Your response

Your response should include details of:

- a description of the relevant technology;
- a view of the potential impact of the technology on the sectors we regulate, preferably
- identifying the impact against the criteria listed in section 3.16 of the call for inputs;
- the current state of development of the technology, including any demonstrations of
- feasibility;
- any unresolved issues which need to be addressed for the technology to achieve full
- potential;
- references to key publications and the leading groups working on the technology; and
- whether you would be open to discussing the technology in more detail with Ofcom.

Your response

Starlink Internet Services UK, Ltd, a subsidiary of Space Exploration Technologies Corp. (SpaceX), welcomes the opportunity to contribute to Ofcom's Call for inputs: Emerging technologies and their potential impact on the communications industry. Ofcom's technology discovery program - designed to identify and understand new communications technologies under development - is crucial to facilitating rapid deployment and adoption of emerging technologies and services to connect citizens, consumers and businesses in the United Kingdom and support its economic growth. As a company known for innovative technology design, manufacturing and operations, SpaceX supports Ofcom's quest for policies that drive capable and cutting edge technology.

SpaceX is a private company founded in 2002 to revolutionize space technologies, with the ultimate goal of enabling humanity to become a multi-planetary species. The company designs, manufactures, and launches advanced rockets and spacecraft. Since its founding in 2002, SpaceX has achieved a series of historic milestones. In December 2010, SpaceX became the first private company ever to successfully launch and return a spacecraft (Dragon) from low-Earth orbit (LEO). In May 2012, the company again made history when Dragon berthed with the International Space Station (ISS), delivered cargo for the astronauts on station, and returned safely to Earth–a technically challenging feat previously accomplished only by governments. To date, SpaceX has successfully launched a total of 100 missions across its initial Falcon 1 and current Falcon 9 and Falcon Heavy fleet of launch vehicles. SpaceX is also a pioneer in launch reusability. In December 2015, SpaceX successfully returned a Falcon 9 first-stage rocket booster to land after carrying a payload to space, and has since landed almost 60 times, both on land and at sea. As of today, SpaceX has reflown more than 40 boosters, including successfully reflying a single booster six times. This pioneering capability to reuse orbital class rockets has made space more accessible for a diverse set of operators and science missions. SpaceX is also leveraging this launch reusability to accelerate deployment of its own satellites for the Starlink satellite broadband constellation.

Additionally, SpaceX is proud to have to safely carried astronauts to and from the International Space Station (ISS), the first private company to do so. In addition to this public-private

partnership with the US National Aeronautics and Space Administration (NASA), SpaceX is now offering commercial flights for private passengers to both Earth and Lunar orbit.

SpaceX is leveraging the reusability of its rockets and its accumulated expertise in manufacturing and design to develop Starlink, a constellation of satellites designed to provide high-speed, low-latency, competitively-priced broadband service to locations in the United Kingdom and around the world where access to the Internet has been unreliable, expensive or completely unavailable. Starlink is poised to offer satellite broadband connectivity directly to end-users in the United Kingdom, with initial services available before the end of 2020 and then to the remotest corners of the country.

The first Starlink constellation consists of over 4,400 non-geostationary orbit (NGSO) satellites employing advanced communications and space operations technology. To date, SpaceX has launched over 700 Starlink satellites in a little over 15 months, and is now the largest operational satellite constellation by a more than factor of two. Since 2018, SpaceX has invested hundreds of millions of dollars in Starlink and is currently building 120 satellites per month, along with thousands of end-user terminals each month.

1 Description of the relevant technology

The Starlink satellite broadband project is designed to leverage SpaceX's experience in building rockets and spacecraft to deploy the world's most advanced broadband internet system. Starlink is a constellation of advanced-design satellites operating close to the earth to deliver high speed, low-latency broadband connectivity across the globe, including to locations where traditionally internet has been too expensive, unreliable, or entirely unavailable.

The U.S. Federal Communications Commission (FCC) has authorized SpaceX to operate a constellation of 4,409 satellites using Ku/Ka-band frequencies; in addition, the FCC has approved the addition of V-band to these satellites and augment with a further 7,500 V-band lower-flying satellites. SpaceX also has an application pending with the FCC for constellation of 30,000 additional satellites in Ku/ Ka-band for future development.

In 2019, the FCC approved a SpaceX request to operate the constellation at a lower altitude—moving from 1,150 km to 550 km—in order to further improve space safety. This relocation allows optimization of spacecraft design and operations and reduces latency to below 50 milliseconds, which is nearly unnoticeable to consumers. A modification to move the remainder of the initial Ku-/Ka-band constellation to lower altitudes is now pending with the FCC.

