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CHALLENGES OF EMERGING TECHNOLOGIES - SMALL SATELLITES AND HAPS PLATFORMS

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Abstract: This paper aims to provide a brief retrospective of the possibilities of both small satellites and HAPS platforms and to answer the question of which solution would have the more significant potential for possible application in the near future. The paper provides a theoretical framework to consider the possibilities of applying both solutions. In order to conduct the analysis, the analytical hierarchical process was used. Decisions were made based on key criteria that have a significant impact on the applicability of the systems. The study showed that HAPS platforms represent a system that offers greater application possibilities compared to small satellites in the near future. The reason is based on the fact that, with further advances in technology, HAPS platforms have the potential to represent a genuinely multipurpose system capable of successfully performing a wide range of missions at relatively low costs.

Keywords: Satellites, Small satellites, HAPS, AHP method, Usability

1. INTRODUCTION

Thanks to the dynamic progress of technology (which primarily refers to the IT sector), we are witnessing a general trend of miniaturization and reduction of satellite manufacturing costs. Certainly, the most popular form of satellites is small satellites, which are divided into several groups based on mass. Advances in technology also have a major impact on the development of another type of machine embodied in HAPS platforms. Satellites and HAPS have the potential to be a major competition to each other in the field of providing numerous services in the years to come. Both systems have its advantages and disadvantages and due attention will be paid to that aspect during the analysis.

At this stage of the technological development of human civilization, it is more than obvious that small satellites have primacy. We are talking about the present moment, devoid of looking at the very near future. What will be a challenge is the time yet to come where attitudes are formed based on a broader picture and a deeper perspective. Therefore, this paper aims to provide a brief retrospective of the possibilities of both small satellites and HAPS platforms and to answer the question of which solution would have the greater potential for possible application in the near future.

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2. SMALL SATELLITES

According to the orbits they use, satellites can be categorized into geostationary, medium or low orbit satellites (GEO, MEO and LEO). Geostationary satellites move at a speed that is aligned with the Earth's rotation at an altitude of 35,000 km. the satellite is therefore at a fixed location in the sky relative to a potential observer on the ground. Low (orbit less than 2.000 km) and medium Earth orbit (orbit ranging from 2.000 to 35.000 km) use satellites that move relative to some fixed point on Earth. Orbits can be equatorial, polar or inclined - that is, the satellite can use a combination of each (GSMA, 2022). During 2015, there were about 1,100 active satellites and about 2,600 that are no longer operational. The role of GEO satellites is mainly reserved for communication needs or TV program transmission. MEO satellites are mainly used to provide navigation services to their users. The remaining part is made of LEO satellites, the number of which has increased radically in recent years, and their missions include weather-observing missions, scientific missions, communication missions, Earth observation and imaging missions (Sebestyen, et al., 2018). Unlike medium or large-sized satellites, which are complex both to manufacture and to place in orbit, small satellites offer the possibility of an easier launch and they are an affordable solution. The dramatic growth in the number of small satellites embodied in so-called swarms increases the complexity and imposes great challenges before regulatory bodies such as the United Nations (UN) and the International Telecommunication Union (ITU). Namely, a large number of satellites (measured in the thousands) requires the allocation of certain frequencies and orbital slots, as well as when it comes to geostationary satellites (Nair, 2019). A rapid increase in the number of small satellite constellations will result in a sharp increase in space debris. Accumulation of the aforementioned waste represents a major threat to the safety of space exploration and exploitation and has a major impact on the environment (Yang & Wu, 2022). There is also a possibility of misuse of small satellites for the realization of criminal and terrorist activities (Nair, 2019). Table 1. shows the classification of minisatellites based on their mass.

