NEW SPACE AND SPACE 4.0

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New Space / Space 4.0 shall have a huge potential to profoundly change our live on earth -Credit: NSR

1. INTRODUCTION AND CONCEPTS

During the first decades of the 21st century, humanity's approach to space has undergone significant changes. The European Space Agency (ESA) has referred to these changes as **Space 4.0**. The first space era dealt with astronomical observation, whereas during the second space age, nation-states sent objects and people into outer space. The third space age was marked by cooperation between national space agencies and culminated in the construction of the International Space Station (ISS). Space 4.0 is characterized by opening space to private and academic organizations and individuals.[1]

According to Jan Wörner, Director General of ESA, *"Space 4.0 will be the driver for contemporary technologies in automation, miniaturization, advanced manufacturing, machine to machine/human interaction, connectivity, big data, biotechnology and more. It stimulates the interaction of different sectors with spin-in, spin-off and spin-together.*

Space 4.0 marks a new era, in which space is an enabler. It enables knowledge, jobs and growth, decision and policymaking, inspiring and motivating the next generations." [2]

And NewSpace? It can be thought of it as a subset of Space 4.0 or the most visible consequence of Space 4.0 or even as a synonym of it.

In fact, precisely defining the meaning of NewSpace is not a simple task, as it involves many different topics. NewSpace can have a multitude of meanings, from delivering basic connectivity in underserved areas to developing a village on the moon and the prospect of using it to go deeper into space. But whatever the meaning is, this space industry reinvigoration is inspiring nations - both in developed and developing regions of the world - to look at space differently.[3]

NewSpace means access to space. Not only for the few, but for the many. With NewSpace comes the notion of democratization in access to space - a feeling that space is for everyone and that, if there is a desire to become part of it, it can become a reality. There is a new attitude towards space and how it can be used, and in general nations with an innovative profile are eager to get involved. Nations are beginning to believe that they can also be part of space.

Today, the satellite industry is in the midst of the NewSpace revolution, dominated not by satellite developers, but by service providers. Racing to offer space-based Earth imaging, communications, connectivity, and/or monitoring services (to name a few) at viable price points, these NewSpace ventures have taken the extraordinary step of bringing small satellite manufacturing operations inhouse.[4]

From a technical point of view, NewSpace is an approach that focuses on lowering the barriers to entry to space industry, by providing cheaper access to space (where reusable rockets and ride share are major drivers) and the development of small and nano satellites in low/medium orbit more provides high-quality and affordable data from space that can be put to use here on Earth, for the benefit of scientists and the general public.

Actually, this seems to be one of the major characteristics of the NewSpace era – the fundamental shift from an industry which was heavily dependent on government agencies (and taxpayers' money) to a more agile and an independent private sector that relies on innovation, working with much smaller budgets than the early space industry.[5]

A great driver of this shift was the globalization of the "cubeSat" concept.

Started in 1999, the CubeSat Project began as a collaborative effort between Prof. Jordi Puig- Suari at California Polytechnic State University (Cal Poly), San Luis Obispo, and Prof. Bob Twiggs at Stanford University's Space Systems Development Laboratory (SSDL). The purpose of the project is to provide a standard for design of picosatellites to reduce cost and development time, increase accessibility to space, and sustain frequent launches. Presently, the CubeSat Project is an international collaboration of over 100 universities, high schools, and private firms developing picosatellites containing scientific, private, and government payloads.[6]

A 1U CubeSat is a 10 cm cube with a mass of up to 1.33 kg, and a nU cubeSat will be "n" cubeSats assembled together, such as 1U , 1.5U, 3U, 3U+.

In the NewSpace era, small satellites are being manufactured not as end products but as platforms to provide space-based services. These integrated companies directly manage larger verticals, including the marketing and sales of the services as well as construction and operation of the satellites. NewSpace companies are data service providers that keep manufacturing inhouse as a way of controlling costs. Indeed, its business models are predicated upon stringent cost-effectiveness in highly competitive markets.

But the concept of NewSpace, in our opinion, could have a broader reach, including GEO satellites also, since new concepts and technologies have also shaken up the ecosystem.

