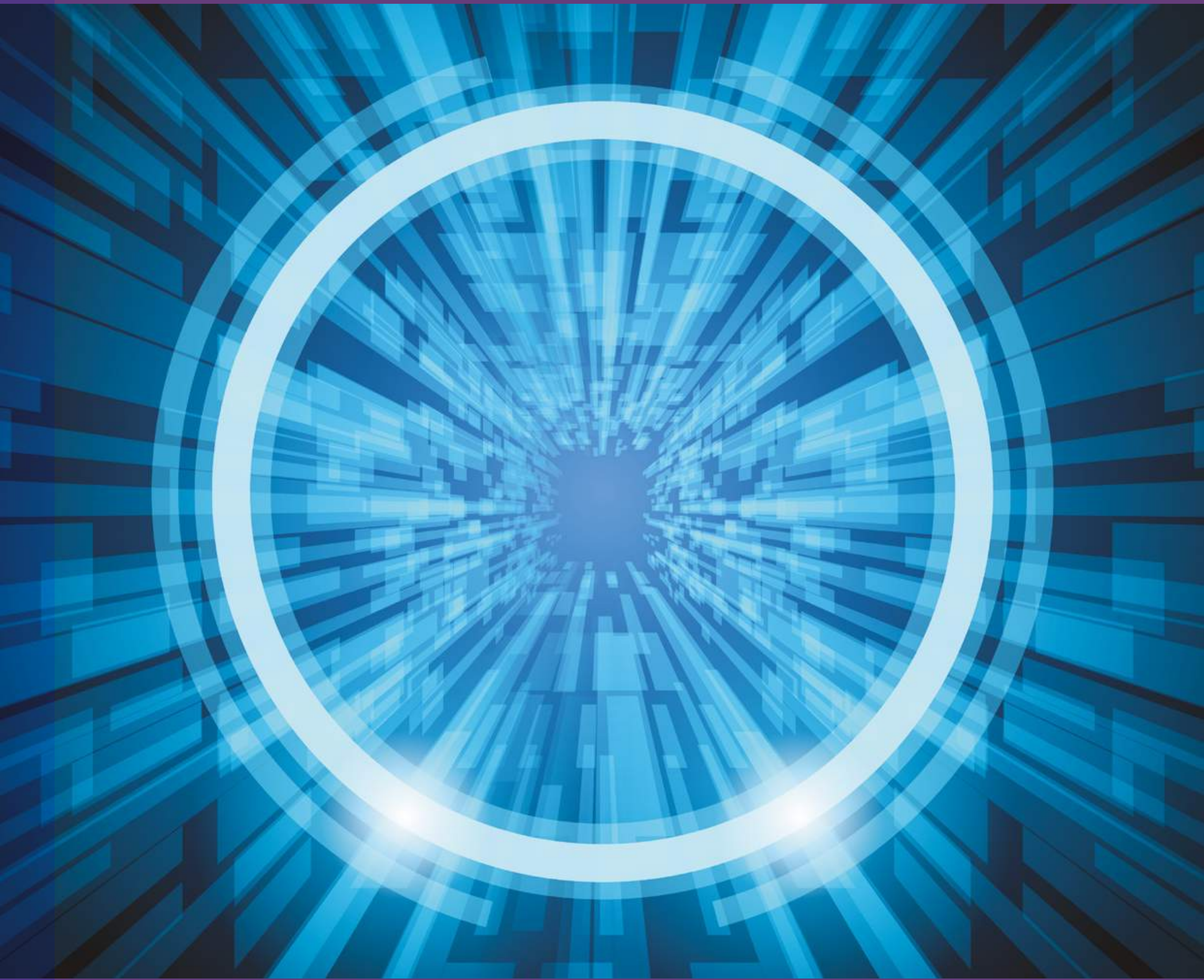

Working Group on Technologies in Space and the Upper-Atmosphere

Identifying the potential of new communications technologies for sustainable development

September 2017

BROADBAND COMMISSION
FOR SUSTAINABLE DEVELOPMENT

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inmarsat
The mobile satellite company

Foreword

The world is undergoing an extraordinary technological revolution in satellite and high altitude communications. A dramatic increase in broadband capacity across the globe, spurred by new technologies (including geostationary high throughput satellites, massive constellations of non-geostationary satellites, and recent innovations in broadband High Altitude Platform Station (HAPS) systems), is bringing reliable and affordable broadband connectivity to the hardest-to-reach corners of the Earth, enabling new capabilities and applications in areas already connected to the global network, and helping drive down access costs for many people. Due to their coverage, reliability, mobility, and flexibility, these new space-based technologies represent an important solution for expanding the reach and density of the global Internet, and achieving the Sustainable Development Goals (SDGs).

As this report of the Broadband Commission Working Group on Technologies in Space and the Upper-Atmosphere details, recent technological advances and an explosion in capacity will enable space-based technologies to play a critical role in connecting the 'other 4 billion' unconnected people and meeting the SDGs. Innovation is happening on many fronts: Innovative network designs have caused breakthroughs in the capacity, capabilities, and service quality of satellite and high altitude technologies. Hardware improvements, both in infrastructure and user terminals, are enabling service providers to do more, with smaller equipment, while consuming less power. Satellite and high altitude communications systems are expanding and densifying their global coverage footprints, while also leveraging technological advances, expanded capacity, and other efficiencies to drive down costs. At the same time, advances like network virtualization and small multi-band antennas will make it easier to integrate satellite and high altitude technologies with other networks such as Wi-Fi, LTE, and wireline and above all to enable consumers to access the Internet and broadband services over space-based networks via an ultra low cost terrestrial mobile device.

The Working Group found that satellite and high altitude systems offer significant advantages for expanding broadband coverage in developing countries. In addition to their broad coverage, versatility, and reliability, deployment of these systems can be relatively quick, cost-effective, and environmentally responsible. As this Report documents, satellite and high altitude communications are driving solutions essential to meeting the SDGs and helping make smart societies a reality in both developed and developing countries.

We have only just begun to understand the transformative potential of these technologies to enable holistic solutions for leveraging information and communications technologies in the service of development. They can provide high quality and reliable connectivity to all of a nation's citizens, facilitating development and deployment of educational, health, and economic platforms necessary for the creation of digital natives who can use that connectivity for creativity and value-added commerce. And these technologies provide the global reach to scale and globalise local digital innovation hubs created by those digital natives. I believe that as countries develop and revisit their broadband plans, they should consider the profound ways in which satellite and high altitude technologies can help them reach their goals

.**Rupert Pearce** CEO, Inmarsat

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Executive Summary

The United Nations Broadband Commission for Sustainable Development is very clear: broadband plays a vital role in achieving the global agenda for development. It drives economic prosperity, social inclusion, and environmental sustainability, as described in the 2030 Agenda for Sustainable Development, and is essential to meeting the Sustainable Development Goals (SDGs). Achieving this vision, however, requires affordable, universal and available Internet access for all.

If the young 21st century has already seen the steady spread and development of broadband Internet access, substantial progress remains to be made. In recent years, the global demand has grown in line with the promise broadband offers: since 2,000, global access to the Internet has grown from 6.5% to 43%[1]. Yet more than half the world's population is still unable to connect regularly to the Internet. The problem is particularly acute in the United Nations-designated Least Developed Countries (LDCs), many of which have characteristics, such as challenging geography and low population densities, which make them difficult to serve with terrestrial wired and wireless broadband systems. In these countries only one in seven people are online[2].

Fortunately, this is a time of extraordinary technological revolution in space and upper-atmosphere communications. New technologies, such as high-throughput satellites (HTS), massive non-geostationary satellite orbit (NGSO) constellations, and high-altitude platform stations (HAPS) systems are starting to offer broadband capacity across the globe, bringing reliable connectivity to the hardest-to-reach corners of the Earth. Their ubiquitous coverage, high reliability, high mobility, and high flexibility make space-based and upper-atmosphere technologies ideal solutions for expanding the reach of the global Internet. Moreover, the utility of these technologies is not limited to rural and remote areas: they can contribute to new capabilities and applications in urban and suburban under-connected areas by enabling terrestrial systems and complementing 5G networks.

Because of their versatility, innovation, and increasing performance, space-based and upper-atmosphere technologies in particular can integrate with mobile broadband systems, playing an important role in achieving the SDGs and facilitating seamless digital applications. As such, these technologies will be critical to building a truly ubiquitous and affordable broadband ecosystem, partnering with other telecommunications technologies to meet increasing broadband demand in urban areas, while providing reliable broadband to rural and sparsely populated ones.

The Broadband Commission established a *Working Group on Technologies in Space and the Upper-Atmosphere* with the objective of "Identifying the potential of new communications technologies for sustainable development"[3]. In this report, the Working Group documents the substantial innovation in space-based and upper-atmosphere communications technologies that has occurred over the last ten years and which will continue to change the broadband landscape over the next ten years. It identifies the unique characteristics and benefits of various space-based and upper-atmosphere technologies, and examines some of the use cases and applications that leverage these technologies to achieve the sustainable development goals. Finally, the report addresses regulatory and commercial considerations related to implementing these solutions, and offers some policy recommendations to assist administrations in developing countries in tapping into the benefits of this technology revolution.

Technological Evolution in Space and the Upper-Atmosphere

Space-based and upper-atmosphere technologies have evolved dramatically in the last decade. While satellites have long been a part of the telecommunications ecosystem, recent technological innovation and an explosion in capacity has enabled them to play a key role in emerging broadband markets. Similarly, recent developments in HAPS have made that technology a promising way to provide quick deployment and cost-effective coverage across entire regions, focused on backhaul operations in support of mobile broadband systems. Evolution, for the purposes of this report, refers to ways in which technologies in space and the upper-atmosphere are constantly improving throughput, increasing existing and developing new capabilities, becoming more efficient users of spectrum and orbital resources, and driving down costs.

Hardware Innovations. Evolution has happened at each component level of space-based and upper-atmosphere communications technologies. Improved power generation and storage, combined with efficiencies in propulsion and control systems have made greater power available for satellite payload operations. Advancements in aerial platforms, battery technology, lightweight composite materials, autonomous aviation and solar technology are opening new opportunities for HAPS. In parallel, transmission and reception technology at both ends of the communication path—including RF components, digital communication techniques, spectral efficiency, and terminal improvements—have developed to enable system operators to do even more with their input resources.

Operational Improvements. Innovative network designs have caused breakthroughs in the capacity, capabilities, and service quality of space-based and upper-atmosphere technologies. In the case of satellites, some of the most significant advances in services have evolved from the development of HTS, which leverage multiple, narrower spot-beams from satellites in geostationary orbit to increase frequency reuse and deliver exponential growth in system capacity. Additionally, new entrants to space-based and upper-atmosphere communications are generating innovative business and service delivery models. Massive constellations of hundreds of NGSO satellites in low-Earth orbit (LEO) are being planned and manufactured that, when fully deployed, will blanket the globe in low-latency, high-bandwidth capacity, including one large scale constellation planning to offer 50 Mbps speeds to users[4]. These advances in technology will also allow solar-powered HAPS to provide cost-efficient and high-speed broadband to underserved markets while providing tens of gigabits of backhaul capacity.

Expanded Reach. Current and planned space-based and upper-atmosphere communications systems enable a truly global reach. Unlike some legacy networks, which focused deployments in densely populated urban areas with high consumer demand, new satellite and HAPS deployments are emphasising ubiquity and bringing connectivity to areas previously unserved or underserved These systems are designed specifically to provide global reach and coverage.

Increased Capacity. New HTS systems, massive NGSO constellations, and HAPS deployments each feature substantial increases in capacity compared to their predecessors. But even more transformational is the fact that many of these systems are coming online simultaneously. Over 100 HTS systems will be in orbit by 2020-2025, delivering terabytes of additional capacity[5]. This does not account for multiple NGSO constellations in development; the introduction of HAPS may see thousands of platforms deployed in previously unserved and underserved areas.

Substantial Cost Reductions. The technological advances, operational improvements, expanded reach, and increased capacity discussed above are combining to drive down costs, making space-based and upper-atmosphere technologies more accessible than ever before. Although space-based and upper-atmosphere technologies traditionally have been perceived as costly solutions, they are becoming increasingly economical. The price per gigabit per second (Gbps) of throughput has dropped continuously for the past decade and will continue to do so. New manufacturing techniques, smaller satellite form factors, reusable launch vehicles, developments in unmanned aviation, and reduced reliance on fuel are driving down the cost of developing and deploying space-based and upper-atmosphere technologies. Moreover, in many cases, these costs are for systems that cover huge areas, enabling them to be recouped from various markets across the life of a system.

Advantages of Space-Based and Upper-Atmosphere Solutions for Development

There are substantial benefits making space-based and upper-atmosphere technology solutions ideal platforms for expanding broadband coverage in developing countries.

