Abstract  This chapter focuses on the connectivity required to achieve good governance, both in terms of e-governance through virtual voting and other mechanisms, and through the other capabilities that are enabled through better connectivity, such as education and awareness of issues that directly and indirectly relate to governance. An overview of current space-based Internet and communication technologies is provided as well as a thorough overview of the constellation-based Internet technologies that will be available in the near-future, with widespread possible benefits for governance in Africa.

3.1 Introduction

High speed broadband Internet to locations where access has been unreliable, expensive, or completely unavailable.¹

Elon Musk (Starlink)

Good governance requires the ability to monitor a region’s resources, both natural and human-made. Space technologies enable overwatch of almost everything that may support a country or region and facilitate faster and more accurate governance decision making.

This chapter examines the specific way in which governance can be improved through the use of space technologies. It should be noted that these technologies must be used in conjunction with systems on the ground. Space technologies mainly allow communication and visualisation and cannot themselves perform any of the actions necessary to improve governance. While these technologies do not necessarily directly contribute to the ideas and projects mentioned in Chaps. 1 and 2, they make vast indirect contributions, forming a backbone for all digital governance activities.

¹TIMESOFINDIA.COM, Elon Musk’s ‘Internet from space’ service coming in six months, 24 April 2020, https://timesofindia.indiatimes.com/gadgets-news/elon-musk’s-Internet-from-space-service-coming-in-six-months/articleshow/75356989.cms (accessed 20 Mai 2020).
Currently, Africa suffers the highest lack of connectivity of any continent, with even Antarctica having higher average connection speeds per person present. Only about 20% of Africans have some form of Internet connection, much of which has extremely poor performance in terms of bandwidth, data allocation and latency.²

Because of Africa’s large surface area and harsh terrain, very little cable-based connectivity exists in the region, and with huge upfront costs, enterprises are unwilling to invest in infrastructures necessary to establish fibre or copper-based Internet connectivity. Copper is especially an issue as cable theft is highly prevalent throughout the African continent.³ Figure 3.1 shows just how far behind Africa is in terms of connectivity.

Satellite-based Internet has existed commercially since 2003,⁴ with its extraterrestrial position enabling Internet connection to any location on Earth covered by the satellite’s footprint, making it advantageous for use in Africa.⁵

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²“ICT Facts and Figs. 2005, 2010, 2017”, Telecommunication Development Bureau, International Telecommunication Union (ITU).

³Mitch Mitchell, “The real cost of electrical cable theft to the SA economy: R187 billion per year”, 2019, https://www.pressportal.co.za/energy-and-environment/story/17875/the-real-cost-of-electrical-cable-theft-to-the-economy-r187-billion-per-year.html (accessed 26 November 2019).

⁴“First Internet Ready Satellite Launched”, 29 September 2004, Space Daily.

⁵See, for example: C. Kotze, A Broadband Apparatus for Underserves Remote Communities: Connecting the Unconnected (Cham: Springer, 2020); T. Hugbo, “The Importance of Internet Accessibility and Smart City in Sub-Saharan African Region Through Space Technology”, in Embedding Space in African Society: The United Nations Sustainable Development Goals 2030 Supported by Space Applications, ed. A. Froehlich (Cham: Springer, 2019), 105–112; and A.S. Martin, “Internet by Satellite for Connecting the African Continent: A Glance on the Partnership Between Rwanda
This chapter will look at existing and future space-based communication technology, as well as criticisms thereof, and potential benefits for governance and Africa.

### 3.2 Current Geostationary Internet Technologies

There are currently a number of competing geostationary Internet providers. A Geostationary Orbit (GEO) satellite orbits the equator at a distance of about 35,800 km from the Earth’s surface. This means that it orbits at the same speed that Earth rotates and therefore always covers the same region of Earth. Figure 3.2 shows this configuration.

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and the Private Company OneWeb”, in Space Fostering African Societies: Developing the African Continent through Space, Part 1, ed. A. Froehlich (Cham: Springer, 2020), 61–70.
3.2.1 Technical Attributes

The principle benefits of a geostationary Internet satellite are that it can cover a large area and is always available, subject only to the weather.