Table 1. Classification of small satellites in terms of mass (Nair, 2019)

Classification of small satellites in terms of mass		
Satellite class	Mass range	Functionality
Femtosatellite	10-100 g	In swarms
Picosatellite	100 – 1000 g	In swarms
Nanosatellite	1 – 10 kg	Individually & in groups
Microsatellite	10 -100 kg	Individually & in groups
Small satellite	100 – 500 kg	Individually & in groups

There is no international agreement regarding the definition of the term small satellite. All satellites are grouped into categories based on their mass. The International Telecommunication Union considers that satellites whose mass does not exceed 500 kg can be considered “small satellite”. Space agencies (NASA, ESA, JAKA, CSA and others), as well as numerous industries and research institutions have accepted the technology of small satellites due to the possibility of realizing cheap and fast missions. Their missions include Earth observation, atmospheric science and space weather, astronomy, telecommunications, mission operation and technology, biology, astrobiology, pharmaceutical research, etc. (Koudelka, 2016). Further focus will be on micro, nanosatellites, and their capabilities.

The use of microsatellites is based on a large number of satellites of small dimensions and mass compared to standard satellites and orbiting at heights of approximately 1200 km above Earth. In terms of communication microsatellites are characterized by low latency, the possibility of covering the entire earth's surface (when they are used in larger number), as well as the possibility of fast transmission. Microsatellites have enabled real-time observation of the earth's surface in better resolution and have led to the availability of completely new services (Kinjo, 2016).

Any satellite whose mass ranges from one to ten kilograms, can be considered a nanosatellite (Majumdar, 2022). The first nanosatellites were launched in the period from 1958 to 1968, and during that time they represented experimental satellites whose primary role was to, apart from testing new technologies, provide insight into relevant data about living conditions that prevail in low Earth orbit. The miniaturization trend of nanosatellites continued from 1968 to 1996, resulting in the emergence of active nanosatellites and eventually leading to CubeSats in 2003, which, at a cost of $50,000–$300,000, enabled universities and small space companies to participate in satellite exploration projects. The trend of nanosatellite launches has seen exponential growth since 1997, with Trent closely resembling Moore's Law, with the number of ships launched doubling every 2.44 years (Janson, 2020). CubeSat is by its characteristics a nanosatellite. The standard CubeSat dimensions are called a unit (U). The dimensions of each unit are 10x10x11 cm. CubeSat size can be 1U, 2U, 3U or 6U. The mass for 1U is slightly less than 1.33 kg (Mohammed Chessab Mahdi, 2018). Regarding the use of launched CubeSats, 48% are used by commercial companies, 40% are used by universities, while 12% are used by government institutions (Eddine Kerrouche et al., 2022). In March 2018 The US Federal Communications Commission (FCC) has approved SpaceX's request regarding the launch of 4,425 LEO satellites, which represents the first phase of almost 42,000 satellites which should be in orbit. And other companies follow the trend like OneWeb with 2,720 satellites, Amazon with 3,236 satellites and Samsung with 4,600 satellites (Suwijak & Shouping, 2021).

3. HAPS

HAPS are autonomous, unmanned aerial vehicles that fly or hover at heights of about 20 km. These are autonomous systems that have the ability to be stationed and the ability to take off and land gives the systems the ability to change their configuration or to perform maintenance (GSMA, 2022). High-altitude platforms, or pseudo-satellites (HAPS), are a type of airborne platform that possesses the capability to mimic the performance of satellites at the local level (Gonzalo et al., 2018) HAPS includes several types of platforms. These aircraft include balloons, free-floating balloons, dirigibles, or powered fixed-wing aircraft that use either solar power or an on-board power source. It is important to note that all systems are unmanned (GSMA, 2022). Balloons are aircraft of low mass and power, and they are characterized by low payload. Fixed-wing platforms have more mass, power and the ability to fly longer than balloons. They can be precisely placed in the desired location. Airships are physically the largest platforms, with greater capabilities in terms of power carrying capacity and flight autonomy. as well as fixed-wing aircraft offer the possibility of precise positioning (GSMA, 2021). The HAPS platform is characterized by the possibility of local coverage of a certain part of the territory, a relatively fast positioning procedure as well as the possibility of very fast transmission (Kinjo, 2016). The application of HAPS platforms covers the whole range of missions, but those that potentially bring the greatest benefit are related to telecommunications, Earth observation, GNSS or scientific applications. The implementations of HAPS projects are accompanied by certain technological problems. Primarily a structure that is sensitive to turbulent and windy environments as well as limited load capacity. When it comes to HAPS aircraft embodied in the form of Airships, there are problems related to the production and handling of very large parts of the structure. (Gonzalo et al., 2018).