Wide Area Coverage. Space-based and upper-atmosphere technology solutions only require limited ground infrastructure to connect presently unserved and underserved areas. This advantage, coupled with related capital and operational savings, have enabled satellite deployments that already cover the entire globe. The wide areas covered by space-based and upper-atmosphere technologies make them economically viable in areas where other technologies are hard to deploy due to challenging geographies and long distances from urban centres. Unlike wired broadband systems, in which deployment costs rise dramatically as population density decrease, capital expenditure for space-based and upper-atmosphere technologies is largely independent of user density.

Geography Agnostic. Large swathes of underserved areas contain difficult or protected terrain that raise the cost of terrestrial deployments above viable levels. Areas of geological instability and challenging weather have also challenged conventional broadband infrastructure. However, none of these issues affect space-based and upper-atmosphere technologies, which provide equal and seamless coverage regardless of terrain and are invulnerable to many geological issues.

Instant Infrastructure. The broad geographic coverage of satellites and HAPS systems mean that once deployed, connectivity flows immediately and indefinitely. Broadband is accessible from any ground terminal in the coverage area. In addition to facilitating large-scale simultaneous broadband rollout, this also allows for rapid extensions of connectivity during events that require it, from one-time civil needs to natural disasters. This includes emergency broadcast public service communications.

Ease of Deployment. Since global satellite coverage already exists, network deployment can be as simple as providing ground terminals. To the extent a new satellite mission is required, one satellite can cover a third of the globe with only minimal terrestrial facilities required. Other space-based and upper-atmosphere technologies, such as HAPS, have shorter mission spans that are offset by their much easier deployment and redeployment.

Reliability. Reliability is a key issue faced in underserved countries. Space-based and upper-atmosphere technologies are, by nature, highly reliable. They are immune to most risks that face terrestrial networks, including accidental damage, theft, conflict areas and natural disasters, and are designed for continuous operation. Satellites are designed with multiple layers of redundancy, giving nearly 100% uptime. In the unlikely event that one satellite does fail, multiple spare satellites are immediately available, preventing service interruption. HAPS systems, engineered with continuous reliable operation in mind, offer similar levels of redundancy.

Green. Space-based and upper-atmosphere technologies represent advances in clean and green connectivity solutions. Especially in light of developments in solar technology and electric propulsion, the carbon impact from satellites is nearly zero once deployed. Reusable launch vehicles promise to further reduce the environmental impacts of satellite operations. HAPS, which already require very limited amounts of power to operate, are designed to take full advantage of solar-power and be entirely reusable.

Long-Term Deployment and Support. Space-based and upper-atmosphere technologies can provide an effective long-term solution for connectivity. Satellite systems are designed for lifetimes of 20 years or more, allowing for longer deployment and support of equipment.

Applications of Space-Based and Upper-Atmosphere Solutions for Sustainable Development

In addition to connecting individuals to the Internet, space-based and upper-atmosphere technologies enable diverse applications that will be key to achieving the United Nation's 17 Sustainable Development Goals. Investment in these services can have a profound effect across various aspects of society, ranging from industry, health, and education, to sustainability, e-government, and facilitating the development of smart cities and societies.

Education. Robust broadband communications facilitated by space-based and upper-atmosphere technologies connects remote and vulnerable communities to national educational programs and international resources through the Internet and broadcast content, including mobile or displaced populations, to ensure equality of educational opportunity and empowerment no matter the location.

Health. Technology-enabled healthcare applications coupled with Internet connectivity are critical to achieving the SDGs relating to health and wellbeing. Connecting communities means that healthcare workers can receive remote training in detecting diseases and making recommendations for preventive care, while clinics and medical providers can connect with each other to collect data and share information, facilitating better health outcomes across a country. In-home monitoring systems also mean patients in remote areas will be able to avoid the cost involved in travel to regular check-ups.

Banking. Isolated communities are disadvantaged if they have no access to banking and financial services. If there is not a bank within walking distance, or cellular coverage to access banking apps, individuals and businesses simply cannot be part of the growing digital economy. Space-based and upper-atmosphere technologies can provide residents with convenient, flexible, reliable and secure financial access, whether through connecting remote bank branches to head offices, or spreading point-of-sale devices that allow bank card payments for local businesses.

Agriculture. Space-based and upper-atmosphere technologies can provide real-time monitoring of fields and hydroponic installations to maximize yield in harsh environments. Broadband connectivity enables farmers to monitor pricing trends to determine the optimum time to bring their crops to market.

Oil / Gas Exploration. Deployable, portable, and mobile connectivity supports exploration of new reserves and extraction of natural resources including oil and gas and minerals, and monitoring the operations of industrial facilities and infrastructure.

Smart cities and infrastructure. Broadband communications connect low power sensors to monitor use, broadcast content, and manage resources responsibly for a range of municipal services including electricity, water, waste management, transportation, and lighting.

Maritime. Space-based and upper-atmosphere connectivity is not limited to land-based operations. These platforms can support sustainable fishing through monitoring to meet requirements stemming from commercial and regulatory initiatives towards conservation, marine sustainability, and welfare of fishermen. They also facilitate "smart shipping" applications, including video conferencing, remote vessel assistance/diagnostics, telemedicine, video surveillance and information management systems for maritime 'big data' applications.

Environmental Management. The ubiquity and resilience of space-based and upper-atmosphere technologies supports remote sensing and data collection to track environmental and climate change, including in marine and terrestrial ecosystems, to aid in management of forests, nature preserves, and biodiversity.

Disaster Response. Highly reliable and rapidly deployable, space-based and upper-atmosphere technologies establish critical lifelines following major natural disasters such as hurricanes or earthquakes when terrestrial facilities are knocked out, permitting humanitarian relief operations to clear blockages to aid and to focus on the most critically impacted communities.

Government Services. The ability to ensure that all citizens can engage with their governments is essential to their well-being and to extending the benefits of public services to an entire population. The more public services are put online, the more broadband is required in all corners of a country: a function for which, as this report has described elsewhere, satellite and upper-atmosphere technologies are especially well-suited.

Space-based and upper-atmosphere technologies truly facilitate holistic solutions for leveraging information and communications technologies in the service of development. These technologies provide high quality and reliable connectivity to all a nation's citizens. The services facilitate development and deployment of educational, health, and economic platforms necessary for the creation of digital natives who can use that connectivity for creativity and value-added commerce. And these technologies provide the global reach to scale and globalise local digital innovation hubs created by those digital natives.

Endnotes

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1 Introduction

To expedite implementation of the United Nations' Sustainable Development Goals (SDGs), the Broadband Commission established a Working Group on Technologies in Space and the Upper-Atmosphere with the objective of identifying the potential of new communications technologies for sustainable development[1]. In order to achieve the Broadband Commission's goal of global connectivity and solving all parts of the digital divide, the Working Group considers eliminating barriers to space-based broadband to be essential.

Adequate technology could become the catalyst to all nations' meeting the SDGs by addressing the major challenges to broadband deployment. Unfortunately, in the case of broadband, demand does not always drive supply. Demand has been shown to exist even in low density areas that are least accustomed to making use of broadband: a recent study showed that 28% of people in a sub-Saharan village had tried forms of online trading, with poor results due to the lack of adequate broadband infrastructure[2].

The majority of countries that are underserved by conventional broadband technologies share certain characteristics. They tend to have challenging geographies, sparse population distribution, large rural populations (who make up 70% of people without access to broadband)[3], and are less economically developed and therefore less able to afford broadband investment. Space-based technologies and those in the upper-atmosphere offer broad coverage, high reliability, high mobility, and high geographical flexibility. They can provide broadband to a rural user at the same cost as an urban user. This cost structure has allowed technologies in space and the upper-atmosphere to extend coverage to hard-to-reach areas, supplementing terrestrial providers of broadband for whom this cost structure is not viable.

Thanks to innovation, significantly improved performance, and increased versatility, space-based and upper-atmosphere technologies can efficiently integrate with mobile broadband systems to facilitate seamless digital platforms. For example, even in areas covered by terrestrial wireless systems, satellite systems could be used to complement the wireless networks by offloading certain non-latency-sensitive traffic or making commonly accessed content available using multicast/broadcast capabilities. These technologies are therefore a critical link in the chain to building a ubiquitous and affordable broadband ecosystem, both in partnership with and competition with more traditional telecommunications providers.

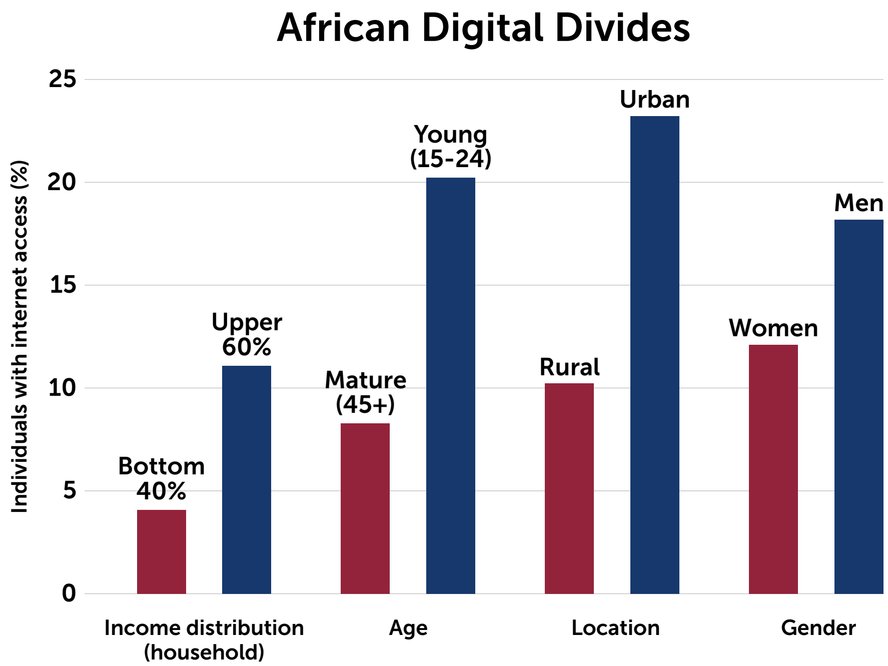
Most importantly, space-based and upper-atmosphere technologies have advanced rapidly in the last decade. With vastly reduced investment costs and new methods of delivery, they now promise to play a key role in connecting the unconnected. While satellites have long been a part of the telecommunications ecosystem, recent technological advances have fueled an explosion of capacity that will enable them to play a key role in broadband markets. New HAPS are now viable as a way to provide quick and cost-effective coverage across entire regions. In short, technologies in space and the upper-atmosphere are constantly evolving to provide more throughput, more efficiently, and at less cost, and governments and national stakeholders need to be aware of these developments to make informed policy and commercial choices.

1.1 The Promise of Broadband

Broadband services offer important solutions to meet the needs of underserved and remote these countries' needs by providing access to resources outside of the isolated community. Indeed, offering a link to the outside world, if only through broadcast content, turns the vicious cycle into a virtuous one: it boosts growth by expanding trade and access to markets, improves productivity, drives efficient delivery of government services, creates jobs, fosters new business, and generally improves access to information. The International Telecommunication Union (ITU) has found that a 10% increase in national broadband penetration could raise economic growth between 0.25% and 1.4%. Doubling the average speed of Internet connectivity worldwide could increase world GDP by 0.3%[4].

In recent years, the global demand has grown in line with the promise broadband offers: since 2,000, global access to the Internet has grown from 6.5% to 43%[5]. But if the speed of bringing people online is an achievement, it is an achievement that primarily benefits the developed world: in the 48 countries designated as LDCs, only one in seven people are online[6]. Despite global advances in broadband connectivity, "digital divides" persist between populations with Internet access and those without. Rural-urban divides are noticeable across both developed and developing regions of the world[7], where lower population densities offer low or no return on investment to ISPs. In these places, the rapid growth in broadband access has left behind precisely those who need the Internet the most: poorer, isolated populations, of whom women, the elderly, and the most economically vulnerable have least access. Figure 1 illustrates this digital divide in Africa, where the problem of low Internet penetration rates is exacerbated for the most vulnerable social-groups.

Figure 1: Comparing the divide in Internet access amongst vulnerable groups in Africa*



*Source: Ericsson Mobility Report June 2016, available at: www.ericsson.com/res/docs/2016/ericsson-mobility-report-2016.pdf. *World Bank, "World Development Report 2016: Digital Dividends" (2016), p. 9.*

Ensuring broadband access to these underserved markets is no easy challenge. Despite demand, geography itself makes deployment of broadband difficult, as does cost, lack of reliable speeds, and solutions that offer lower quality services. The cost of connecting the next three billion people to broadband using conventional technologies such as fibre-optic cables or wireless terrestrial networks or satellites remains prohibitive. One ITU analysis evaluated multiple regional and global studies of the cost of broadband deployment, and concluded that the cost to connect 1.5 billion more individuals with broadband deployment is conservatively USD 450 billion (EUR 417 billion) (see Table 1).

