ETHICAL CONCERNS OF MEGA-CONSTELLATIONS FOR BROADBAND COMMUNICATION

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ABSTRACT

This article studies ethical concerns of private satellite mega-constellations in low-earth-orbit (LEO) deployed to provide broadband services globally. These concerns have been understated thus far. The issue at hand is framed in terms of distributed morality. Three morally relevant aspects are analyzed, namely, the problem of space debris, the design of autonomous maneuvering systems on board of satellites, and the limited availability of orbital slots and parts of the radio spectrum. To address the aforementioned issues the following solutions are discussed. First, the application of the responsible research innovation framework to the private activities in outer space. Second, ethical policies of aggregation of good actions paired with disaggregation of morally bad ones.

KEYWORDS: distributed morality; mega-constellations; LEO; space debris; outer space treaty; space ethics.

1. INTRODUCTION

The commercial exploitation and, to a lesser extent, the exploration of outer space raises several challenges. While technical, political and legal issues abound this chapter focuses on the implications of space exploitation from the ethical perspective (Rao, Gopalakrishnan, & Abhijeet, 2017). It does so by analysing recent efforts by private companies to provide universal broadband access by way of mega-constellations of satellites (numbered in the tens of thousands) deployed in low-earth-orbit (henceforth, LEO). The argument unfolds as follows. First, section two provides the relevant background on the progressive privatization of space. Then, it offers a primer on the legal sources governing the use of outer space, and it describes the phenomena of mega-constellations. While some may not find it surprising that global planned infrastructures to provide broadband access raise interesting ICT & societal challenges, others might be sceptical. Thus, section three argues for the importance of discussing the subject matter from the perspective adopted throughout this book.

Later, section four frames the issue at hand in terms of distributed morality, drawing on the work of Floridi. It describes three macro ethical concerns raised by mega-constellations, the first is the problem of space debris, the second the design of autonomous systems to avoid conjunctions in LEO, while the third arises from the finite nature of resources such as orbital slots and the radio spectrum. On this basis, section five provides two directions to address these issues. It suggests the application of the responsible research and innovation framework to

private space activities, and the development of ethical policies of aggregation. Section six concludes.

2. BACKGROUND

Only recently, the space capabilities of private enterprises have made them relevant from an ethical perspective. Further, several nation-states have already developed normative frameworks for the privatization of outer space while others are likely to follow suit. Luxembourg, for example, has enacted legislation intended to attract capital and companies in the space business (law of the 20th of July 2017[1]) and the results are promising so far. The U.S. has made similar efforts toward the privatization of space (Trump, 2018).

The opening of outer space to private activities is a welcome development. Private enterprises will likely foster innovation in the space sector as well as generate significant economic growth in the years to come, both morally desirable outcomes. Areas such as asteroid mining or space tourism appear poised to contribute to human flourishing in the long-term. Think, for example, as the scenario imagined by Jeff Bezos concerning the operations of his Blue Origin. Moving the externalities caused by some manufacturing activities from the fragile earth to our more resilient moon is highly desirable from a multitude of perspectives. Moreover, innovation in space technologies reduces existential risks for humanity by contributing to the goal of becoming an interplanetary species, therefore it is morally desirable (Munevar, 2019; Schwartz, 2011). However, the opening of the space frontier to private enterprises raises a multitude of challenges[2]. Of relevance for this contribution is the ineptitude of the legal framework governing space activities. Amongst its several shortcomings, current space law does not provide enough guarantees to ease ethical concerns raised by the privatization of space. To see why a brief digression on the sources of space law is in order.