SpaceX has developed a host of innovative technologies for its Starlink project. Starlink satellites are a novel compact, flat-panel design that minimized volume, allowing SpaceX to launch as many as 60 Starlink satellites in each Falcon 9 rocket to deploy as much as a terabyte of capacity per mission. To date, SpaceX has completed 13 Starlink missions. SpaceX has developed an autonomous collision avoidance system to reduce human error in space operations and avoid space debris and other spacecraft. Starlink satellites are the first to be krypton-propelled, using efficient ion-thrusters to orbit-raise, maneuver in space, and de-orbit at the end of their life. Custom in-house-built navigation sensors enable precision placement of broadband capacity. Each Starlink satellite has four phased-array antennas, enabling an enormous amount of throughput to be placed and redirected in a short term, for efficient spectrum usage and lower costs by an order of magnitude. Upcoming versions of Starlink will connect satellites in space using optical intersatellite links to allow the Starlink network to exchange data between satellites in orbit, instead of transmiting to- and from- the ground and consuming spectrum resources. SpaceX

recently announced that in-orbit tests of two Starlink satellites equipped with these space lasers allowed the transfer hundreds of gigabytes of data. Once SpaceX has these space lasers working consistently throughout the network, Starlink expects to become one of the fastest options available to transfer data around the world.

SpaceX's Starlink satellite constellation is already generating 5 trillion bytes of data on a daily basis and getting software updates on a weekly basis. Each launch of 60 Starlink satellites contains more than 4,000 Linux computers, and because that Linux platform infrastructure is shared with SpaceX's Falcon rockets and Dragon spacecraft, they benefit from more than 180 vehicle-years of on-orbit test time.

When fully deployed, Starlink will provide services globally. As each satellite is launched and brought into operation, it is immediately integrated into the Starlink system to expand geographic coverage and add capacity to enhance broadband service offerings. Starlink is supported by a ground network of gateway earth stations deployed around the earth. Gateways use multiple parabolic dishes that are co-located or sited near major Internet peering points to provide the required Internet connectivity to the satellite constellation. Customers connect to Starlink with individual user terminal, advanced antennas that use the same phased-array technology that is on-board Starlink satellites, for reliable, low cost, and easy to install connections. Once connected to power, customers only need to point the user terminal at the sky and plug it in—the device itself will automatically locate the constellation. Starlink user terminals are intended to be ubiquitous, with the planned deployment of hundreds of thousands of terminals, with one or more terminals per end user premise. In the U.S., for example, the FCC granted SpaceX a blanket license to deploy up to 1,000,000 end user terminals across the United States; a request to increase that amount by 5 million is pending. SpaceX has invested over $70 million to develop and produce thousands of consumer user terminals per month, even before ramping up to high-rate production.

Starlink has been designed from the outset to make efficient use of radio spectrum, and relies on frequency ranges that are aligned with international spectrum allocations identified by the International Telecommunication Union (ITU) and national allocations in the United Kingdom. Starlink links to the customer user terminals in Ku-band up- and downlink frequencies, with gateway links in Ka-band. Through the use of phased array technology in space and on the ground, and multiple satellites in view from any point on the ground, SpaceX's system guarantees efficient use of spectrum to maximize frequency reuse, a key consideration in ensuring diverse options available to UK citizens, consumers and businesses. Introduction of optical rather than RF-based intersatellite links into the constellation will enable efficient network management without taking up spectrum resources. A focus on technologically advanced antennas, technologies and operations ensure that Starlink has optimum flexibility necessary to coordinate with other terrestrial and space-based spectrum users, while still delivering robust service, even in a crowded spectrum setting.

2 Potential impact of the technology on regulated sectors

To demonstrate the potential impacts of the Starlink constellation on the sectors that Ofcom regulates, SpaceX identifies how its network and services will satisfy the goals and targets listed in section 3.16 of the call for inputs.

2.1 Enable the delivery of new services which are valued highly by people and businesses.

SpaceX is rapidly advancing Starlink deployments and consumer services development, and expects to be able to offer initial services in the United Kingdom before year-end 2020, approvals permitting. The current pandemic and economic and social effects have caused not only a surge in broadband demand, but also an evolution in how broadband applications and services are utilized.