However, because of the huge distance, there are several drawbacks. The first is latency (or ping), defined in milliseconds where lower is better. Latency is different to Internet speed in that it defines the response time of a server to a user’s request. In simple terms it may be thought of as the time needed to find a website, while Internet speed would be the time needed to load the said website. In geostationary Internet, the speed of light heavily limits latency. Equation 3.1 shows the physical time needed for a signal to travel to or from a geostationary satellite. Speed is the speed of light in m/s.

\[\text{Latency to satellite} = \frac{\text{Distance}}{\text{Speed}}\]
\[= \frac{358000000}{3 \times 10^8} = 119.3 \text{ ms}\]

Equation 3.2 shows the total minimum theoretical latency for a request from a user to a satellite, and then the receipt of the request from a server, hence multiplying by four. Since most users and servers will be further than 35,800 km apart, as they will not be directly underneath the satellite, and some time is needed for processing, the average latency for geostationary satellite Internet is around 600 ms. This makes video calling or other real-time applications extremely challenging, as there will be almost a full second of delay between requests and responses.

The second disadvantage is that the signal is of very low intensity after travelling such a distance. While this originally limited the speed, this has been improved through the use of the Ka-band (up to 40 GHz) to be able to reach gigabit speeds. However, because the signal is small, it handles interference poorly and requires a large gain on either side. This means that inclement weather can affect the signal heavily (known as rain fade), and that large receivers are necessary, often needing small dishes (known as very small aperture terminals—VSAT) to maintain good connectivity (Fig. 3.4). The satellites themselves have to be very large (solar arrays can be 50 m or longer), as seen in Fig. 3.3, and consume large amounts of power.

Lastly, the geostationary orbit has a limited amount of space. Because of this, there is a limit to the possible number of Internet satellites that can be put there. 
3.2 Current Geostationary Internet Technologies

Also, because of the distance from Earth, it is virtually impossible to de-orbit from this location (due to both lack of atmospheric drag and the amount of fuel it would need), and satellites are placed further out into what is known as a graveyard orbit.
when they have completed their active lifespan. It is also very expensive to reach this orbit, incurring high launch costs for geostationary operators. Figure 3.5 shows the comparative distance of geostationary orbits to those much lower, as well as the graveyard orbit.

### 3.2.2 Cost and Availability of Geostationary-Based Internet in Africa

Since geostationary satellites cover one specific area of the world and cannot move in relation to the Earth, most Internet satellites are currently located over North America, Europe and Asia. However, there are some that provide access to Africa.
3.2 Current Geostationary Internet Technologies

Al Yah Satellite Communications (Yahsat) launched the Y1B satellite in 2012, which uses multi-spot Ka-band to deliver Internet to most African regions. Multi-spot uses multiple feed antennas to reflect off the same large dish at multiple frequencies, reducing interference and allowing a much greater multiple of users, the most recent advancement in geostationary Internet provision. Yahsat offers up to 7 mbps downlink and 1.5 mbps uplink. However, this costs US$ 1038 per month as of 2019, and has a limit of 100 gb, which is far more expensive than land or cellular-based services.

Per-country options may be slightly cheaper. Vodacom, a telecoms company in South Africa, advertises 4 mbps satellite Internet with a maximum data usage of 30 gb for US$ 150 per month. It does not disclose which satellite it uses. However, South Africa has large amounts of infrastructure compared to most African countries, and it has to be priced lower to remain competitive.

3.3 Large-Constellation Satellite Internet Background

In order to address the disadvantages mentioned earlier, and the high price-points, large constellation based Internet is being developed. Large constellation (or mega-constellation) means a massive number of satellites operating together to serve one purpose or network. These satellites are usually much smaller than the single large satellites that currently provide access to the Internet. Figure 3.6 shows a simulation of SpaceX’s Starlink network, providing a theoretical latency of 82 ms between London and Johannesburg, far faster than that of the current Internet.

There are two primary reasons why these constellations can be developed. The first is the overall improvement of computer processing. Processors are now significantly smaller, more powerful and more energy-efficient than they were in the early years of the space age. A modern smartphone is powerful enough to control the launch of 1 million Saturn V’s (12,190 instructions per second vs 16 billion (2 GHz processor and 8 cores). This is in accordance with Moore’s law, which states that every two years the number of transistors on a piece of silicon doubles. Figure 3.7 shows the real-life proof of this trend, showing the decrease in the size of flash memory.