The legal framework for space activities is made up of four international treaties, the last one signed in 1979 (United Nations, 2017). These international treaties are: the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies" or OST opened for signature on January 1967; the "Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched in Outer Space" or Rescue Agreement for short of 1968; the "Convention on International Liability for Damage Caused by Space Objects of 1972, also known as the Liability Convention; the "Convention on Registration of Objects Launched into Outer Space" of 1976, and the "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" of 1984. It is enough to note how all these sources were drafted decades before the privatization of space. It is also worth noting that the Moon agreement is not relevant with only 18 ratifications, none of which from space fairing nations. While a thorough analysis of the inadequacies of current space law lies outside of the scope of this chapter, a few remarks are in order.

On the one hand, current space law was not drafted with small satellites in mind (Marboe, 2016a, 2016b; Shaw & Rosher, 2016). In the early days of space endeavours, satellites were - generally - measured in meters while nowadays, the majority of future satellites (e.g. CubeSats and pico-satellite) are measured in centimetres (Matney, Vavrin, & Manis, 2017; Millan et al.,

[1] Official text available here http://legilux.public.lu/eli/etat/leg/loi/2017/07/20/a674/jo

[2] For an overview of ethical concerns related to space activities see (Arnould, 2011).

2019). This is the first inadequacy of current space law. On the other hand, commercial exploitation of outer space was not a primary concern of the drafters of international space law. Their focus, amid the cold war, was likely to prevent the proliferation of nuclear weapons in space as well as its militarization. Therefore, current space law is also inadequate to deal with private commercial efforts such as asteroid mining, private moon bases, space tourism, or mega-constellations (Rao et al., 2017). The shortcomings of space law for the current times are hardly a new topic[3]. For our purposes, this brief digression on the sources of space law entails that, when dealing with ethical concerns related to private space activities, space law does not offer much support. One must look elsewhere to other methods and techniques to ensure that the private space era develops in a morally desirable direction.

Lastly, it is necessary to spend a few words on mega-constellations. Mega-constellations consist of the deployment of a vast number of satellites (from a few hundred to tens of thousands) by a single entity to provide a service. The use of more than one satellite is not new; for example, the GPS relies on 31 satellites. However, the sheer number of satellites deployed in mega-constellations is a qualifying difference, which raises numerous concerns. This contribution focuses on the particular issue of private mega-constellations to provide global internet broadband. Companies such as SpaceX and Boeing are spearheading these efforts while others are planning more mega-constellations. In the table 1 below, a list is provided of the planned mega-constellations in the coming years. If the forecasts are correct, then several thousands of satellites will be launched. It is important to note that the previous number refers only to mega-constellations for broadband communication.

Table 1. Planned Mega-Constellations[4].

Constellation	**Number of Satellites**	**Orbit**
Boeing	1.396-2.956	1.200 km
LeoSat	78-108	1.400 km
Starlink	4.425-42.943	550-1.325 km
Telesat LEO	117-512	1.000-1.248 km
CASIC Hongyun	156	160-2.000 km
CASC Hongyan	320	1.100 km

To put it in perspective, the index of Objects Launched into Outer Space maintained by the Office for Outer Space Affairs at the United Nations lists - at the time of writing - 9.447 objects[5]. It is clear that mega-constellations are a paradigm shift concerning space activities. Against this background, it is now time to spend a few words to explain the relevance of this argument from the purview of this book.

[3] Instead of many see (Larsen, 2009)

[4] Data collected by the author.

[5] The index accounts for most of the observable objects orbiting the earth, which include disposed rocket parts, exhausted boosters, non-functioning satellites as well as operational ones.

3. THE MORAL RELEVANCE OF MEGA-CONSTELLATIONS

The relevance of the issue at hand from the perspective adopted throughout this book is multifold. On the one hand, concerns arise within the purview of the smart society if one prominent private player becomes a natural monopolist in providing broadband connectivity from outer space. In this case, the essential facilities doctrine might curb the risks of a private global monopoly. According to this doctrine developed within the antitrust area, if several conditions hold, then the natural monopolist is forced to contract at a fair price with its competitors[6]. However, it is not clear if this legal doctrine would be sufficient. Doubts arise in areas such as the applicable law as well as the jurisdiction; there is no global space court after all.