Other analyses have estimated the average per-household cost of deploying broadband infrastructure in Africa, the Arab States, and the Asia-Pacific region to be USD 557 (EUR 517)[8]. This is a prohibitive threshold for the many low-income economies in these regions, where gross national income (GNI) per capita is below USD 1025 (EUR 963) per year[9].

of this, but backhaul from satellites or HAPS can instantly and economically-viably connect these populations. Satellite constellations offer global coverage regardless of geographic challenges, and high-altitude platform stations (HAPS) can be deployed from distant air fields for long- or short-term connectivity. Both these technologies can change the balance for broadband access in these markets, providing the necessary catalyst for rapid economic growth.

Space-based and upper-atmosphere technologies overcome cost issues. Physical barriers to investment in broadband have also produced financial barriers, leaving least developed countries (LDCs) with some of the highest broadband costs in the world.

Table 1: Cost of Broadband Deployment to 1.5 Billion Individuals

Region	Individuals not using the Internet*	Number of households per region*	Total investment costs (USD)*
Asia & Pacific	932.20	288.81	313,689.07
Africa	267.59	53.00	62,207.04
The Americas	121.30	34.42	25,658.45
Arab States	86.87	17.40	14,122.80
Europe	50.90	21.16	17,877.10
CIS	41.14	15.64	14,336.81
Total	1,500.00	53.00	447,891.26

**Values shown are expressed in millions. Source: Broadband Commission; I. Philbeck, "Working Together to Connect the World by 2020: Reinforcing Connectivity Initiatives for Universal and Affordable Access", Broadband Commission, p.8.*

If deployed aggressively, space and upper-atmosphere broadband solutions could be a development game-changer for these countries.

1.2 Strategic Needs

Space-based and upper-atmosphere technologies can overcome geography. Many countries have geographies that make terrestrial infrastructure difficult to build. They have deserts or mountain ranges, or are landlocked or island states. Small island developing states (SIDS) are often isolated from the global fibre-optic backbone and smaller populations prevent economically viable rectification

While a broadband connection costs, on average, 1.5% of monthly income in Europe, the average for developing countries is over 100% – access in one country in East Africa runs to 1070.8% of the average monthly income[10] – a trend that only becomes more severe in landlocked developing countries (LLDCs) where cables must be routed through neighbouring countries[11]. Space and upper-atmosphere technologies offer a way for economically challenged economies to affordably access high quality connectivity.

Space-based and upper-atmosphere technologies can help ensure communications infrastructure independence. LLDCs may be dependent on their neighbours for interconnections to the wider Internet, but these neighbours often face many of the same infrastructure or regulate their telecoms sector in ways that limit interconnection. Space-based and upper-atmosphere connectivity can be a way for LLDCs to overcome these limitations and gain access to higher quality and lower cost connectivity.

Space-based technologies offer the same speeds regardless of market and are a competitive alternative in cities. With high speed Internet access, small businesses in a SIDS can access the same global IT services, support, and global market share as a multinational in a developed country. In the urban environments of LDCs – even when there is terrestrial infrastructure – they can provide reliable high-speed broadband, which can support essential applications. This provides value not just for government services, but also can empower individuals and small businesses. Such high-speed accessibility forms the backbone of new and innovative economic developments fostering overall economic growth.

Space-based and upper-atmosphere technologies also work alongside and integrate with incumbent terrestrial operators, and in this model they are not in competition. Because they fill gaps that incumbent operators find harder to serve, space-based and upper-atmosphere technologies can complement incumbent systems. Interoperabilty between terrestrial systems and space-based and upper atmosphere technologies in a complementary way would add many benefits for the people covered. For example, users would be able to enjoy the best connectivity and capacity available wherever they are located and potentially to limit power consumption on devices by connecting to terrestrial networks, where they are in reach.

Satellite or HAPS connectivity can also be used effectively as backhaul in support of terrestrial low power wide area networks (LPWAN) or mobile deployments to extend the range of those networks. Satellite operators often work in commercial partnership with terrestrial telecommunications networks to offer integrated service to users, and new HAPS capabilities will focus predominantly on supplementing existing networks with additional backhaul capacity. This allows satellite operators to leverage their partner's brand and customer base to provide more capacity, and enables terrestrial telecommunications networks to reach new users in areas where it was previously uneconomical to provide services. This sort of partnership enables users to take advantage of the lower-cost devices and other positive characteristics of wider terrestrial mobile ecosystem in areas in which those systems otherwise would not have deployed, facilitated by the ubiquity and high reliability of space-based and upper atmosphere communications. Similarly, HAPS might most effectively be deployed as a middle-mile solution, connecting local wireless infrastructure in rural and remote regions to an Internet point-of-presence (POP) elsewhere.

Space-based technologies are affordable and available now. Many satellite operators have already made significant investments to upgrade their existing systems, and new generations of HTS have already begun to come online. Services are available in many parts of the world. Though the upfront costs of these investments for operators are high, the capacity increase they represent is enormous. Further, they enable service delivery over decades and require essentially no ongoing maintenance costs, whereas terrestrial infrastructure can be costly to maintain. These capabilities combined with low or no marginal costs translate into a compelling capacity to price ratio for the end user.

The future of services based in space and the upper-atmosphere promises even more opportunity for these countries. These underserved countries face some of the most difficult challenges when it comes to attaining the SDGs[12].

Broadband access is an indispensable tool to accelerate progress towards realizing the SDGs. In addition, a new generation of HTS and other space-based technology is coming to fruition that will augment the existing ubiquity and resilience with greater speed, capacity, and affordability. The increasing availability and lower costs promise to unlock broadband services for even more governments, businesses, and individuals worldwide.

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12 TST Issues Brief: Needs of Countries in Special Situations – African Countries, Least Developed Countries, Landlocked Developing Countries and Small Island Developing States, as well as the specific challenges facing Middle-Income Countries, UN Development Program (2016)

2 Technological evolution in space and the upper-atmosphere

Even with the continued progress in extending satellite broadband worldwide, some four billion people remain without access to high speed broadband[1]. This leaves space for significant innovations from the space sector and the emergence of HAPS as a complementary service layer. Some attempts to use satellite and HAPS constellations to provide wide-scale, commercial applications in the late 90s and early 2000s proved technically unachievable[2], but this is no longer the case. Broadband HAPS has become a promising option to augment global capacity and expand coverage. In parallel, satellite technologies have improved in terms of performance, range, flexibility, power and efficiency with each passing year.

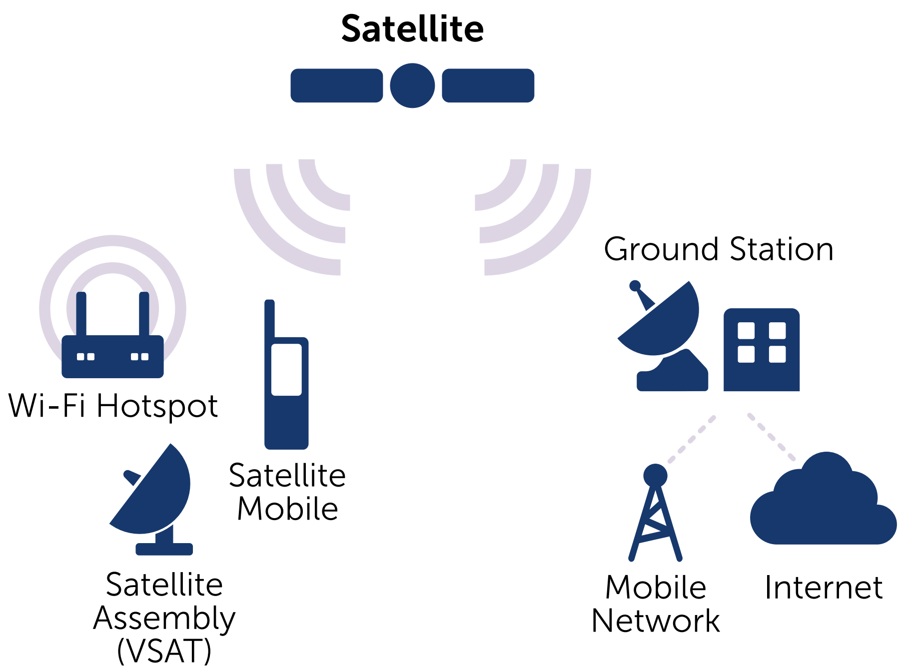
2.1 Satellites

Characteristics

Satellites' ability to provide global, ubiquitous coverage means they can reach where terrestrial-based broadband cannot, including sparsely populated and geographically challenging areas where there has been no investment in communications infrastructure. Using small mobile and fixed user terminals, satellites can bring broadband services across the "last mile" directly to individual users. In combination with smaller wireless or wireline networks, they can also provide backhaul links connecting remote networks to the global Internet. This makes satellites a key ingredient in the mix of technologies necessary to connect the unconnected on a global scale.

Satellite technologies have seen dramatic improvements in capacity, cost and reach over the last decade. The power available has increased enormously, due to improved solar arrays and better battery technology[3]. This is complemented by more efficient propulsion, thermal control and payload technology, enabling space-based and upper-atmosphere technologies to be more effectively powered and piloted so that more power can be dedicated to payload operations[4].

Figure 2: Architecture of traditional satellite communications[5]

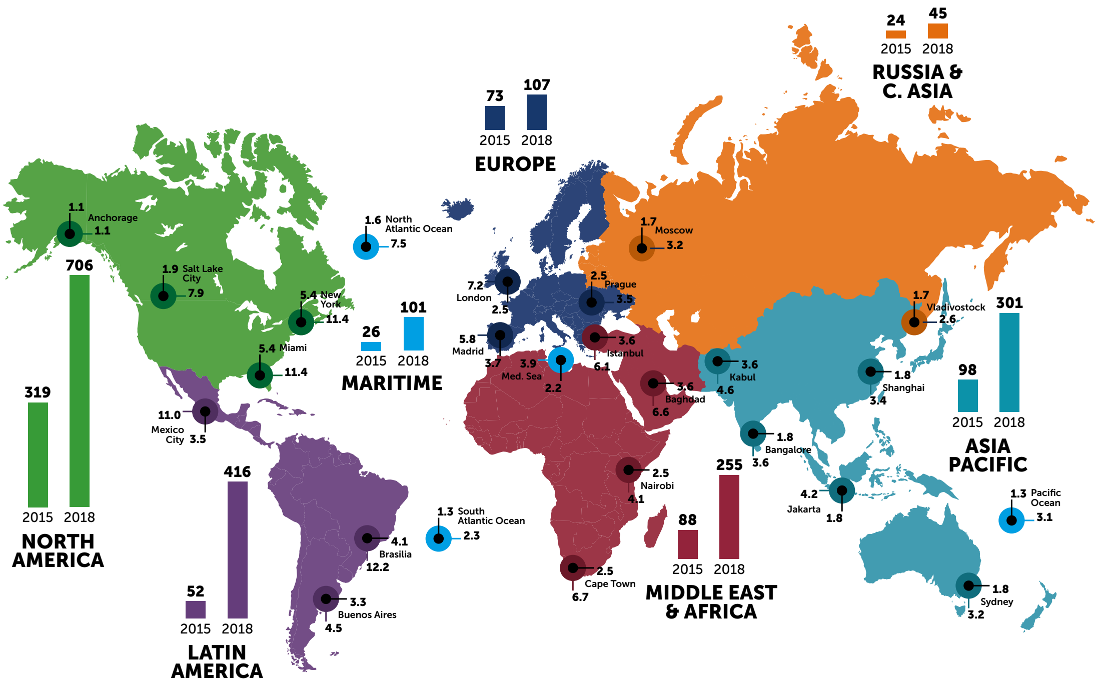


Efficiencies in launch design and improvements in payload design and operation also have led to performance increases. Satellites have moved from single to multi-beam antennas, allowing much higher capacity and better coverage[6]. Light-weight reflectors, more integration and processing power, reduced RF components and more efficient high-power amplifiers have all improved the performance and capability of the payloads themselves[7]. Improved channel models, fade mitigation techniques, improved digital communication, modulation and coding techniques, and multiple access techniques have improved the performance of space-based and high altitude transmission and reception[8].

Moreover, ground terminals have evolved in parallel. Reductions in size and cost coupled with increases in capability, including enhanced mobility, are opening up new applications for satellite connectivity where previously only terrestrial networks were seen as viable.