Examples are the development and launching of HTS and VHTS (High and Very High Throughput Satellites) systems with their inherent capacity of lowering the cost per MBps, leveraged by the use of Software Defined Platforms, usually associated with smart antennas capable to produce dynamic reconfigurable beams and the application of Artificial Intelligence (AI) to learn and respond fast to customer's demand change.

2. NEW SPACE, NEW TECHNOLOGIES

As mentioned before, we can say that NewSpace/Space 4.0 is characterized by the explosion of new satellite systems with creative solutions and increased flexibility and capacity.

These features are made feasible by the combination of the following technology achievements:

2.1 MEO and LEO Constellations

Along the last two decades (2010 – 2020), the world has seen dramatic technological advances in space, translated for instance in development of advanced state-of-the-art spaceflight qualified digital application-specific integrated circuit (ASIC) technologies, which has resulted in more than a 1000× decline in the energy required for satellite operation and in commensurate cost reduction in this period.[7] This and other technologies achievements provided a solid ground for the development and deployment of a large number of medium, small, nano and picosatellites / CubeSats constellations, with several benefits for mankind, such us broadband internet access to underserved population, as well as low cost and low latency fixed and mobile broadband communications everywhere.

In particular, the latest generation of low-cost small satellites, especially the CubeSats, have already proven very useful for providing connectivity for local or global Internet of Things (IoT) applications. The same is true for scientific research given how inexpensive and flexible they are, having the added advantage of rapid construction with off-the-shelf components.[8]

In the larger smallsat arena, heading the news in 2020 where Starlink, OneWeb, Telesat (It has performed 20 tests with different operators and service providers including Telefonica. In addition, has filed for an extension to build a constellation of up to 1,600 satellites to cater to future demand), Amazon's Kuiper constellation (with an impressive number of smallsats and funding from the richest man in the world, with commitment to invest US$ 10 B on the project) and SES, which contracted four more O3b mPOWER satellites at $566 million.[9]

Last, but not least, there are the Chinese. At least four Chinese low-Earth orbit (LEO) satellite constellations oriented toward broadband communication shows that their ambitions on the NGSO arena have to be taken seriously:

- Hongyun, which plans 864 satellites and will emphasize service in China's remote regions;
- Hongyan, which plans around 320 satellites, in principle target to the maritime, aviation, and mobile backhaul service markets and;
- Galaxy Space, which seems to be focused on 5G backhaul and Internet of things applications and plans to deploy almost 13,000 small satellites on Ka and V bands.[10]

A interesting case happened with OneWeb: after filing for Chapter 11 bankruptcy protection in March 2020, OneWeb filed an application to expand its fleet to ~48 000 smallsats in May. The original Phase Two proposal filed with the FCC, envisioned a system with 32 planes of 720 satellites each at an inclination of 40 degrees, 32 planes with 720 satellites each at an inclination of 55 degrees, and 36 planes with 49 satellites each at an inclination of 87.9 degrees, for a total of 47,844 satellites, all in orbits 1,200 kilometers high. Those would be in addition to its initial constellation of about 650 satellites the company is currently deploying, which is not affected by the proposed modification.

The U.K. government and India's Enterprises (Barthi Group) formed a consortium to buy the company. In July 2020, Hughes Network Systems, LLC joined the consortium.

The participation of the UK government in the consortium raised the speculation that OneWeb would form part or all of the UK government's plans for its own GNSS (Global Navigation Satellite System) following the completion of Brexit at the beginning of 2021.[11]

As consequence of new capital flow, on December 17th, a Soyuz rocket launched 36 more satellites to join OneWeb constellation in space.

Finally – and surprisingly – in January 2021 OneWeb announced it is sharply reducing the size of the proposed next-generation satellite system from nearly 48,000 to less than 6,400 satellites.