Emerging densified 5G networks are expected to deliver new capabilities in more densely-populated urban environments, they are unlikely to support rural or remote communities in the foreseeable future. The densified satellite constellation that SpaceX is deploying is optimized to support robust broadband to more widely-dispersed customers, and will substantially increase capacity and connectivity options for the most remote and rural of customers. While the Starlink constellation represents a small fraction of overall antennas compared to those being deployed for terrestrial technologies, its spectrally-efficient designs and intensive spectral reuse will allow it to make available to all rural areas of the UK the type of high-speed broadband services and accessible prices previously reserved only for urban customers. The single global network nature of Starlink also can ensure that ongoing enhancements and upgrades are made available to all users, avoiding the widening gap of broadband capabilities available to those outside of metropolitan areas.

The need for connectivity has never been more stark, whether to support children doing homework, parents working from home, doctors providing telehealth services, first responders coordinating activities to address emergencies, or any number of other important and critical activities. While existing networks have stood up admirably during the COVID pandemic, the current crisis is laying bare the true cost for those stuck on the wrong side of the digital divide.

- Homework gap: Students increasingly must go online for educational instruction and to complete homework assignments. But nearly two million UK households still have no Internet connection and tens of millions more rely on pay-as-you go mobile data plans that leave them without Internet connectivity once data caps are reached. This hits the poorest, most rural and most vulnerable populations the hardest.
- Telework: According to the Office of National Statistics (ONS), nearly half of workers in the UK reported working from home at some during the COVID-19 crisis and that portion is likely to remain high. As the UK's employment rate saw the largest declines in a decade—hitting younger workers, older workers, and less skilled workers most—broadband connections are essential for job searches and job interviews that now are being undertaken primarily on-line and through videoconferencing.
- Telehealth: Demand for remote medicine has spiked this year as UK doctors adapt to the pandemic, which relies on high-speed broadband connectivity for video consultations.
- Precision agriculture: A lack of rural broadband connectivity particularly hinders the agriculture industry. For example, the National Farmers Union recently reported that over 40% of UK farmers do not have adequate broadband access necessary to conduct business.
- National security: In times of emergency, immediate access to information is critical to secure the country, and advanced satellite systems like Starlink are vital to the provision of resilient communications.
- First responders: Emergency medical personnel, police, firefighters, and other public safety officials depend on high-speed connectivity to coordinate their operations and keep us safe.

2.2 Broaden and deepen access to services.

To address surging demand of broadband connectivity, terrestrial providers are densifying their networks. While 4G networks required roughly 10 times as many cells as 3G networks, 5G networks will require yet another tenfold increase. Wireless operators are planning to deploy many thousands of cells across the country over the next several years, while wireline operators have deployed fiber that can both deliver services direct to customers and also support 5G expansion. Together, these investments are focused on providing services to those living in urban, suburban, and even some rural areas.

However, terrestrial networks are not optimized to reach those in rural and remote areas without massive costs and time lags that are increasingly problematic in today's context. Only 10% of the UK is currently covered by full-fiber broadband-to-the-premises and it is estimated that upgrading the entire country would cost an estimated GBP 33.4 billion and take the next 30 years to complete. Without an infusion of new tactics and technology capabilities, reaching the rest of the population—and providing a choice to millions more who have limited options—could take years or even decades, assuming it is ever achieved, despite its high priority as a UK government goal.

Fortunately, dramatic innovation in space launch services, satellite and terminal technology in systems such as Starlink can meet the growing need for connectivity. SpaceX is leading this revolution in space, and has already deployed sufficient Starlink satellites to commence beta testing and introduce initial continuous broadband services in the UK. With ongoing satellite deployments on manifest, Starlink is underway to reach a constellation scale necessary to meet not just current demand, but also future calls for truly high-speed, low-latency broadband even to underserved and unserved areas.

2.3 Increase the performance of networks, improving the experience for people using them.

The demands brought to the fore today will outlast the current crisis. The volume of internet traffic flowing over the world's networks continues to grow, with one report estimating more traffic in 2022 alone than in the 32 years combined since the Internet started, and more than six people in ten in the world being online. SpaceX's densified satellite constellation will substantially increase capacity and drive up the number of consumers even in rural and remote areas with truly robust broadband while using only a small fraction of the number of antennas being deployed for terrestrial 5G networks.

By operating at low altitudes and employing cutting-edge phased-array technology, the Starlink system maximizes data capacity available, using smaller spot beams and greater satellite diversity, for a higher degree of frequency reuse. And by ensuring that every consumer has multiple satellites in view from any given point on the ground, SpaceX's next-generation system will have flexibility to deliver robust service, even in a crowded spectrum environment.