Satellite technologies also have the ability to deliver services to support mobile phones and other technologies. Mobile and fixed satellite communications are a critical part of the Internet connectivity ecosystem for consumer, commercial and government data services through VSATs, smaller access points, machine-to-machine (M2M) and Internet of Things (IoT) connections. Many key sectors – including electric utility, water, oil and gas and transportation (trucking, aviation and shipping) – now require remote connectivity. As "smart" uses grow so does the use of satellite connections: HTS capacity will grow from >700 Gbps in 2015 to around 3,000 Gbps in 2020, while capacity will grow beyond expected demand by 2020[9]. So like other technologies, satellites continue to meet demand from needs of industrial, consumer, and governmental users in urban and rural areas alike.

Figure 3: World map of HTS supply (in Gbps) for 2015 and 2018[10]



All these aspects are particularly important in the context of future 5G networks. Policy-makers – both nationally and within international bodies like the International Telecommunication Union (ITU) – have set high bench marks for 5G networks, expecting faster, higher capacity, more reliable, more ubiquitous services to be provided by infrastructures that can be fast deployed across the globe. To attain 5G's high expectations, the ITU IMT-2020 Focus Group (which explored the potential architecture and needs of 5G networks) concluded that IMT-2020 demands a fundamental change that will involve multiple radio access technologies, including satellite, in access-agnostic ways as a single network[11].

In other words, 5G will need to be an ecosystem of technologies – a network of networks – with satellites and HAPS filling key roles to enable the entire system. The ubiquity and capacity of satellite coverage means it will be an important component of 5G networks. Ubiquity allows satellites to be an important backstop for gaps in terrestrial networks. Satellite capacity could also be an important way to route certain types of traffic to the end user, such as bandwidth-intensive video streaming, provision of components of connected intelligent transportation systems, cyber overlays and others.

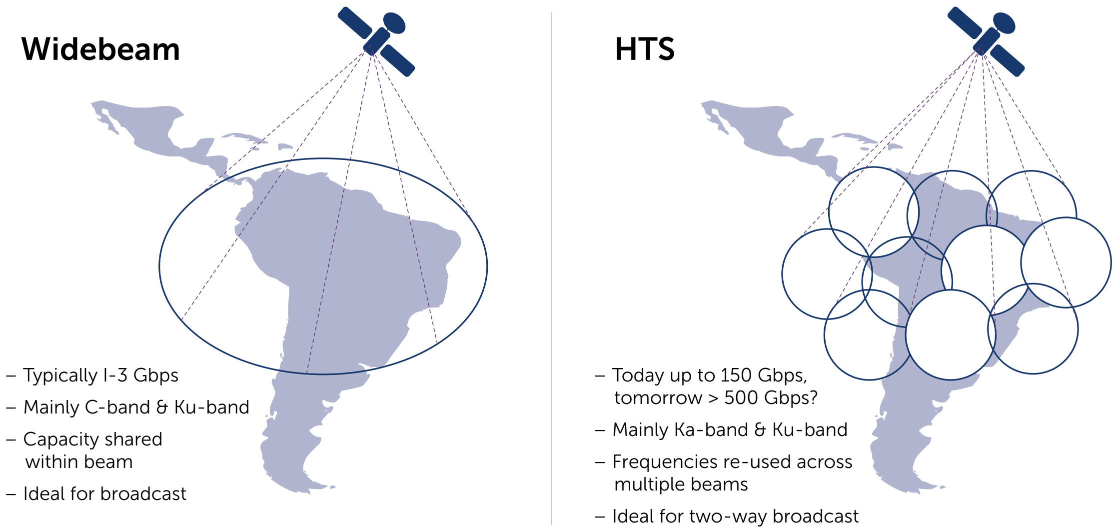
Variants

Different types of satellite networks operate in either geostationary orbit[12] or non-geostationary orbits[13] the latter of which are further classified as low, medium or high earth orbit. The different orbits' technical advantages and the frequency bands in which they operate – such as the L-, S-, C-, Ku-, Ka-, V-, Q-bands and potentially higher bands – mean they can provide service through either fixed links tied to one location or mobile links that allow the user to remain connected even as they move from one place to another. New satellite systems are planned for even higher frequency bands (E-bands and optical).

Geostationary Satellites

Early services provided by geostationary satellites were supported by leased or dedicated satellites via global or regional

Figure 4: Comparison between regular satellite and HTS



coverages in low frequency bands as L-, S- or C-. Those services required large antennas in order to support low data rates. As technology has evolved, the general trend has been moving towards higher frequency bands (Ku- and Ka-, and now V- and Q-), allowing a proportional increase in capacity and related cost/MHz reduction. But the real disruptive enabler for greatly decreasing the cost per MHz has been the deployment of HTS in the Ku- and Ka-bands. The key characteristic of this satellite technique is the use of a multi-beam coverage which allows spectrum re-use schemes.

HTS uses smaller beams than conventional fixed-satellite service (FSS) satellites. Previous wide-beam architecture was good for broadcast, but required sharing capacity within the area of the beam, making it a struggle for two-way.

The challenge for HTS technology is to respond to the variation in demand across a coverage area (between urban hot spots and low population density rural areas). This demand variation drives the need for flexibility in re-allocating capacity between spot-beams, and increased flexibility can dramatically increase the usage for these satellites. The satellite industry is therefore driving towards maximum satellite throughput whilst simultaneously able to allocate the capacity in a flexible manner across both time and location (high capacity concentrated over small areas vs average capacity spread over wide areas).

This HTS technology revolution is enabling operators to plan for scalable products and services that are available to users around the globe at a viable price point. The network speeds are comparable to or better than developed-country cable and fibre, improving the cost and latency of traditional geostationary satellite providers and allowing them to offer residential broadband services via high-speed satellite. Because of its flexibility, accessibility, and range of capabilities, high-speed satellite broadband is often preferred not just by rural users who face limited terrestrial alternatives, but also by urban users whose demands for very high speeds and high capacity may not be fulfilled by the available terrestrial infrastructure. And HTS will be global. One planned constellation for 2017 will add an additional 1 Tbps capacity per each of its three planned satellites, targeted at consumers worldwide[14].

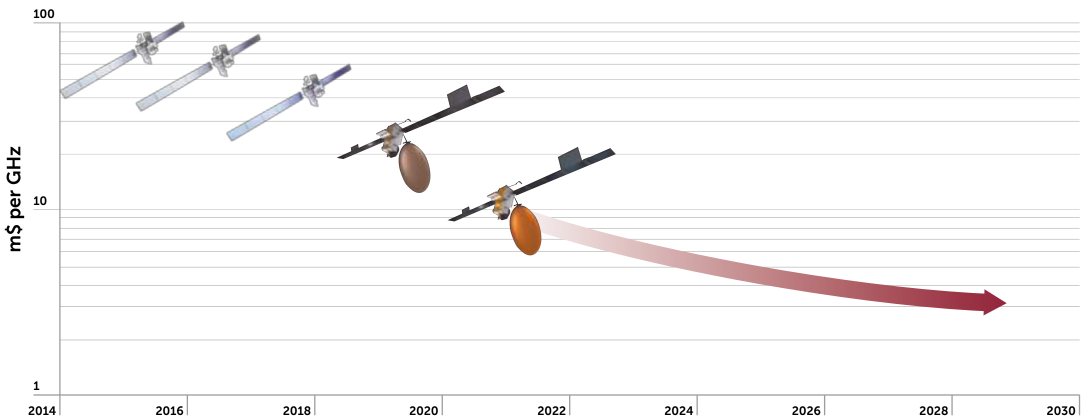
Table 2: Impact of technology development in the capacity of HTS generations

Case	Gbps	CAPEX (USD millions)	USD millions per GBPS
Regular	3	235	78
HTS-1	10	400	40
HTS-2	50	450	9
HTS-3	100	500	5
HTS-4	350	700	2
HTS-5	1,000	500	0.5

Source: Euroconsult[15]

This new generation of HTS systems is being deployed and the cost/MHz is exponentially decreasing.

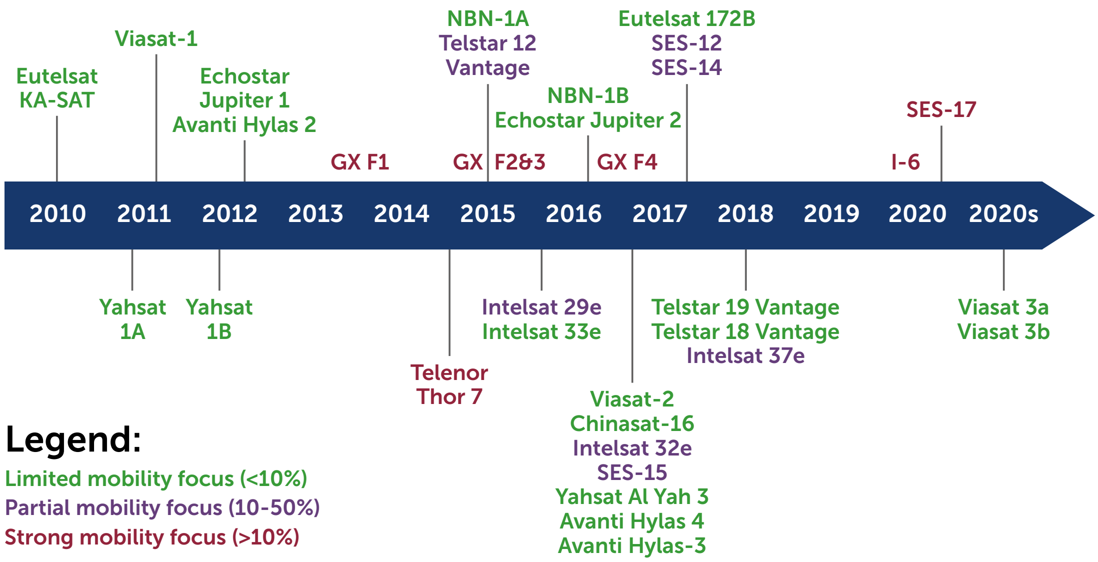
Figure 5: Impact of HTS technology development on cost per GHz



By 2020-2025 there will be over 100 HTS systems in orbit delivering terabytes of connectivity across the world using the Ku- and Ka- bands, reducing unit bandwidth costs and bringing satellite services to parity with terrestrial solutions[16].

2,000 km above the Earth, and medium earth orbit (MEO) satellites which operate between 2,000 to 36,000 km above the Earth. Both constellations require multiple satellites in order to support continuous communications within their coverage.

Figure 6: 25 years of HTS suppliers



Source: Public website data

Non-Geostationary Satellite Orbits (NGSOs)

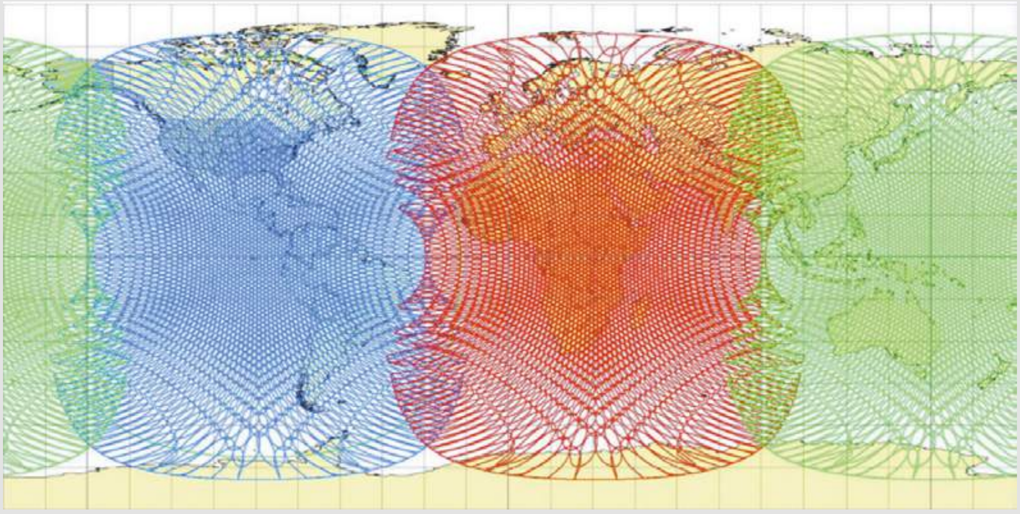
NGSOs operate at lower orbital altitudes than geostationary satellites with two main variants: low earth orbit (LEO) satellites, which operate around 500 to

NGSO systems, such as the Iridium and Globalstar constellations, have been a feature of the space science and Earth exploration domains for decades, providing voice communications, positioning, and data services to governments and industry verticals such as utilities, oil and gas, and maritime.