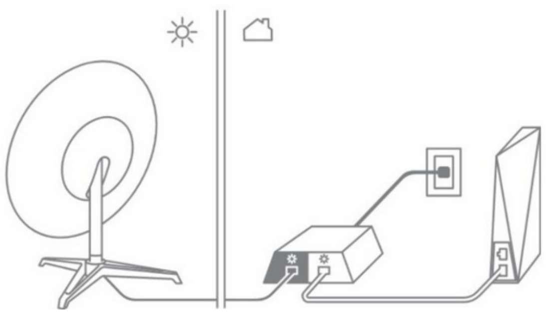
The revised system retains the same number and arrangement of orbital planes but reduces the number of satellites in each of the 40-degree and 55-degree planes from 720 to 72. The satellites in the 87.9-degree orbital planes are unchanged, reducing the total size of the system to 6,372 satellites.[12]

But definitely SpaceX Starlink is the shining star among all. Starlink is reshaping the commercial satellite industry, leading the way and seeing legacy and new players adapting to or following its moves.

At the dawn of 2021, SpaceX has 1,260 satellites in orbit (after launch of 60 s/c on last March 14th), plan to add around 120 satellites per month, have permission for around 12,000, and have requested permission for 30,000 more.

It is important to consider that, unlike GEO systems that take a decade to be replaced by more updated spacecraft, Space X has already announced that the next 1200 satellites will show improvements, such as higher capacity and intersatellite laser links on most of them.

It just started (3rd quarter of 2020) the "*Better Than Nothing Beta*" test, utilizing 900 active LEO satellites delivering target speeds of between 50 megabits per second and 150 megabits per second, at latency from 20 ms to 40 ms, to remote, unserved and underserved end users. Starlink is working to boost the test performance while cutting the service's initial buy-in cost of $600 ($499 for hardware and $99 per month for service). Public beta testing will expand in late January or early February 2021[13].



Installation screen grab from Starlink app.
Photo: Starlink app

Besides these High Throughput LEO satellite constellations, there are ninety or more planned CubeSat/microsat/nanosat constellations[14], from which some 22 are dedicated to IoT/M2M missions.

From those, in addition of the three survivals of the 90's LEO ventures (Iridium, Orbcomm and Globalstar), the most promising seams to be Lacuna Space, Myriota, Astrocast, Fleet Space, Kepler Communications and Swarm Technologies.

Finally, it is important to mention that in addition to all those smallsat and cubsat/microsat/nanosat satellites devoted to Internet access and IoT/M2M applications, there is also a bunch of spacecrafts for weather, scientific research and earth observation roles, which increases the number of expected man-maid artefacts in near-earth orbits.

2.2 Cutting Satellite Launch Costs

New launchers using new technologies (particularly reusable rockets 1st stage), are increasing competition and lowering costs. Examples of partially reusable medium-lift launch vehicle (by definition, capable to lift between 2,000 to 20,000 kg of payload into LEO) are Space X[15] (the only commercially available reusable rocket), Blue Origen[16], China's Long March 8[17] and (still under early stages of development) project Themis, contracted by ESA to ArianeGroup.[18]

Space X is definitely leading this segment, with its Falcon 9 Full Thrust (also known as Falcon 9 v1.2) rocket. As of 19 December 2020, Falcon 9 Full Thrust had performed 83 launches without any failures, which makes it the most reliable orbital launch vehicle currently in operation[19]. The great advantage of Space X, in addition to already having a consistent 1st stage recovery technology (both onshore and offshore, with drone ships *I still love you* and *Just follow the instructions*), allowing them to be reused on future missions, is its capability to design and develop in-house all the constellation components, from satellites to rockets for launching.

In addition to these new medium-lift launchers, there is more than a hundred small-lift ones (below 1,000 kg into LEO), from which it is worthwhile to mention Relativity Space and Rocket Lab, both aiming to provide commercial, high-frequency launch services for the small satellite industry with the help of 3D-printed rockets, the former being capable to lift 900 kg payload to LEO orbit, the second 300 kg payloads to the same orbit.

Relativity Space plans to use 3D printing to produce entire launch vehicles, an approach it claims can be more cost effective than traditional manufacturing techniques. By being able to manufacture a rocket with 3D printing, vehicles can be built faster and less expensively because far less human labor is needed. It also allows the company to revise vehicle designs quickly, without sunk costs in tooling tied to certain designs[20].

Rocket lab is also planning to develop technology to recover and reuse the first stage of its Electron rockets, using a parachute system[21].