On the other hand, control over the infrastructure that provides broadband connectivity enables censorship as well as discrimination of the network traffic. This is relevant both from the smart society perspective and the broader ICT ethics. In this case, since the applicable law to the provider is generally the one of the launching state, risks might be mitigated if the prominent players are established in jurisdictions that uphold the value of net neutrality and offer other guarantees. The scenario changes if the provider of a mega-constellations is established in a jurisdiction with fewer safeguards.

Lastly, the issue of space debris affects the technological affordances of humanity. The worst-case scenario described by the so-called Kessler syndrome entails precluding access to outer space for generations to come (Kessler, Johnson, Liou, & Matney, 2010). The effective avoidance of orbital conjunctions demands that next-generation satellites be equipped with autonomous manoeuvring capabilities, such that they appear to qualify as moral agents in the context of the multiagent system of outer space[7]. Thus, the design of autonomous anti-avoidance systems is also relevant from the computer ethics perspective.

4. ON SOME ETHICAL CONCERNS OF MEGA-CONSTELLATIONS

This section frames the deployment of mega-constellations in terms of distributed morality to highlight its ethical concerns. The phenomenon of distributed morality occurs when moral consequences are "the result of otherwise morally neutral or at least morally-negligible interactions among agents constituting a multiagent system" (Floridi, 2013, p. 729). Regarding mega-constellations, the launch of a batch of satellites by one agent can be considered a morally neutral action. That is, moral consequences are -generally - limited. The same holds for operating a spacecraft. However, the thousands of satellites orbiting roughly the same altitude of LEO, as is the case when satellites are launched to provide broadband access, might have moral consequences when their actions are aggregated. It is possible to describe the outer space scene as a multiagent systems (MAS). Relevant agents are the launching companies, the state responsible for the launch (along with the associated liabilities for space object), the rockets and satellites that possess autonomous manoeuvring capabilities, along with the other objects already in orbit and their operators. An example clarifies this framing. The operators of satellites currently are under no legal obligation to manoeuvre them if the probability of orbital conjunction raises above a certain threshold, however, the case for the presence of a moral

[6] See, in general (Lipsky Jr & Sidak, 1998)

[7] This holds if the notion of moral agents is consistent with the one described in (Floridi & Sanders, 2004).

obligation in this scenario appears straightforward. The single morally negligible action of operating a spacecraft becomes charged with moral weight once other agents (both human and artificial) are present in the system. On the basis of the framework of distributed morality, this section discusses three morally relevant aspects of mega-constellations deployed to provide global broadband communication. The first once concerns the issue of space debris.

Mega-constellations exacerbate the problem of space debris because of the sheer number of launches required to place thousands of satellites into orbit. Each launch leaves something behind. Moreover, due to the reduce cost of manufacturing and launch, the small satellites deployed will likely have a higher failure rate than other missions. The lack of appropriate safeguards against orbital conjunctions as well as sound decommissioning protocols might result in an unacceptable level of risk (Bergamini, Jacobone, Morea, & Sciortino, 2018). This is especially relevant from the moral perspective if the risk becomes crippling existing infrastructures that rely on satellites placed in LEO or if it endangers the access to outer space for the foreseeable future (Jakhu, 2010).

The second ethical concern raised by mega-constellations is closely related to the problem of space debris. It appears highly desirable to implement autonomous software onboard a spacecraft to prevent collisions with other objects, thus lowering the risk of conjunctions to more acceptable levels and improving the current email-based warning mechanism. In this case, even if the LEO orbit is quite vast, it is possible to imagine a scenario in which an autonomous system must decide which of two likely collisions to avoid. Thus, a space version of the famous trolley problem – which we could name the conjunction avoidance choice - can be described in the context of autonomous systems deployed on a satellite orbiting in LEO. This shows that developers of satellites ought to take into considerations moral scenarios. In an easy example of conjunction avoidance choice, the manoeuvring software should always privilege colliding with a piece of junk or a non-functioning spacecraft instead of an operational one. Yet harder cases are not hard to imagine. What if the collision with a piece of space junk is likely to generate debris of an order of magnitude greater than an operational satellite? Which collision should be privileged when the alternatives are a science mission or a telecommunication satellite? It is not the task of this contribution to provide an answer to the previous questions. Yet, it shows another morally relevant aspect of the launch of mega-constellations, however, this concern is relevant for other space objects with autonomous manoeuvring capabilities.