Case Study: ViaSat

The world's highest capacity communications satellite, ViaSat-1, provides a clear example of how broadband services over satellite have evolved to the present day. Its total capacity, in excess of 140 Gbps was, at the time of launch in 2011, more than all the other satellites covering North America combined[17]. The high capacity and high speed and data allowances it offers marked a major departure from the perception of satellite broadband as slow and low-capacity. Where the first generation of HTS offered an aggregate capacity of 10 Gbps across all North America, covering huge areas but requiring all users to share a relatively low capacity, ViaSat-1 is able to offer competitive speeds and data allowances[18].

Figure 7: Planned Viasat-3 global HTS footprint



The satellite is now operating at capacity, serving 700,000 subscribers and more than 500 commercial airlines providing in-flight Wi-Fi services, underpinning the case for satellite broadband. The increase in capacity enables further increases in service speeds, and does so even as the amount of bandwidth consumed by each customer increases much faster than analysts predicted[19]. This great expansion of broadband demand makes satellite the appropriate solution not only for households, but for aviation and maritime services, oil and gas exploration, government needs or disaster relief. As expectations rise and services used in rural and underserved areas require more bandwidth, such models will allow these areas to keep pace with more densely populated, terrestrially-served areas.

Today, new classes of commercial NGSO systems are under development with plans to launch hundreds or possibly thousands of satellites, often over phased deployments. In recognition of the possibilities, new NGSO systems have received a wave of investment from key players, both from within and outside the traditional satellite industry.

This extraordinary transformation is enabling NGSO systems to make business cases that once seemed over-ambitious. The new systems promise to

Case Study: OneWeb

Among a family of new mobile satellite constellations using the Ka-band, OneWeb is planning a constellation of 648 satellites to offer ubiquitous coverage from an innovative platform that demonstrates the separate but nonetheless significant evolution of these smaller low-earth-orbit satellite constellations. The size and capacity of the satellites will reduce cost-per-satellite to less than USD 500,000[20],down from the average CAPEX of USD 300 million[21]. These much smaller satellites ("smallsats") will operate in 18 polar orbit planes, and should weigh below 200 kg each, resulting in lower launch costs. The network will operate in the Ku-band at an altitude of around 1,200 km. The low cost-per-satellite will allow a more balanced global network that offers high aggregate capacity to underserved areas, with the constellation costing $6 billion in total[22], for which the network will offer download speeds of up to 50 Mbps worldwide. Upload speeds of up to 25 Mbps will also encourage local content creation, spurring greater participation in digital culture from these areas, as well as making telemedicine or tele-education possible[23]. The first 10 satellites scheduled for launch in early 2018.

Figure 8: OneWeb constellation

OneWeb's constellation, combined with the enormous throughput of the newest geostationary systems will provide competitive broadband access on broadly the same commercial terms as terrestrial networks, while providing the reach and remote access that have always been the strongholds of space-based communications networks. Most significantly for the communications sector, M2M and IOT service providers are exploring connectivity solutions based on low cost smallsat infrastructure such as OneWeb's to support ubiquitous access.

Table 3: OneWeb at a Glance

Constellation size	648 satellites
Total capacity	~10 Tbps
Frequency	Ku-band
Orbit	LEO (1,200 km)
Cost per satellite	< USD 500,000
Mass	< 150 kg/satellite
Satellite life	~7 years
Latency	~30 ms

Source: Euroconsult[24]

make low latency broadband accessible anywhere in the world, including difficult-to-reach places and far northern latitudes. This means that people in remote areas will be able to access the same services as those currently available in developed regions.

These constellations plan to extend terrestrial broadband connectivity and provide direct-to-consumer Internet connectivity in remote areas. Given their relatively low altitude, these networks will have low latency levels that are competitive with terrestrial fibre, high capacity, and wide coverage of the globe. These links could support mobile backhaul, traditional fixed services, or offer broadband capacity directly to end-users. To this aim, NGSO systems are using the same HTS techniques as geostationary systems, mainly in Ku- and Ka-bands.

Advantages for Connectivity in Underserved Countries

Cable-based broadband's capital expenditure has a floor of around USD 3,500 per subscriber, with costs rising dramatically at densities below ten subscribers per mile. In areas of low population density or, equally, where few can afford to subscribe to broadband, this cost rapidly becomes prohibitive[25]. By contrast, capital expenditure for satellite broadband systems is independent of population density. Systems able to fill gaps in connectivity and that could help meet the SDGs are already funded and operational, under active procurement, or scheduled for launch[26].

Satellite systems do not require ongoing maintenance, supporting their cost-effectiveness. Previous studies have noted that maintenance poses a challenge to connectivity in

Table 4: Comparison of terrestrial infrastructure cost estimates to meet connectivity targets and commercial satellite system investments

Terrestrial Infrastructure Investments[27]	
European Union	EUR 73-221 billion estimated costs to realize all European national broadband targets (both speed and coverage, without satellite or WiMAX)
24 Sub-Saharan African Countries of Africa Infrastructure Country Diagnostic	USD 6.0 billion estimated costs to provide universal coverage USD 4.5 billion estimated costs to provide coverage to commercially viable areas only
Middle East and North Africa	USD 28-35 billion estimated to reach universal coverage (fibre and LTE)
Latin American and Caribbean	USD 355 billion to construct a next generation network

Satellite investments[28]	
Inmarsat I-5	USD 1.6 billion total expected program cost
Inmarsat-6 satellites	USD 300 million each, providing peak point speeds of 1.5 Gb/s
Intelsat Epic	USD 2.5-3 billion for seven high throughput satellites
ViaSat-2 and ViaSat-3	USD 1.4 billion for ViaSat-2 constellation with 350 Gb/s global capacity and ViaSat-3 constellation with 1 Tb/s global capacity
O3b	USD 1.5 billion for 12 satellites offering 192 Gb/s total system capacity and up to 2 Gb/s per spot-beam
OneWeb	USD 6 billion for approximately 700 low earth orbit satellites offering global coverage.

some markets[29] which, along with a need for electrification in rural areas, can be a particular issue for terrestrial technologies, increasing prices of cable deployment[30]. Satellites avoid these costs entirely, meaning LDCs can access the same services available anywhere else in the world without higher capital investment costs.

The mobility of satellite access is a key feature, and can keep highly mobile populations connected. Porous borders, combined with an estimated 59.5 million displaced persons in 2014[31], mean that conventional technologies are unable to provide broadband access to large numbers of people within underserved countries. Mobile populations, permanent or temporary, require mobile solutions that satellites can enable; most importantly, portable terminals are becoming increasingly common and usable[32]. The global coverage of satellite technologies, combined with mobility and accessibility of equipment, ensures that broadband access is always available to these populations and not dependent on their proximity to a fixed point on the map. There are several different ways that satellite can be used in mobile solutions. Mobile satellite broadband can provide IP communications to large aircraft, ground vehicles, and maritime vessels. For example, Inmarsat's Jet ConneX is a global, high-speed Wi-Fi option available for business jets today. It offers the same fast and reliable connectivity in the air that has previously only been available on the ground. Using Inmarsat's advanced Ka-band satellite network, Jet ConneX offers data plans up to 15Mbps and consistent global coverage across 100% of major airline routes[33]. In addition, antenna subsystem modules (ASMs) can provide flexible satellite connectivity for both fixed and mobile applications. For example, Intelsat and Kymeta have partnered to bring the new KĀLO service which will provide a fully provisioned end-to-end connectivity solution for sectors that have been historically difficult to support such as rail, energy, IoT, first responders, buses, connected cars and more[34].

Satellite technologies support highly reliable networks. The full benefits of providing broadband access to unconnected populations can only be realized if critical services are able to migrate online, which requires fully-reliable networks. When underserved countries lie in conflict zones or areas of geological instability, there is a threat to the provision of long-term, reliable terrestrial networks. Terrestrial infrastructure may be at greater risk of damage, especially in denser, urban areas. Older copper networks have seen high levels of theft of copper cable that causes large losses to financially-stretched terrestrial telecommunications companies, in part due to the collateral damage done to nearby fibre cables[35]. Satellite technologies have a long history of use during natural and humanitarian disasters; networks are unaffected by ground-level incidents, supporting reliable, resilient, and secure services.

Satellites support more affordable broadband solutions for many populations. Recent advances in technology and innovative new uses of unmanned platforms have driven down the costs of satellite technologies[36]. As prices for fixed broadband services plateau worldwide, it is likely costs will continue to fall for space-based provision of broadband, and unit costs are predicted to drop by a factor of 10 by 2025. Much as many developing countries "leapfrogged" over the installation of fixed-line telephony, saving incalculable amounts of money and giving their citizens the newest and best available technology, satellite services can allow countries to leapfrog over the deployment of costly fibre optic networks to remote areas.

Satellite-enabled broadband can underpin and amplify other development efforts. The value of broadband connectivity reaches far beyond its impact on the lives of individual users of the Internet. State initiatives supporting education, health services, smart cities, or environmental monitoring (and protection) benefit from satellite connectivity in unique ways and significantly contribute to meeting the SDGs. Satellite connectivity significantly contributes to advancement of SDGs that underpin economic development in the following areas:

- Education: connecting remote and vulnerable communities to national educational programs and international resources through the Internet, including for mobile or displaced populations, to ensure equality of educational opportunity and empowerment.
- Telemedicine/eHealth: remote service, consultation and monitoring by medical specialists not available in the community, contributing to universal health coverage, maternal and child health, disease prevention and mitigation, and reducing the need for costly or life-threatening travel to appropriate facilities.
- Smart cities and infrastructure: connecting sensors to monitor use and manage resources responsibly for a range of municipal services including electricity, water, waste management, transportation, and lighting.
- Environmental management: remote sensing and data collection to track environmental and climate change, including in marine and terrestrial ecosystems, to aid in management of forests, nature preserves, and biodiversity.
- Disaster response: establishing critical lifelines following major natural disasters such as hurricanes or earthquakes that incapacitate terrestrial facilities, permitting humanitarian relief operations to clear blockages to aid and to focus on the most critically impacted communities.
- Mobile finance: providing access to banking and financial services lacking in remote communities, such as temporary bank branches, point of sale systems, and mobile money applications.
- Agriculture: providing real-time monitoring of fields and hydroponic installations to maximize yield in harsh environments. Broadband connectivity enables farmers to monitor pricing trends to determine the optimum time to bring their crops to market.
- Sustainable fishing: monitoring to meet requirements stemming from commercial and regulatory initiatives towards conservation, marine sustainability, and welfare of fisherman

The utility of satellite technologies for connecting the unconnected is not theoretical; it has been demonstrated across a range of scenarios. It is important to note that satellite is not only good for delivering broadband in the developing world but, in fact, developed countries also rely on satellite technology for the delivery of broadband. For example, according to the United States Federal Communications Commission, approximately 10% (34 million) of all Americans lacked access to "advanced telecommunications capability"[37]. Satellite technology could be used to provide broadband access to some of the unserved Americans, reducing the digital divide. In addition, there is a recommendation in the FCC's National Broadband Plan to ensure that broadband satellite service is a part of any emergency preparedness program[38]. The European Union's Digital Agenda for Europe provides for satellite connections in 28 countries to cover the three million people not covered by fixed and mobile broadband networks[39].

Chapter 2

Use Cases

Improving rural health outcomes with telemedicine – Africa is home to many of the world's least developed countries. Benin is an example, where over half the population lives in rural areas[40]. Many rural villages in Benin do not have a permanent healthcare facility, and sporadic visits from under-resourced medical professionals are insufficient to provide inhabitants with timely and adequate care. Telemedicine can be a critical solution to meeting the medical needs of these rural communities, but only if solutions are affordable and reliable. To address this problem, Inmarsat teamed up with SOS Children's Villages Benin and Safe Triage Ltd. to deliver Safe Triage, an eHealth solution that holds a range of medical data from patients on a shared server. Inmarsat's cost-effective BGAN link service sends data via satellite in real time to the server, which doctors in urban hospitals and clinics access to remotely monitor and diagnose the villagers' health. At the end of a three-month trial program, doctors had used the eHealth solution to identify more than 70 Beninese with serious conditions that required immediate treatment[41].

Expanding rural telecommunications network coverage – In the Democratic Republic of the Congo (DRC), telecommunications provider Vodacom has partnered with Intelsat to expand its coverage area. Both to meet universal service obligations, expand its user-base, and grow revenue, Vodacom and Intelsat built a plan to quickly expand into rural and remote areas, such as the rugged South Kivu region, at low cost. Together they designed a network of over 800 rural sites connected using Intelsat's Ku-band connectivity. These base stations are easily portable, energy efficient and powered by solar panel, and installed within a single visit. Through Intelsat's new Epic HTS platform, which is backwards compatible with its previous system, Vodacom can also offer improved data services without needing to invest in new infrastructure. Through this partnership, Vodacom and Intelsat enabled telecommunications services – both voice and data – to thousands of rural Congolese for the first time quickly and at low cost[42].