Relativity's 3D-printed Aeon 1 engine, shown on the test stand at NASA Stennis Space Center in Mississippi, is designed to produce 15,000 pounds of thrust. (Relativity Space)

2.3 IOSP – In-Orbit Service Providers

The rise of in-orbit services providers, acting as

- Gas station in space for refueling GEO satellites (project being developed by Orbit Fab)[22];
- Attaching to satellites and assuming station keeping, as Space Drones, from Effective Space Solutions[23], recently acquired by Astroscale[24];
- Tugging dead spacecraft out of service or repositioning them and robots for repair on space, tasks already performed by MEV-1, from Northrop Grumman's Space-Logistics. [25]

In a broadband vision, the present role of IOSPs are:[26]

Services / Missions	Operations and Definitions
Life Extension	Providing station-keeping and refueling
Salvage	Correcting the orbital parameters of a satellite
Relocation	Changing orbital parameters and BIU/orbital slot holding
De-Orbiting	End of life disposal
Robotics	Repairing, upgrading, diagnostics, inspection and monitoring of assets
Space Situation Awareness (SSA)	Space surveillance, monitoring and tracking of near-Earth objects

And a list of all the main players are: [26]

Player	Services
O. CUBED Services	Inspection, repair, life extension, salvage, EOL disposal/de-orbit, Relocation, ADR
Astroscale	EOL disposal/de-orbit
NORTHROP GRUMMAN	Refueling, inspection, repair, life extension, robotic manipulation, EOL disposal
ALTIUS SPACE MACHINES	EOL disposal/de-orbiting, refueling
ATOMOS NUCLEAR AND SPACE	Relocation, life extension, recovery, EOL disposal

Player	Services
Effective Space solutions	Relocation, EOL disposal/de-orbiting, BIU, salvage, life extension, active debris removal
Chandah	On orbit inspection, SSA
MOMENTUS	"Vigoride", "Ardoride", "Fervoride" Space Tugs
INFINITE ORBITS	Relocation, EOL disposal/de-orbiting
D-ORBIT	Relocation, constellation phasing

Other Players			
Other Players	ORBITFAB	olis robotics	HONEYBEE ROBOTICS Spacecraft Mechanisms Corporation

2.4 SCBS – Satellite Cloud Based Services

Amazon and Microsoft (probably more to come) development of Satellite Cloud Based Services, allowing its customers to control their satellite communications, process data, and scale operations without having to build or manage their own ground station infrastructure, providing a service that could be called "Ground Station as a Service (GSaaS)".

Amazon Web Services (AWS) in June 2020 launched a new business segment dedicated to serving the aerospace and satellite industry. The new AWS Aerospace and Satellite Solutions division aims to reimagine space system architectures; transform space enterprises; launch new services that process space data on Earth and in orbit; and provide cloud solutions to support government and commercial space missions.

AWS Ground Station, which is part of the department, still plans to establish 12 ground systems, and it recently opened its eight ground station in Hawaii.[27]

Microsoft is building its own ground stations, and also partnering with satellite companies Amergint, Kratos Defense, KSAT, Viasat, and US Electrodynamics Inc. as partner ground stations. Kratos and Amergint are partners for software processing capability. Microsoft also has a partnership with SES that allows SES to build and sell managed services using Orbital, and Kubos is bringing mission control capabilities to Azure. [28]

2.5 Software Defined Satellites

Among the technologies of great impact on future communication systems, network softwarization is the main candidate solution to respond quickly to changing market needs and interoperability of different systems.

Basically, it represents an overall transformation trend for designing, implementing, deploying, managing and maintaining network equipment and components via software programming, leveraging concepts such as Network Function Virtualization (NFV) and Software Defined Networking (SDN).[29]

Bringing these concepts to the satellite communications ecosystem, creating the figure of Software Defined Satellites (SDS), can be a major breakthrough, especially for GEO systems, which with their life span of 15 or more years, will greatly benefit with this opportunity to respond efficiently to new markets or changing in user's profile without having to wait for a new generation replacement.

2.6 SCaaS – Satellite Constellation as a Service

The provision of end-to-end "Satellite Constellation as a Service" (SCaaS), with companies, such as Loft Orbital[30], offering complete end-to-end services (i.e., Satellite, Licensing & Regulation, Launch, Ground Segment and Financing & Insurance) to costumers. Another company with similar objective is Rocket Lab[31], which evolved from a launch provider to an end-to-end space solutions company, offering turnkey satellites and spacecraft components, launch, and on-orbit operations.