This allows very small satellites to have ample processing power to perform even the most complex of computing tasks, such as the signal processing needed for large-scale communications. Even though processor designers are reaching a physical limit

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6“Yahsat 1B”, 2012, https://www.satbeams.com/satellites?norad=38245, (accessed 26 November 2019).
7“Yahclick Broadband”, https://ts2.space/en/yahclick/ (accessed 1 December 2019).
8“Vodacom Satellite Internet”, https://www.vodacombusiness.co.za/business/solutions/Internet/broadband-connect-satellite, (accessed 1 December 2019).
9Moore, Gordon E., “Cramming more components onto integrated circuits”, Electronics, 19 April 1965.
in terms of transistor size due to electron spacing (the transistors may be too close together and electrons may randomly “jump” between them), quantum computing will enable a new avenue of higher performance to be explored.
The second is that the cost-of-launch has decreased greatly as well. Rocket Labs provides a dedicated launch for US$ 5.7 million,\textsuperscript{10} which is extremely affordable in terms of space. Traditionally, space activities have been dominated by the big governmental actors who could afford the vast amount of time and resources needed to achieve success. Presently, even launch, one of the hardest aspects of space, has become highly commercial. The Russian Soyuz rocket family has changed from a Cold War icon into a transportation method that almost any entity can purchase. SpaceX has been pushing lower and lower costs by focusing on reusability, getting much closer to the unobtained goals of the Space Shuttle than the Space Shuttle ever could. Figure 3.8 shows this decreasing cost of U.S. launch providers.

For these two main reasons, along with other technological improvements such as additive manufacturing and better solar panels, large constellations of satellites that all form a single mega-system can now be launched. The Earth-Observation (EO) company Planet has the world’s first working large constellation, operating at least 140 satellites at any point in time. However, EO is in some measures cheaper and less complicated to achieve than communications.

SpaceX’s Starlink Internet division\textsuperscript{11} is currently leading the mega-constellation Internet gambit. As of 2019 they had launched 120 satellites\textsuperscript{12} each weighing 227 kg. Starlink has targeted an operational orbit of 550 km (LEO). This orbit provides two benefits, the first is that latency is extremely low at 25–35 ms, comparable to high-end cellular networks. The second is that this orbit will allow easier de-orbiting

\textsuperscript{10}Guy Gugliotta, \textit{Air & Space}, 2019, https://www.airspacemag.com/as-next/milestone-180968351/ (accessed 1 December 2019).
\textsuperscript{11}“Starlink Website”, https://www.starlink.com/.
\textsuperscript{12}“Starlink Press Kit”, \textit{SpaceX}, 15 May 2019.
Fig. 3.9  Starlink satellites attached to bus. Photo from SpaceX

and eventual natural orbital decay due to atmospheric resistance, which will help minimise space debris. Figure 3.9 shows the second batch of 60 satellites about to be deployed from the rocket bus.

Starlink’s satellites incorporate very high-end technology, including phased-array Ku-band antennas and inter-satellite optical links. Starlink has promised speeds of up to 1 Gbps with a full network.13 SpaceX has further said it will achieve some commercial operational regional coverage by 2020. It will need 480 satellites to achieve minor global coverage.14 The biggest ambition of SpaceX is to establish a full global constellation of 12,000 satellites. Even with cheaper satellites and much lower cost launch, this will require a huge amount of capital to achieve.

OneWeb is currently the second biggest LEO Internet operator, with six pilot satellites operational and approximately 2000 more planned. OneWeb’s satellites are planned for an orbital altitude of about 1200 km,15 which will make them significantly harder to de-orbit than SpaceX’s.

Amazon’s Project Kuiper16 has also planned some 3000 satellites but as of 2019 has not shown or launched any spacecraft.

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13Don Reisinger, “Update on Starlink”, *Fortune*, 22 October 2019, https://fortune.com/2019/10/22/elon-musk-twitter-spacex-starlink/ (accessed 14 December 2019).
14Elon Musk, “Much will likely go wrong on 1st mission. Also, 6 more launches of 60 sats needed for minor coverage, 12 for moderate” *(Tweet)*—viaTwitter, 11 May 2019.
15“OneWeb Satellite Startup to Set up Manufacturing in Florida”, *Wall Street Journal*, 3 January 2016.
16“Project Kuiper“, https://www.amazon.jobs/en/teams/projectkuiper (accessed 14 December 2019).
3.3 Large-Constellation Satellite Internet Background

3.3.1 Criticisms of Large Constellation Satellite Internet

A major issue that was identified in 2019 was a by-product of the launch of the Starlink satellites, as illustrated in Fig. 3.10. The large number of satellites at low altitude were extremely visible to astronomers, disrupting many images and measurements, and appearing as a bright train across the night sky.