Supporting government public broadband access initiatives – Despite the fact that Mexico is home to a rapidly expanding telecommunications sector, approximately twenty million Mexicans still live in rural areas with limited or no access to the Internet[43]. Many urban Mexicans enjoy the economic and social opportunities of the Internet, while their rural counterparts are unable to take part in the digital economy. This digital divide exists in large part because terrestrial broadband infrastructure cannot be deployed to Mexico's rural or mountainous areas without incurring significant costs and facing lengthy rollout timeframes. To help bridge this divide, Hughes, a provider of broadband satellite services, partnered with the Mexican government and Pegaso Banda Ancha, a Mexican Internet service provider and satellite operator, to deliver high-throughput connectivity to over 5,000 rural schools, hospitals, universities, parks, and government development and disaster prevention agencies. Using the bandwidth efficiency and robust capacity of the Hughes JUPITER system, Pegaso Banda Ancha's satellites were able to swiftly rollout high-speed Internet service across Mexico's rural communities, enabling previously disadvantaged segments of Mexican society in 29 states to reap the economic and social benefits of the digital economy[44].

Enhancing education with globally available resources – Outernet, a global broadcast data company in partnership with ViaSat, is utilizing satellite technology to expand educational opportunities in underserved areas. Outernet and ViaSat's satellites can deliver educational material to any area of the world, including rural and remote locations where access to education is traditionally limited. To distribute content, which is provided to end-users for free,

Featured Insight: Ensuring The Sustainable Use Of Outer Space

Simonetta Di Pippo, Director, United Nations Office for Outer Space Affairs (UNOOSA)

While "sustainability" is usually considered an Earth-bound issue, the long-term sustainability of outer space activities is a topic of concern for States. In the six decades since the first artificial satellite was launched, over 40,000 objects have been tracked orbiting the Earth, of which less than 20% are satellites that form the underpinnings of modern civilization. The rest are "space debris" and are an acknowledged risk to present and future space activities.

In addressing this issue, the United Nations Committee on the Peaceful Uses of Outer Space has taken a number of steps. In 2007, the General Assembly endorsed the Committee's Space Debris Mitigation Guidelines which are now voluntarily followed by many "space nations". Presently, the Committee is discussing a compendium of guidelines for the long-term sustainability of outer space activities. Though the issues are complex and myriad, States have demonstrated a strength of commitment to this endeavour that attests to its importance and necessity.

As the Secretariat of the Committee, the United Nations Office for Outer Space Affairs is encouraged by the level of participation and ongoing active engagement by States on this topic that will ensure that humanity's newest resource – outer space - benefits current and future generations.

the satellites broadcast data to one of Outernet's low-cost receivers. The receiver acts as a Wi-Fi hotspot to which up to five devices can be connected. Upon connecting to the Wi-Fi, users are able to download their files to their device for offline consumption. This technology has already been deployed to provide educational resources to 1,000 schools in Latin America, and future plans for a solar-powered receiver promise to connect those who do not have access to electricity[45].

2.2 High-Altitude Platform Stations (HAPS)

Developments in aeronautics and radio technologies have made HAPS a viable option to supplement existing network technologies and help bring broadband backhaul to unserved and underserved regions of the world, particularly remote and rural areas of developing countries.

Characteristics

HAPS have been studied by the ITU for over two decades, and are defined as "station[s] located on an object at an altitude of 20 to 50 km and at a specified, nominal, fixed point relative to the Earth"[46]. In practice, HAPS can be manned or unmanned airplanes, balloons, or airships. Recent projects have taken the form of unmanned aircraft stationed for several months at an altitude of approximately 20 km to maintain coverage of a constant service area on the ground.

In the 1990s, when spectrum for the first generation of HAPS was initially identified by the international community, network engineers foresaw a range of residential, commercial, and public-sector applications. The state of technology at the time resulted in platforms with inadequate aeronautics and communication technologies to fulfil this vision. These are greatly improved today, and broadband HAPS now can provide cost-effective connectivity solutions.

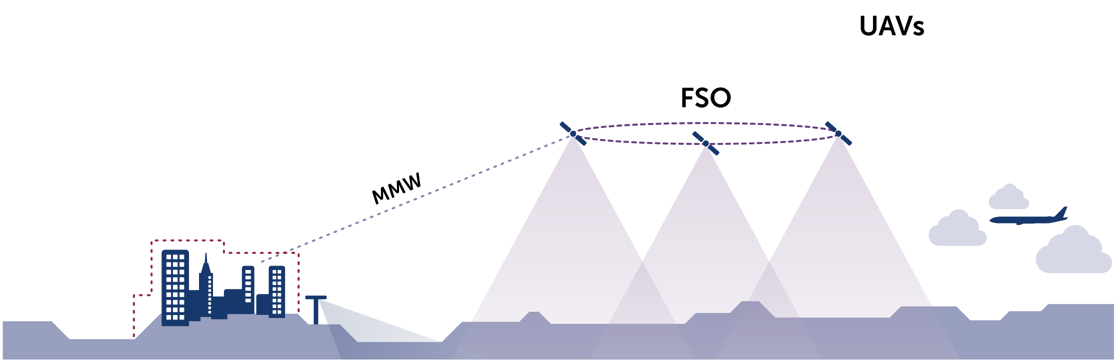
HAPS have become viable thanks to evolutions in five key technical areas: advancements in aerial platforms, battery technology, lightweight composite materials, solar technology, and spectral efficiency (including antenna technology).

Recent innovation in antenna and other technologies have enabled broadband HAPS to achieve tens of gigabytes of broadband capacity. With the 100 km average coverage diameter, operators using broadband HAPS could structure networks to optimise either capacity or coverage. For instance, a fleet of HAPS may be deployed to cover a broad area efficiently, or to provide more capacity to a medium population density area.

The new generation of HAPS uses advances in green technologies such as solar panels to produce no emissions while requiring minimal maintenance[47]. These features make HAPS well adapted for the needs of many developing countries that still have large, unconnected populations. For example, solar-powered platforms in the stratosphere can now be used to carry payloads that offer backhaul connectivity over large areas in a reliable and cost-effective way. Project Aquila, a remotely-piloted high-altitude solar-powered aircraft developed by Facebook, has already made two successful test flights, showing steady progress in platform design and providing developers with real-world data to optimize battery and solar system design. There is more testing and technology development left to be done to make Project Aquila a commercial reality, but initial full-scale test results are very promising and a growing number of applications for the new generation of broadband HAPS are now under development.

In addition, leading aviation and technology companies such as Airbus, Lockheed Martin, Google, Thales Alenia Space and a number of Chinese companies (grouped within the China Aerospace Science and Technology Corporation (CASC)) have shown substantive interest in HAPS and are pushing towards commercial operations. The technology is particularly well suited to complementing other networks deploying next-

Figure 9: One example of HAPS communications architecture[52]



generation communication systems – both terrestrial and satellite. It is both backwards-compatible with existing network technologies, as well as an effective future-proofing option for many regions. Additionally, some studies suggest that due to their low altitude, signals from HAPS may suffer less degradation and attenuation relative to signals from some satellites[48].

Variants

HAPS can be delivered through two primary approaches:

- **Lighter-than-air:** Unmanned balloons normally at an altitude of between 18 and 25 km, although they can reach as high at 50 km[49]. They provide stable and low-power platforms which can be used to create aerial wireless networks.

- **Heavier-than-air:** An unmanned aircraft that does not require pilot intervention in the management of the flight"[50]. Operating on batteries and solar panels, these aerial vehicles can be engineered for long flight times at high altitude to provide wide coverage.

Studies of broadband HAPS recognise the important role that they can play in achieving the SDGs, particularly due to their flexibility, which can be leveraged to serve users in different geographical and social environments. To further this strength, the collaborative business models that are envisaged for broadband HAPS promise to meet the specific connectivity needs of different user communities.

Advantages for Connectivity in Underserved Countries

Because of their characteristics, enabled by recent technological advances, broadband HAPS can play an important role in meeting the need for high-speed, reliable broadband, particularly in large, underserved areas. While prices for mobile broadband are falling rapidly, mobile networks have only been deployed in 38% of least developed countries[51]. With these challenges in mind, one pillar – perhaps the central pillar – of the solution is the broader deployment of broadband backhaul. An estimated 30% of the population of sub-Saharan Africa is beyond the reach of the backbone network, compared to 20% in the Middle East and 40% in the Asia Pacific. This means these populations are also out of reach of physical backhaul links and last mile connections[53]. The price of extending such backhaul to rural and remote users with terrestrial technologies alone would certainly contribute substantially to the cost of deployments. But even when closer to the network backbone, the high sunk costs associated with the rollout of fixed connection last mile infrastructure also creates several challenges for gaining access, including high barriers to provider entry, lack of infrastructure-based competition, and resulting high broadband retail prices. These high costs make the affordability of broadband one of the main bottlenecks to growth[54].

Terrestrial and satellite operators have invested heavily in telecommunications network infrastructure and have developed new commercial arrangements to meet rising consumer demand, but this does not change the high upfront cost of building out terrestrial infrastructure that cannot be remunerated outside of urban centres in low income regions. For broadband access to improve in these areas, and for these populations finally to be able to enjoy the benefits of the digital economy, different, efficient, non-terrestrial broadband technologies can be efficiently leveraged to supplement existing terrestrial networks. The effect of broadband HAPS therefore could be transformative.

HAPS can also be launched and maintained at a fraction of the cost and time it takes to lay cables underground, and can be easily and inexpensively moved, allowing for scalable coverage as needs emerge. They can also be deployed rapidly to match demand during high traffic periods or to fill an unanticipated gap when terrestrial infrastructure may fail, enhancing network resilience.

These advantages unlock new possibilities not just for users but for broadband providers as they design their networks. By leveraging both conventional and emerging technologies, providers can build more efficient, flexible, and resilient hybrid networks that better meet the needs of both densely populated areas and rural, underserved areas. In the near future, a provider using HAPS can design a network to optimize capacity and coverage, where HAPS may be deployed to cover either a large rural area, or to provide more capacity in a more densely populated area.

Broadband HAPS will likely succeed particularly well where a mix of terrestrial, aerial, and satellite backhaul and access technologies combine in a single network and are leveraged to satisfy different use cases in a way that is efficient, cost-effective, and reliable. In this context, HAPS will add value to future 5G mobile telecommunications systems by leveraging different technologies to build a network of networks. Planned 5G systems already are based on the principles of flexibility and hybridity. HAPS can function as another node in the diverse architecture of these systems, adding value in terms of capacity, coverage, network resilience, and ease of deployment. In many cases, rather than competing with existing network technologies, HAPS will complement them, providing ISPs the ability to expand their capacity, improve their service offerings, and expand their service areas.

A number of specific advantages of the new generation of HAPS have been identified[55], and are described below, using solar planes as an example.

HAPS provide a wide-area of coverage. A single plane will be able to serve footprints with a diameter of 100 km, and recent technological advances in the development of optical inter-HAPS links now enable the deployment of multiple linked HAPS, in fleets that can cover large rural areas. Connecting large, difficult-to-access areas will open new opportunities for mobile network operators, who can use HAPS to overcome backhaul challenges and extend the benefits of the digital economy to communities living anywhere, including in sparsely populated remote areas.

Costs of operation are lower than some other options. Operating solar planes is projected to be more economical than some other connectivity solutions. Mass production of the aircraft may significantly decrease upfront capital expenditure for deployment compared to many currently deployed broadband solutions. Reductions in operating and capital expenses for the operator may allow the cost of broadband to fall, making services accessible to more users, the volume of which will itself encourage further investment.

HAPS offer sustained continuity of service over a long period. Advances in battery life mean the new generation of HAPS will be able to operate continuously for up to three months without having to return to the ground for maintenance[56]. This also will keep the overall cost of service lower.

Broadband HAPS can be deployed to complement existing technologies. HAPS are positioned to succeed particularly well in hybrid, flexible networks composed of terrestrial, aerial, and satellite backhaul in a way that is efficient, cost-effective, and reliable. HAPS can add value in terms of capacity, coverage, network resilience, and ease of deployment.

HAPS have wide reach in challenging environments. Broadband HAPS will operate at around 20 km above ground, above weather and commercial air traffic. They will offer high capacity, low-latency transmissions, and will provide backhaul for an effective solution to deliver high throughput broadband applications. HAPS that use the architecture of solar planes can also provide connectivity where limited power supply can impair deployment of terrestrial infrastructure: remote sites on land or sea, to the benefit not just of remote populations, but also to a range of industries operating in these environments.

Broadband HAPS services can be deployed with shorter lead times than other technologies. HAPS can quickly return to the ground as needed for maintenance or payload reconfiguration. This gives the new generation of HAPS an unmatched flexibility in deployment, and allows operators to move existing planes from one area to another as the need arises.