Their potential of turn into reality several well elaborate concepts and systems under early stages of development is extremely valuable.

Worth to mention is Nanoavionics, a global IoT Constellation-as-a-Service aimed at IoT/M2M Communications Providers [32].

3. NEW SPACE, NEW PROBLEMS

3.1 Impact on Astronomy and Cultural Practices with Dark Skies and Space

When Space X started the deployment of its mega-constellation of small satellites, in the 2nd quarter of 2018, astronomers around the world complained that their bright, reflecting sun light when they were crossing the dark sky, represented a burden for their optical investigations of outer space.

After astronomer's associations and research centers complains, Space X wrapped their smallsats with a non-reflective layer and darkened the latest batches of the spacecraft. It also installed a device capable to block sunlight from falling on the bulk of the satellite, called DarkSat. With those two modifications, the satellites should only be visible to the naked eye when they are in their final orbits – although that won't stop them potentially damaging the view of anyone using even the smallest telescope.[33]

A view of the dusk sky over a sunflower farm in southern Brazil captures a number of passing Starlink satellites. This image is a composite of 33 stacked images with 13 seconds of exposure. Many astronomical studies can expect similar satellite trails in exposures of star fields, galaxies, and so on.

The satellite trails here rival in brightness the meteor streak accidentally captured in the upper-right of the image.[34] Credit: egon Filter.

But this burden is expected to exponentially increase. From the considerations presented on the previous item about satellite constellations and launching activities, it seems reasonable to consider that by 2030 there could be something like 100,000 satellites on low earth orbit or near-Earth space.

Optical and infrared astronomy shall suffer a tremendous impact if (or when) these forecast come true, according to a report issued by a group of renowned astronomers who get together on June-July 2020 in a workshop named SATCOM 1.

The SATCON1 workshop, the first of several ongoing investigations by the international astronomical research community into the impacts posed by upcoming constellations of up to 100,000 LEOsats by the end of the decade, concluded that negative impacts to ground-based optical and infrared astronomy are unavoidable, affecting practically every facet of astronomy.[35] In other words, the additional foreseen objects around the earth could fundamentally change astronomical observations of the night sky and the Universe, and eventually make it unreliably.

To dampen the effects of these giant constellations as much as possible, the group is proposing 10 recommendations to mitigate satellite influence on astronomy. But considering the mentioned 100,000 satellites added to near-Earth orbit, as a consequence of several planed constellations, there's no way to completely erase their effects. [36]

Credit: NOIRLab/NSF/AURA/P.

Additionally, the occupation of space around our planet, in such a disorganized and aggressive way, goes beyond the just concern of astronomers. As mentioned in [8], in addition to their direct impact on astronomy, *the manner and pace of 'occupying' near-Earth space raises the risk of repeating the mistakes of colonization on a cosmic scale.*

In this way, it is crucial to consider the impact of satellite constellations, and related future initiatives, on the essential human right to dark skies and on cultural sky traditions across all peoples. With this aim, all stakeholders involved in near-Earth space commercial and scientific exploration should be included in the process of *developing new policies for space treaties and planetary protection, the consequences of which will reach far beyond this century*. The authors advocate for a *radical shift in the policy framework of international regulatory bodies towards the view of space as an ancestral global common that contains the heritage and future of humanity's scientific and cultural practices*.[8]

3.2 Space Debris

There are already some 34,000 pieces of orbital debris larger than a fist (more than four inches across); and more than 128 million pieces smaller than a bolt (less than a half inch across), according to a recent study made by the European Space Agency (ESA)[37]. However, experts say the riskiest debris are the 900,000 pieces estimated between those two size ranges, since a piece larger than a bolt moving at 27,000 km/h can still punch a hole large enough to cripple a satellite[38].