This is not as serious as it may first appear however, as the satellites will spread out and become orders of magnitude fainter as they reach operational orbit, limiting their disruption to astronomy. However, there is a large difference between 120 and 12,000 satellites, and it remains to be seen what the overall effect will be. SpaceX has endeavoured to paint the next satellites it launches matte black, to further reduce their visibility.

Furthermore, as previously noted, there is increasing worry about a space debris incident, especially when these constellations effectively double the amount of satellites in orbit in the next decade. SpaceX has at least incorporated hall-effect thrusters into its satellites that will enable a degree of collision avoidance and controlled de-orbits. It has even planned to introduce automatic avoidance similar to Tesla’s Autopilot software.17 OneWeb has also declared they are committed to avoiding collisions.

The final major criticism is that these mega-constellations will interfere with existing space-based communications in geostationary orbits. Especially vulnerable

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17 Tim Fernholz, “SpaceX’s new satellites will dodge collisions autonomously (and they’d better)”, QZ, 2019, https://qz.com/1627570/how-autonomous-are-spacexs-starlink-satellites/ (accessed 14 December 2019).
will be the existing VSAT dishes, which already have a high sensitivity and low-interference tolerance. Both Starlink\(^\text{18}\) and OneWeb\(^\text{19}\) have said they will orientate their satellites differently and lower their power level as they pass over the equator to minimise interference.

### 3.3.2 Governance Benefits of Satellite-Based Internet

The primary benefit of Internet connectivity is communication. Remote populations can communicate far more effectively with the rest of a country, or their leadership, and can alert others to a problem more quickly and accurately. For example, while a phone call may be able to tell someone that a sinkhole has occurred, a photo or video would show the absolute extent of such an issue, allowing a government to better react. Email enables detailed reports to be compiled and sent, while video calling supports detailed discussions. Developed countries already use these technologies thoroughly in practice, while most African countries simply cannot as there is no Internet backbone to support them.

The second benefit of the Internet to governance is education and awareness. Internet availability to the public not only increases standards of living but also education and awareness on current issues. Internet is taken for granted in first world countries, and heavily supports secondary and tertiary education. Video tutorials and online encyclopaedias have hundreds of thousands of viewers. There are full online university courses that people can access for low cost or free. And e-learning has been essential in developed countries during school lockdowns as a result of the current Covid 19 pandemic.

Africa is currently the least-educated region of the world by far. Figure 3.11 shows the 2010 comparative Education Index compiled by the UN. It uses adult literacy and years of education as metrics to determine education levels. Africa is the worst continent by far. Giving Internet access to remote African schools, libraries and civic centres will be sure to bolster the education of everyone it is available to. The simple act of using the Internet improves literacy. The exact impact that access to the Internet has on education is hard to measure but is surely massive.

The effect that education has on governance is well-known. There is a clear relationship between good education and good governance.\(^\text{20}\) It is the difficulty of breaking into this cycle that hinders many African countries.

Figure 3.12 shows the results of a study that analysed the education level and

\(^{18}\)Joanna Bailey, “SpaceX wants to launch more Starlink satellites… 30,000 of them”, *Get Connected*, 2019 [https://www.getconnected.aero/2019/10/spacex-starlink-30000-more/](https://www.getconnected.aero/2019/10/spacex-starlink-30000-more/) (accessed 14 December 2019).

\(^{19}\)Peter B. de Selding, “OneWeb Fails (At Least for Now) To Soothe Satellite Interference Fears”, *Space News*, 2015, [https://spacenews.com/oneweb-fails-at-least-for-now-to-soothe-satellite-interference-fears/](https://spacenews.com/oneweb-fails-at-least-for-now-to-soothe-satellite-interference-fears/) (accessed 14 December 2019).

\(^{20}\)Maureen Lewis, “Governance in Education: Raising Performance”, *World Bank*, 22 December 2009 (accessed 14 December 2019).
Fig. 3.11  Education Index of the world. Dark green is best, dark brown is worst (Tony0106 at English Wikipedia [CC BY 3.0 (https://creativecommons.org/licenses/by/3.0)], “Education Index Map”, 2010, https://commons.wikimedia.org/wiki/File:Education_index_UN_HDR_2008.svg (accessed 16 December 2019))

Fig. 3.12  Crime versus education level of US individuals (Raymond R. Swisher, Christopher R. Dennison, “Educational Pathways and Change in Crime Between Adolescence and Early Adulthood”, Journal of Research in Crime and Delinquency, 2016, https://doi.org/10.1177/0022427816645380)
crime reports of almost 15,000 individuals in the U.S.. Crime clearly decreases with education level significantly.