Broadband HAPS are an environmentally friendly connectivity solution. HAPS can run exclusively on solar power for long periods, connecting people with almost no environmental impact.

Broadband HAPS can help meet development objectives, particularly in the world's most underserved rural areas. Key features that make HAPS systems well suited to deliver positive outcomes are their ability to provide line-of-sight links to cover wide areas, very rapid deployment and relatively simple maintenance operations. The capabilities of HAPS technology can play a role in meeting the Commission's "ambitious but achievable" targets to ensure their populations fully participate in emerging knowledge societies:

Broadband HAPS can be tailored to regional needs. Because of the size of the areas they are able to cover they are best suited to offer services on a regional basis. Therefore, it is crucial to consider the potential of HAPS to integrate in synergy with terrestrial and satellite networks. From this perspective, some broadband HAPS communication usages foreseen by the ITU-R are.

- Natural disaster relief missions, where HAPS are quickly deployable to support communication for coordination and situational awareness between humanitarian aid organisations.
- Fire detection, monitoring and firefighting missions to ensure communication between actors.
- Law enforcement communication needs between local actors and regional headquarters.
- Exploration missions with communication needs between exploration teams and regional home base.

The benefits that broadband HAPS will confer to developing economies notwithstanding, European stakeholders have also spent many years refining how HAPS can be best deployed. The 5G Infrastructure Public Private Partnership (5G PPP), a group that brings together the European Commission, manufacturers, telecommunications operators, service providers, SMEs, and researchers, recognized that HAPS will augment the 5G service capability that will become so central to the European digital economy. 5G PPP also made clear that HAPS can complement 5G in addressing challenges such as multimedia traffic growth, ubiquitous coverage, and machine-to-machine communications while optimizing value for money to the end-users[57].

Use Cases

Diverse system architectures for multi-gigabit capacity – The Chinese government has indicated that, thanks to recent innovation in antennas and other technology, they believe HAPS can achieve multi-gigabit broadband capacity. Based on these considerations and on HAPS' potential when deployed to serve rural areas, China has envisaged system architectures for both lighter-than-air and heavier-than-air platforms to provide high-quality broadband services to a small number of aggregation terminals within the HAPS footprint[58].

Airbus Zephyr – The solar-powered "Zephyr" HAPS designed by Airbus will deliver numerous payload capabilities including broadband for commercial purposes. In February 2016, Airbus received a request for the production and operation of two Zephyr planes from the UK, with flights scheduled to take place in 2017. This is the first contract in the world for providing operational HAPS of this kind[59].

European Demonstrations – The European Commission supported numerous initiatives to develop HAPS, including the HeliNet Project[60], the Advanced Research in Telecommunications Systems (ARTES)[61] Project, USEHAAS[62], and CAPANINA[63]. CAPANINA explored the development of broadband communications capabilities from HAPS, with the aim of demonstrating the technology's ability to support different applications. Earlier trials included one in 2004 in the UK, and consisted of a set of several tests based on a 300m altitude tethered aerostat. The aerostat demonstrated and assessed Broadband Fixed Wireless Access (BFWA) at speeds of up to 120 Mbps to a fixed user using the 28 GHz band, end-to-end network connectivity, high-speed Internet, and video on demand service, using a similar platform-user architecture as HAPS[64]. In October 2005, the second trial was conducted in Sweden, using a 12,000-cubic meter balloon, flying at an altitude of around 24 km for nine hours. Conducting radio frequency and optical trials, the radio equipment supported data rates of 11 Mbps at distances ranging up to 60 km[65].

Project Aquila – One design by Facebook, known as "Project Aquila", is a remotely-piloted high-altitude solar-powered aircraft that can maintain a nominally fixed station at altitudes above 20 km in the stratosphere. It provides coverage of a service area on the ground for three months to one year at a time. Project Aquila aircraft are being designed to cover a 75-100 km diameter area while generating data capacity in excess of 10 Gbps. In a fully deployed system, each aircraft would be connected to other aircraft through laser links and connected to ground stations through broadband wireless links. Although Project Aquila has the wingspan of an airliner, it is designed to consume at its peak only 5,000 watts of energy (the equivalent of three hair dryers). Facebook is designing and testing these aerial platforms to provide backhaul links from fibre points of presence to service aggregation points such as cell towers or Wi-Fi access points, allowing for both licensed (LTE) and unlicensed (Wi-Fi) services to the end user.

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3 Advantages of space and upper-atmosphere technologies for development

Communications networks that are not ground-based offer clear advantages over those that are.

3.1 Wide-Area Coverage

Operators of space and upper-atmosphere technologies have already deployed infrastructure that covers the entire globe. Modern space-based and upper-atmosphere technologies use a system of semi-hemispheric, high-density spot-beams[1]. While the coverage area of these beams appears smaller than previous generations, communications payloads are now able to use several spot-beams together, creating an overlapping lattice of high capacity coverage over wide areas. A similar networked approach is possible with HAPS, with recent advances allowing optical inter-HAPS links. In combination, these innovations add capacity and redundancy to already ubiquitous networks[2].

3.2 Geography Neutral

Difficult geography has proven challenging for deployment of terrestrial broadband technologies. Large swathes of underserved areas contain difficult or protected terrain, including deserts, mountain ranges, rainforests or wetlands which dramatically raise the cost of installing ground infrastructure, often above viable levels, given that these same areas often have lower population densities. For islands and land-locked countries, this barrier has been almost impassable, with broadband penetration rates being noticeably lower in these areas and services more expensive[3].

Areas of geological instability have also challenged conventional broadband infrastructure. Cable networks are vulnerable to earthquakes, landslides and volcanic events, as well as more general geological movements over time. This is a particular issue for subsea cables, which are particularly vulnerable to geological instability and shipping, and are more difficult to repair or replace. Subsea cable failures have been responsible for several high-profile broadband interruptions in recent years[4].

However, none of these issues affect space-based and upper-atmosphere technologies, which provide equal and seamless coverage regardless of terrain. As such, they are capable of remedying the unequal access to broadband experienced in geographically challenging areas, extending coverage and lowering costs. Additionally, space-based and upper-atmosphere technologies are invulnerable to most geological issues.

3.3 Instant Infrastructure

The nature of satellite and HAPS broadband means that once the unit is aloft and functioning, connectivity flows immediately and indefinitely. Broadband is accessible from any ground terminal in the coverage area, ending the reliance on large-scale and expensive ground infrastructure. Towers do not need to be installed or refurbished as technology advances further. In underserved areas, this instant infrastructure confers various advantages. Extending connectivity becomes much less expensive, and the wide coverage areas that are instantly established by space-based and upper-atmosphere technologies allow for precisely targeted connectivity initiatives. Since global ubiquitous satellite networks already exist, this also allows for rapid extensions of connectivity during events that require it, from one-time civil needs, such as international events, to natural disasters.

3.4 Ease of Deployment

As global satellite coverage already exists, network deployment can be as simple as providing ground terminals. Deploying satellites themselves is a more complex effort, but one that operators have decades of experience in handling with efficiency and safety. Ongoing innovation around the launch of satellites offer the chance to dramatically reduce deployment costs, building on already reduced capital expenditure costs. However, one additional benefit in deploying satellites is that, regardless of future investment, a planned, costed and funded pipeline of satellite launches already exists. As a result, without any further spurring, satellite operators will deploy dramatic improvements in capacity and user speeds over the next 10-15 years[5].

Other space-based and upper-atmosphere technologies, such as HAPS, have shorter mission spans that are offset by their much easier deployment. HAPS allow long periods of connectivity (with gaps covered by inter-HAPs links or redundant units) interspersed with short maintenance periods. However, while HAPS will need to land for this period, this allows much simpler repair of the unit and upgrade of the systems and communications payload as technology improves. Relaunch of the unit does not require expensive ground infrastructure; conventional airfields and launch pads are sufficient.

3.5 Reliability

Reliability is a key issue faced in underserved countries. In order to take full advantage of the benefits of connectivity, networks must meet high standards for reliability and continuous service. A lack of reliable grid power, network outages that inhabitants are unable to solve themselves and a lack of skilled personnel have all been observed as major barriers to reliable networks in underserved areas[6]. Without the assurance of reliable connectivity, the benefits offered by e-governance, commerce, and education will not be realized.

Space-based and upper-atmosphere technologies are, by nature, highly reliable. They are immune to most risks that face terrestrial networks, including accidental damage, theft, conflict areas and natural disasters, are designed for continuous operation. Due to the difficulty of repair or replacement in space, satellites are designed with multiple layers of redundancy, giving nearly 100% uptime. In the unlikely event that one satellite does fail, multiple spare satellites are immediately available, preventing service interruption. HAPS systems, due to their much lower unit costs and inter-HAPS optical links, offer similar levels of redundancy. As such, space-based and upper-atmosphere technologies are uniquely reliable and capable of delivering the network resilience needed to fully realize the benefits of connectivity.

Cable-based networks have proven vulnerable to damage and theft. Subsea cables in particular are relied on for broadband provision, but damage to them has led to notable incidents of worldwide outages[7 8 9]. Difficulties in maintaining installed networks has been a major reason challenge to previous terrestrial connectivity initiatives[10]. Older copper networks have seen episodes of theft, resulting in financial losses for telecommunications companies, in part due to the collateral damage done to nearby fibre cables (and in some places the cables themselves are harvested for non-broadband uses)[11].

By contrast, once orbital and operational, satellite failure rates are very low. The vast majority of failures occur before this point – a phenomenon known to the industry as “infant mortality”. Barring the rare incidence of satellite collision, the physical risks to a system are negligible, but well mitigated, as a result of on-ground or in-orbit spares. Similarly, HAPS are being engineered with continuous operation in mind, since they are designed for markets that may lack technological expertise or resources. Since they are being designed for mass manufacture, building HAPS networks with adequate redundancy levels will not be prohibitively expensive.

Dependability and redundancy are critical to spreading the benefits of connectivity, especially where it is needed for safety applications. Countries could not reap the benefits of, for example, intelligent transport systems, if they cannot meet the logistical challenges associated with protecting terrestrial infrastructure. NGSO constellations or broadband HAPS, can contribute to solving these issues by providing the low latency required to power these technological developments.

3.6 Carbon Efficiency

These technologies provide an environmentally sustainable route to spreading broadband. They greatly reduce the tension between the twin imperatives of economic development and curtailing the effects of climate change. Satellites' carbon emissions rates decline to zero once deployed. This allows carbon emissions generated during manufacturing and launch to be effectively amortized over their long mission lives. Now that launch vehicles are moving toward reusability, carbon emissions drop again, and launches are reducing along the supply chain. Moreover, new broadband networks are deeply necessary for managing carbon emissions through optimization of ground, air, and seaborne traffic.

These technologies pose far lower risk to sensitive natural environments, as there is simply less ground infrastructure required to provide the same level of connectivity. Whereas terrestrial infrastructure may need to be deployed through these environments even if connectivity is not needed there (except for station keeping functions), satellite ground infrastructure can be targeted to the areas required. Ground equipment with which these systems connect can also be powered independently with their deployment. Finally, solar panels on both satellites and HAPS, offering a secure, reliable and carbon free power source reduce the carbon footprint of these technologies further still[12].

3.7 Long-Term Deployments and Terminal Use

Technologies in space and the upper-atmosphere, due to their longevity, reliability, and resilience, provide a stable basis on which governments can build or implement policy. With a typical satellite mission life being some 20 years, the cost structure of a satellite network is predictable and this translates to stable pricing over mission life. Where terrestrial networks' pricing can vary due to market dynamics or variable maintenance needs over the lifespan of the network, satellite networks require essentially no maintenance cost.

Individual HAPS may fly for many months before requiring ground-based maintenance, but they are designed to be re-used, so that the total mission life will be greatly extended. If needed, HAPS can return to the ground, enabling regular maintenance and payload reconfiguration operations. This will ensure that small faults do not develop into larger ones, keeping the overall cost of maintenance lower and, in turn, realizing a more stable pricing structure.

This also allows for long-term deployment of equipment, such as ground terminals, reducing upgrade and maintenance costs[13].

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4 Achieving the sustainable development goals

This section sets out the routes to achieving the Sustainable Development Goals (SDGs) in two senses: how space and upper-atmosphere technologies can help achieve them and how governments can enable them to do so.

The first part of this section is a prospectus for broadband – however provided – in support of the SDGs. Space-based technologies are not unique in what they can enable. They are unique because of their economical coverage of wide areas, their immunity to changing ground situations, their ease of deployment and their comparative environmental sustainability; because they can spread the benefits of broadband to new areas. This presents a compelling option to policy-makers in all countries.

The second part sets out the regulatory, commercial and other considerations that governments should consider when trying to integrate HAPS and satellite capability into their national broadband plans.

