group (SMPAG). However, as this is a global threat, a greater level of international coordination and integration of the efforts made by single entities is necessary to produce an effective response. Should the threat of catastrophic impact from a large asteroid materialize, the world cannot afford a disorderly and fragmented response, such as that seen with past global crises (e.g., the Covid-19 pandemic). Time will be limited so the plans have to be prepared and agreed upon, ready to be executed in order to produce a timely response and perform the necessary mission.

From a technical perspective, besides the challenges to improve detection capabilities and potential impact predictions, the development and testing of methodologies and technologies to deflect a large object (as this currently seems the most realistic and effective method of intervention) have to progress to the point that it could be deployed with a high level of confidence in its success.

3.Earth Environment

Following the theme of the protection of the Earth, climate change is a significant threat to our environment with potentially disastrous consequences, and is an area where Satellite Technologies can help in tackling the challenge. On a global scale, satellites provide impartial information to monitor the environment and develop and validate models improving our predictive capabilities. But greater effort has to be placed in producing actionable information related to specific needs and issues, reducing the vast amount of data to simpler interpretations that can inform the political discourse.Both institutional and private Earth Observation (EO) markets demand very high resolution and coverage, as well as a short revisit time, with the aim to achieve real time Earth Observation. From surveillance to disaster monitoring and management of resources, there are literally hundreds of applications, but still there is a relatively low market adoption. This becomes obvious if we compare satellite EO with satellite telecommunications, as in the latter sector there is an abundance of purely commercial organizations that operate (without institutional support) in a user-driven market, whereas the EO market is still most often enabled by institutional budgets. There is a clear trend toward a more commercial EO sector that is facilitated by smaller sized and cheaper satellites and several companies offering cost effective solutions promising technically-acceptable performance at a price that the market can bear. However, there is very high competition in a market that still has too small a number of customers.

4.Low Cost Space Technologies

This democratization and mercerization of space is evident in the growth of the cub satmarket. Here, space HW is available at prices so low that it has attracted a growing number of customers (from Space Agencies to institutions like universities and schools), which in turn have enabled the creation of start-ups and spinoffs. However, the performance of these systems is very limited, and often the constraints come from their physical size (e.g., the size of the optics limits the resolution that can be achieved, or the size of the solar panels limits the amount of power that can be collected).

This has led to the development of deployable structures to package relevant elements into small (cube sat compatible) volumes and then deploy them in space to achieve the required level of performance. Sometime these act as demonstrations for applications aimed at larger satellites, like drag sails.There are other technical issues that affect all smaller mass satellites, not just cube sats, and present significant challenges, like the need to achieve high platform stability. This is crucial for all missions supporting highly accurately targeted optical payloads (e.g., high-resolution cameras/telescopes or laser communication systems) or devices that demand stability for inertial types of measurements.

The issue lies with the minimization of the micro-vibrations that are produced by essential on-board equipment, and that can, for example, produce unacceptable oscillations of the line of sight. This issue is more severe for smaller craft as there is less mass (inertia), which naturally reduces the vibration level. Ground testing and modeling to predict in-orbit performance are still inaccurate and practical applications rely on the use of large margins rather than accurate models. Active control of micro-vibrations is still very difficult and too expensive to be implemented, in particular at the lower end of the market, where most growth is expected. In terms of their overall performance, cubesat capabilities are often oversold to an inexperienced public, and there is a general need for higher quality products with the involved hardware that still maintain affordability.

5.Large Space Structures

At the other end of the spectrum, with respect to cubesats, in terms of size, are Large Space Structures (LSS). These have been considered and studied for decades, but real progress has been slow.The capability to deploy LSS is another factor that, similarly to advances in propulsion, would enable a range of applications, but they present a series of significant challenges which depend on the specific areas.On the one hand there are instruments like telescopes, cameras, and antennas that require large (>10 m and possibly an order of magnitude larger) high-precision reflective surfaces.

Here the current methodologies (e.g., based on the deployment of precisely machined and polished mirrors whose positions and shape can be adjusted by a series of actuators) are limited by the size and number of segments that can be deployed [e.g., James Webb Space Telescope (JWST)4], and the overall staggering cost.