Education also improves the ability of the general population to report potential issues before they worsen and even solve problems on their own. Education indirectly makes some avenues of governance easier to achieve. Again, good governance is required to achieve good education as well.

As already said, access to the Internet can also increase awareness of current events. For example, it can alert people beforehand of possible disasters such as flooding, allowing them ample time to evacuate. It can also allow people to see the actions of their leaders, helping expose possible corruption. Of course, the Internet can be used to control a population through censorship and misinformation, but this is a necessary risk as the potential benefits of providing Internet to Africa are so great.

3.3.3 Potential Avenues to Implement Satellite-Based Internet in Africa

Existing geostationary satellite-based Internet remains far too expensive for widespread use in Africa. These future constellation systems currently have no set pricing, however the companies behind them promise they will be competitive with land-based Internet systems. Provided this is true, regional governments could bid for these Internet services at wholesale or discount prices and implement them at points-of-interest in many rural areas that lack any Internet service. Those countries whose economy cannot even afford that may approach these suppliers for charitable donations of Internet service (some GEO operators have already offered free dishes and low-cost services to some remote African towns21). It remains to be seen whether this approach will work, but since it will not cost any major land-based infrastructure to achieve this, these companies may be willing to supply limited (but still high-speed) bandwidth.

These mega-constellation systems will still require ground stations, albeit much smaller and easier to deploy than VSAT dishes, and will therefore need to be placed upon some structure where there is a clear view of the sky. This link could then connect to a traditional Wi-Fi router to allow access for normal devices. Governments could implement these connection points first at major libraries and schools in large towns that lack traditional Internet connections, and then provide for smaller and smaller settlements. Since so little infrastructure is needed, this could be expanded rapidly provided the funding is there. Government-owned clinics, police stations and offices could also provide Internet service to the surrounding area. Even if the main link provides an unlimited amount of data, they could, at first, limit the daily amount to each person to reduce abuse of the system.

21Kgaogelo Letsebe, “Konnect Africa offers rural community-based WiFi”, IT Web, 2019, https://www.itweb.co.za/content/kxA9PO7Nk8EMo4J8 (accessed 16 December 2019).
Governmental free Wi-Fi has already been introduced in some areas of South Africa with great positive effect. Ekurhuleni Metro of eastern Johannesburg has had a pilot programme that has notably allowed at least one person to start a successful business and aided many others in their studies.22 South Africa, however, already has vast fibre systems near main centres, which most other African countries lack completely.23

Figure 3.13 describes a potential timeline for government provided free Wi-Fi. This is based on implementation timeframes of similar African infrastructure engineering projects. It may seem optimistic as most African governmental actions currently take far longer. However, the costs associated with this constellation-based Internet should be so low that it should be very easy to fit in a governmental budget. The install time is also very low, as it will just require one small antenna mounted on a rooftop and connected to a power source, rather than the kilometres of cable needed for a fibre connection. Hundreds of people could be given Internet access within the span of a few hours.

This, however, assumes that constellation Internet systems such as Starlink and OneWeb are successful. The technology does seem highly promising but remains unproven until the full network is established and in operation.

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22“Wi-Fi changes life in Ekurhuleni”, South African Governmental News Agency 2016, https://www.sanews.gov.za/south-africa/free-wi-fi-changes-life-ekurhuleni (accessed 16 December 2019).
23James Francis, “The Future of Fibre”, IT Web, 4 March 2019.
3.4 Conclusion

The Internet and communication form a vital component of modern development and commerce. Its importance in governance is without question and can help governance indirectly in Africa in a myriad of ways.

Traditional satellite Internet remains costly with high latency but is still somewhat useful for African development. However, in the next decade constellation-based Internet such as Starlink and OneWeb will become operational, which will have the potential to greatly alter developmental activities in Africa.

Communication between communities in Africa will become better and enable digital governance and management of rural areas to become much better, as well as communication between leaders. The effect of governmental decisions may also be felt much faster, as well as emergency management. Education has the possibility of being greatly enhanced, as suddenly many rural children are exposed to the Internet and e-learning.

These possibilities are heavily dependent on how African governmental bodies implement such systems. With good planning, and provided the technologies are proven to work as intended, governance in Africa may be revolutionised in a short space of time with relatively low costs.