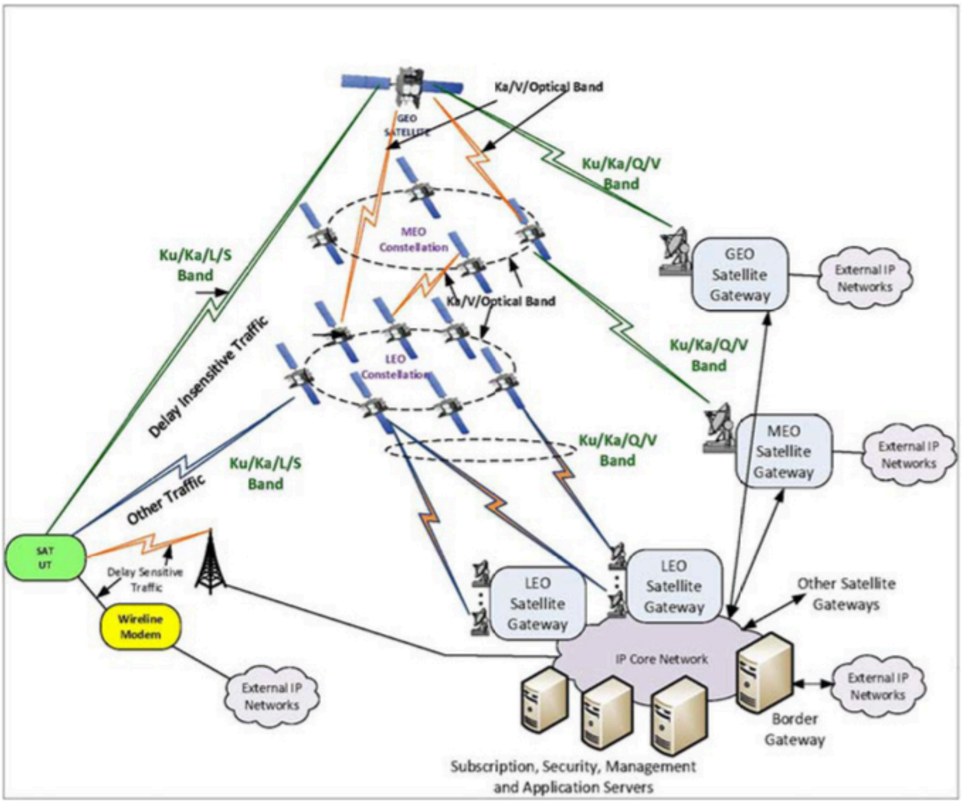
This will get much worst with the ongoing mega-constellations projects, since if satellites collide in orbit, they produce clouds of debris that can destroy other satellites, potentially starting a chain reaction known as the Kessler syndrome, increasing exponentially the burden of space traffic management, which is, at best, in an early stage of existence.

4. SUMMARY AND CONCLUSIONS

In summary, at the down of the most expected 5G era of telecommunications, mega satellite constellations in low earth orbit (LEO) and medium earth orbit (MEO), providing full global coverage, enhancing overall capacity and improving the quality of service (QoS) available through lower propagation latency, complemented by geostationary earth orbit (GEO) satellites systems, could be merged with terrestrial network components under a hybrid communications architecture, enabling universal 5G service across the world while supporting diverse 5G use cases.

Figure below depicts a typical hybrid communications architecture for a next-generation LEO satellite mega-constellation augmenting terrestrial, GEO, and MEO systems. Different satellite gateways service these satellite constellations. This figure also shows an example of a user terminal (UT) with multiple modems that allow it to communicate simultaneously with multiple Radio Access Technologies (RATs) — namely, satellite, terrestrial, and wireline.

As also shown, user links may use Ku and/or Ka bands for high-throughput scenarios, although, thinking about higher availability with smaller end-user devices, it is also proposed that the satellite and UTs consider the support of both L-band and S-band operation. Although feeder links are shown to be Ku/Ka/V/Q bands, other bands are also possible,} including optical feeder links.[39]



Hybrid communication architectures showing merging of LEO/MEO/GEO satellite mega-constellations and Terrestrial components (wired and wireless)

To conclude, In the not-so-distance future the convergence of innovation in satellite communications, 5G terrestrial systems and cloud technology promises a ubiquitous networking solution, offering a wide range of features, including but not limited to: universal multi-access coverage at extraordinarily high speeds & capacity, multi-tenancy, fixed and wireless access network convergence, software controlled agile service provisioning, allowing on-demand service-oriented resource allocation.

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