2.4 Lower barriers to entry into markets, giving people a greater choice of providers.

In addition to providing an alternative or complementary choice of end-user broadband providers beyond terrestrial fixed and mobile, SpaceX believes in a robust, competitive broadband market driven by innovation and efficiency that maximizes consumer choice. Policies that incentivize spectrum efficiency will deliver the most service to UK citizens, consumers and businesses, and approaches that encourage spectrum sharing based on private coordination will increase access to spectrum for all users—whether terrestrial or satellite.

For both space and ground segments, SpaceX has designed its system to coexist with existing spectrum users and allow for the greatest operational flexibility possible among licensed systems. SpaceX supports policies that are specifically tailored to encourage operators to use spectrum efficiently and to come to quick resolution in their coordination discussions. Ideally, any spectrum policies primarily set the terms for successful coordination between operators.

To promote efficiency and scale, spectrum rules that assign the first choice of spectrum to the more efficient system creates a race-to-the-top in which operators compete to develop the most spectrally efficient technology. Too often, operators propose intentionally inefficient systems designed specifically to crowd out competitors, or retain spectrum holdings far after their business utility has passed. To avoid these anti-competitive outcomes that harm consumers, the

government would be well-served to establish aggressive performance metrics where industry competes with innovative technology and operations to meet that metric. This will lead to more competition, meaning consumers accrue the benefits of more choices and lower costs.

Similarly, satellite regulatory processes should not rely on arbitrary dates of regulatory filings as a surrogate for public policy considerations. Specifically, SpaceX supports processes that encourage – and indeed, require -- effective and timely spectrum coordination between satellite system operators in the first instance, particularly for systems in non-geostationary orbit (NGSO). Existing spectrum coordination practices that rely on outmoded date-stamp approaches to assign spectrum no longer reflect the spectrum sharing capabilities or timelines of today's satellite sector. A regulatory approach based on competition and driven by spectral efficiency incentives will yield more and ever-improving communications services for UK citizens, consumers and businesses.

2.5 Reduce the cost of delivering services, increasing access, and maximizing value for customers.

Extending true broadband connectivity to those on the wrong side of the digital divide—especially those in remote areas—will not be easy and necessitates innovative approaches and cutting-edge technologies that complement existing infrastructure. Terrestrial broadband providers are taking this on by deploying millions of miles of fiber and hundreds of thousands of new densified 5G small cells to serve urban, suburban, and some rural areas.

SpaceX is complementing these efforts by investing in a satellite system that operates at the scale necessary to provide high-capacity, low-latency broadband service to reach even those in rural and other underserved areas. Critically, SpaceX will achieve this goal by making efficient use of spectrum that does not cause harmful interference to other licensees, ensures safety of the orbital environment, and preserves the wonder of the night sky.

2.6 Change the way we authorize and regulate networks and /services.

Spectrum access is essential to accommodating ever-increasing broadband demand, crucial for both terrestrial and satellite users that are all seeking scarce resources. Both government and industry need to recognize that spectrum users act like other rational actors—they respond to economic and policy incentives. Therefore, because our shared goal is to increase spectrum access for all users, the regulatory framework, including rules governing authorizations and licenses, must include inventive means to reward and encourage those who develop and use efficient technologies. This emphasis on driving technology leadership may also generate opportunities for British innovation.

Rapid deployment of SpaceX's services to the UK will rely as much on securing spectrum and siting authorizations as on the network deployment. Ensuring that SpaceX can deliver crucial broadband connectivity throughout the country requires minimizing siting requirements and streamlining licensing processes for gateway earth stations. SpaceX's end-user terminals use the 10.7-12.75 GHz (downlink) and 14.0-14.5 GHz (uplink) bands. Expanding access to these bands on an unlicensed basis for end-user terminals is key, even if on a shared basis.

2.7 Assure the security and resilience of service delivery.

When major disasters strike—whether hurricanes, floods, fire, or earthquakes—overhead lines, underground cables, and towers may be damaged or destroyed, knocking out terrestrial fixed and mobile broadband services. Satellite can becomes the only reliable connection for emergency personnel to respond to the crisis, for relief workers to deliver food, water, and medical supplies, and for those stuck in disaster areas who need to communicate with loved ones. Recognising this

critical infrastructure, resiliency is built into SpaceX's satellite system, offering diversity of many satellites in view and redundant gateways to circumvent vulnerable terrestrial infrastructure and providing essential connectivity during emergencies.