Compared to satellites, HAPS have certain advantages. They are primarily reflected in the form of less signal delay, less path loss, less pseudo range errors and provide the possibility for continuous coverage to reduce the number of receptions for users in the part of the territory over which the aircraft is located (Zheng et al., 2023). There are limiting factors when it comes to the need to use HAPS platforms. Despite certain advantages compared to nanosatellites and microsatellites, there are also serious obstacles to their further commercialization. In the first place, we are faced with technological barriers, then with barriers embodied in terms of legislation that regulates the commercial application of UAS and the third reason lies in the allocation of commercially available radio frequency bands in the stratosphere (Kinjo, 2016). The successful materialization of HAPS requires the full integration of existing and new technologies in order to make aircraft operations feasible and profitable. There are also challenges in solving problems related to communication systems. It should be emphasized that HAPS projects are a large capital investment that requires large human resources and costs (Widiawan & Tafazolli, 2007).

Projects of HAPS platform prototypes implemented so far that have served as technology demonstrators include aircraft such as: SHARP, Pathfinder, Centurion &Helios, SkyNet, CAPANINA, X-station, Elevate, Loon, Zephyr S, Aquila, Stratobus, HAWK30 and PHASA-35 (Kurt et al., 2021). Currently available platforms under development include HAPSMobile, Sceye, Stratobus, Stratomast and Zephyr (GSMA, 2022). Table 2. shows the characteristics of HAPS platforms that are in different stages of development.

Table 2. Some of the characteristics of HAPS demonstrators (GSMA, 2022)

HAPS	First test flight	Weight and dimensions	Endurance time	Cruising altitude / Speed	Primary application
HAPSMobile	2020	Wingspan:78m	Several months	20 km / 110 km/h	Communication; Disaster relief; IoT;
Sceye	2016	N.A.	N.A.	18-20 km / N.A.	Telecommunications; GHG emissions monitoring; Natural resource surveying, mapping, monitoring, etc.
Stratobus	Expected 2024	10.000 kg / 140 m long with 32 m diametar	Up to 1 year	18-20 km / 20 m/s	Intelligence; Surveillance and Recognition; Disaster relief, etc.
Stratomast	2020	4.000 kg / wingspan 56 m	6-9 days	18 km / 277,8 km/h	Neutral host mast in the sky
Zephyr	2010	75 kg / wingspan 25 m	26 days / next generation 6-12 months	18 – 20 km	Connectivity; Other secondary connectivity applications: Earth Observation.

4. MARKET VIEW

According to current reports concerning the small satellite market, there is a prediction that the global market will be four times larger in 2028 than it was in 2021. This growth was embodied in an increase from $5.8 billion to $22.9 billion during that period for a compound annual growth rate (CAGR) of 22.2% (Taylor, 2022). By 2030, there is a need to launch 11,746 small satellites for the new constellation and to replace the existing ones that are no longer in operation. 97.7% of the total mass launch demand will be generated by commercial operators, with the largest contributions such as Space X, EarthNov and Oneweb. 37 small satellite commercial operators will generate more than 90% of the demand for small satellite launches (Frost & Sullivan, 2019). Rocket Lab is using its Electron rocket in 2018 to launch small CubeSats into Earth orbit. Rocket Lab charges $5 million per flight for its service, which equates to a cost of about $10,000 per pound of payload. SpaceX charges about $62 million per launch for the same services using its Falcon 9 rocket, or about $1,200 per pound of payload to reach low Earth orbit (Chow, 2022).

5. ANALYSIS OF PREDOMINANCE IN TERMS OF USE

For the purposes of analysis, the existing situation in the field of small satellites and HAPS platforms will be taken into account, as well as the development trends of both technologies. Table 3. shows the characteristics of GEO, MEO, LEO satellites and HAPS platforms.