The third morally charged aspect related to mega-constellations and other large-scale space missions is that useful orbital slots and the radio spectrum are scarce natural resources. Then, this scenario is similar to the tragedy of the commons, which is successfully studied in terms of distributed morality[8]. Therefore, the allocation of these scarce resources is another morally relevant aspect aggravated by the rise of mega-constellations. Currently, a part of the spectrum is allocated by the International Telecommunication Union (henceforth, ITU) to the satellite operators to perform uplink and downlink transmissions. The ITU also notes the orbital parameters to prevent interference with other satellites, that is the orbital slot of each spacecraft. It is important to note that the primary function of the ITU is related to the allocation of the radio spectrum and not with the assignment of orbital planes. The management of orbital planes is often left to the satellites' operators if, for example, two satellites are operating in a close orbital position with two different radio frequencies. The allocation of the spectrum is

[8] For a framing of the problem as a common see (Salter, 2015).

performed on a first come, first served principle and since space activities are disproportionally concentrated in developed countries equity concerns arise.

Developing countries became concerned that the most demanded frequencies and the most beneficial orbital slots would be occupied by the time they developed space capabilities[9]. To address this the 1977 WRC elaborated an alternative mechanism of spectrum management aimed at ensuring equitable access to orbital-frequency resources—the allotment of radio frequencies. According to this mechanism, specific radio frequencies are included in the so-called a priori plans and thereby reserved for the use by specific states (Radio Regulations, 2016, No. 1.17). However, mega-constellations raise new concerns. Other mechanisms should be put in place to ensure that the useful parameters for providing global broadband services in LEO are not exhausted by private enterprises of developed countries.

These are just three moral issues related to the launch of mega-constellations highlighted by considering outer space as a multiagent system under the framing of distributed morality. The next section examines two mitigations strategies to foster human flourishing beyond planet earth.

5. MITIGATION STRATEGIES

This section deals with two strategies to curb the ethical concerns of mega-constellations. The first draws from the responsible research innovation research while the second is aggregation policies of morally desirable actions.

These two approaches are closely intertwined as the design and launch of a vast number of satellites are not the result of morally reprehensible conducts. The problem lies in the fact that mega-constellations are problematical from an ethical perspective, even if their promoters have the best possible intentions. Therefore, moral considerations anchored on intentionality might not provide useful solutions, as shown in the context of multiagent systems in which human agents and artificial agents interact (Floridi, 2013, 2017; Greco & Floridi, 2004). Addressing the ethical concerns highlighted in the previous section ought to be done at an earlier stage before mega-constellations are technically mature. So that neglecting fundamental ethical principles is less of a risk for correcting it in the design phase is more feasible than once thousands of satellites are already placed in LEO.

Concerning the first proposed approach, the definition of RRI adopted is taken from the work of Von Schomberg, that is "Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products" (Von Schomberg, 2013, p. 59). It is evident how the application of the RRI framework to the issue at hand poses significant difficulties. First, ethical acceptability is difficult to ascertain when mega-constellations are poised to impact the entire globe. Which ethical framework should be adopted? Are the norms found in the space treaties enough to provide a benchmark for it? Second, it is not clear if appropriate methods for technology assessment and foresight are being used within the space industry concerning the

[9] This problem is more relevant in the case of geo-stationary orbits (where the speed of the satellites matches the rotation of the earth so that the spacecraft appears stationary from the earth perspective). However, the issue might become more prominent if the number of satellites in LEO vastly increases.

unprecedented nature of mega-constellations. What seems critical in this context is the lack of global deliberation for a technological infrastructure design to operate globally and, more importantly, managed by a handful of private enterprises. Third, the precautionary principle proper of EU law does not extend its reach to outer space as it is not mentioned in the international sources governing space activities. Moreover, national implementations of it might not be effective since enterprises can easily change the applicable law leveraging the multifold nature of the notion of launching state.