Rural Broadband: Addressing SDGs 3, 4, 5, 9 and 10

Space and upper-atmosphere technologies are well-suited to covering areas with limited terrestrial communication infrastructures. Governments of less developed countries and telecommunications operators can address connectivity needs effectively with these technologies because they are relatively inexpensive, are quicker to deploy, and are highly scalable and are usable as needed. Where the new technologies can beam connectivity over large areas, networks can augment this capability to provide broadband coverage to large, sparsely populated geographies. By extending the broadband infrastructure layer to underserved communities, space and upper-atmosphere technologies can enable a number of essential services, such as education, citizen safety, banking, and health in rural areas cost-effectively.[1]

Disaster Relief Services: Addressing SDGs 11 and 16

The rapid deployment and easy mobility of these technologies makes them highly suitable for providing emergency communications during disasters. Space and upper-atmosphere technologies can facilitate essential communications links between the emergency services at the disaster site and maintain a broadband connection in the area, which could permit remote assistance from a base station. Disasters often overload traditional networks, and ground-based infrastructure is itself vulnerable to damage. This may prevent a timely interconnection of the hub gateway into an international core network, in which case HAPS to satellite links would be a valuable alternative.

Multicasting/Broadcasting: Addressing SDGs 4 and 5

Satellites underpin moments of global cultural significance by enabling video broadcasts across the globe. From the first such broadcast in the early 1960s to today, news and other organizations have been able to share moments such as Olympic games and the day-to-day experience of other cultures. This has furthered a sense of global community and connects the unconnected in a figurative, as well as literal, sense. Studies find that owing to their altitude, some next-generation space and upper-atmosphere technologies can find additional use cases as an alternative solution for DVB/DAB repeater/ transmitter.[2]

Intelligent Transport Systems: Addressing SDG 9, 10, 13

Seamless connectivity layers are a prerequisite for the deployment of intelligent transport systems such as connected and driverless cars and trucks. Additional coverage provided by space and upper-atmosphere technologies in remote areas will allow avoidance of interruptions to the functionality of vehicle-to-vehicle or vehicle-to-infrastructure links, and guarantee significant improvements to road safety.

Communications at Temporary Venues: Addressing SDG 9

Large-scale temporary news or sports events can create extremely high demand for network capacity for a very short timeframe. Space and upper-atmosphere technologies can provide this infrastructure without the high upfront costs and even provide redundancy after the event. Thanks to their flexible and rapid deployment, these technologies can provide a solution to such exceptional peaks in traffic without requiring exceptional investment.

Overlay of Terrestrial Data Links for Resilience or "Link Failure Recovery": Addressing SDGs 9 and 11

Terrestrial networks can often have many nodes. In the event of a link failure, such as a damaged cable, service can only be rapidly restored by adopting an alternative route. Space and upper-atmosphere technologies can be used to restore service by providing a private circuit replacement for the damaged link.

Terrestrial Backhaul in Urban Areas: Addressing SDG 9

Space and upper-atmosphere technology characteristics, such as a reduced vulnerability to building interference, mean the technology can find applications in urban environments with high traffic rates by supplementing backhaul capacity to terrestrial networks and increasing coverage in mobile not-spots.

Sustainable Oceans: Addressing SDG 14

Satellites, including HTS technology and mobile satellite services, can play an important role in the conservation and sustainable use of oceans, seas, and marine resources for sustainable development. Satellites can be used for mapping Marine Protected Areas, to monitor biodiversity, ocean acidification, ocean pollution and overfishing, and by providing vital safety and distress communications, both in national jurisdictions as well as the high seas.

Civil Defence: Addressing SDG 16

Space-based and upper-atmosphere technologies can provide nodes in wireless networks used to provide civil defence, providing a secure link with low probability of interception for mission-critical communications.[3]

4.1 Regulatory Considerations

Rapid developments across the communications sector have placed high and increasing demand on spectrum resources, with corresponding effects on spectrum management practices. New technologies, including HAPS, next generation satellite constellations, terrestrial wireless broadband, all require spectrum allocations to reach their potential, and their interests occasionally will conflict with each other and with other technology providers.

Similar issues exist in the development of common standards. National standards predominate, especially around still-emerging technologies such as HAPS. Although there are internationally recognised HAPS spectrum identifications that date from 1997, HAPS technology and deployment models have evolved significantly since then.

Satellite regulations and standards are more unified at an international level, but small satellites do not fit well within these, which can sometimes cause difficulties. Additionally, some innovative uses of satellite technology, such as connectivity to Earth Stations in Motion (ESIMs) in FSS spectrum may require examination and update of some national regulatory or licensing regimes. While there are already spectrum allocations for satellite services and frequency bands identified for HAPS in the Radio Regulations, the forthcoming World Radiocommunication Conference 2019 will consider additional allocations and mechanisms to facilitate further deployment of these technologies.

Security and safety are essential aspects of these systems, and are again areas where existing best practice can be adapted. As earlier noted, ground-best technologies have faced issues with damage or disruption caused by theft[4] or deliberate attacks, which has been a particular problem in underserved countries.[5] While space and upper-atmosphere technologies avoid many of these issues, VSATs and ground-based receivers should be installed to high standards of safety and be made secure, for example by deploying pre-fabricated, lockable equipment shelters or using independent power sources, such as roof installed solar panels.[6]

Cybersecurity best practices should be implemented throughout the development, deployment, and use of these technologies, with the cost of cyber-attacks estimated by one report to rise to USD 2.1 trillion by 2019[7]. The creation of new network infrastructure offers the opportunity to build in cybersecurity.[8]

4.2 Other Considerations

Fostering user trust.

In order for any system to be adopted and its full benefits achieved, the system must be trusted. This is especially true in areas that would be most beneficial to the economic development of LDCs, including banking, e-commerce and e-government. However, trust in technology is increasingly low in developed countries[9], with very few people expressing confidence in the security of their digital records, with some countries seeing particularly low trust scores[10]. For space and upper-atmosphere technologies to be effectively implemented, this constraint must be overcome. The provision of applications that are of immediate use to populations and therefore, encourage use – and corresponding trust that evolves with familiarity – may be useful in an incentive scheme. Examples might include providing local weather reports or access to local agricultural markets[11], or government awareness and campaigns to provide education and encourage use are important.

Financial Considerations.

Satellite broadband and other upper-atmosphere technologies are a cost-effective way to provide connectivity in rural and remote regions. There are some financial resources that governments can turn to help fund the deployment of satellite broadband and other upper-atmosphere technologies ranging from public-private partnerships to multi-lateral development banks[12]. In addition, the new technologies have the potential of bringing about new innovative financial solutions by giving more control to the users in respect of managing their service needs thereby optimising the cost of service.

Endnotes

1 ITU, "Broadband Situations in Rural and Remote Areas", p.39

2 ITU, "Broadband Situations in Rural and Remote Areas", p.140

3 Saeed H. Alsamhi, N. S. Rajput An, "Intelligent HAPS for Broadband Wireless Communications: Developments, QoS and Applications", International Journal of Electronics and Electrical Engineering (2015) p. 139

4 Cable theft effect (Olifantsfontein: mybroadband, 2012)

5 Growing Concerns over Telecoms Infrastructure Vandalism, Sites Closure (Lagos: THISDAY, 2016)

6 The Provision of Satellite Broadband (Washington DC: W Wagner, R Brazil David, A Garcia Zaballos, 2016) p.46

7 The Future of Cybercrime & Security: Financial and Corporate Threats & Mitigation (Basingstoke: Juniper Research, 2015) https://www.juniperresearch.com/press/press-releases/cybercrime-cost-businesses-over-2trillion

8 The Provision of Satellite Broadband (Washington DC: W Wagner, R Brazil David, A Garcia Zaballos, 2016) p.46

9 The state of privacy in post-Snowden America (Washington DC: Pew Research Centre, 2016)

10 Building Technology Trust in a Rural Agricultural e-Marketplace: A User Requirements Perspective (Hong Kong: N Isabirye, S Flowerday, A Nanavati, R Von Solms, 2015)

11 The Provision of Satellite Broadband Services in Latin American and the Caribbean (Washington DC: W Wagner, R Brazil David, A Garcia Zaballos, 2016) p.38

12 ITSO, Satellite as a Compelling Solution: "Financing Considerations for Implementing Satellite Broadband to Reach Universal Connectivity (Washington: 2016)

5 Conclusions

Technological innovation alone will not be sufficient to enable space-based and upper-atmosphere technologies to reach their full potential for helping to realize the SDGs. Governments and other stakeholders should support policy decisions that will promote the further development and adoption of these technologies. Accordingly, the Working Group recommends the following:

Spectrum

- **Ensure sufficient protection.** Policy makers should strive to create an environment that promotes further growth and adoption of space-based and upper-atmosphere technologies while optimising resource use consistent with the needs of their populations. In developing a balanced spectrum policy and making frequency assignments, regulators should avoid steps that would increase harmful interference to, or reduce flexibility of, these technologies. In shared bands, this includes ensuring that space-based and upper-atmosphere systems are protected from interference from existing and new services.

- **Harmonize spectrum where possible.** Globally-harmonized spectrum for broadband technologies create economies of scale that drive faster deployments at lower cost, more reuse of infrastructure, and flexibility for service providers. These efficiencies are ultimately passed on to consumers. Governments should therefore expedite access to globally-harmonized radio frequencies for satellites and broadband HAPS.

- **Access to necessary spectrum.** Governments should ensure that broadband HAPS and broadband satellites have access to the spectrum they require to succeed in their mission of serving the underserved and relieving capacity constraints. Consistent with a balanced spectrum approach, this may include identifying new spectrum for these platforms, facilitating spectrum sharing arrangements and implementing policies allowing accelerated deployment.

Regulation

- **Rethink regulation.** Operators, infrastructure providers, equipment manufacturers and governments are encouraged to rethink the traditional approach to building, deploying and regulating telecommunications networks and services. This calls on policy makers to foster an environment that encourages new technologies that can complement existing networks to address some of the connectivity challenges in both developed and emerging economies.

- **Technology-neutral policy making.** Making effective broadband policy is not a one-technology-fits-all challenge. Regulatory regimes, such as universal service funding, should be technology and competitively neutral to be most beneficial. Rules created with one type of technology in mind may not serve the public interest when applied to other technologies. Regulations and eligibility requirements based on outdated assumptions about particular technologies may preclude new and innovative technologies, benefiting the original service at the detriment of society. Adopting policies that put valuable technologies on an equal footing will help ensure that the services needed by consumers are readily available on a cost-effective basis. Similarly, competitively and technology neutral universal service regimes that focus on connecting users rather than deploying specific technologies will ensure that consumers, even in the most remote locations, have available broadband services.

- **Streamline satellite and HAPS licensing.** Administrations should permit blanket licensing for space-based and upper-atmosphere user terminals. The ability to obtain a single authorization for technically identical user terminals has reduced the time and administrative effort associated with licensing multiple user devices, bringing services to users on a faster basis. To have sufficient capacity to meet user needs, and to promote the benefits of competition, governments should eliminate foreign ownership restrictions to land satellite traffic. Additionally, to expand the reach of satellite services and maximize their benefits, governments should put processes in place for the authorization of Earth stations in motion (ESIMs).

Technology

- **Support experimentation.** To better understand the solutions these technologies can provide across a country or region, governments should sponsor case studies and pilot projects within their territories on an expedited basis. In addition to developing solutions that are customized to a country's particular needs, such studies and pilots may help to build the body of evidence required to support legal, regulatory, procurement, and deployment decisions.

- **Promote innovation.** Realizing the full potential of space-based and upper-atmosphere technologies to connect unconnected areas and achieve the SDGs will rely upon continued innovation in broadband satellite technologies and broadband HAPS. Stakeholders can promote this innovation through support for standards and technology development. The technical community should emphasize development of standards that facilitate interoperability or integration among broadband radio services, including through network virtualization.

- **Carbon neutrality.** Governments should provide incentives to reduce carbon emissions by leveraging infrastructure and terminals that require less power, which leads to less use of fossil fuels and longer-lived components.

- **Drive international consensus on broadband HAPS.** Because HAPS platforms can be owned by national service providers, governments should work to ensure that UN bodies such as the International Telecommunication Union, the International Civil Aviation Organization and associated regional bodies develop standards for HAPS platforms as quickly as possible to ensure trust in the systems and deployment of the networks.

6 Glossary

CAPEX: Capital expenditure

HAPS: High-Altitude Platform Stations

HTS: High throughput satellite

ITU-D: The International Telecommunication Union Telecommunication Development Sector

LDCs: Least developed countries.

LLDCs: Landlocked developing countries.

SDG: Sustainable development goal

SIDS: Small island developing states

VSAT: Very small aperture terminal

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Notes

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