Table 3. Some of the characteristics of GEO, MEO and LEO satellites and HAPS (GSMA, 2022)

System	Satellite for global coverage	Timer per orbit (hours)	Time in site per gateway	Latency: RTT (ms)	Mass (kg)	Lifetime (years)
GEO	3	24	Always	600/700	~3500	15
MEO	10-30	5-12	2-4 Hours	<150	~700	12
LEO	100+	1.5	15 minutes	<50	5-1000	<5-7
HAPS	/	/	Always	<10	<320 Balloon <100 Aircraft	>5 Balloon >8 Aircraft

The Analytic hierarchy process (AHP) as a decision making model, developed by Saaty (1980) and decision making software Expert Choice (Expert Choice, n.d.) will be used for the analysis.

Table 4. Global importance of criteria that have an impact on the system

Criteria	Global importance of criteria
Maturity of technology	0.028
Signal coverage	0.078
Signal quality	0.064
Legislation	0.217
Allocation of commercially available radio frequency	0.204
Implementation costs	0.050
Adaptability to perform different missions	0.112
Interfering with other research endeavours	0.035
System reliability	0.103
Risk of possible misuse	0.110

Global importance of criteria shown in Table 4. is presented in form of matrix W3:

$$W3 = \begin{bmatrix} 0.028 \\ 0.078 \\ 0.064 \\ 0.217 \\ 0.204 \\ 0.050 \\ 0.112 \\ 0.035 \\ 0.103 \\ 0.110 \end{bmatrix} \quad (1)$$

Importance of alternatives (systems) compared to criteria can be presented in form of matrix W4:

$$W4 = \begin{bmatrix} 0.833 & 0.750 & 0.833 & 0.200 & 0.500 & 0.250 & 0.800 & 0.750 & 0.250 & 0.667 \\ 0.167 & 0.250 & 0.167 & 0.800 & 0.500 & 0.750 & 0.200 & 0.250 & 0.750 & 0.333 \end{bmatrix} (2)$$

Matrix of importance of alternatives is then calculated and presented in form of matrix:

$$W = \begin{bmatrix} \text{HAPS} \\ \text{Satellites} \end{bmatrix} = W4\ xW3 = \begin{bmatrix} 0.508 \\ 0.492 \end{bmatrix} \quad (3)$$

The importance and ranking in terms of usability according to the AHP methodology was presented in Table 5.

Table 5. Ranking of the systems based upon AHP methodology

System	Weight	Rank
HAPS	0.508	1
Small satellites	0.492	2

6. CONCLUSION

It is quite certain that in terms of technology maturity, legislation, implementation costs, and system reliability, small satellites have the advantage. When we talk about signal quality, signal coverage, and adaptability to perform different missions in terms of interfering with other research endeavors, the risk of misuse is possible, and the advantage is on the side of the HAPS platform. In both cases, big problems can be expected regarding the allocation of commercially available radio frequency. Despite the usability benefits of the HAPS platform, it faces two major challenges. The first concerns legislation and the second concerns is about reaching the necessary level of technological development in order for the platforms to show their full potential. The problem with the legislation is primarily related to the fact that HAPS platforms would have to share the same airspace with other aircrafts, but their flight zone would include the stratosphere, or rather, they would operate at twice the altitude used by civil aviation. When we are talking about the level of technical development, most HAPS platforms at this stage of development are demonstrators. However, time is undoubtedly on the side of the HAPS platform, thanks to the great potential that is just waiting to be fully exploited. What should be emphasized when it comes to small satellites is the fact that with an increase in their number, there is an enormous increase in space debris, which can radically increase the probability of collisions between objects (and lead to Kessler syndrome) and greatly affect outer space activities (Steinkogler, 2016). Overall, taking into account all the mentioned factors and certain conditions that must be met, HAPS can be considered as a very useful universal platform in the years to come. In the analysed scenario, the focus is on the competitiveness between the two systems. The mentioned analysis in no way calls into question the existence of a scenario that would include certain interoperability between those two technologies.

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