Against the difficulties of applying the RRI methodology to the case of mega-constellations, the following remarks are made. The OST provides a starting point for evaluating the ethical acceptability of these systems, art. 1 states that "[t]he exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of mankind". Thus, the question one needs to ask is if private mega-constellations for broadband communications benefit and are in the interest of all. Prima facie, the answer is affirmative. Providing global high-speed internet access is a desirable and acceptable endeavour to undergo, because it will cover most of the population, including rural and remote areas. However, a balance must be struck against the risks outlined in the previous section; two possibilities come to mind. First, codes of conduct should be adopted by the companies involved stating how they intend to act to mitigate the risks of mega-constellations. In passing, code of conducts could also address other areas of concern. Second, the adoption of standards and self-regulation should be encouraged in this area. The issue here lies in establishing globally accepted measures in the fragmented landscape of space regulations. Third, it would be highly desirable to include the precautionary principle in the body of space law; however, this is unlikely to occur. In the global environment, an agreement among the major space fairing nations seems far in the future. Absent such principle, the need for deliberative mechanisms with stakeholders along with more public engagement and debate becomes stronger. Considering the launch of mega-constellations and their associated risks, on-going public discussion and monitoring of public opinion would be desirable. These are just some of the possible future directions to study; more in-depth considerations are left to another time.

The second suggested approach to curb the ethical concerns of mega-constellations consists of the aggregation of possibly good actions and the fragmentations of undesirable ones, i.e. ethical policies of aggregation (Floridi, 2013, 2017). The international space community might do the former by sharing data, best practices and codes of conduct. Moreover, ethical aggregation ought to be complemented by incentives as well as disincentives put in place by legislation and policies. Ideally, such mechanisms would occur at the international level, however, it might be the case that in the short-term, national initiative will be more effective. As for the fragmentation of morally bad actions, it is possible that the space community might continue to shun irresponsible actions such as the wilful increase of space debris (e.g. by the intentional destruction of satellites via anti-satellites missiles) or acts against international space law such as the launch of space objects without registration. It is clear that much work needs to be done to study these mechanisms, a task beyond the scope of this contribution. For now, it is sufficient to highlight the most viable strategies to, not only ease ethical concerns of mega-constellations but also to harness the power of distributed morality in the multiagent system of outer space.

6. CONCLUSION

The goal of this chapter was to highlight ethical concerns related to mega-constellations for broadband communication. In passing, the shortcomings of international space law have been discussed. The main contribution of this work is framing the environment of outer space in terms of distributed morality. That is, I contend outer space to be a multiagent system in which human and artificial agents act singularly in morally negligible or neutral ways that, nonetheless can have critical moral consequences when aggregated. Also, the conjunction avoidance choice sketched in section 4 clarifies some of the moral concerns of the new era of space exploitation and exploration. Three moral issues related to the topic at hand have been discussed, namely, the exacerbation of the problem of space debris, the design of autonomous space objects for collision avoidance, and the mechanism for allocating the radio spectrum along with orbital slots. Two strategies have been suggested to ease the concerns of the deployment of mega-constellations. The first is to draw from the RRI framework. The second concerns ethical policies of aggregation. Due to the nature of this contribution, several questions demand future work. I hope to have provided interested researchers with a starting point to tackle these challenges. Endeavours in outer space are vital to the human flourishing, and the path to the business ethics of private space exploitation has just begun.

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