Concerning the antennas, a variety of deployable solutions have been proposed, from inflatable to tensegrity structures, but Europe still needs to develop an appropriate commercial solution for current and future applications. Overall, new lighter-weight technologies have to be deployed, to increase packaging efficiency without compromising the quality of the final reflector.On the other hand, there are future applications like Satellite Solar Powerwhere the sheer size of the structure (square kilometers) is the challenge, rather than the geometrical precision that must be achieved by the assembled structure. Extreme light weight and packaging efficiency have to be achieved, as well as in-orbit deployment and assembly capabilities that are beyond the state of the art.

In-Orbit Servicing and Active Debris Removal

This brings us to the opportunities offered by robotic in-orbit servicing and the development of flexible technologies that can support multipurpose missions. These opportunities include the servicing and potential repairing of current satellites, to active debris removal.

These are not new concepts, as in 1984 the Space Shuttle Discovery mission STS-51-A, brought back to Earth two old satellites no longer functioning (probably the first example of Active Debris Removal), and similarly the mission of the shuttle Endeavor in 1993 (and other following missions) provided essential fixes and services to the Hubble Space Telescope. However, the opportunity here is to develop robotic technologies able to perform these types of missions at a fraction of the cost. The non-cooperative nature of the target, which could be tumbling, presents the first challenge to any approaching vehicle that has to rendezvous with this object.

Techniques to stabilize the target and devices to safely grasp it have to be developed (and standardized) as well as improvements made in the relative navigation (vision-based navigation), hardware, and software. Some progress has been made and some devices tested in-orbit, but we are still far from a real capability to perform Active Debris Removal or in-orbit servicing with sufficient confidence and at an affordable price.

III.CONCLUSION

This Paper has described some of the challenges that the space sector is facing, but there are more, and these come with opportunities for new developments (for example, those offered by multifunctional space structures, or technologies like optical and quantum inter satellite communication. The solutions to the various issues, which in time will be developed, will provide stepping stones for future applications and enterprises that will benefit societies across the world.

REFERENCES

[1]Aglietti, G. S., Taylor, B., Fellowes, S., Salmon, T., Retat, I., Hall, A., et al. (2020). The active space debris removal mission RemoveDebris. Part 2: in

orbit operations. Acta Astron. 168, 310–32.doi: 10.1016/j.actaastro.2019.09.001

[2]Brünner, C., Königsberger, G., Mayer, H., and Rinner, A., (eds.) (2018). Satellite-Based Earth Observation Trends and Challenges for Economy and Society. Springer.

[3]Cukurtepe, H., and Akgun, I. (2009). Towards space traffic management system. Acta Astron. 65, 870–878. doi: 10.1016/j.actaastro.2009.03.063

[4].Davoli, F., Kourogiorgas, C., Marchese, M., Panagopoulos, A., and Patrone, F. (2019). Small satellites and CubeSats: survey of structures, architectures, and protocols. Int. J. Satellite Commun.Netw. 37, 343–359. doi: 10.1002/sat.1277

[5]Devezas, T. C. (2018). Space propulsion: a survey study about current and future technologies. J. Aerosp. Technol. Manage. 10. doi: 10.5028/jatm.v10.829. [Epub ahead of print].

[6]Forshaw, J. L., Aglietti, G. S., Navarathinam, N., Kadhem, H., Salmon, T., Pisseloup, A., et al. (2016). RemoveDEBRIS: an in-orbit active debris removal demonstration mission. Acta Astron. 127, 448–463. doi: 10.1016/j.actaastro.2016.06.018

[7].Gohardani, A. S., Stanojev, J., Demairé, A., Anflo, K., Persson, M., Wingborg, N., et al. (2014). Green space propulsion: opportunities and prospects. Prog.Aerosp. Sci. 71, 128–149. doi: 10.1016/j.paerosci.2014.08.001

[8]Grimm, D. (2019). Guest edited collection: gravitational biology and space medicine. Sci. Rep. 9:14399. doi: 10.1038/s41598-019-51231-8