2.8 Reduce the total environmental impact of delivering communications services and associated activities.

Minimizing environmental impacts is a central focus at every stage of design, development, and implementation. SpaceX takes seriously its responsibility to protect the shared orbital environment and is on the leading edge of on-orbit debris mitigation, meeting or exceeding all regulatory and industry standards. To meet this responsibility, SpaceX is leveraging the built-in advantages of operating at low altitude and applying its unique iterative and integrated approach to take a series of unprecedented steps that minimize the effect its constellation will have on other operating spacecraft and other orbital resources and the space environmental more generally to preserve its sustainable use.

From the beginning of its deployment, every satellite launched as part of SpaceX's system has been—and will be—equipped with SpaceX's advanced propulsion system. This cutting-edge capability is used in concert with industry-leading navigation functions to conduct active maneuvers to avoid collisions with both debris and other spacecraft throughout the life of its satellites, even through the de-orbit phase and until the spacecraft enters the atmosphere.

Yet, rather than rely solely on this capability, SpaceX has also designed its system to leverage the inherent advantages of operating at very low altitudes. The system is designed so that normal operations should not generate any debris, but in the unlikely event that an issue arises at any stage of operation, atmospheric drag will ensure that any debris quickly disintegrates in the atmosphere and poses no further danger to space operations or life on the ground or in the air. Moreover, its satellites will have sufficient maneuverability to avoid other satellites and orbital debris throughout their mission lifetime and through the de-orbit process. These complementary aspects of SpaceX's safe-by-design architecture ensure its constellation can maintain an orbital environment sustainable for competitive services in the future, while driving broadband capacity to customers even in the most remote corners of the country.

But the need to preserve the orbital environment goes beyond protecting services for people on Earth. Sustainability is essential for exploration. SpaceX is dedicated to ensuring its satellite systems have no meaningful impact on astronomy—or anyone looking to the skies. SpaceX has worked closely with leading optical astronomers around the world to ensure its satellites do not impede scientific discoveries from ground-based optical telescopes. SpaceX is employing discoveries made through that collaboration to drive first-of-breed mitigation technologies and techniques that reduce satellite brightness at all operational phases.

3 Current state of technological development

To date, SpaceX has deployed over 700 satellites and has commenced beta testing with customers throughout the Northern United States, with hundreds of test undertaken both within the company's employee base and with external customers. SpaceX expects to begin offering Starlink as a commercial service before the end of this year in the northern United States and southern Canada, with plans near-global coverage of the populated world in 2021. In the UK, SpaceX has applied to Ofcom for an Innovation and Trials Licence for 1,000 user terminals operating in Ku-band. SpaceX is working with local site hosts to authorize UK-based gateways operating in Ka-band, and intends to apply for licensing of additional Ka-band gateways to support UK services as the relevant frequencies become available. Once approved, these links would permit initial non-commercial beta testing of the Starlink service as early as the fourth quarter of 2020. SpaceX plans

to follow these early non-commercial tests with a public beta trial in the UK in early 2021, followed by commercial Starlink broadband services. Approval of a European standard for the Starlink user terminals, ETSI EN 303-981, is currently being finalized.

SpaceX has not yet released information on its ongoing U.S. consumer beta tests, but has collected latency data and performing standard speed tests of the system through initial SpaceX employee tests. These initial results show very low latency and download speeds greater than 100 mbps, fast enough to stream multiple high-definition movies at once and still have bandwidth to spare. As ongoing beta tests are undertaken and results compiled, SpaceX would be pleased to provide updates to Ofcom.

4 Unresolved issues to address to achieve full potential

The type of ground-breaking development that enabled the deployment of Starlink requires a regulatory environment that anticipates and rewards innovation, encourages competition, and moves at the speed of technological development. For next-generation satellite networks to achieve their full potential to close the digital divide, governments should adopt flexible, sensible and efficient regulatory frameworks that incentivize and reward innovation and results. The current Ofcom regulatory framework meets many of these objectives now, and compares favourably to many counterparts. SpaceX encourages regular reviews of existing regulations and sun-setting any outdated provisions or requirements that have been made obsolete with new technology or new approaches. Ongoing review of spectrum allocation for new technologies should be of high priority, particularly where the current users and new technology can demonstrate co-existence. In these instances, Ofcom may wish to consider accelerating spectrum allocation reviews, as well as policies to incentive operator-to-operator coordination, in order to ensure that incumbents do not unduly deter or delay deployment of options for UK consumers and that spectrum sharing is undertaken at a pace in keeping with rapid technological developments.

5 Key publications and groups

6 Further discussions with Ofcom

SpaceX appreciates this opportunity to highlight its role in emerging technologies and welcomes further discussions with Ofcom to delve into more detail about Starlink and the socio-economic benefits the system will bring to the UK.

Please complete this form in full and return to emerging.technology@ofcom.org.uk