[9].Hall, M. (2020). Space Philosophies: Who, How, What?.Space Daily. Available online at: https://www.spacedaily.com/reports/NewSpace_Philosophies_Who_How_What_999.html

[10].Hodkinson, P. D., Anderton, R. A., Posselt, B. N., and Fong, K. J. (2017). An overview of space medicine. Br. J. Anaesth. 119, i143–i153.doi: 10.1093/bja/aex336

[11] ITU (2012). Regulation of Global Broadband Satellite Communications. Available online at: http://www.itu.int/ITU-D/treg/broadband/ITU-B~Reports_RegulationBroadbandSatellite.pdf

[12] Lal, B., Balakrishnan, A., Caldwell, B. M., Buenconsejo, R. S., and Carioscia, S. A. (2018). Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM).IDA Document D-9074 Science & Technology Policy Institute.

[13]Levchenko, I., Xu, S., Mazouffre, S., Lev, D., Pedrini, D., Goebel, D., Garrigues, L., et al. (2020). Perspectives, frontiers, and new horizons for plasma-based space electric propulsion editors-pick. Phys. Plasmas 27:020601. doi: 10.1063/1.5109141

[14].Liao, S., Yong, H., Liu, C., Shentu, G.-L., Li, D-D., Lin, J., et al. (2017). Long-distance free-space quantum key distribution in daylight towards inter-satellite communication. Nature Photon 11, 509–513. doi: 10.1038/nphoton.2017.116

[15] Morozova, E., and Vasyanin, Y. (2019). International Space Law and Satellite Telecommunications.Oxford Research Encyclopedia of Planetary Science. Available online at: https://oxfordre.com/planetary science/view/10.1093/acrefore/9780190647926.001.0001/acrefore-9780190647926-e-75

[16].Office of Audits (2014). NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards IG-14-030 (A-13-016-00).Office of Audits - Audit Report.

[17]Pelton, J. N., Madry, S., and Camacho-Lara, S. (2017). Handbook of Satellite Applications. Springer.

[18].PWC Report (2019). Main Trends and Challenges in the Space Sector. Available online at: https://www.pwc.fr/fr/assets/files/pdf/2019/06/fr-pwc-main-trends-and-challenges-in-~the-space-sector.pdf

[19].Remedia, M., Aglietti, G. S., and Richardson, G. (2015) A stochastic Methodology for predictions of the environment created by multiple microvibration sources. J. Sound Vibr. 344, 138–157. doi: 10.1016/j.jsv.2015.01.035

[20]Rycroft, M. J., and Crosby, N. (2013). Smaller Satellites: Bigger Business?: Concepts, Applications and Markets for Micro/Nanosatellites in a New Information World. Springer.

[21]Sairajan, K. K., Aglietti, G. S., and Mani, K. M. (2016). A review of multifunctional structure technology for aerospace applications. Acta Astron. 120, 30–42. doi: 10.1016/j.actaastro.2015.11.024

[22].Simpson, M. K. (2015). "Planetary defense, global cooperation and world peace," in Handbook of Cosmic Hazards and Planetary Defense, eds J. Pelton and F. Allahdadi (Cham: Springer), 1055–1067.

[23]Turner, M. J. L., Salgado, M. C. V., and Belderrain, M. C. N. (2009). Rocket and Spacecraft Propulsion: Principles, Practice and New Developments, 3rd Edn. Springer; Praxis Books.

[24].Underwood, C., Denis, A., Viquerat, A., Taylor, B., Sanders, B., Stewart, B., et al. (2019). Inflatesail de-orbit flight demonstration results and follow-on drag-sail applications. ActaAstronautica 162, 344–358. doi: 10.1016/j.actaastro.2019.05.054

[25]Wilde, M., Harder, J., and Stoll, E. (2019). On-orbit servicing and active debris removal: enabling a paradigm shift in spaceflight. Front. Robot.AI. 6:136. doi: 10.3389/frobt.2019.00136

[26].Wuebbles, D. J. (2012). Celebrating the "Blue Marble". EOS Trans. Am. Geophys. Union 93, 509–510.doi:10.1029/2012EO490001